

Wildlife-Vehicle Collision Mitigation for Safer Wildlife Movement across Highways: State Route 260

Final Report 603
December 2012



Arizona Department of Transportation
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16. Abstract <p>Researchers investigated wildlife-highway relationships in central Arizona from 2002 to 2008 along a 17-mile stretch of State Route (SR) 260, which is being reconstructed in five phases and will have 11 wildlife underpasses and 6 bridges. Phased reconstruction allowed researchers to use a before-after-control experimental approach to their research. The objectives of the project were to:</p> <ul style="list-style-type: none"> • Assess and compare wildlife use of underpasses (UPs) • Evaluate highway permeability and wildlife movements among reconstruction classes • Characterize wildlife-vehicle collision (WVC) patterns and changes with reconstruction • Assess relationships among traffic volume and WVCs, wildlife crossing patterns, and UP use • Assess the role of ungulate-proof fencing with WVCs, wildlife UP use, and wildlife permeability <p>Researchers used video surveillance to assess and compare wildlife use of six UPs, at which 15,134 animals and 11 species were recorded; 67.5 percent crossed through UPs. Modeling found that UP structure type and placement was the most important factor influencing the probability of successful crossings by elk (<i>Cervus elaphus</i>) and Coues white-tailed deer (<i>Odocoileus virginianus</i>). Researchers used Global Positioning System (GPS) telemetry tracking of 100 elk and 13 white-tailed deer to assess and compare permeability. Elk permeability on reconstructed sections was 39 percent lower than controls, while deer permeability was 433 percent higher on reconstructed sections. The elk-vehicle collision (EVC) rate on fenced reconstructed sections was the same as before-reconstruction levels, but on unfenced sections the EVC rate was nearly four times higher. In addition to a safer and more environmentally friendly highway, the economic benefit from reduced EVCs on SR 260 averaged \$2 million/year since the completion of three reconstructed highway sections.</p>			
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ACRONYMS AND ABBREVIATIONS

AADT	average annual daily traffic
AC	alternating current
ADOT	Arizona Department of Transportation
AGFD	Arizona Game and Fish Department
AIC	Akaike's Information Criterion
ANCOVA	analysis of covariance
ANOVA	analysis of variance
BACI	before-after-control-impact (design)
CV	coefficient of variation
df	degrees of freedom
DPS	Department of Public Safety
EVC	elk-vehicle collision
ft	foot
FHWA	Federal Highway Administration
GIS	Geographic Information System
GMU	Game Management Unit
GPS	Global Positioning System
hr	hour
HR ^{0.5}	home-range distance (linear metric)
IGA	intergovernmental agreement
MCP	minimum convex polygon
mi	mile
min	minute
ROW	right-of-way
SE	standard error
SR	State Route
TNF	Tonto National Forest
UP	underpass
V	volt
VHF	very high frequency
WT	white-tailed (deer)
WVC	wildlife-vehicle collision
yr	year

LIST OF SPECIES

Animals

black bear	<i>Ursus americanus</i>
caribou	<i>Rangifer tarandus</i>
coyote	<i>Canis latrans</i>
elk	<i>Cervus elaphus</i>
gray fox	<i>Urocyon cinereoargenteus</i>
grizzly bear	<i>Ursus arctos</i>
javelina	<i>Tayassu tajacu</i>
moose	<i>Alces alces</i>
mountain lion	<i>Puma concolor</i>
mule deer	<i>Odocoileus hemionus</i>
pronghorn	<i>Antilocapra americana</i>
raccoon	<i>Procyon lotor</i>
roe deer	<i>Capreolus capreolus</i>
Coues white-tailed deer	<i>Odocoileus virginianus couesi</i>
wolf	<i>Canis lupus</i>

Plants

Douglas-fir	<i>Pseudotsuga menziesii</i>
Gambel oak	<i>Quercus gambelii</i>
juniper	<i>Juniperus</i> spp.
manzanita	<i>Arctostaphylos</i> spp.
pinyon pine	<i>Pinus edulis</i>
ponderosa pine	<i>Pinus ponderosa</i>
scrub live oak	<i>Quercus turbinella</i>
white fir	<i>Abies concolor</i>

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The ADOT Research Center's Technical Advisory Committee for this project provided many suggestions for improving the project's effectiveness and applicability. The research team greatly appreciates the committee's tremendous support, oversight, and commitment throughout the duration of the project.

EXECUTIVE SUMMARY

This report concludes eight years of continuous wildlife-highway relationships research conducted along a 17 mile section of State Route (SR) 260 in central Arizona, from 2001 to 2008. This stretch of highway was being reconstructed in five phases from a two-lane roadway to a four-lane divided highway to incorporate 11 wildlife underpasses (UPs) and 6 bridges. Phased reconstruction made it possible for researchers to use a before-after-control experimental approach to assess the impact of the construction and success of measures to reduce wildlife-vehicle collisions (WVCs) and promote wildlife permeability. The objectives of this research project were:

- Assess and compare wildlife use of wildlife UPs and examine factors that influence wildlife UP use.
- Evaluate wildlife movements across SR 260 among highway reconstruction classes (before, during, and after reconstruction) using GPS telemetry.
- Characterize WVC changes associated with SR 260 highway reconstruction and assess the potential economic benefit of wildlife UPs and other measures.
- Evaluate the relationships among highway traffic volume, wildlife highway crossing patterns, and wildlife use of UPs.
- Assess the role that ungulate-proof fencing plays in the incidence of WVCs, wildlife use of UPs, and overall wildlife highway crossings.

To evaluate factors influencing wildlife use of underpasses, researchers monitored wildlife crossings at six UPs constructed on three sections of SR 260. The focus of this monitoring was (1) to document wildlife use of UPs by video camera surveillance and to compute passage rates (number of animals crossing/number of animals approaching) and compare the probabilities of successful UP crossing by different species and among different UPs, (2) to evaluate the influence of UP structural characteristics, duration of monitoring, and other factors on successful UP crossings by elk and white-tailed deer, and (3) to develop recommendations to maximize UP effectiveness.

To assess the effectiveness of passage structures and fencing in minimizing highway collisions, the research team documented WVCs along SR 260 to determine the success and benefits of wildlife UPs and ungulate-proof fencing. The aim was to assess (1) the incidence of WVCs and the relationship of elk-vehicle collision (EVC) rates to highway reconstruction classes, (2) the role of ungulate-proof fencing in conjunction with UP structures in minimizing EVC, and (3) highway safety and economic benefits associated with reduced EVC. Researchers compared mean EVC rates (EVCs per mile) for highway sections by analysis of covariance, controlling for annual traffic effects. Two separate analyses were done using different highway reconstruction classes. The first analysis compared EVC rates among three treatment classes (before, during, and after reconstruction). The second analysis assessed the influence of ungulate-proof fencing on EVC rates by comparing the before-fencing and after-fencing treatment sections of each

reconstructed highway section; the after-fencing treatments reflected fencing added to the limited amount originally planned by ADOT.

This overall research effort underscores the ability to integrate transportation and ecological objectives into highway reconstruction, yielding tangible benefits to both highway safety and wildlife permeability. The combination of phased construction, adaptive management, and effective monitoring of UPs and ungulate-proof fencing were instrumental in achieving these objectives. It is recommended that such an approach to highway construction be pursued whenever possible at the time of initial highway design or reconstruction. The paragraphs that follow highlight the key conclusions and recommendations of arising from the study.

Wildlife UPs were highly effective in promoting below-grade wildlife crossings, with two-thirds of more than 15,000 animals recorded on videotape having crossed through an UP. These UPs were important to improving highway safety through the reduction of WVCs and promoting wildlife permeability. Structural design characteristics and placement of UPs are important considerations in maximizing their success in promoting wildlife passage, and structural characteristics were the most important factor in determining the probability of achieving successful crossings by wildlife. UP openness is crucial to achieving high probability of successful use.

The distance that animals must travel through a UP is an especially important factor in maximizing crossing success and should be minimized. Elk avoided a UP where concrete retaining walls were erected, compared to a neighboring UP with 2:1 earthen slopes. The use of concrete walls for wildlife UPs should be avoided. UPs with clear through visibility should be maximized, and adjacent bridges should be placed in line whenever possible to maximize visibility by animals through the structures. Wildlife UP placement should avoid concentrated areas of human disturbance or congregation that occur outside daytime hours. Elk and deer exhibited dramatically different passage rates for the same UPs, pointing to the need to address multispecies passage and permeability requirements.

Wildlife UPs in conjunction with adequate ungulate-proof fencing substantially reduced the incidence of EVCs compared to before-fencing levels. The limited-fencing approach with highway reconstruction resulted in a nearly fourfold increase in EVCs over before-reconstruction EVC levels; once fenced under an adaptive management approach informed by GPS telemetry, EVCs declined 76 percent to before-reconstruction levels. Such fencing is necessary to funnel elk toward UPs to cross SR 260 below grade, thus contributing to substantially improved highway safety.

Just as previous SR 260 research found that traffic volume differentially affected elk depending on whether they approached and crossed at grade or at UPs below grade, similar results were obtained for white-tailed deer. Traffic volume had minimal impact on deer crossings at UPs, especially compared to animals attempting to cross at grade; this finding was of paramount importance to understanding the success of UPs in promoting both elk and deer permeability.

GPS telemetry afforded an unprecedented opportunity to assess and compare wildlife permeability among reconstruction classes for two ungulate species with different levels of mobility. For white-tailed deer, a species with relatively limited mobility, mean passage and crossing rates on reconstructed highway sections were considerably higher than for control sections; UPs and bridges on the widened upgraded sections improved deer permeability over the narrow control sections that were a significant barrier to deer passage. By contrast, highway control sections had the highest mean passage rate for elk, a more far-ranging species. The mean control section elk passage rate, at 39 percent, was lower than the reconstructed section mean of 44 percent of approaches. However, this level of reduced permeability between two-lane undivided and four-lane divided highways was considerably lower than that documented elsewhere, reflecting the benefit of combining UPs with ungulate-proof fencing.

The spacing of passage structures on reconstructed highway sections had a significant influence on elk passage rates, with a strong inverse relationship between permeability and passage structure spacing. A minimum spacing distance of 1.0 mile between structures is recommended to balance cost of structures and provide adequate opportunity for elk to cross highways. Placement of passage structures in areas of high concentrations of EVCs or preferred habitats (e.g., meadows) is important; however, this may not be feasible owing to factors including, but not limited to, right-of-way (ROW) clearances, terrain, the presence of structures at the time of reconstruction, and roadway design considerations.

With the completion of the three reconstruction sections of SR 260 that exhibited the worst historical incidence of WVCs, the integration of wildlife UPs and fencing yielded not only substantial benefits to improved highway safety and wildlife permeability but also a significant economic benefit. In the three years following the completion of the reconstructed sections, the economic benefit tied to reduced incidence of EVCs averaged \$2 million per year. The collective benefit to wildlife, highway safety, and financial savings underscores the degree to which wildlife UPs and fencing along SR 260 can be considered a great success.

1.0 INTRODUCTION

1.1 BACKGROUND

Direct and indirect highway impacts have been characterized as some of the most prevalent and widespread forces altering ecosystems in the United States (Noss and Cooperrider 1994; Trombulak and Frissell 2000; Farrell et al. 2002). Estimates of annual collisions involving deer in the United States have ranged from 700,000 (Schwabe and Schuhmann 2002) to as high as 1.5 million (Conover 1997). Wildlife-vehicle collisions (WVCs) cause human injuries, deaths, and tremendous property loss (Reed et al. 1982; Schwabe and Schuhmann 2002). Over 38,000 human deaths attributable to WVCs occurred in the United States between 2001 and 2005, and the economic impact exceeds \$8 billion/year (Huijser et al. 2007).

WVCs disproportionately affect threatened or endangered species populations and recovery efforts (Foster and Humphrey 1995; Parker et al. 2008). Forman and Alexander (1998) estimated that highways have affected more than 20 percent of the nation's land area through habitat loss and degradation. Perhaps the most pervasive impact of highways on wildlife is the barrier and fragmentation effects resulting in diminished habitat connectivity (Noss and Cooperrider 1994; Forman and Alexander 1998; Forman 2000).

Highways block animal movements between seasonal ranges or other vital habitats. This barrier effect fragments habitats and populations, reduces genetic interchange (Gerlach and Musolf 2000; Epps et al. 2005), and limits dispersal of young (Beier 1995); all disrupt viable wildlife population processes. Long-term fragmentation and isolation renders populations more vulnerable to the influences of catastrophic events and may lead to extinctions (Hanski and Gilpin 1997). Fencing constructed to block wildlife and livestock access across highways without provisions for adequate passage may exacerbate barrier effects.

Though numerous studies have alluded to highway barrier effects on wildlife (e.g., Forman et al. 2003), few have yielded quantitative data relative to animal passage rates, particularly in an experimental (e.g., before- and after-highway reconstruction) context. Many studies have focused on the efficacy of passage structures in maintaining wildlife permeability (Clevenger and Waltho 2003; Ng et al. 2004) or have relied on modeling to assess permeability (Singleton et al. 2002). Assessments of highway fragmentation effects on relatively low-mobility small mammals (Swihart and Slade 1984; Conrey and Mills 2001; McGregor et al. 2003) have proven easier to accomplish than assessments for far-ranging species that are limited by cost-effective capture and tracking techniques. Paquet and Callaghan (1996) used winter track counts adjacent to highways and other barriers to determine passage rates by wolves, something few other studies have reported. Some studies have used very high frequency (VHF) radio telemetry to assess wildlife movements and responses to highways. Such studies have often pointed to avoidance of highways and roads (Brody and Pelton 1989; Rowland et al. 2000) but have seldom directly addressed permeability, as Gibeau et al. (2001) did for grizzly bears.

Numerous assessments of WVC patterns have been conducted, most focusing on deer (Reed and Woodard 1981; Bashore et al. 1985; Romin and Bissonette 1996a; Hubbard et al. 2000). Only recently have WVC assessments specifically addressed elk-vehicle collision (EVC) patterns (Gunson and Clevenger 2003; Biggs et al. 2004). Insights gained from such assessments have been instrumental in developing strategies to reduce WVC incidents (Romin and Bissonette 1996a; Farrell et al. 2002), including planning passage structures to reduce at-grade crossings and to maintain permeability (Clevenger et al. 2002). Consistent tracking of WVCs constitutes a valuable tool to assess the impact of highway construction (Romin and Bissonette 1996b) and efficacy of passage structures and other measures (e.g., fencing) in reducing WVCs (Reed and Woodard 1981; Ward 1982; Clevenger et al. 2001a; Dodd et al. 2007b).

Though WVC data are valuable, no study investigated or validated the relationships between WVCs and spatial and temporal crossing patterns exhibited by wildlife involved in collisions until recently (Dodd et al. 2006). Barnum (2003) reported that WVC data were not useful in identifying crossing zones, largely due to inaccurate reporting of locations. Efforts to increase the accuracy of WVC reporting will provide valuable information to transportation agencies for planning purposes (Gunson and Clevenger 2003). However, for those species that avoid roadways and seldom cross them (e.g., pronghorn), tracking WVCs may be ineffective, and wildlife movement data may be needed to make sound management decisions on the placement of passage structures.

Increasingly, structures designed to promote wildlife passage across highways are being implemented throughout North America, especially large bridges (e.g., underpasses or overpasses) designed specifically for large-animal passage (Clevenger and Waltho 2000; Bissonette and Cramer 2008). Whereas early passage structures were typically approached as single-species mitigation measures to address direct impact (Reed et al. 1975), the focus today is more on preserving ecosystem integrity and landscape connectivity benefiting multiple species (Clevenger and Waltho 2000). Transportation agencies are increasingly receptive to integrating passage structures into highways to address both safety and ecological needs (Farrell et al. 2002). However, there is increasing expectation that such structures will indeed benefit multiple species and enhance connectivity (Clevenger and Waltho 2000) and that the effectiveness of such structures will improve with continued scientifically sound monitoring and evaluation of wildlife responses to them (Clevenger and Waltho 2003; Hardy et al. 2003). Corlatti et al. (2009) argued for long-term monitoring of wildlife passages to evaluate their effectiveness in maintaining connectivity and promoting population and genetic viability, thus justifying their high cost.

Wildlife use of crossings has been measured differently by researchers. Most studies have reported underpass (UP) use based on track counts (Clevenger and Waltho 2000; Gloyne and Clevenger 2001), event recorders (Foster and Humphrey 1995), or single-frame camera images (Ng et al. 2004). Using information about frequency of animal occurrence to compare passage structure use is potentially biased due to heterogeneous animal distribution or differential funneling of varying amounts of wildlife-proof fencing; this fails to account for animals not using passage structures or those exhibiting behaviors

such as resistance to crossing. To address such biases, Clevenger et al. (2001b) estimated expected passage frequencies derived from track assessments of relative abundance, and Clevenger and Waltho (2003) calculated species performance ratios from radio telemetry, pellet transects, and habitat suitability indices. Reed et al. (1975) compared animal evidences at the entrance and exits of UPs to calculate activity indices, while Gordon and Anderson (2003) used behavioral quantification as a measure of wildlife response. Dodd, Gagnon, Manzo, et al. (2007) demonstrated video surveillance of UPs as a useful measurement to assess wildlife passage rates.

1.2 HIGHWAY RECONSTRUCTION AND STUDY APPROACH

The reconstruction of State Route (SR) 260, incorporating 11 large-wildlife passage structures and 6 bridges (1 passage structure/mi) to address wildlife permeability and highway safety considerations, constitutes one of the most comprehensive wildlife connectivity projects in North America. This project compares with landmark efforts to address wildlife permeability and WVCs in Banff National Park, Alberta, Canada, with 24 passage structures in 28 miles (mi) (0.86/mi; Clevenger and Waltho 2003), as well as those planned for U.S. Highway 93 reconstruction in Montana, with 42 passage structures over 56 miles (0.75/mi; Huijser et al. 2010).

1.2.1 Phased Construction and Adaptive Management

In addition to addressing WVCs, two other aspects of the SR 260 reconstruction project are noteworthy: (1) its phased construction approach and (2) its application of adaptive management. The phasing of the highway reconstruction in five separate sections has facilitated effective construction oversight by ADOT and allowed reconstruction to occur on priority sections with limited funding sources. The incidence of WVCs was a key factor in the planning and prioritization of the order in which highway sections have been upgraded.

The phased reconstruction of SR 260 has also facilitated the feedback of preliminary research findings and insights to ADOT project managers to address wildlife-related issues. Such insights have been applied to SR 260 sections already under construction or planned for construction to improve wildlife passage structure design and to identify appropriate stretches needing ungulate-proof fencing to maximize UP effectiveness and minimize WVCs. Such an adaptive management approach, where research data are used to make continuous improvements during subsequent construction activities, can benefit the quality of highway construction, especially relating to highway safety. However, adaptive management carries the potential risk of increased costs should construction delays and increased project budget expenditures occur.

1.2.2 Experimental Approach

The phased reconstruction of SR 260 allowed the researchers to assess the impact of highway reconstruction on wildlife at various stages. Hardy et al. (2003), Roedenbeck et

al. (2007), and Underwood (1994) stressed the value of conducting before-after-control-impact (BACI) assessments to determine the effects of highway construction and the efficacy of measures to reduce WVCs and promote permeability. The phasing of SR 260 reconstruction into five highway sections and the presence of experimental controls provided the opportunity to conduct such an assessment. During the project, the research team has been able to assess wildlife relationships and response to various stages of highway reconstruction (Table 1).

Table 1. SR 260 Reconstruction Dates and Duration of Research by Highway Section.

Highway Section	Reconstruction Upgrade		Research Duration (in years)		
	Begun	Completed	Before ^a	During ^a	After ^a
Preacher Canyon	1999	2001	0	0	8
Christopher Creek	2002	2004	1	2	5
Kohl's Ranch	2003	2006	2	3	3
Little Green Valley		Control	8	0	0
Doubtful Canyon		Control	8	0	0

^a Before, during, or after highway reconstruction.

This project focused on evaluating the effectiveness of design measures along SR 260 to minimize the incidence of WVCs, especially those involving elk, and maintaining wildlife permeability across the highway. This research was initiated in 2001 and consisted of eight continuous years of field evaluation and monitoring, making it one of the longest-running monitoring projects in the United States, especially since the average length of such projects has been only 1.4 years (Clevenger and Waltho 2003). This commitment to environmental protection, research, and adaptive management has made it one of the most comprehensive projects of its type in the United States (Cramer and Bissonette 2007), and one that has garnered well-deserved recognition for ADOT and its partners—including a 2004 FHWA Exemplary Ecosystem Initiative Award and the 2008 National Association of Environmental Professionals' National Environmental Excellence Award.

1.2.3 Research Phases

The SR 260 research project, which was funded by ADOT's Arizona Transportation Research Center, occurred in three phases from 2001 to 2008.

Phase I

The first phase, initiated under an intergovernmental agreement (IGA) executed with ADOT in January 2002 (JPA 01-152), focused on the Preacher Canyon section, the first reconstructed section (Table 1). Research under this phase served as a "pilot study" for

the development and evaluation of several research techniques (e.g., video camera surveillance and GPS telemetry) to assess the effectiveness of various measures to minimize WVCs and facilitate wildlife passage across the highway corridor. Field activities under this phase were initiated in early 2001, before the execution of the first IGA.

Phase II

Research continued during Phase II under a second IGA executed with ADOT in December 2003 (JPA 04-024T). This phase focused on the Christopher Creek section, where reconstruction was completed in late 2004 (Table 1), with continued monitoring of the first Preacher Canyon section. This IGA extended research through July 2006. After the second phase, the research team completed the first comprehensive final project report on research findings (Dodd, Gagnon, Boe, et al. 2007); Section 1.4 below summarizes the findings of that first research report.

Phase III

Phase III of the research project, which was conducted under a third IGA executed with ADOT in November 2005 (JPA 06-004T), focused on the Kohl's Ranch reconstruction completed in early 2006 (Table 1) and continued monitoring of previously completed sections. Research under this phase continued through December 2008. This final report addresses Phase III research findings, as well as those of the previous phases.

1.3 RESEARCH OBJECTIVES

Research conducted during all three phases of the SR 260 study addressed the following six primary objectives.

Objective 1 Assess and compare wildlife use of SR 260 wildlife UPs and examine factors that influence wildlife UP use

The study of wildlife response to passage structures has employed various approaches (Hardy et al. 2003), including use of track counts (Rodríguez et al. 1997; Clevenger et al. 2001b; Clevenger and Waltho 2000, 2003), event recorders (Reed et al. 1975; Foster and Humphrey 1995), and infrared-motion or heat-sensor single-frame cameras (Servheen et al. 2003; Brudin 2003; Ng et al. 2004). Only a few studies have used video cameras to assess passage structure use (Reed et al. 1975; Gordon and Anderson 2003; Plumb et al. 2003). Video surveillance has an advantage over other techniques because animal behavior can be assessed, especially when crossing resistance or failed crossings occur (Hardy et al. 2003). Video surveillance also allows for identification and classification (e.g., sex, age) of individual animals when compared to track counts (Hardy et al. 2003). Though video camera surveillance has been used minimally, such monitoring has

nonetheless provided insights not obtained from other methodologies (Reed et al. 1975; Gordon and Anderson 2003).

Under this objective, Phase I research evaluated the application of video surveillance to assess and compare wildlife response to UPs constructed during the reconstruction of SR 260 (Dodd, Gagnon, Manzo, et al. 2007) by focusing on the two Preacher Canyon section UPs. The research team developed an unbiased, comparable metric to evaluate wildlife use of UPs (Dodd, Gagnon, Manzo, et al. 2007). In Phase II of the research project, the researchers expanded video surveillance to a total of five UPs, and in Phase III to a total of six UPs. The researchers compared wildlife use at these UPs to relate differences in response to UP structural characteristics and placement, traffic volume (Gagnon, Theimer, Dodd, Manzo, et al. 2007), and duration of monitoring.

The comprehensive findings for video surveillance conducted in 2002–2008 under this objective are presented in Chapter 3.

Objective 2 Evaluate highway permeability and wildlife movements across SR 260 among highway reconstruction classes (before, during, and after highway reconstruction) using GPS telemetry

The application of GPS telemetry in wildlife movement studies has become increasingly popular, cost effective, and reliable (Rodgers et al. 1996). With continuous automated tracking at set time intervals, reduced observer bias (compared to VHF telemetry), and potential to collect large datasets, GPS telemetry has revolutionized wildlife movement assessment, and it holds tremendous potential to facilitate highway permeability assessment and determine spatial and temporal highway crossing patterns by wildlife.

Under this objective, the research team used GPS telemetry to investigate wildlife permeability across SR 260, comparing before- and after-highway-reconstruction passage rates of sections under various stages of reconstruction. Under Phase I of the project, the research team developed and evaluated quantitative measures of elk highway permeability using GPS telemetry, assessed spatial and temporal influences on elk movements, and compared permeability as a function of highway reconstruction classes, within a single reconstructed section (Dodd et al. 2007a). Under Phase II, the research team assessed the role of ungulate-proof fencing on elk permeability (Dodd et al. 2007b) and assessed permeability by highway reconstruction classes with two reconstructed sections. Under Phase III, the research team continued its assessment of elk permeability across highway reconstruction classes, now with three reconstructed sections exhibiting a variation in the distance between passage structures that allowed the team to evaluate the influence of UP spacing on elk permeability. Also under Phase III, the team expanded telemetry data gathering to include white-tailed deer to assess permeability relationships for another ungulate species.

The findings for this objective are presented in Chapter 5 (elk permeability) and Chapter 6 (white-tailed deer permeability).

Objective 3 Characterize WVCs and changes associated with SR 260 highway reconstruction (before, during, and after reconstruction) and assess economic benefit of wildlife UPs and other measures

WVCs present a serious and growing problem for wildlife safety, motorist safety, and property loss (Reed et al. 1982; Farrell et al. 2002; Schwabe and Schuhmann 2002). The incidence of WVCs along SR 260 was a major impetus for incorporating wildlife UPs and ungulate-proof fencing into the highway reconstruction project. Most assessments of WVCs in North America have focused on deer (Reed and Woodward 1981; Bashore et al. 1985; Romin and Bissonette 1996b; Hubbard et al. 2000). Only recently have assessments specifically addressed EVC patterns (Gunson and Clevenger 2003; Biggs et al. 2004; Dodd et al. 2006; Dodd, Gagnon, Boe, et al. 2007).

The reconstruction of SR 260 in phases allowed the research team to assess the impact of highway reconstruction on WVCs, including EVCs, across reconstruction classes and with and without fencing (Dodd et al. 2006; Dodd et al. 2007b). During Phase I, the research team characterized the nature of EVC patterns along SR 260 and compared collision incidence associated with the highway under various stages of reconstruction. The team compared spatial and temporal patterns of EVCs to elk highway crossings determined by GPS telemetry to validate the usefulness of collision data in developing strategies to reduce collisions and promote permeability. Under Phases II and III, continued monitoring of WVCs was accomplished, with a minimum of three years of after-reconstruction assessment accrued on three reconstructed sections. Research under these phases also addressed the economic benefit of wildlife mitigations.

The comprehensive 2001–2008 findings for minimizing WVCs under this objective are presented in Chapter 4.

Objective 4 Evaluate the relationships among highway traffic volume, wildlife highway crossing patterns, and wildlife use of UPs

Traffic may serve as a “moving fence” that can render highways impermeable to wildlife (Bellis and Graves 1978). One theoretical model (Iuell et al. 2003) predicted that highways become impermeable barriers to most wildlife at 10,000 vehicles/day, potentially leading to fragmentation and rapid genetic isolation of wildlife populations like that documented for bighorn sheep (Epps et al. 2005). Alternatively, because traffic volume varies by season, day, and time, some animals may be able to cross even high-traffic-volume highways during periods when the volume is relatively low.

During the latter part of Phase I and during Phase II, the research team investigated the relationship of average annual daily traffic (AADT) levels with elk GPS telemetry relocations to determine the influence on at-grade crossings and elk distribution (Gagnon, Theimer, Dodd, and Schweinsburg 2007). This was made possible by a permanent traffic counter installed by ADOT along the study stretch of SR 260. The team also used video surveillance to assess the influence of traffic volume on elk crossings below grade at five UPs (Gagnon, Theimer, Dodd, Manzo, et al. 2007). Under Phase III, the team assessed

the influence of AADT on at-grade crossings and traffic volume on below-grade UP crossings by deer, complementing telemetry research previously conducted on elk.

The findings for this objective are presented in Chapter 5 (elk permeability) and Chapter 6 (white-tailed deer permeability).

Objective 5 Assess the role that ungulate-proof fencing plays in the incidence of WVCs, wildlife use of UPs, and wildlife permeability across the highway

Though fencing is effective in reducing WVCs (Romin and Bissonette 1996a; Forman et al. 2003), some studies have reported mixed results (Falk et al. 1978; Feldhamer et al. 1986). Since fences constitute effective barriers to ungulate passage across highways (Falk et al. 1978), fencing itself may exacerbate the reduction in wildlife permeability associated with highways alone, particularly where effective measures to accommodate animal passage are lacking. In addition, fencing is costly and can require substantial maintenance (Forman et al. 2003). Therefore, transportation agencies have been reluctant to fence extensive stretches of highways, including SR 260, especially without information or guidelines for the application of fencing in conjunction with wildlife passages.

During the reconstruction of SR 260, ADOT applied a general model for integrating 8-ft ungulate-proof fencing with UPs and bridges. Limited (<300 ft) wing fences were erected outward from bridge abutments to funnel animals toward the structures. Research was needed to evaluate both this limited-fencing approach and the strategic placement of fencing to intercept crossing wildlife as determined from GPS telemetry under adaptive management (Dodd et al. 2007a).

Under Phases I and II, the researchers looked at the role of both the limited-fencing approach on WVCs (Dodd et al. 2006) and the strategic fencing approach based on GPS telemetry-based elk crossing patterns (Dodd et al. 2007b). The researchers further evaluated this during Phase III.

The findings for this objective are presented in Chapter 3 (UP use by elk and deer), Chapter 4 (WVC minimization), and Chapter 5 (elk permeability).

Objective 6 Provide ongoing, on-site highway construction implementation guidance and instruction throughout all reconstruction phases

As the research project was integrated with an ongoing adaptive management approach to SR 260 reconstruction, the research team provided recommendations and guidelines for maintaining wildlife permeability, minimizing WVCs, and improving wildlife UP design.

Under Phases I and II, adaptive management activities were focused on applying research findings to improving UP design (Dodd, Gagnon, Manzo, et al. 2007) and determining the extent of ungulate-proof fencing needs based on GPS telemetry (Dodd et al. 2007a,

2007b). Under Phase III, the research team continued to assess the effectiveness of the various adaptive management modifications made to UP design and fencing applications.

Research findings related to adaptive management are presented in Chapter 3 (UP use), Chapter 4 (wildlife-vehicle collisions), and Chapter 5 (elk permeability).

1.4 PHASES I AND II FINAL REPORT SUMMARY

With completion of Phases I and II, the research team prepared a final report (Dodd, Gagnon, Boe, et al. 2007) detailing the findings of its research activities conducted through 2006. The following is a summary of the extensive findings from the first two phases of SR 260 research.

1.4.1 Assessment of Wildlife Underpass Use

Researchers recorded 11 different wildlife species and 8,455 animals, of which elk accounted for 74 percent. UP passage rates ranged from 0.10 to 0.68 crossings/approach. UPs were highly effective in promoting below-grade wildlife crossings, with two-thirds of recorded animals having crossed through one. UPs were instrumental in improving highway safety through the reduction of WVCs, and in promoting wildlife permeability. Structural design characteristics and placement of UPs were important considerations to maximizing their efficacy in promoting wildlife passage. Structural characteristics were the most important factor in determining the probability of achieving successful crossings by wildlife.

UP openness is crucial to achieving high probability of successful UP use. The distance the animals must travel through a UP was an especially important factor in maximizing efficacy. Elk more often avoided UPs with concrete retaining walls that were erected for soil stabilization than neighboring UPs with more natural 2:1 sloped earthen sides. Researchers documented a recurring seasonal pattern where elk UP passage rates dropped from summer levels >0.90 crossings/approach to below 0.40 during the fall when migratory elk moved through the SR 260 corridor. Migratory elk did not appear to exhibit the same propensity for habituation to UPs as resident elk. Ungulate-proof fencing in conjunction with UPs should expedite the wildlife learning process and help address this seasonal drop in passage rates.

1.4.2 Traffic Effects on Elk Underpass Crossings

Traffic levels on SR 260 fluctuated greatly on an hourly, daily, and seasonal basis and nearly doubled from an AADT volume of 4,500 in 2001 to 8,700 in 2003. At the five UPs where video surveillance occurred, the researchers documented whether traffic levels affected elk passage rates when elk approached and crossed by simultaneously counting traffic passing above the UPs. Passage rates at low, intermittent traffic volume (0.59–0.75 passage rate) and at higher traffic levels (0.71–0.73) did not differ from the mean passage rate determined when no vehicles were present (0.65). Passage rates varied

seasonally due to the presence of migratory elk, but even during migratory periods, traffic volume levels had minimal effect on passage rate. Thus, the researchers found that traffic volume had no effect on elk passage rates when they crossed the highway below grade at UPs. This finding was crucial to understanding the efficacy of UPs in promoting wildlife permeability.

1.4.3 Elk Permeability from GPS Telemetry

GPS telemetry afforded the researchers an unprecedented opportunity to assess and compare wildlife permeability among highway reconstruction classes. In the first phase of GPS telemetry (2002–2004), the researchers fitted 33 elk with GPS receiver collars. These collars accrued 101,506 GPS location fixes, with 45 percent occurring within 0.6 mi of the highway. Nearly two times the proportion of locations occurred within 0.6 mi of the highway compared to randomly generated locations. Elk were attracted to the highway corridor by riparian-meadow foraging habitats that were seven times more concentrated within the 0.6-mi zone around the highway, compared to the mean proportion within elk home ranges. Elk crossed the highway 3,057 times; crossing frequency and distribution were strongly aggregated rather than randomly distributed. The mean passage rate for elk crossing the highway section where reconstruction was completed (0.43 crossings/approach) was half that of the sections under reconstruction and control sections combined (0.86). Permeability was jointly influenced by the size of the widened highway and associated vehicular traffic on all lanes. The researchers used crossing frequency to delineate where ungulate-proof fencing yielded maximum benefit in intercepting and funneling crossing elk toward UPs and in reducing EVCs.

1.4.4 Traffic Effects on Elk Highway Crossings

A permanent traffic counter was installed within the study area to provide continuous traffic data to compare to elk highway crossing data. From 44 elk collared in both telemetry phases, researchers linked 38,709 GPS locations to hourly traffic volume data (6,470,000 vehicles) to determine how elk distribution varied with traffic and how elk highway crossings were affected by traffic volume. The probability of elk occurring near the highway decreased with increasing traffic volume; elk primarily used the habitat near the highway when traffic volumes were relatively low (<100 vehicles/hr). The researchers found that increasing traffic volume reduced the overall probability of at-grade elk highway crossings, but this effect depended on both seasonality and the proximity of riparian-meadow habitats. Elk crossings occurred later in the evening when traffic levels abated, and unsuccessful attempts, or “repels,” by elk to cross SR 260 at grade typically coincided with high traffic volume.

1.4.5 Role of Ungulate-Proof Fencing

In the second phase of GPS telemetry (2004–2005), the research team compared permeability on one reconstructed section nearly one year before and one year after ungulate-proof fencing was erected. The research team fitted 22 elk with GPS receiver

collars and accrued 87,745 GPS locations. The elk highway passage rate after SR 260 was opened to traffic, but before fencing was erected (0.54 crossings/approach), was 32 percent lower than the level during reconstruction work (0.79). However, once ungulate-proof fencing was erected, the passage rate increased 52 percent to 0.82 crossings/approach. Thus, fencing with UPs promoted wildlife permeability as animals were funneled toward UPs by fencing where they crossed below grade with minimal impact from traffic (compared to crossings at grade where traffic did have an influence).

In addition to playing an instrumental role in promoting permeability, ungulate-proof fencing was crucial to achieving effective use of UPs, especially those not located near meadow habitats. Without fencing, elk and deer continued to cross SR 260 at grade immediately adjacent to UPs. With just 49 percent of one section strategically fenced to intercept peak elk highway crossings determined from GPS telemetry, an 87 percent reduction in ECVs was realized in the year after fencing. Fencing constitutes an integral component of wildlife mitigations in promoting permeability.

1.4.6 Wildlife-Vehicle Collision Relationships

The research team assessed spatial and temporal patterns of EVCs from 1994 to 2006 ($n = 571$). The team used data from the first phase of GPS telemetry to assess spatial and temporal patterns of elk highway crossings and compare those patterns with EVC patterns. Annual EVCs were related to traffic volume and elk population levels. EVCs occurred in a nonrandom pattern. The EVC mean for sections under reconstruction (up until ungulate-proof fencing was erected) was higher (11.6 EVCs/yr) than the before-reconstruction EVC mean (4.4 EVCs/yr) and the after-reconstruction EVC mean (6.5 EVCs/yr). On the first section completed in 2001 with limited fencing (13 percent), EVCs did not differ among before, during, and after reconstruction classes, even though mean traffic volume increased 67 percent from before- to after-reconstruction levels, pointing to the benefit of three passage structures and fencing. On another section, EVCs increased more than 2.5 times when opened to traffic but before strategically located ungulate-proof fencing was erected. Once fencing was erected along half the section linking passage structures, EVCs dropped 87 percent.

The researchers compared EVCs and crossings at five spatial scales; the strongest relationship was at the highway section scale. Strength of the relationship and management utility were optimized at the 0.6-mi (ca. 1 km) scale. The strong association between EVCs and highway crossings underscored the utility and value of WVC data in planning wildlife mitigation measures ranging from passage structures to ungulate-proof fencing. EVCs were associated with proximity to riparian-meadow habitats adjacent to the highway. Although EVCs and crossings during the fall season exceeded expected levels, the proportion of EVCs in September-November (49 percent) exceeded the proportion of crossings and coincided with the breeding season, elk migration, and high use of riparian-meadow habitats adjacent to the highway. A higher proportion of EVCs (59 percent) occurred relative to crossings (33 percent) in the evening (1700–2300 hr); 34 percent of EVCs occurred within one hour after sunset, and 55 percent within two hours

after sunset. EVC data are valuable in developing strategies, including locating passage structures, to maintain permeability and increase highway safety.

1.4.7 Economic Benefit of Wildlife Measures

With reconstruction of just two SR 260 sections completed with UPs and ungulate-proof fencing, 2006 was the first year that the incidence of actual EVCs dropped below the level predicted from modeling based on traffic volume and elk population levels. Modeling predicted even greater benefit as traffic volume is anticipated to increase. The complement of measures implemented to date has achieved its objective in mitigating the impact of highway reconstruction and increasing traffic volume. The researchers expect the benefit to grow now that the third section is complete and the entire first reconstructed section has been fenced under an enhancement grant project. In 2006, the researchers estimated the annual economic benefit from reduced EVCs to be \$850,000. With only a modest increase in traffic volume, the researchers estimated that the annual benefit will exceed \$1 million/year.

1.4.8 Conclusion

This study of Phases I and II underscored the ability to integrate transportation and ecological objectives into highway construction activities, yielding tangible benefits to highway safety and wildlife permeability, as well as economic benefits from reduced WVCs. The combination of phased construction, adaptive management during reconstruction, and effective monitoring was instrumental to jointly achieving transportation and ecological objectives.

1.5 REPORT ORGANIZATION

This final report is organized as follows: Chapter 2 sets the highway reconstruction and biological context for the research project; Chapters 3–6 detail the SR 260 research objectives and associated research findings; and Chapter 7 synthesizes those findings across objectives and summarizes key recommendations that reflect the increased understanding of the complex interactions between wildlife and highways. Literature cited throughout the report is listed in a single reference section at the end of the report. Scientific names for plant and animals species used throughout are listed in the report's front matter; scientific names are not used elsewhere in the report.

2.0 STUDY AREA

This study was conducted along a 17-mi stretch of SR 260 (mileposts 260–277), beginning 9 mi east of Payson and extending to the base of the Mogollon Rim in central Arizona (latitude 34°15′–34°18′N, longitude 110°15′–111°13′W; Figure 1). SR 260 links metropolitan Phoenix to several tourism-dependent White Mountain communities (e.g., Show Low, Pinetop-Lakeside, Springerville-Eagar) and popular summer (e.g., camping, fishing) and winter (e.g., skiing) recreation areas on the White Mountain Apache Reservation and the Apache-Sitgreaves National Forest. SR 260 also serves as the primary connector to Interstate 40.

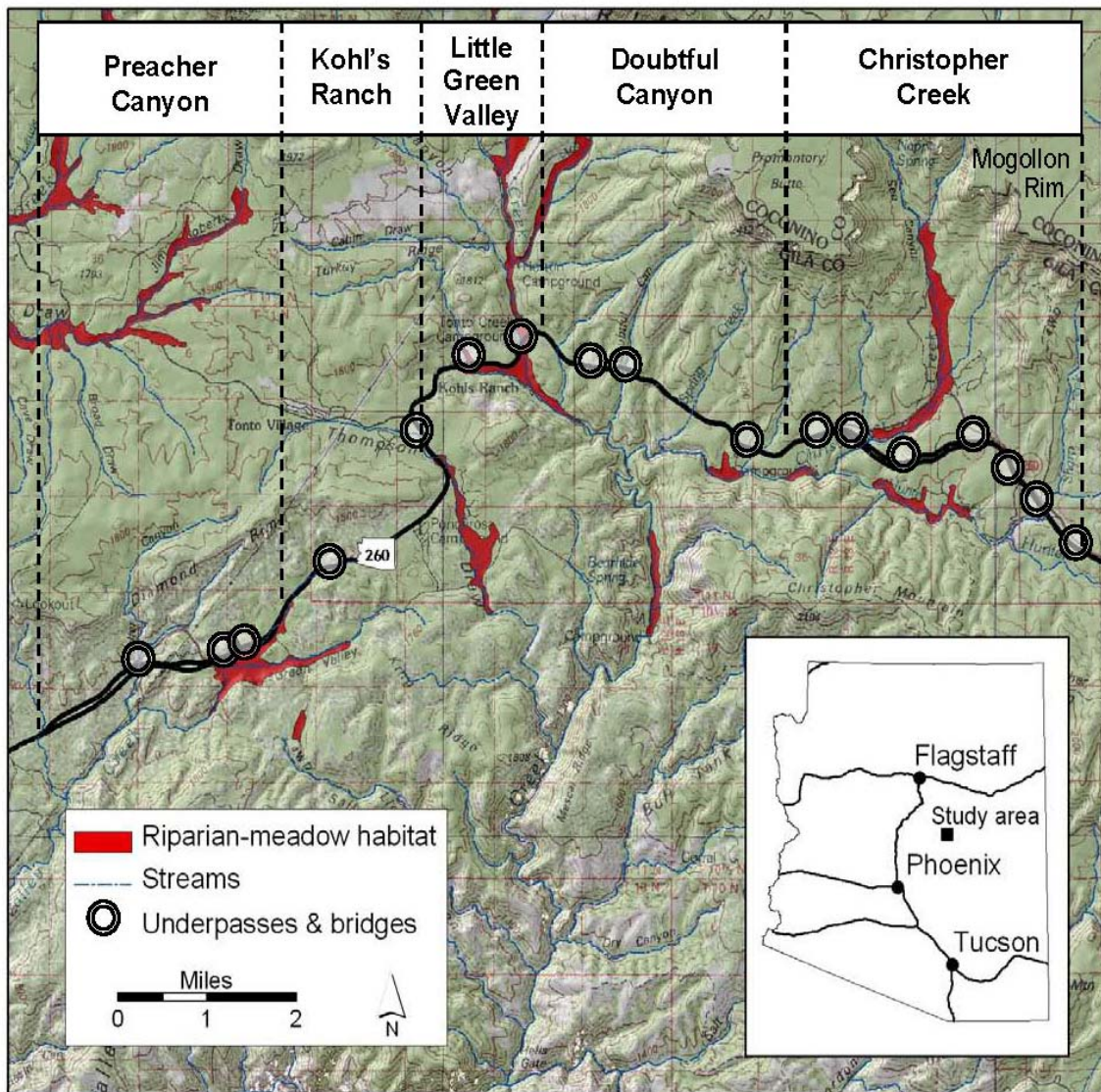


Figure 1. Location of the 17-mi SR 260 Study Area and the Five Highway Reconstruction Sections with Wildlife Underpasses, Bridges, and Riparian-Meadow Habitats.

Starting in 2000, sections of the two-lane highway have been upgraded to a four-lane divided highway (Figure 2). In places, the footprint of the upgraded highway exceeds 0.3 mi wide (Figure 2). The reconstructed highway will incorporate 11 wildlife UPs specifically intended to reduce at-grade elk crossings and WVCs, as well as 6 bridges over large canyons and streams that will accommodate wildlife use (Figure 1; Table 2). Reconstruction of three sections with 7 UPs and all 6 bridges is now completed (Figure 1; Table 2). Reconstruction of the last two sections, Little Green Valley and Doubtful Canyon, with 4 UPs started in 2010.



Figure 2. Existing Two-Lane Roadway, Doubtful Canyon Section (Left), Being Reconstructed into a Four-Lane Divided Highway, Preacher Canyon Section (Right).

Table 2. Summary of SR 260 Reconstruction Sections.

Highway Section	Reconstruction Status	Highway Mileposts	Length (mi)	Wildlife Passages	
				UP	Bridge
Preacher Canyon	Completed 2001	260.0–263.0	3.0	2	1
Little Green Valley	Control	263.1–265.5	2.5	1	0.5
Kohl’s Ranch	Completed 2006	265.6–269.5	4.0	1	1.5
Doubtful Canyon	Control	269.6–272.5	3.0	3	0
Christopher Creek	Completed 2004	272.6–277.0	4.5	4	3
	All	260.0–277.0	17.0	11	6

2.1 RECONSTRUCTED SECTIONS AND CHRONOLOGY

Understanding the status of the three reconstructed highway sections and the time frames associated with the reconstruction process is important for contextualizing the BACI experimental design (Underwood 1994; Hardy et al. 2003; Roedenbeck et al. 2007) that was integral to this research project. Also important is an understanding of the

modifications made to the original reconstruction plans under the adaptive management process, primarily those involving the application of 8-ft ungulate-proof fencing along each section. Design characteristics and photos of the completed wildlife UPs are included in Chapter 4.

2.1.1 Preacher Canyon Section

The first highway section, Preacher Canyon, was completed in November 2001. This section included two UPs and a large bridge over Preacher Canyon (Figure 1; Table 2). Upon completion, only 0.4 mi (13 percent) of the section's length was fenced with ungulate-proof fencing, associated with the two UPs near Little Green Valley. As a result of continuing WVCs (see Chapter 5), an enhancement project was implemented to raise the existing 3.5-ft right-of-way (ROW) fence to 7.5 ft (with barbed-wire and electric fence) along the remaining unfenced portion of the section. The 2.5 mi of fence modification were completed in December 2006 (Gagnon et al. 2010). The research team conducted six years of after-reconstruction–before-fencing treatment monitoring and two years of after-reconstruction–after-fencing treatment evaluation.

2.1.2 Christopher Creek Section

The majority of heavy reconstruction on the Christopher Creek section, including construction of 3 bridges and 4 UPs, was completed by May 2003. Upon completion, wildlife could pass through the unfenced passage structures (Figure 1; Table 2); however, vehicular traffic was confined to two lanes until early July 2004, when all four lanes were opened to traffic. Erection of ungulate-proof fencing was not completed until mid-December 2004. Original construction designs incorporated ungulate-proof fencing along 0.7 mi of the section (22 percent). This extent of fencing was increased to 2.4 mi (49 percent) by raising the ROW fence through the adaptive management process to address peak elk highway crossing zones determined by GPS telemetry (Dodd, Gagnon, Manzo, et al. 2007). Research during Phases I and II projected that added fencing would intercept 45 percent of elk crossings, for a total of 58 percent crossing interception (Dodd, Gagnon, Manzo, et al. 2007). Initially, a 0.2-mi gap was left in the fence midway along a 2.0-mi stretch of fenced highway due to complexities associated with integrating fencing at a lateral access road into the community of Christopher Creek; this gap was fenced in November 2007. Overall, the research team's data collection and evaluation covered 1 year of before-reconstruction, 3.5 years of during-reconstruction, 1 year of after-reconstruction–before-fencing, and 3.5 years of after-reconstruction–after-fencing. (Figure 3).

2.1.3 Kohl's Ranch Section

The Kohl's Ranch section, completed in March 2006, included 1 wildlife UP and 1.5 bridges (only one bridge span was built over Thompson Draw, and the other will be built under the Little Green Valley section). The original wildlife UP designs were modified substantially under adaptive management (Dodd, Gagnon, Manzo, et al. 2007; see

Chapter 4 of this report), as was the planned length of ungulate-proof fencing (<0.5 mi; 12 percent). The fencing was increased to include the eastern third of the section (1.3 mi), projected to intercept 60 percent of the GPS-determined elk crossings. Here, however, only limited fencing was extended westward from the peak crossing area associated with the Indian Gardens UP. For this section, the research team conducted two years of before-reconstruction, three years of during-reconstruction, and nearly three years of after-reconstruction–after-fencing treatment evaluation.



Figure 3. SR 260 Study Area at the Pedestrian-Wildlife Underpass on the Christopher Creek Section, with Mogollon Rim Escarpment (Background) and Solar Panels for Powering Video Camera Surveillance System (Foreground).

2.2 NATURAL SETTING

The study area lies within the ponderosa pine association of the montane coniferous forest community (D. Brown 1994). Elevations along SR 260 range from 5,220 to 6,560 ft. The Mogollon Rim escarpment to the north is the dominant landform, rising precipitously to 7,860 ft (Figures 1 and 3). Vegetation adjacent to the highway grades ranges from mixed ponderosa pine, pinyon pine, juniper, and live oak forest on the lower-elevation Preacher Canyon and Little Green Valley sections to forests dominated by ponderosa pine interspersed with Gambel oak at higher elevations to the east on the

Christopher Creek section. Chaparral (e.g., manzanita) with sparse pinyon pine, live oak, and ponderosa pine is prevalent on the drier south-facing slopes. Mixed-conifer forests of ponderosa pine, Douglas fir, white fir, and Gambel oak occur in canyons emanating from the Mogollon Rim. Numerous riparian and wet meadow habitats occur at several locations along the highway corridor (Figure 1), with some meadows more than 60 acres in size (Figure 4). Several perennial streams flow adjacent to portions of the highway, including Little Green Valley, Tonto, Christopher, Hunter, and Sharp creeks (Figure 1).



Figure 4. Aerial View of Little Green Valley Riparian-Meadow Complex Adjacent to Preacher Canyon Section of the SR 260 Study Area.

Climatic conditions within the study area are mild, with a mean maximum monthly temperature of 90.3° F (July) and a mean minimum monthly temperature of 19.6° F (January). Annual precipitation averages 20.7 inches, with a mean of 21.3 inches of snowfall in winter; precipitation has averaged two-thirds of normal since 2002.

The research team focused its study on Rocky Mountain elk for several reasons. First, elk accounted for more than 80 percent of all collisions between vehicles and wildlife (Dodd et al. 2006; see Chapter 5 of this report) and for the vast majority of property loss and human injuries associated with collisions with vehicles. Elk are large animals that are relatively easy to trap and that can readily support GPS telemetry collars, which can yield substantial long-term data on wildlife highway movements.

Both resident and migratory elk herds occurred within the study area. Resident elk were common, especially in proximity to wet meadows. Nonresident elk migrate off the Mogollon Rim with the first snowfall greater than 12 inches, typically in late October (R. Brown 1990, 1994). Brown (1990) reported that 85 percent of the elk residing within this Mogollon Rim herd unit migrate to an area below but within 6 mi of the base of the Mogollon Rim, which encompasses the SR 260 study area. Migratory elk return to summer range with forage green-up at higher elevations (Brown 1990). The 2008 estimated resident elk population in Game Management Units (GMUs) 22 and 23 encompassing the study area was approximately 2,500 (Arizona Game and Fish Department, Game Management Branch, Phoenix), though not all elk resided in proximity to SR 260. White-tailed deer were frequently present near SR 260, while mule deer were less common and more localized on the eastern portion of the study area.

2.3 TRAFFIC VOLUME

AADT volume on this portion of SR 260 (at the ADOT Control Road traffic monitoring station) nearly tripled in 10 years from 3,100 in 1994 to 8,700 in 2003 but has been static since (Figure 5; ADOT Data Management Section). Since 2002, AADT has been determined by a permanent traffic counter installed at the center of the study area along the Little Green Valley section. Traffic volumes were highest during daytime hours (Figure 6) when passenger cars accounted for 81 percent of all vehicles traveling along SR 260 (2004–2007); commercial vehicles account for 19 percent of the traffic volume but often exceeded 40 percent during nighttime hours (Figure 6).

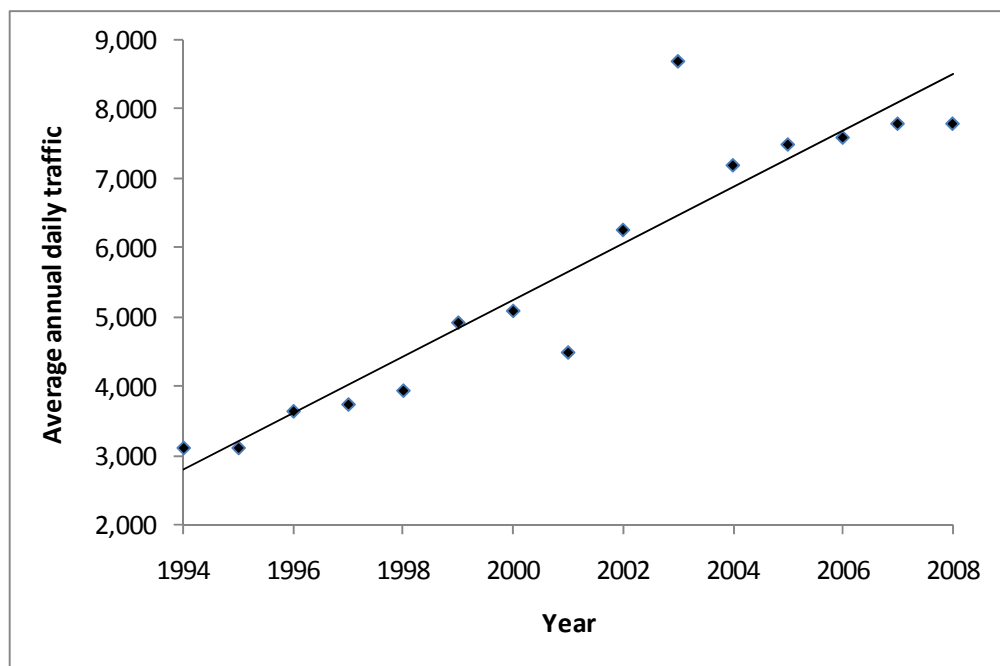


Figure 5. Average Annual Daily Traffic Volume Levels for SR 260 (at the ADOT Control Road Monitoring Station), 1994–2008.

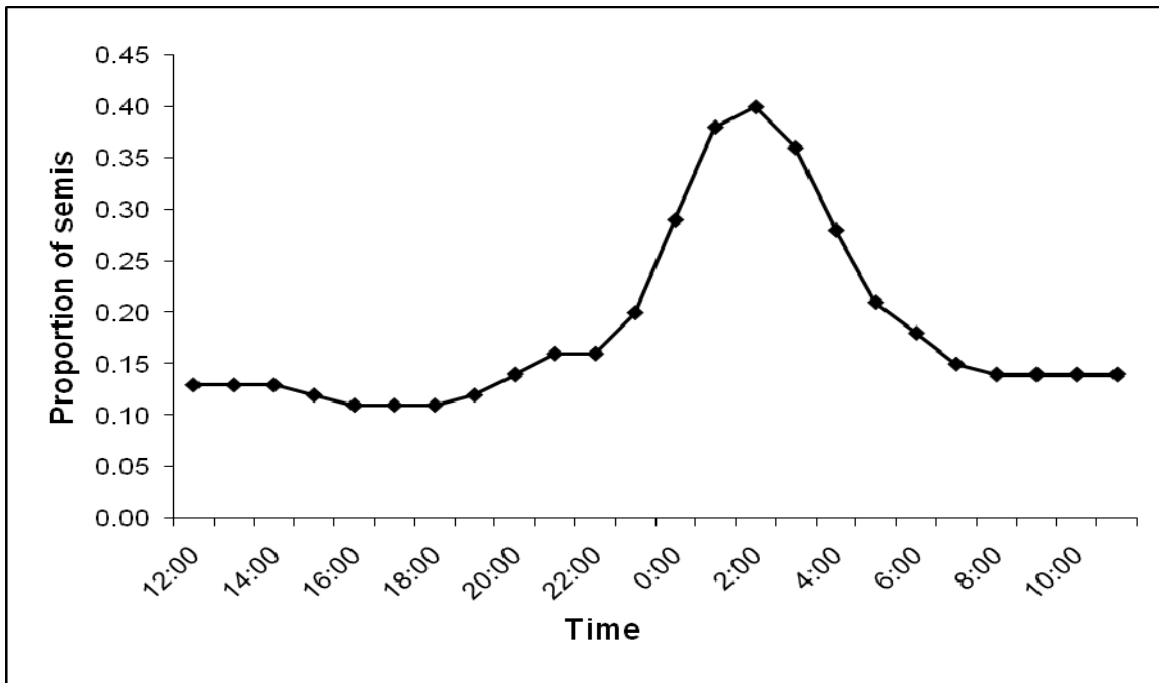
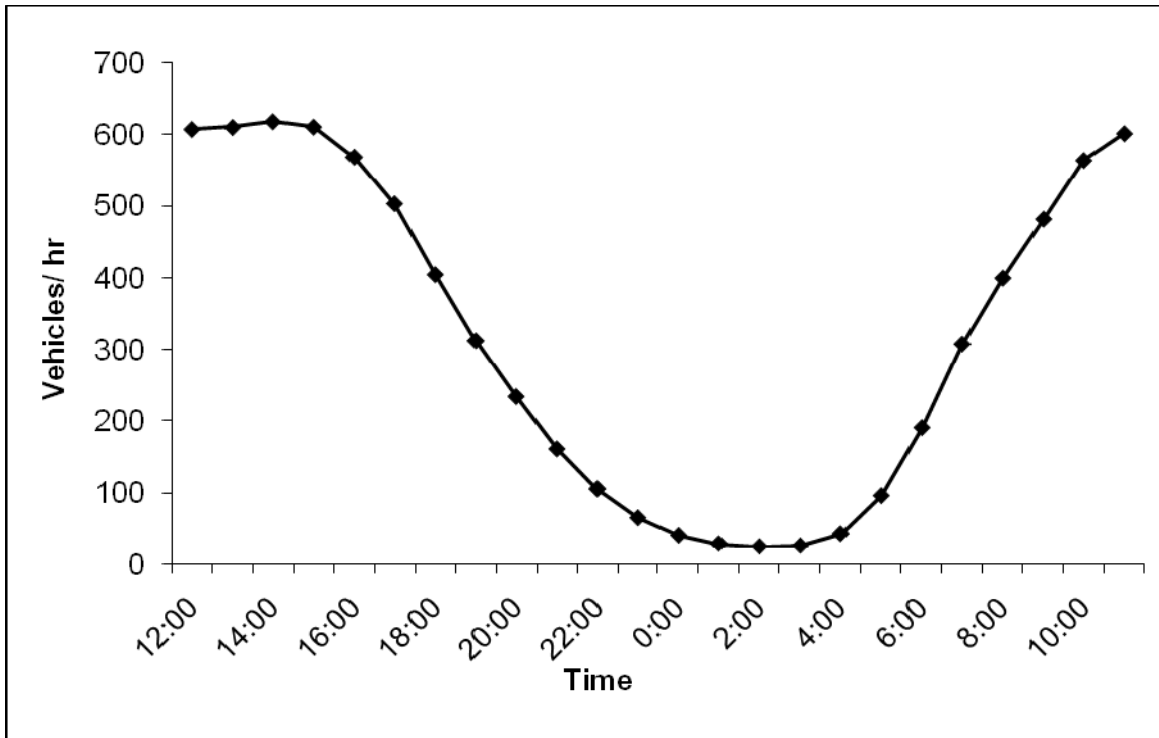


Figure 6. SR 260 Vehicular Traffic Patterns by Time of Day. Top Graph: Traffic Volume for All Vehicles. Bottom Graph: Proportion of Commercial Vehicles.

Note: Data obtained from traffic recorded by a permanent traffic counter on SR 260 between 2004 and 2008.

3.0 EVALUATION OF FACTORS INFLUENCING WILDLIFE USE OF HIGHWAY UNDERPASSES

3.1 INTRODUCTION

As road and highway networks throughout the world are upgraded to accommodate increasing traffic, opportunities for wildlife to cross at grade diminish as animals suffer increased mortality from vehicle collisions or exhibit road avoidance (Jaeger et al. 2005). Highways act as barriers to free movement of wildlife, fragmenting and isolating habitats and resources, reducing genetic interchange (Epps et al. 2005) and the probability of population persistence (Jaeger et al. 2005), and increasing population susceptibility to stochastic events (Forman and Alexander 1998; Trombulak and Frissell 2000). Mortality from vehicle collisions is a serious and growing problem for wildlife populations, motorist safety, and property loss (Reed et al. 1982; Farrell et al. 2002).

Highway reconstruction projects are increasingly incorporating wildlife passage structures to promote wildlife passage across highways and to preserve landscape connectivity; these structures have proven successful for many species (Clevenger and Waltho 2000, 2005; Foster and Humphrey 1995; Dodd, Gagnon, Manzo, et al. 2007; Bissonette and Cramer 2008). Passage structure use can minimize or eliminate the effects of vehicular traffic (Mueller and Berthoud 1997), allowing for unimpeded movement across roadways (Gagnon, Theimer, Dodd, Manzo, et al. 2007). Transportation agencies have been receptive to integrating passage structures in projects to address safety and ecological needs (Farrell et al. 2002), and there is increasing expectation that these structures will yield tangible biological and economic benefits (Clevenger and Waltho 2000). As such, scientifically sound monitoring of wildlife use of passage structures is vital to improving future effectiveness and justifying their continued application (Clevenger and Waltho 2003; Hardy et al. 2003).

Structural characteristics and placement of wildlife crossing structures are important to maximizing wildlife use (Reed et al. 1975; Reed et al. 1979; Foster and Humphrey 1995; Clevenger and Waltho 2000, 2003; Dodd, Gagnon, Manzo, et al. 2007). Prior studies modeled structural factors accounting for differences in wildlife use (Clevenger and Waltho 2000, 2005; Ng et al. 2004). Design and placement is important to passage structure success, particularly if flawed design or inadequate funnel-fencing results in animals avoiding a passage structure altogether and crossing the highway at grade, presenting a risk to motorists and animals (Dodd, Gagnon, Manzo, et al. 2007).

Various techniques have been used to assess passage structure usage by wildlife, including track counts (Rodríguez et al. 1997; Clevenger et al. 2001a; Clevenger and Waltho 2000, 2003), triggered event recorders or counters (Reed et al. 1975; Foster and Humphrey 1995), and infrared-motion or heat-sensor single-frame cameras (Budin 2003; Servheen et al. 2003; Ng et al. 2004), including digital infrared cameras (Olsson et al. 2008). Only limited use of video cameras has occurred (Reed et al. 1975; Sips et al. 2002; Gordon and Anderson 2003; Plumb et al. 2003; Dodd, Gagnon, Manzo, et al. 2007).

Video surveillance has advantages over other techniques because it allows for evaluation of animal behavior, especially when avoidance or failed crossings occur (Hardy et al. 2003; Gordon and Anderson 2003; Dodd, Gagnon, Manzo, et al. 2007), and for simultaneous observation of passing traffic (Gagnon, Theimer, Dodd, Manzo, et al. 2007).

Several measures have been used to quantify wildlife use of passage structures. Most studies have enumerated frequency of use (Clevenger and Waltho 2000; Gloyne and Clevenger 2001; Sips et al. 2002; Ng et al. 2004; Olsson et al. 2008). However, frequency of use can be a biased index because it may be subject to differential funneling of animals by topography, varying amounts of fencing, and heterogeneous animal distribution. Frequency of use does not account for nonuse attributable to structural characteristics or alternative crossing locations (Reed et al. 1975; Clevenger et al. 2001a; Clevenger and Waltho 2003, 2005). Dodd, Gagnon, Manzo, et al. (2007) used passage rate (number of crossing animals/number of animals approaching) as a comparative measure of passage structure use to address this bias. Passage rates determined by video surveillance are relatively unbiased by differential wildlife densities associated with various passage structures, and such rates provide a calculation of the proportion of animals that refuse to cross through structures (Dodd, Gagnon, Manzo, et al. 2007). Dodd, Gagnon, Boe, et al. (2007) also modeled probability of use by logistic regression, which was useful in comparing underpass use by wildlife and complemented passage rate as a metric of UP use.

Hardy et al. (2003) and Clevenger and Waltho (2003) stressed the importance of long-term monitoring of wildlife passage structure use. The latter reported that for 18 studies, the average monitoring duration was 1.4 years. They documented dramatic changes in wildlife use patterns over the course of their five-year evaluation of newly constructed passage structures. Numerous studies have reported that ungulates and other wildlife require time to adapt to crossing structures (Reed et al. 1975; Clevenger and Waltho 2000, 2003; Dodd, Gagnon, Manzo, et al. 2007; Olsson et al. 2008). While Clevenger and Waltho (2003) and Dodd, Gagnon, Manzo, et al. (2007) found relatively rapid acceptance of new UPs by elk, achieving peak use within two years, other species took longer to habituate to passage structures. Use of passages reflected both structural characteristics and species-specific adaptation to them over time (Clevenger and Waltho 2003).

Olsson et al. (2008) believed that differential learning rates by species were related to differences in home-range sizes and exposure to passages. Dodd, Gagnon, Manzo, et al. (2007) reported dramatically different seasonal elk passage rates along SR 260 (<0.40 in winter and >0.80 in summer) attributable to the influx of migratory elk in winter that, unlike resident animals, lacked regular exposure to UPs; they believed that this might pose a long-term impediment to achieving consistent yearlong use by elk. Since those reported results, nearly four additional years of monitoring have occurred along the highway, including monitoring at an additional four UPs (six total). As with Clevenger and Waltho's (2003) assessments based on long-term monitoring, the researchers now have the ability to assess wildlife use patterns and passage rates over time.

The objectives were to:

- Assess wildlife use of UPs by video camera surveillance and compute passage rates as a comparative measure of UP use by different species and among UPs.
- Evaluate the influence of UP structural characteristics and other factors important in predicting successful UP crossings by elk and white-tailed deer, species for which sufficient data were collected across all UPs.
- Consider the influence of the duration of UP monitoring and how it might influence interpretations of the efficacy of wildlife UPs.
- Develop recommendations to maximize the effectiveness of UPs in promoting wildlife permeability, thus providing transportation agencies additional options for resolving wildlife-highway conflicts.

3.2 METHODS

3.2.1 Video Surveillance Systems

The research team monitored wildlife use at six UPs constructed on three sections of SR 260 (Figures 7 and 8), with monitoring ongoing at individual UPs anywhere from 2.5 to 5.5 years (Table 3). Video surveillance of the Preacher Canyon section began in late 2002, yielding 5.5 years of monitoring; surveillance of the Christopher Creek section began in early 2004, yielding 4 years of monitoring; and surveillance of the Kohl's Ranch section began in spring 2006, yielding 2.5 years of monitoring.

The team used integrated animal-triggered four-camera video surveillance systems to examine the number and types of wildlife species that used the six UPs. Each surveillance system included two cameras that recorded animals approaching the UP from one side of each UP; the other two cameras recorded animals as they passed through the UP (Figure 9). The Indian Gardens and Pedestrian-Wildlife UP surveillance systems were powered by arrays of solar panels, while the other four systems were powered by 120 V AC. Dodd, Gagnon, Manzo, et al. (2007) used time-lapse validation to show that the use of photo-beam triggers to detect approaching and crossing animals was an accurate and reliable mode of video recording, with benefits of efficient videotape analysis time and costs.

3.2.2 Assessment of Wildlife Use of Underpasses

The research team limited the overall analysis of results for the six UPs to a comparison of passage rates and did not include behavioral response as reported by Dodd, Gagnon, Manzo, et al. (2007). Passage rates were determined by the proportion of animals crossing through each UP to those that approached each UP. The research team considered a UP approach to occur when animals crossed over the 4-ft ROW fence approximately 130–150 ft from the mouths of the UPs and showed movement toward the mouths. Passage rates were calculated from animals approaching from only one side of the UPs.

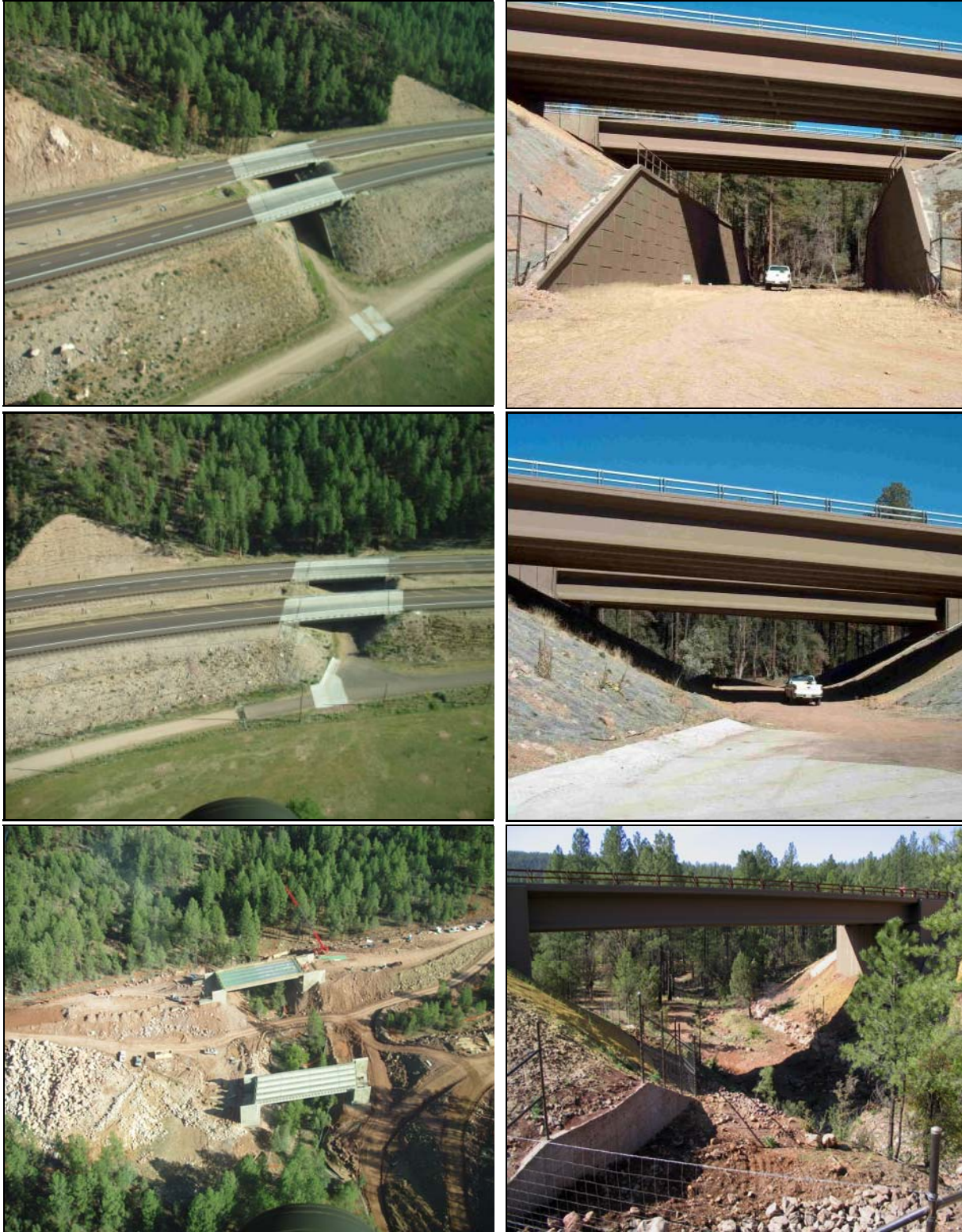


Figure 7. Aerial and Ground Photographs of SR 260 Underpasses, Including Little Green Valley West (Top) and East (Middle) Underpasses and Indian Gardens Underpass (Bottom; Aerial Photograph on Bottom Left Depicts Underpass Construction).



Figure 8. Aerial and Ground Photographs of SR 260 Underpasses, Including Pedestrian-Wildlife Underpass (Top), Wildlife 2 Underpass (Middle), and Wildlife 3 Underpass (Bottom).

Table 3. Physical Characteristics Associated with SR 260 Wildlife Underpasses Monitored by Video Camera Surveillance, 2002–2008.

Wildlife Underpass	Highway Section	Span (ft)	Height (ft)	Length (ft) ^a	Atrium (ft) ^b	Monitoring Duration (in years)
East Little Green Valley	Preacher Canyon	135	22	175	36	5.5
West Little Green Valley	Preacher Canyon	135	38	365	36	5.5
Pedestrian-Wildlife	Christopher Creek	110	22	420	155	5
Wildlife 2	Christopher Creek	130	32	390	105	5
Wildlife 3	Christopher Creek	125	17	210	None	4.5
Indian Gardens	Kohl's Ranch	135	215	120	2.5	

^a Length = distance for animals to fully negotiate passage structure, from mouth to mouth, including fill material.

^b Atrium = width of opening between eastbound and westbound bridge spans.

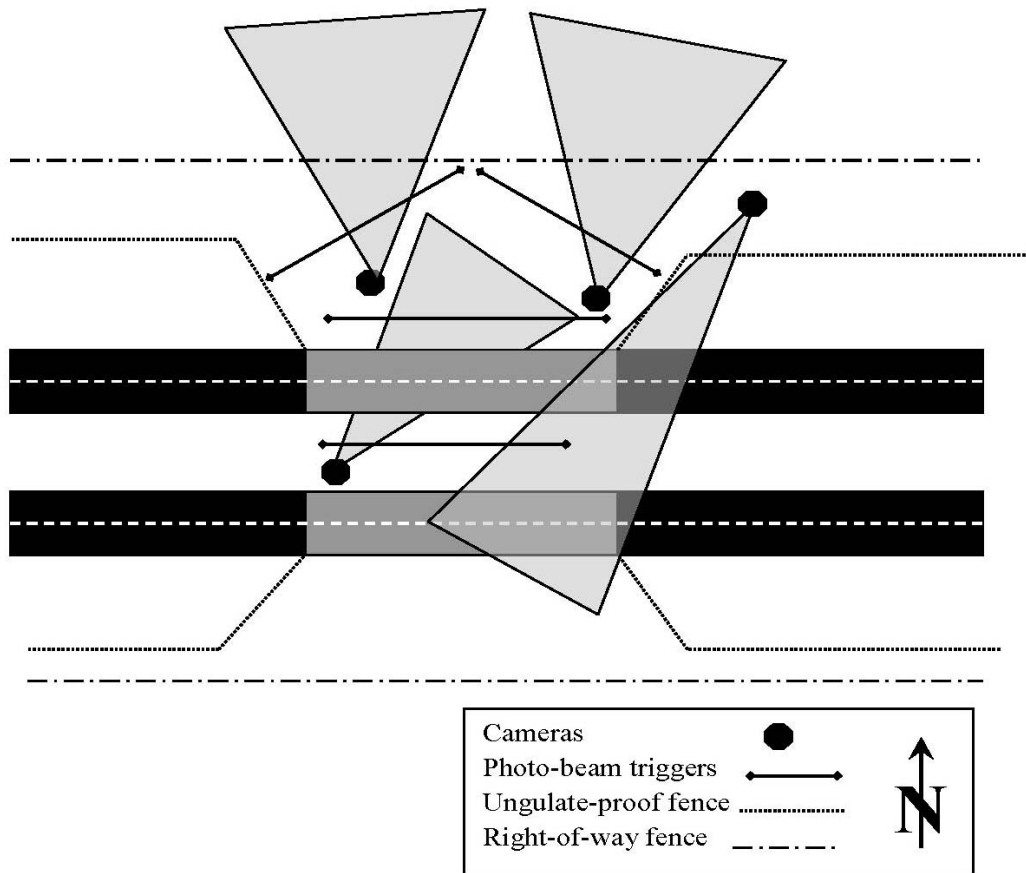


Figure 9. Layout of Video Surveillance System Components at Six SR 260 Wildlife Underpasses.

Note: Video cameras were oriented to record wildlife approaching the underpass (two cameras), animals crossing through the underpass from both directions (one camera), and simultaneous traffic on the highway while animals approached and crossed the underpass (one camera).

The research team used multiple logistic regression analysis to select factors important in predicting a successful crossing through the UPs (Agresti 1996). These calculations were limited to data for elk and white-tailed deer, since they were the only species adequately represented across all UPs. The binomial response variable was based on a successful crossing or noncrossing once a group (≥ 1) of elk or deer approached a UP. The research team deemed factors important by using likelihood-ratio tests to test the significance of each selected factor given the other factors incorporated in the model (Agresti 1996). The team selected factors for analysis based on what previous studies reported were important in affecting elk and deer movements associated with highways. The researchers also believed that temporal availability of structure use was a potentially important factor influencing UP use. Although other wildlife species used the UPs, the sample sizes for those species were inadequate across all UPs to predict their probability of crossing. The research team instead provided overall passage rates and use by all species associated with each UP monitored.

The research team limited its analytical modeling to five factors that generally influenced ungulate movements to determine whether the temporal movements of elk outweighed the importance of UP structure:

- *UP structure and placement* (Clevenger and Waltho 2000, 2005; Gagnon et al. 2006; Dodd, Gagnon, Manzo, et al. 2007)—This factor served as a categorical variable to evaluate the importance of UP structure among the other variables and to compare differences in wildlife use among UPs.
- *Months monitored* (Clevenger and Waltho 2003; Dodd, Gagnon, Manzo, et al. 2007; Olsson et al. 2008)—This factor served as a continuous variable to determine changes in wildlife use since completion of construction.
- *Season* (Bruinderink and Hazebroek 1996; Gunson and Clevenger 2003; Dodd, Gagnon, Manzo, et al. 2007)—This factor evaluated changes in seasonal weather conditions and elk migration patterns:
 - Winter December–February
 - Spring March–May
 - Summer June–August
 - Fall September–November
- *Time of day* (Bruinderink and Hazebroek 1996; Haikonen and Summala 2001; Dodd, Gagnon, Boe, et al. 2007; Dodd, Gagnon, Manzo, et al. 2007)—This factor evaluated four 6-hr periods:
 - Morning 0400–0959 hr
 - Daytime 1000–1559 hr
 - Evening 1600–2159 hr
 - Nighttime 2200–0359 hr

- *Day of week* (Rost and Bailey 1979; Witmer and deCalesta 1985; Gunson and Clevenger 2003; Gagnon 2006)—This factor served as a surrogate variable for traffic level, since SR 260 traffic levels were typically 30 percent higher on weekends than weekdays (Gagnon 2006). Based on local traffic levels, weekday (Monday through Thursday \cong 6,000 AADT) and weekend (Friday through Sunday \cong 8,000 AADT) days served as categorical variables.

The research team limited its logistic regression analysis to the five UPs that were monitored for at least four years to give an adequate representation of seasonal differences and use over time. The team did not analyze data for the Indian Gardens UP since only 2.5 years of data existed and this UP reflected structural changes made adaptively from prior monitoring (Dodd, Gagnon, Manzo, et al. 2007). Once the research team determined the factors that were important to predicting elk and white-tailed deer UP crossing probability, they further analyzed these factors graphically to assess associated patterns. The team examined the significance of the influence that each factor (except months monitored) had in the model in each of the four years. The research team tested model fit using a Hosmer and Lemeshow goodness-of-fit test (Hosmer and Lemeshow 1989). The team used a general linear model with a logistic regression link to determine probabilities of a successful crossing for each of the selected factors and to further provide the odds ratios of a successful crossing for each of the scenarios selected as important by the analysis. The research team used the following equation to calculate probabilities of successful UP crossing:

$$Probability = \left(\frac{\exp(\alpha + \beta x)}{1 + \exp(\alpha + \beta x)} \right)$$

This calculation can be interpreted as the probability of a successful crossing under a given scenario versus that of a failure (1 – probability) once an elk approaches a UP. The α and β terms represent the intercept and log odds, respectively. The research team used months monitored, the only continuous variable, in combination with all other significant factors separately for graphical representation. To calculate the comparative odds ratios for successful elk and deer crossings at any two UPs, the research team divided the odds of a successful crossing at one UP by the odds for the other one being compared.

To evaluate whether elk crossing probabilities at the five UPs changed over the first four monitoring years (potentially affecting conclusions regarding UP efficacy), the research team used analysis of variance (ANOVA) to compare differences among mean UP crossing probabilities for each year (Hays 1981). The team tested the null hypothesis that no differences in elk crossing probabilities and passage rates existed as a function of year. A Tukey test for unequal sample sizes assessed the statistical significance of post hoc pairwise comparisons among years (Hays 1981). The team transformed all proportion data for the ANOVA using an arcsine transformation before analysis (Neter et al. 1996).

3.3 RESULTS

3.3.1 Wildlife Underpass Use

From 2002 to 2008, the research team logged 9,305 days of video surveillance monitoring and recorded 1,428 hours of videotape footage of approaching and crossing wildlife at the six UPs. The video surveillance systems recorded 15,134 animals and 11 different species (Table 4); 10,216 animals, or 67.5 percent, crossed through the UPs. Elk accounted for 68 percent of all animals documented at the UPs, while white-tailed deer and mule deer accounted for 13 percent and 6 percent, respectively (Table 4). The average passage rate for all species at the six UPs was 0.58 crossings/approach; the Indian Gardens UP had the highest overall passage rates (0.78 crossings/approach) for all species combined (Table 4).

In general, the research team noted an increasing degree of species diversity and evenness in distribution recorded at the UPs along a gradient from west to east, corresponding to an increase in elevation. At the west end of the study area, elk accounted for more than 90 percent of all animals recorded on videotape approaching and crossing the two Preacher Canyon section UPs (East and West Little Green Valley); at these same UPs, white-tailed deer accounted for 6 percent, and mule deer <1 percent. At the Indian Gardens UP near the midpoint of the study area, elk accounted for 64 percent of the total animals recorded, white-tailed deer 13 percent, and mule deer still <1 percent (Table 4). At the three UPs on the Christopher Creek section at the eastern end of the study area, elk accounted for 47 percent of all recorded animals, while white-tailed deer accounted for 19 percent and mule deer 15 percent.

In addition to the species listed in Table 4, surveillance systems at five UPs recorded 14 black bears, 7 (50 percent) of which passed through, and 22 mountain lions, 9 of which (41 percent) passed through. The research team did not document any predator-prey interactions at any of the UPs, as described by Little et al. (2002). The surveillance systems recorded javelina at four UPs; the vast majority of javelina (>450) were recorded at the Indian Gardens UP.

The research team recorded an overall mean UP passage rate for elk of 0.61 crossings/approach, ranging from 0.20 at the Wildlife 3 UP to 0.83 at the Indian Gardens UP. For white-tailed deer, the team documented an overall mean passage rate of 0.39 crossings/approach, ranging from 0.06 crossings/approach at the East Little Green Valley UP to 0.96 at the Wildlife 3 UP; the Pedestrian-Wildlife UP had the highest white-tailed deer use (936 on videotape) and a mean passage rate of 0.51 crossings/approach (Table 4).

Table 4. Number and Types of Animals Recorded by Video Surveillance at Six SR 260 Underpasses, 2002–2008.

Wildlife UP	Wildlife Species Recorded on Videotape									
	Elk	WT Deer	Mule Deer	Coyote	Gray Fox	Raccoon	Other	All		
West Little Green Valley	2,179	198	9	14	15	5	146	2,445		
East Little Green Valley	3,789	279	2	91	49	24	248	4,482		
Pedestrian-Wildlife	1,098	965	66	45	127	168	71	2,455		
Wildlife 2	1,743	96	798	27	55	20	136	2,778		
Wildlife 3	125	145	90	2	2	99	24	487		
Indian Gardens	1,398	286	2	21	4	17	461	2,189		
Total	10,332	1,996	967	200	252	333	1,084	15,134		
West Little Green Valley	1,626	30	0	5	10	5	143	1,819		
East Little Green Valley	2,927	42	0	23	27	24	256	3,299		
Pedestrian-Wildlife	789	660	37	24	78	68	16	1,672		
Wildlife 2	1,160	46	647	9	35	9	83	1,989		
Wildlife 3	33	116	72	2	2	98	18	341		
Indian Gardens	1,295	174	2	14	4	14	341	1,844		
Total	7,830	1,068	758	77	156	218	857	10,216		
West Little Green Valley	0.71	0.11	—	0.67	0.67	1.00	0.83	0.67		
East Little Green Valley	0.71	0.06	—	0.22	0.58	1.00	0.90	0.58		
Pedestrian-Wildlife	0.68	0.51	0.42	0.28	0.64	0.57	0.10	0.46		
Wildlife 2	0.48	0.27	0.61	0.55	0.59	0.35	0.53	0.48		
Wildlife 3	0.20	0.96	0.61	—	—	0.90	0.45	0.62		
Indian Gardens	0.83	0.44	—	0.67	1.00	0.67	0.57	0.78		
Total	0.61	0.39	0.55	0.46	0.70	0.75	0.56	0.58		

3.3.2 Factors Influencing Successful Elk Underpass Crossings

Of the five factors included in the logistic regression model, four were important in predicting the probability of a successful elk crossing during the first four years of monitoring (Table 5). These factors included UP structure and placement, months monitored, season, and time of day. Day of the week, the surrogate factor for traffic volume, did not have a significant influence on crossing probabilities when elk crossed the highway below grade at UPs, similar to that found by Gagnon, Theimer, Dodd, Manzo, et al. (2007); model fit was adequate for continued analysis (Hosmer and Lemeshow test; $\chi^2 = 7.58$, $df = 8$, $P = 0.480$).

Table 5. Likelihood-Ratio Test Results for Factors Influencing Elk Crossings at SR 260 Underpasses.

Model Factor ^a	df ^b	Likelihood-Ratio χ^2	χ^2 Probability
UP structure and placement	4	170.6	<0.001 ^c
Months monitored	1	52.1	<0.001 ^c
Season	3	27.5	<0.001 ^c
Time of day	3	4.7	0.019 ^c
Day of week	1	<0.1	0.990

^a Factors modeled by logistic regression for determining the probability of a successful elk crossing at five underpasses during the first four monitoring years by video camera surveillance, 2002–2008.

^b df = degrees of freedom

^c Corresponds to those factors that had a significant influence on elk underpass-crossing probabilities.

Modeling identified UP structure and placement as the most important factor, therefore suggesting that this factor likely was of primary importance in predicting the probability of successful elk passage (Table 5). The duration of UP monitoring was the second most important factor, followed closely by season. Time of day had the least influence on probability of elk successfully crossing at a UP. UP structure and placement was a significant influence in all four years, season in the first three years, and time of day only in the first year; day of week did not have a significant influence in any individual year (Table 6).

Table 6. Significant Factors in Predicting the Probability of Elk Crossings at SR 260 Underpasses.

Model Factor	Year Monitored ^a			
	1	2	3	4
UP structure and placement	X	X	X	X
Season	X	X	X	NS
Time of day	X	NS	NS	NS
Day of week	NS	NS	NS	NS

^a X = significant factor; NS = not significant factor.

The probability of a successful elk crossing among UPs ranged from 0.76 at the East Little Green Valley UP to only 0.08 at the Wildlife 3 UP (Table 7). Statistical analysis using pairwise comparisons showed that the odds of elk crossing at the East Little Green Valley UP were higher than all others—ranging from 37.7:1 odds, compared to a successful crossing at the Wildlife 3 UP, to 1.3:1 odds, compared to a successful crossing at the West Little Green Valley (Table 8). The odds of a successful elk crossing at the Wildlife 3 UP were lower than all other UPs.

Table 7. Probability of Successful Elk and White-Tailed Deer Crossings at SR 260 Underpasses.

Wildlife Underpass	Elk	White-Tailed Deer
East Little Green Valley	0.76	0.08
West Little Green Valley	0.73	0.09
Pedestrian-Wildlife	0.65	0.52
Wildlife 2	0.52	0.20
Wildlife 3	0.08	0.67

Table 8. Comparison of Odds of a Successful Elk Crossing at SR 260 Wildlife Underpasses.

Wildlife Underpass	East Little Green Valley	West Little Green Valley	Pedestrian-Wildlife	Wildlife 2	Wildlife 3
East Little Green Valley		1.3:1	1.8:1	3:1	37.7:1
West Little Green Valley	1:1.3		1.4:1	2.3:1	29.8:1
Pedestrian-Wildlife	1:1.8	1:1.4		1.7:1	21.6:1
Wildlife 2	1:3	1:2.3	1:1.7		12.9:1
Wildlife 3	1:37.7	1:29.8	1:21.6	1:12.9	

Note: Number on the left side of each ratio is associated with the structures listed in each column.

3.3.3 Factors Predicting Successful White-Tailed Deer Underpass Crossings

Of the five factors included in the logistic regression model, UP structure and placement was the only factor important in predicting the probability of a successful white-tailed deer crossing during four years of monitoring (Table 9). None of the other factors had a significant influence on deer crossing probability in any individual year (Table 10).

The probability of a successful deer crossing among UPs contrasts to those for elk, ranging from 0.08 at the East Little Green Valley UP to 0.67 at the Wildlife 3 UP (Table 7). A statistical analysis with pairwise comparisons between the five UPs indicated that the odds of successful deer crossing at the Wildlife 3 UP were higher than for others, ranging from 21.4:1 odds compared to the East Little Green Valley UP to

2:1 odds compared to the Pedestrian-Wildlife UP (Table 11). While the odds of a successful crossing were lowest for elk at the Wildlife 3 UP, the odds were higher for deer at that UP than all other UPs (Table 8).

Table 9. Likelihood-Ratio Test Results for Factors Influencing White-Tailed Deer Crossings at SR 260 Underpasses.

Model Factor	df ^a	Likelihood-Ratio χ^2	χ^2 Probability
Underpass structure and placement	4	85.3	<0.001 ^b
Months monitored	1	<0.1	0.982
Season	3	2.6	0.457
Time of day	3	3.8	0.294
Day of week	1	<0.1	0.845

^a df = degrees of freedom.

^b Corresponds to factors that had a significant influence on elk underpass crossing probabilities.

Table 10. Significant Factors in Predicting Probability of White-Tailed Deer Crossings at SR 260 Underpasses.

Model Factor	Year Monitored ^a			
	1	2	3	4
Underpass structure and placement	X	X	X	X
Season	NS	NS	NS	NS
Time of day	NS	NS	NS	NS
Day of week	NS	NS	NS	NS

^a X = significant factor; NS = not significant factor.

Table 11. Comparison of Odds of a Successful White-Tailed Deer Crossing at SR 260 Wildlife Underpasses.

Wildlife Underpass	East Little Green Valley	West Little Green Valley	Pedestrian-Wildlife	Wildlife 2	Wildlife 3
East Little Green Valley		1:1.3	1:10.6	1:2.6	1:21.4
West Little Green Valley	1:1.3		1:7.9	1:1.9	1:16
Pedestrian-Wildlife	10.6:1	7.9:1		1.4:1	1:2
Wildlife 2	2.6:1	2.3:1	1:4.1		1:8.3
Wildlife 3	21.4:1	16:1	2:1	8.3:1	

Note: Number on the left side of each ratio is associated with the structures listed in each column.

3.3.4 Influence of Duration of Video Surveillance Monitoring

The second most important factor influencing the probability of successful elk crossings, the time elapsed since UP installation, measured by UP monitoring, likely relates to the learning curve associated with elk habituation to the structures since construction. The overall probability of a successful elk crossing increased steadily over four years: 0.55 in the first, 0.62 in the second, 0.68 in the third, and 0.73 in the fourth year. The probabilities of a successful elk crossing at individual UPs also steadily increased over time for all UPs except the Wildlife 3 UP (Figure 10). By the fourth year, the probabilities of elk crossing converged for four UPs, all >0.70 (Figure 10); the initially low (<0.10) probability of crossing at the Wildlife 3 UP actually decreased over the four years. Mean elk passage rates followed the same trend as crossing probabilities: 0.50 crossings/approach in the first year, 0.66 in the second, 0.64 in the third, and 0.82 crossings/approach by the fourth.

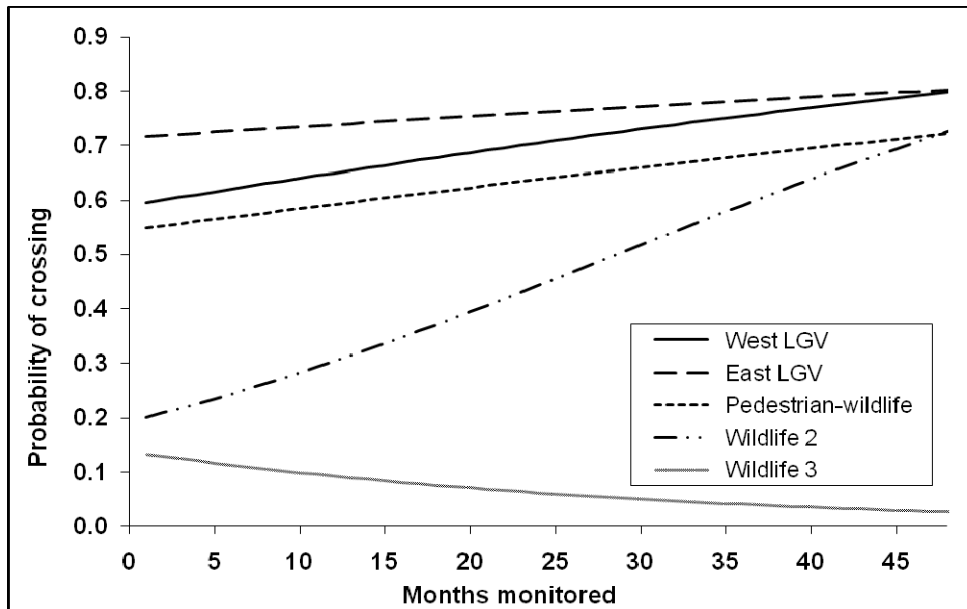


Figure 10. Probability of a Successful Crossing by Elk at Five SR 260 Wildlife Underpasses (LGV = Little Green Valley).

Though the elapsed time (duration of monitoring) was not a significant factor in the logistic regression model predicting white-tailed deer crossings, since probabilities were static over time, a large increase in crossing probability occurred at the Wildlife 3 UP over the four years (Figure 11).

The ANOVA of elk crossing probabilities among the first four monitoring years at the five UPs found that there were differences among the UP means by year ($F_{3, 4} = 4.06$, $P = 0.033$). Post hoc comparisons among years indicated that the differences among years in the ANOVA was limited to that of the first year (mean = 0.47) versus fourth year (mean = 0.62) ($P = 0.045$), over which the mean probability increased 32 percent (Figure 10).

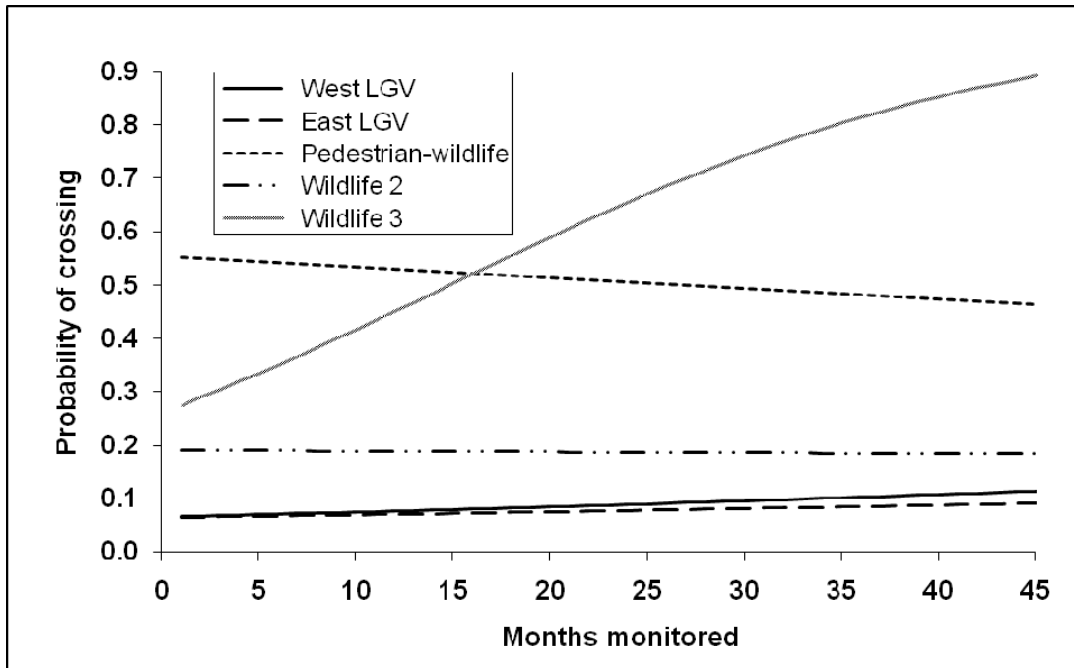


Figure 11. Probability of a Successful Crossing by White-Tailed Deer at Five SR 260 Wildlife Underpasses (LGV = Little Green Valley).

3.3.5 Influence of Season

Season had nearly as great an influence on the probability of successful elk crossing as the elapsed time since installation. The highest number of elk UP crossings occurred in spring during the period of forage green-up in meadows adjacent to SR 260, coupled with elk migration back to the summer range atop the Mogollon Rim (Figure 12). The mean elk passage rate for the five UPs was at its highest in spring and summer (>0.65) but dropped to its lowest (0.55) in fall and winter when nonhabituated migratory elk were present along SR 260 (Figure 12). For the first four monitoring years combined, seasonal crossing probabilities ranged widely from 0.48 in winter to 0.53 in spring to 0.72 in summer, then dropping to 0.31 in fall.

However, like elk crossing probabilities by UP over the four years, crossing probabilities by season converged to >0.65 by the fourth year (Figure 13). Likewise, the recurring pattern of seasonal fluctuations that the research team noted in mean elk UP passage rates evident in the first three years (e.g., <0.40 crossings/approach in fall-winter and >0.80 in spring-summer) did not occur in the fourth year; there was a general upward trend in passage rates over the first four years at the five UPs (Figure 14).

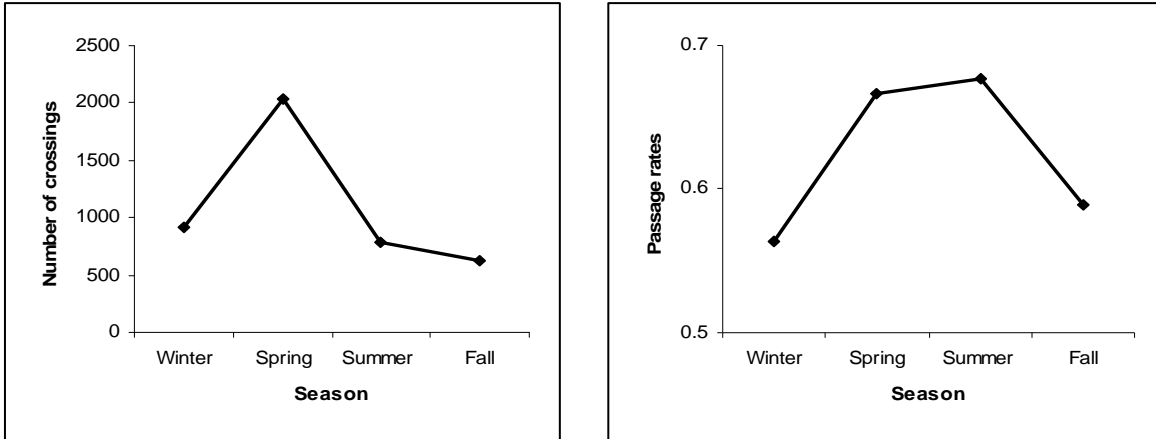


Figure 12. Number of Elk Underpass Crossings (Left) and Mean Passage Rates (Right) by Season at Five Underpasses along SR 260, 2002–2008.

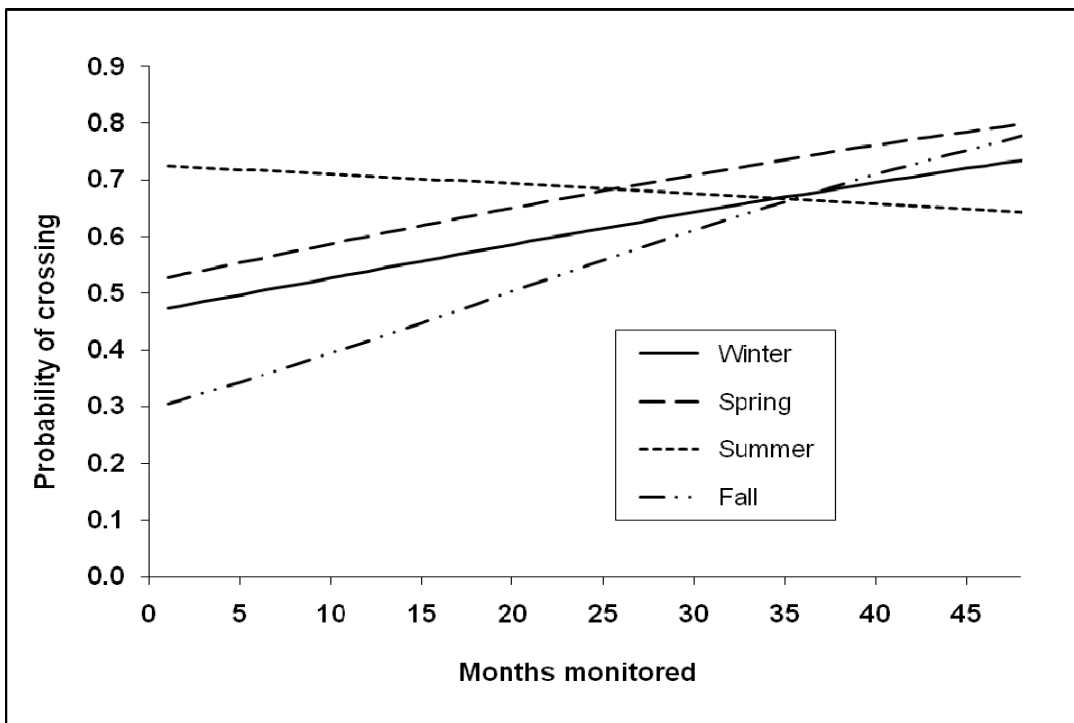


Figure 13. Probability of a Successful Elk Crossing by Season at Five Underpasses along SR 260.

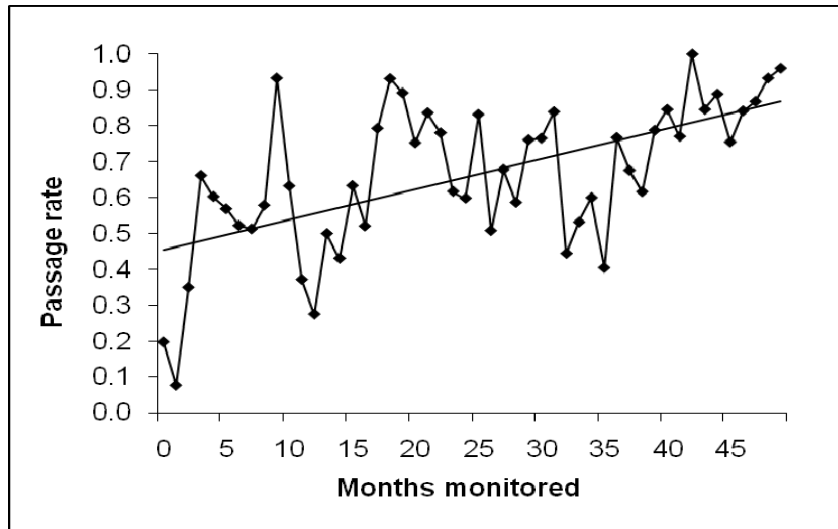


Figure 14. Mean Elk Passage Rates (Crossings/Approach) at Five Underpasses along SR 260, 2002–2008.

3.3.6 Influence of Time of Day

Time of day had an influence on the probability of elk successfully crossing the five UPs (Table 5), though when considered by individual year its contribution was only significant in the first year (Table 6). This is not to say that time of day was not an important factor in elk UP crossings, which showed a strong bimodal pattern of crossings in the evening and morning (Figure 15). Both the elk UP passage rate and the probability of a successful UP crossing (0.55) were highest during the nighttime hours; crossing probabilities were somewhat lower in the evening (0.47) and morning (0.39) and considerably lower during daytime hours (0.22). However, like the convergence of probabilities of crossing by UP and season, the researchers noted a similar convergence in probability of crossing by time of day over the first four years, given that the probability of crossing increased for all four time periods across each of the four monitoring years.

3.3.7 Wildlife Use of the Indian Gardens Underpass

Though not included in the logistic regression analysis, monitoring of the Indian Gardens UP nonetheless provided valuable insights to understanding wildlife use of these structures. Unlike all other UPs that exhibited relatively low elk passage rates in their first year (mean = 0.50 crossings/approach), the passage rate at the Indian Gardens UP after six months was >0.75 crossings/approach and exceeded 0.80 by the end of the first year (Figure 16). The mean elk passage rate for the other five UPs did not attain this passage rate level until the fourth year. The Indian Gardens UP exhibited an above-average passage rate among all six UPs for white-tailed deer (0.44 crossings/approach versus the mean of 0.39), and the highest overall passage rate across all species (0.78 versus the mean of 0.58).

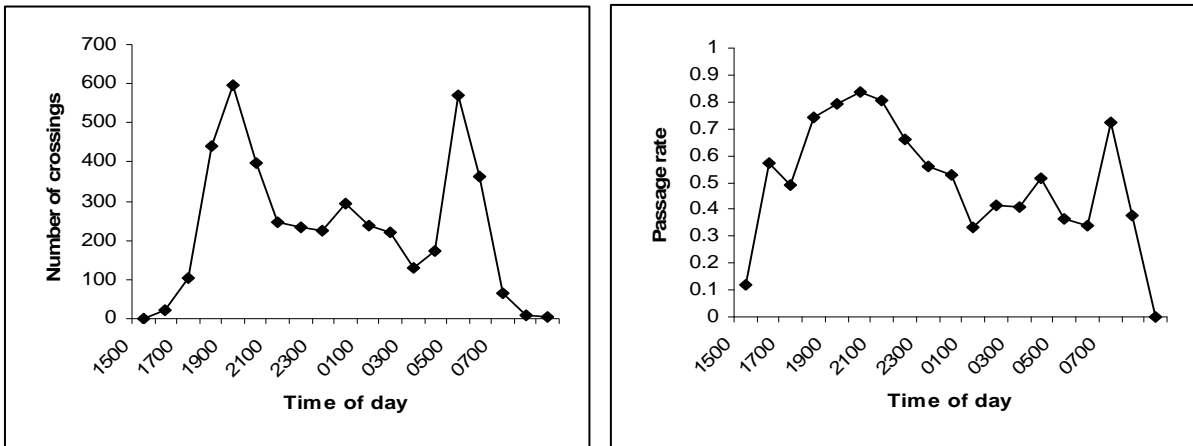


Figure 15. Number of Elk Underpass Crossings (Left) and Passage Rates (Right) by Time of Day along SR 260, 2002–2008.

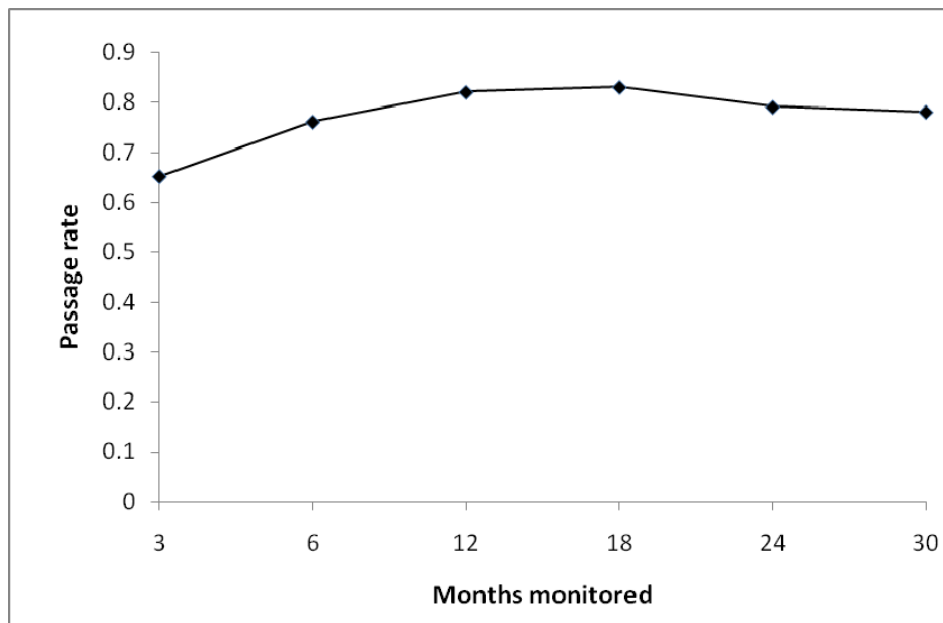


Figure 16. Mean Elk Passage Rates (Crossings/Approach) for Elk Approaching and Crossing Indian Gardens Underpass, 2006–2008.

3.4 DISCUSSION

Video camera surveillance constituted a valuable means to assess and compare wildlife use of the six UPs, particularly with passage rate and probability of UP crossing as metrics for comparison and evaluation of UP efficacy (Dodd, Gagnon, Manzo, et al. 2007). Compared to the extensive replications of similar types and placements of UPs available to Clevenger and Waltho (2000, 2005) and Ng et al. (2004) in their modeling of

structural factors, the replications available for the SR 260 experimental design modeling were limited. Nonetheless, the results still provide compelling insights relative to the influence of UP design, placement, and other factors on wildlife use, including different species' responses to the same UPs. The research team's long-term monitoring illustrates the influence that UP monitoring duration has on formulating conclusions about the efficacy of the UPs, as stressed by Clevenger and Waltho (2003).

3.4.1 General Efficacy of Underpasses

Regardless of the metric, the fact that over two-thirds of the 15,134 animals recorded on videotape at the six UPs successfully crossed SR 260 below grade via the UPs underscores the overall efficacy of these structures in promoting wildlife passage and motorist safety. The research team believes that an equal or greater number of animals likely crossed below grade at the seven other passage structures that the research team did not monitor; those passage structures have larger span widths that make them difficult to monitor but that make them highly suitable for animal passage. Where UPs occur with fencing, the incidence of EVCs has declined dramatically and highway safety has increased (Dodd, Gagnon, Boe, et al. 2007; Dodd et al. 2007b; Gagnon et al. 2010). By the fourth year of monitoring, the mean elk passage rate among UPs exceeded 80 percent and no longer exhibited the dramatic seasonal fluctuations tied to migratory animals that previous research documented and considered a limitation to year-round UP efficacy (Dodd, Gagnon, Manzo, et al. 2007). Given these recent monitoring results, and that elk have historically accounted for the vast majority of WVCs, property damage, and human injuries, the application of wildlife UPs along SR 260 can be considered a success.

3.4.2 Influence of Underpass Structural Characteristics

Because modeling determined UP structure and placement as the most important factor influencing the probability of a successful elk crossing, the research team believes that this factor reflects variation among UPs relative to structural design, placement, or both. However, the team's interpretation is based on limited replications of UP design and placement. Little Green Valley, with its two adjacent UPs (East and West), was the only section where placement could be controlled to allow for a comparison of design alone (Dodd, Gagnon, Manzo, et al. 2007).

Given the differences in UP structural design and placement characteristics among the five UPs, the research team nonetheless believes that the results provide valuable insights on the influence of structural design and placement. Other studies have reported such attributes as crucial to achieving successful wildlife use of UPs (Reed et al. 1975; Beier and Loe 1992; Foster and Humphrey 1995; Clevenger and Waltho 2000, 2005; Forman et al. 2003). Even though elk crossing probabilities converged for four of the five UPs analyzed by the fourth monitoring year, passage rates and comparative odds of successful UP crossing still point to differences in use. Furthermore, while the convergence of the probabilities of crossing at these UPs reflects the habituation and learning potential of elk over time, even among nonresident migratory animals, the differences in use and learning

curves associated with each UP structure still reflect important UP structural and placement characteristics.

Five of the six monitored UPs were of a similar large, twin open-span bridge design (Figures 7 and 8) varying in span length (110–135 ft) and height (17–41 ft). Excluding the Wildlife 3 UP (the only single bridge structure without an atrium) and given enough time to allow habituation to UPs, all SR 260 structures became effective for elk passage; in some instances (e.g., Wildlife 2 UP) they became effective in spite of structural or placement limitations. That elk overcame these limitations should not be construed to imply that transportation agencies should ignore the design characteristics that created the limitations. Rather, the goal should remain to construct the best passage structures possible to maximize both wildlife use and habituation given constraints such as funding, topography, and other factors. The Indian Gardens UP (Figure 17) exemplifies the importance and benefit of adaptive management improvements (Dodd, Gagnon, Boe, et al. 2007; Dodd, Gagnon, Manzo, et al. 2007). Modifications to the Indian Gardens UP design eliminated concrete walls for soil stabilization below the bridge spans, thus opening up the floor of the UP and preserving natural vegetation. These improvements resulted in a range of species rapidly accepting the Indian Gardens UP as a passageway. Considerations to maximize use and learning that reflect insights gained from monitoring structures along SR 260 and elsewhere need not add cost to the construction of passage structures.



Figure 17. Photographs Showing Open Nature and Preserved Native Vegetation of Indian Gardens Underpass on the SR 260 Kohl's Ranch Section.

Dodd, Gagnon, Manzo, et al. (2007) previously reported significantly different probabilities of elk crossing at the East and West Little Green Valley UPs after just 2.5 years of video surveillance. Now, after another three years of monitoring, both UP elk passage rates and probabilities of successful elk crossing are identical. Over time, elk have habituated to the West UP as reflected in steadily increasing passage rate and probability of elk crossing. However, due to the proximity of the two UPs, the research team believes that elk have also learned to avoid approaching the West UP altogether, instead approaching and crossing at the East UP. With 1.8 times more elk having crossed through the East UP (Table 4), some animals have likely habituated to using the West UP, while some simply have avoided approaching it and instead use the East UP, reducing the proportion of failed crossings and thus resulting in higher passage rates and probabilities.

While the success of both Little Green Valley UPs is attributable to their proximity to the preferred meadow foraging area and placement in established drainage travel corridors (Dodd, Gagnon, Manzo, et al. 2007), the higher elk use of the East UP reflects differences in structural attributes. The East UP has a twofold higher openness ratio (Reed et al. 1979), half the distance for animals to traverse through the UP, and 2:1 earthen sloped sides. In addition to these structural attributes, the research team still believes that the concrete retaining walls at the West UP (Figure 7) have continued to influence the lower incidence of elk use compared to the East UP, as described by Dodd, Gagnon, Manzo, et al. (2007). The research team frequently observed animals standing at the mouth or just inside the West UP and looking upward from side to side.

Although the researchers did not specifically address predator-prey interactions, they did not document any such interactions either, as was also the case with Little et al. (2002). Elk nonetheless appeared hypervigilant of predators potentially lurking atop the concrete walls of the West UP. Little et al. (2002) recommended designing UPs for prey species (e.g., elk, deer) to minimize predation risk with short, wide, and high passages. Though several factors contributed to the difference in elk use of the UPs, the research team believes that differential use is largely attributable to ledge effect, unnatural feel, and possible noise properties associated with its concrete walls. As such, even with the now-identical elk passage rate and probability of UP crossing, the research team still recommends that use of mechanically stabilized earth retaining walls be avoided in UP design and construction where possible, as Dodd, Gagnon, Boe, et al. (2007) and Dodd, Gagnon, Manzo, et al. (2007) previously recommended.

Of the five UPs monitored, the Wildlife 2 UP exhibited the most dramatic increase in the probability of successful elk crossing over the first four years of monitoring (Figure 10). This UP was unique in its bridge placement and alignment; the bridges at the other UPs were constructed in line, allowing approaching animals to see completely through the structures. The Wildlife 2 UP bridges were offset along the existing drainage alignment (Figure 8). Fill slopes due to the offset bridge placement obstructed elk views through the UP at floor level. During the first year of monitoring (2004), the elk passage rate for the Wildlife 2 UP was only 0.12 crossings/approach. Since then, the elk passage rate has improved steadily to >0.80 crossings/approach (and the probability of crossing >0.70),

pointing to both the ability of elk to habituate to UPs (Clevenger and Waltho 2003) and the benefit of fencing installed in 2005 that forced animals to use the UPs instead of continuing to crossing at grade (Dodd et al. 2007b). Where UP design and construction involves twin bridges with atria, it is recommended that the bridges be aligned such that visibility through the structures is maximized.

The Wildlife 3 UP was the only single-bridge structure constructed and monitored along SR 260 (Figure 8); this UP had the lowest passage rate and probability of a successful crossing for elk among the UPs monitored. Unfortunately, the research team believes that the placement of the Wildlife 3 UP in proximity to the Arizona ADOT Colcord maintenance yard and residences (with associated human- and pet-related disturbances) overrode the influence of its structural design characteristics. Clevenger and Waltho (2000) found that human activity at wildlife UPs, especially soon after construction, adversely affects wildlife use. The probability of deer successfully using this UP dramatically increased since completion (Figure 11); it appears that resident deer have become accustomed to this structure and the associated human activity.

There was considerable variation in white-tailed deer UP crossing probabilities and passage rates among UPs. UP structure and placement was the only significant factor in predicting the probability of UP crossings. Deer use of both the Little Green Valley UPs and the Wildlife 2 UP was consistently lower than use of other UPs. Even after six years of monitoring, deer use of the Little Green Valley UPs remained very low, though an increase in deer passage was noted in the fifth and sixth years after the fencing was completed (Gagnon et al. 2010).

The low use of the Little Green Valley UPs and the Wildlife 2 UP reflects their placement and adjacent habitat conditions more than their structural characteristics. The Coues subspecies of white-tailed deer in Arizona are secretive and prefer dense cover rather than open grassland areas (Ockenfels et al. 1991). The two Little Green Valley UPs connect ponderosa pine forest cover on the north to the large meadow complex to the south (Figure 7). The research team believes that deer avoidance of the meadow accounts for the low probability of crossing and passage rates at the Little Green Valley UPs. The increase in deer passage at the West Little Green Valley UP after fencing (Gagnon et al. 2010) supports the team's conclusion, since deer that presumably crossed the highway at grade to the west before fencing now are relegated to crossing at the UP. All other SR 260 UPs link cover on both sides of the UP approaches.

The relatively low probability of white-tailed deer crossing at the Wildlife 2 UP may reflect their inability to adapt over time like elk to the offset nature of the UP bridges that caused limited sight distance (Figure 8), especially compared to the Pedestrian-Wildlife UP with its wide atrium. More white-tailed deer crossed through the Pedestrian-Wildlife UP than all other five UPs combined. Contrary to the findings of Clevenger and Waltho (2000), where human presence in proximity to passage structures limited wildlife use, the research team found that human use of the Pedestrian-Wildlife UP for crossing between communities did not appear to diminish elk or deer use of the UP. Most human use was limited to daytime hours, while wildlife use typically occurred at night and thus did not

present a conflict. While elk did not adapt to the more constant and pervasive human presence at the Wildlife 3 UP, deer exhibited increasing probability of use over time (Figure 11) and thus a degree of adaptability to the conditions associated with the UP.

Elk and white-tailed deer exhibited dramatically different passage rates and probabilities of crossing SR 260 UPs. This is not surprising, since other multispecies assessments of passage structure use have shown that different species responded differently to structure configuration and adjacent landscape features and have different learning curves (Clevenger and Waltho 2003). Olsson et al. (2008) noted different responses to use of the same overpasses by moose and roe deer that he believed was tied to differences in home-range size and relative degree to which animals encounter passage structures. Although some SR 260 UPs showed effective use by a single species, such as elk use of the two Little Green Valley UPs or white-tailed deer use at the Wildlife 3 UP, other UPs, such as the Pedestrian-Wildlife and Indian Gardens UPs, exhibited balanced use by multiple species. Successfully accommodating such multispecies passages constitutes another metric of efficacy demonstrated by several of the SR 260 UPs.

3.4.3 Influence of Duration of Video Surveillance Monitoring

Clevenger and Waltho (2003) reported that UP structural dimensions had little effect on wildlife passage associated with 12-year-old UPs along the Trans-Canada Highway, because animals had adapted to them over that period. This was also the case for elk use of UPs along SR 260, with crossing probabilities for four of the five UPs having converged by the fourth year (Figure 11). Dodd, Gagnon, Manzo, et al. (2007) concluded that there were significant differences in elk use of the two Little Green Valley UPs after 2.5 years of monitoring. Had the research team rendered conclusions about UP efficacy for all SR 260 UPs after 1.4 years of monitoring (the mean period of UP monitoring reported by Clevenger and Waltho 2003) instead of after 4 years of monitoring, the team would have reached very different conclusions. The ability of ungulates to adapt and habituate to passage structures has been well documented (Reed et al. 1975; Clevenger and Waltho 2000, 2003; Olsson 2007). Clevenger and Waltho (2003) found relatively rapid acceptance of new UPs by elk, achieving peak use within two years. Dodd, Gagnon, Manzo, et al. (2007) reported a high degree of elk habituation to SR 260 UPs within 1.5 years. The research team now believes that elk learning and habituation continues for as long as four years, even for the relatively large bridge structures.

One of the more significant findings with continued monitoring was the diminished recurring pattern of lower elk passage rates in the winter season (Figure 13). After 2.5 years of monitoring, Dodd, Gagnon, Manzo, et al. (2007) believed that such fluctuations coincided with elk migration off the Mogollon Rim to wintering areas adjacent to SR 260 (Brown 1990); these nonresident elk diluted the influence of habituated resident elk. Migratory elk did not exhibit the same propensity for habituation to UPs as resident elk. Dodd, Gagnon, Boe, et al. (2007) and Dodd, Gagnon, Manzo, et al. (2007) speculated that seasonal declines in passage rates had the potential to limit the achievement of consistently high year-round UP effectiveness. They further believed that ungulate-proof fencing was the key to maximizing UP use by funneling a greater proportion of animals

to UPs and limiting options for elk crossing the highway elsewhere (Ng et al. 2004). With the reconstruction of three SR 260 sections and the erection of ungulate-proof fencing (about every 1.0 mi) to funnel animals to passage structures, the year-round elk passage rate has stabilized. Continued migratory elk habituation to the UPs above what Dodd, Gagnon, Manzo, et al. (2007) had anticipated also has likely contributed to this improvement in yearlong UP passage devoid of seasonal fluctuations (Figure 13).

That elk crossing probabilities by time of day had also converged by the fourth year does not diminish the fact that most crossings occurred after sunset and before sunrise (Figure 15), coinciding with 67 percent of EVCs (Dodd et al. 2006) that occurred in the three hours before and three hours after sunrise or sunset (Haikonen and Summala 2001; Gunson and Clevenger 2003). Rather, the high probability of elk crossing during the peak periods, coupled with increased probability of crossing at other times due to learning, likely accounted for the convergence associated with time of day.

Lastly, the research team did not find that day of the week, the surrogate variable for traffic volume in the logistic regression modeling, had an influence on the probability of elk UP crossing. This was a significant finding, because it indirectly suggests that traffic volume does not influence wildlife UP use. This corroborates the findings by Gagnon, Theimer, Dodd, Manzo, et al. (2007) that traffic volume had little impact on elk passage below grade at wildlife UPs. Conversely, traffic volume was found to influence elk crossing patterns and distribution when animals crossed at grade (Gagnon, Theimer, Dodd, and Schweinsburg 2007). The research team found similar relationships between white-tailed deer crossing patterns, both at and below grade, to traffic volume (see Chapter 6 of this report).

3.4.4 Influence of Fencing on Wildlife Underpass Use

The varying lengths of fencing and the timing of fencing installation along the different highway sections prevented the research team from finding a consistent means to assess the relationship of ungulate-proof fencing associated with each UP. As such, this factor could not be incorporated into the logistic regression analysis. However, various aspects of the research team's monitoring have provided insights on the role of fencing in promoting UP use by wildlife.

Similar to Dodd et al. (2007b), the research team conducted a comparison of wildlife use at the Pedestrian-Wildlife UP and Wildlife 2 UP 9 months before (2004) and 11 months after (2005) the installation of ungulate-proof fencing. Before fencing, the team video recorded 500 elk and deer at the two UPs and documented a passage rate of only 0.12 crossings/approach; 81 percent of animals continued to cross the highway at grade, and 52 EVCs were recorded on the Christopher Creek section in the year before fencing. After fencing, the team video recorded 595 elk and deer and documented an increased passage rate of 0.56 crossings/approach; no animals crossed the highway at grade, and EVCs declined 79 percent. Dodd et al. (2007b) also found that the probability of an approaching animal crossing through a UP increased from 0.09 to 0.56 with fencing,

and the combined odds of a successful crossing through the UP after fencing were 13.6 times higher than before fencing.

In comparison, after the installation of fencing along the entire Preacher Canyon section in 2006, the research team did not note a significant change in elk use of the West Little Green Valley UP, for which the passage rate already exceeded 0.85 crossings/approach before fencing (Gagnon et al. 2010). White-tailed deer use of this UP, however, did increase dramatically with fencing. Whereas only six deer crossed through the UP in the four years before fencing, including only one in the full year before fencing (0.04 crossings/approach), 61 deer crossed in the year after fencing, resulting in an eightfold increase over the before-fencing passage rate (0.30 crossings/approach). The odds of a successful deer crossing after fencing versus before fencing were 38:1. EVCs were reduced by 97.2 percent after fencing, compared to the mean collision incidence from 2001 to 2005.

4.0 EFFECTIVENESS OF PASSAGE STRUCTURES AND FENCING IN MINIMIZING WILDLIFE-VEHICLE COLLISIONS

4.1 INTRODUCTION

The transportation community's recognition of the impact of highways on wildlife populations increased greatly in the 1990s (Forman et al. 2003). Studies have characterized these impacts as some of the most prevalent and widespread forces affecting natural ecosystems in the United States (Noss and Cooperrider 1994; Forman and Alexander 1998; Trombulak and Frissell 2000; Farrell et al. 2002). In addition to direct habitat loss (Forman 2000), mortality from WVCs is a serious and growing problem for wildlife, motorist safety, and property loss (Reed et al. 1982; Farrell et al. 2002; Schwabe and Schuhmann 2002). Over 38,000 human deaths that occurred in the United States between 2001 and 2005 were attributable to WVCs, with an economic impact exceeding \$8 billion/year (Huijser et al. 2007). Estimates of annual collisions involving deer in the United States have been as high as 1.5 million (Conover 1997). Most assessments of WVCs in North America have focused on deer (Reed and Woodward 1981; Bashore et al. 1985; Romin and Bissonette 1996b; Hubbard et al 2000). Only recently have WVC assessments specifically addressed EVC patterns (Gunson and Clevenger 2003; Biggs et al. 2004; Dodd et al. 2006; Dodd, Gagnon, Boe, et al. 2007).

Insights gained from WVC assessments have been instrumental in developing strategies to reduce collisions (Romin and Bissonette 1996a; Farrell et al. 2002), including planning passage structures and fencing to reduce at-grade crossings and maintain permeability (Clevenger et al. 2002; Dodd, Gagnon, Manzo, et al. 2007). Consistent tracking of WVCs is a valuable tool for identifying locations for passage structures (Dodd et al. 2006; Dodd, Gagnon, Boe, et al. 2007), for assessing the impact of highway construction (Romin and Bissonette 1996b), and for evaluating the efficacy of passage structures and other measures (e.g., fencing) in reducing WVCs (Reed and Woodward 1981; Ward 1982; Clevenger et al. 2001b).

Ungulate-proof fencing ranging in height from 6.5 to 8.0 ft has been effective in reducing the incidence of WVCs, especially when used in conjunction with passage structures (Romin and Bissonette 1996a; Forman et al. 2003; Dodd, Gagnon, Boe, et al. 2007; Dodd et al. 2007b). Though fencing is effective in reducing WVCs, fencing without passage structures contributes to a barrier effect and fragments populations and habitats (Forman et al. 2003). In Wyoming, Ward (1982) reported a more than 90 percent reduction in mule deer collisions with vehicles with the combination of UPs and fencing. Woods (1990) reported 94–97 percent reductions in WVCs involving several species in Alberta by the addition of both passages structures and fencing, while Clevenger et al. (2001b) reported an 80 percent reduction in the same area. Similar reductions in moose-vehicle collisions in Sweden were also attributable to fencing combined with structures (Lavsund and Sandegren 1991).

Though such studies have found the addition of fencing to be effective in reducing WVCs, other studies have reported mixed results (Falk et al. 1978), especially where animals cross at the ends of fencing, resulting in zones of increased incidence of WVCs (Feldhamer et al. 1986; Woods 1990; Clevenger et al. 2001b). Fencing is costly and requires substantial maintenance (Forman et al. 2003), making it difficult for transportation agencies to justify fencing long stretches of highways. While fencing is often regarded as an integral component of effective passage structures (Romin and Bissonette 1996a; Forman et al. 2003), limited information or guidelines exist for the application of fencing.

With the reconstruction of SR 260, ADOT's initial approach for integrating 8-ft ungulate-proof fencing was to erect limited (<300 ft) wing fences outward from each UP and most bridge abutments. As research showed this approach to be inadequate, fencing was later guided by an adaptive management approach. Data from prior research phases have been used to make modifications to UP design (Dodd, Gagnon, Boe, et al. 2007) and the strategic placement of fencing to intercept crossing wildlife as determined from GPS telemetry (Dodd et al. 2007a). A key aspect of the research team's efforts was to evaluate the efficacy of this limited-fencing approach employed along SR 260.

The reconstruction of SR 260 in phases afforded the opportunity to assess the impact of highway reconstruction on WVCs, including after-reconstruction WVC incidence with and without fencing. Roedenbeck et al. (2007) stressed the value of conducting BACI assessments (Underwood 1994) to determine the effects of highway construction and efficacy of measures to reduce WVCs. With phased reconstruction, SR 260 research controls were instrumental to the team's ability to fully address and understand the relationship between SR 260 reconstruction and the incidence of WVCs. In contrast to previous SR 260 WVC assessments with limited after-construction treatment evaluation (Dodd et al. 2006; Dodd, Gagnon, Boe, et al. 2007), this research study accrued a minimum of three years of after-reconstruction assessment on all three reconstructed sections. Dodd et al. (2006) and Dodd, Gagnon, Boe, et al. (2007) previously reported on an exhaustive range of SR 260 WVC analyses, including spatial and temporal relationships to GPS crossing data and habitat influences. This chapter focuses on addressing the efficacy and benefits of the integration of costly UPs and fencing during highway reconstruction as measures to limit WVCs. The specific objectives were to assess the following:

- Incidence of wildlife-vehicle collisions along SR 260 and the relationship of EVC rates to highway reconstruction classes.
- Role of ungulate-proof fencing and the limited-fencing approach in minimizing the incidence of EVCs.
- Highway safety and economic benefits associated with reduced EVCs following highway reconstruction with wildlife passage structures and fencing.

4.2 METHODS

4.2.1 Wildlife-Vehicle Collision Tracking

The research team documented the incidence of WVCs along all SR 260 sections using three approaches. First, at the onset of the reconstruction project in late 2000, the team developed and disseminated a standardized WVC tracking form for use by researchers and by agency personnel, including Arizona Department of Public Safety (DPS) highway patrol officers, to document all WVCs. Second, the researchers conducted regular searches of the highway corridor for evidence of WVCs to augment data from the WVC forms. Lastly, the researchers reviewed DPS dispatcher and accident report records for accidents in which agency personnel did not submit WVC forms or searches by the research team did not document evidence of an accident (e.g., roadkill). The database compiled from the consolidated (nonduplicate) records included the date, time, and location (to the nearest 0.1 mi) of the WVC, the species involved, and the reporting agency.

The research team compiled and summarized WVC records by highway reconstruction section by year. For WVC duplications between the DPS reports and the research team highway-search documentation, the team compared the locations to determine their accuracy (Barnum 2003; Gunson and Clevenger 2003). The research team used a database, compiled by the ADOT Traffic Records Branch from DPS accident reports, to determine the proportion of single-vehicle accidents that involved wildlife along reconstruction sections and controls. Huijser et al. (2007) reported that nearly all WVCs are single-vehicle crashes.

4.2.2 Comparison of Elk-Vehicle Collision Rates by Highway Reconstruction Classes

The research team compared the incidence of EVCs among highway sections by calculating mean EVC rates (EVCs/mi/yr) that accounted for differential section lengths. The team employed analysis of covariance (ANCOVA) to test the hypothesis that there were no differences among mean EVC rates by highway reconstruction classes (Neter et al. 1996). ANCOVA was used to control for AADT effects as a covariate in the analysis. Two separate ANCOVA analyses were accomplished using different highway reconstruction classes. The first analysis compared EVC rates among three classes to determine the degree to which mean EVC rates were affected by highway reconstruction under the limited ungulate-proof fencing approach:

- Before reconstruction (including research controls)
- During reconstruction
- After reconstruction (using the entire sections)

The second ANCOVA assessed the influence of ungulate-proof fencing on EVC rates by breaking out the spatially explicit fenced and unfenced treatment sections of each reconstructed highway section. This analysis compared mean EVC rates among four reconstruction classes:

- Before reconstruction (including research controls)
- During reconstruction
- After reconstruction–before fencing
- After reconstruction–after fencing

Where the researchers obtained significant results in the ANCOVA, they performed post hoc pairwise comparisons using a Tukey test for unequal sample sizes to assess differences in mean EVCs among reconstruction classes. All statistical tests were performed using the program Statistica[®]. Results were considered significant at $P \leq 0.05$. Mean values were reported with ± 1 standard error (SE).

4.2.3 Economic Benefit of Reduced Elk-Vehicle Collisions

Dodd et al. (2006) and Dodd, Gagnon, Boe, et al. (2007) assessed the association between annual EVCs, elk population estimates, and AADT using EVC data from 1994 to 2004 (before the installation of substantial fencing along SR 260) by multiple regression analysis (Neter et al. 1996). Elk population estimates (prehunt adults) were obtained from the annual elk management summaries (1994–2005) for GMUs 22 and 23 (Arizona Game and Fish Department, Game Branch, Phoenix, AZ). Dodd et al. (2006) and Dodd, Gagnon, Boe, et al. (2007) combined the estimates because the study area equally falls within the two GMUs. Though the entire estimated elk population for the two GMUs did not reside near SR 260, the estimates were nonetheless used as an index of relative population levels that fluctuate from year to year based on calf recruitment, hunter success, and other conditions that affect elk distribution.

The multiple regression analysis reported by Dodd et al. (2006) and Dodd, Gagnon, Boe, et al. (2007) incorporated both AADT and elk population estimates into a model that accounted for 74 percent of the variation in annual EVCs ($r = 0.861$, $r^2 = 0.741$, $P = 0.004$, $n = 11$). Modeled partial regression coefficients were significant for both AADT (1.10, $P = 0.001$) and elk population estimates (0.846, $P = 0.007$). The equation for this EVC regression function was:

$$\text{EVC} = -158.0 + (\text{AADT} \times 0.005) + (\text{elk population} \times 0.098)$$

The research team then used this regression equation to compute expected annual EVCs for the entire study area for the period 2001–2008, using AADT (from ADOT’s Data Management Section) and elk population estimates for each year. To assess the benefit from reduced EVCs associated with the reconstruction of SR 260 sections, the team compared the expected EVCs derived from the model to the actual EVCs recorded for each year. Economic benefit from reduced EVCs was derived by applying the cost associated with EVCs reported by Huijser et al. (2007) and multiplying that cost by the difference between expected and actual EVCs. Huijser et al. (2007) conducted an extensive review of species-specific costs associated with WVCs, including those associated with vehicle property damage, human injuries and fatalities, removal and disposal of carcasses, and loss of recreational value associated with vehicle-killed animals; they estimated the average cost associated with each EVC at \$18,561.

4.3 RESULTS

4.3.1 Wildlife-Vehicle Collision Tracking

From 2001 to 2008, agency personnel and the researchers documented 364 WVCs along SR 260 (Table 12), for an average of 45.5 WVCs/year (± 2.9). Of these, 87.1 percent involved elk and 11.3 percent involved deer. Of WVCs involving deer identified by species (92.7 percent), white-tailed deer accounted for 71.1 percent and mule deer 28.9 percent. In addition, records showed that two black bears and four mountain lions were killed by vehicles. DPS-reported WVCs represented 65.7 percent of the total, while the research team documented the remainder. All duplicate WVC records varied in their reported location by <0.2 mi, with more than 75 percent <0.1 mi, validating their use in the research team’s spatially explicit analyses relating to highway reconstruction classes. This alleviated concerns raised by Barnum (2003) and Gunson and Clevenger (2003) regarding the accuracy of WVC location documentation by public safety personnel elsewhere in North America.

Annual reported EVCs reflected the staggered reconstruction of three highway sections: 22 EVCs in 2001, followed by a steady increase each year to a peak of 69 EVCs in 2004, and then a steady decline to 27 EVCs by 2008 (Table 12; Figure 18). Overall, 45 percent of all SR 260 single-vehicle accidents recorded by DPS involved wildlife (Table 13). The Christopher Creek section exhibited the highest mean proportion of wildlife-related single-vehicle accidents (0.53) and Preacher Canyon the lowest (0.36). The proportions of wildlife-related single-vehicle accidents after reconstruction were mixed (Table 13). On the Christopher Creek section, the proportion before reconstruction (0.58) dropped 17 percent to 0.48 after reconstruction with limited fencing. Conversely, on the Kohl’s Ranch section with limited fencing, the proportion of wildlife-related accidents actually increased 17 percent after reconstruction. The most dramatic change in the proportion of wildlife-related accidents occurred on the Preacher Canyon section, where the mean proportion (0.45) before the entire section was fenced dropped 78 percent to 0.10 after fencing in late 2006. The mean proportions of wildlife-related accidents on the two control sections were similar, averaging 0.42 (Table 13).

Table 12. Frequency of SR 260 Wildlife-Vehicle Collisions by Species and Year, 2001–2008.

Year	Elk	White-Tailed Deer	Mule Deer	Unknown Deer	Mountain Lion	Black Bear	Total
2001	22	0	0	0	0	0	22
2002	34	1	0	2	0	0	37
2003	39	6	1	0	0	0	46
2004	69	7	4	0	2	0	82
2005	47	6	3	0	1	0	57
2006	41	1	1	0	1	0	44
2007	38	5	1	0	0	2	46
2008	27	1	1	1	0	0	30
All	317	27	11	3	4	2	364
(%)	(87.1)	(7.4)	(3.0)	(0.8)	(1.1)	(0.5)	(100.0)
Mean	39.6	3.4	1.4	0.4	0.5	0.2	45.5
(± SE)	(2.4)	(0.8)	(0.4)	(<0.1)	(<0.1)	(<0.1)	(2.9)

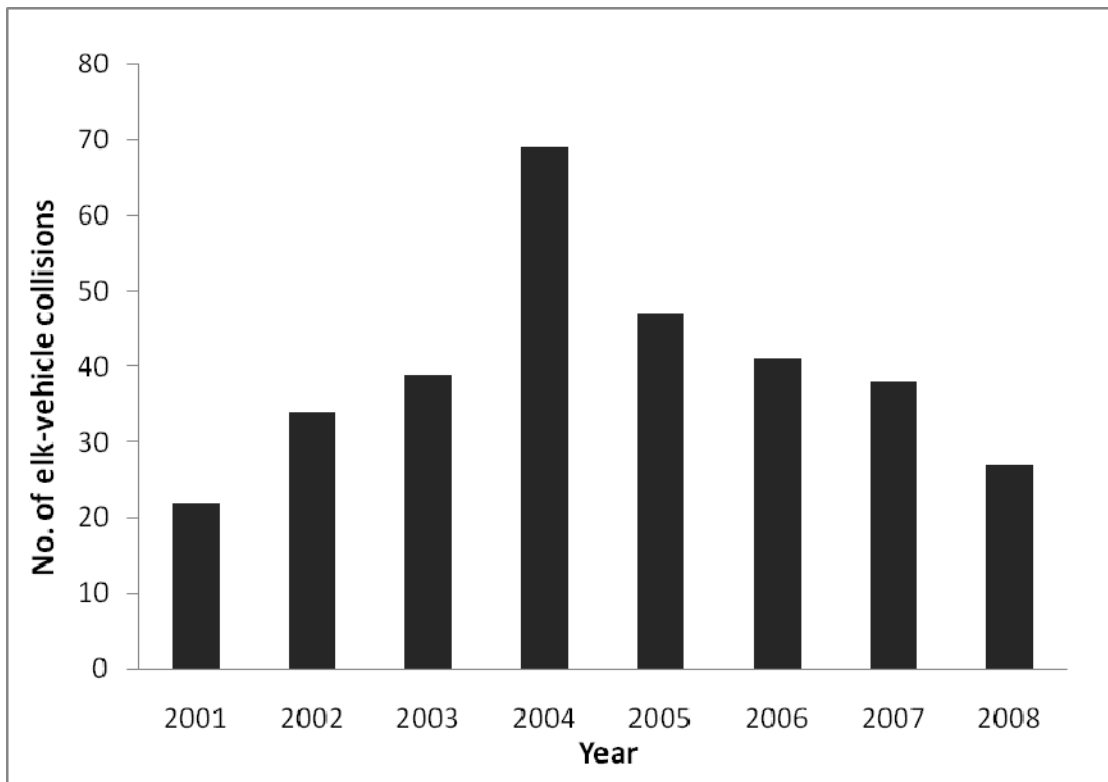


Figure 18. Annual Frequency of Documented Elk-Vehicle Collisions along SR 260 with Completion of the First Three Phases of Highway Reconstruction.

Table 13. Proportion of Single-Vehicle Accidents Involving Wildlife, Documented by Highway Section by the Department of Public Safety.

Year	Highway Section ^a					All Sections	
	PC	LGV	KR	DC	CC		
2001	0.36	0.60	0.60	0.40	0.43	0.48	
2002	0.56	0.00	0.42	0.50	0.68	0.53	
2003	0.45	0.23	0.30	0.44	0.46	0.39	
2004	0.27	0.60	0.21	0.42	0.76	0.52	
2005	0.60	0.80	0.43	0.45	0.55	0.54	
2006	0.47	0.32	0.21	0.39	0.61	0.40	
2007	0.20	0.45	0.61	0.44	0.40	0.42	
2008	0.00	0.33	0.60	0.20	0.38	0.30	
	Mean	0.36	0.42	0.42	0.41	0.53	0.45
	(± SE)	(0.09)	(0.09)	(0.06)	(0.03)	(0.04)	(0.03)

^a PC = Preacher Canyon; LGV = Little Green Valley; KR = Kohl's Ranch; DC = Doubtful Canyon; CC = Christopher Creek.

4.3.2 Comparison of Elk-Vehicle Collision Rates by Highway Reconstruction Classes

The comparison of EVCs among highway reconstruction classes (with a single after-reconstruction class) found that the mean EVCs differed among classes (ANCOVA $F_{2, 35} = 6.07$, $P < 0.005$). However, the mean EVC rate after highway reconstruction (3.2 EVCs/mi) was higher than the before-reconstruction mean (1.2 EVCs/mi; $P = 0.014$), neither of which differed significantly (partly due to small sample size) from the during-reconstruction mean, which was the highest of the classes (3.5 EVCs/mi; Figure 19).

Regarding differences among mean EVCs by reconstruction class, with the after-reconstruction class separated into before- and after-fencing treatments, the ANCOVA results were considerably different from the analysis with a single class (Table 14). Across all highway sections, the mean EVC rates differed (ANCOVA $F_{3, 45} = 14.73$, $P < 0.001$), with the after-reconstruction–before-fencing mean (4.6 EVCs/mi) higher than both the before-reconstruction mean (1.2 EVCs/mi; $P < 0.001$) and the after-reconstruction–after-fencing mean (1.2 EVCs/mi; $P < 0.001$) (Figure 20). The during-reconstruction mean EVC rate (3.5 EVCs/mi) did not differ from the other three classes. At the individual section level, the mean EVC rate differed among classes for all three reconstructed sections (Table 14). In all three instances, the mean EVC rate for after reconstruction–after fencing was lower than the means for during reconstruction and for after reconstruction–before fencing, but it was comparable to the mean EVC rate for before reconstruction.

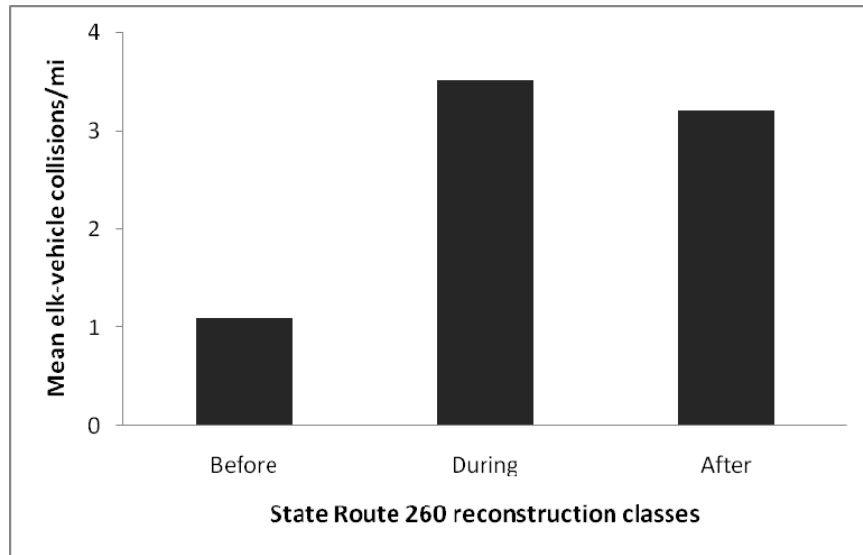


Figure 19. Mean Elk-Vehicle Collisions/mi by SR 260 Highway Reconstruction Class (without Fencing) Data, 2001–2008.

Table 14. Mean Annual Number of Elk-Vehicle Collisions/mi (\pm SE) by SR 260 Highway Reconstruction Class and Section.

Highway Section	Highway Reconstruction Class			
	Before	During	After–Before Fencing	After–After Fencing
Preacher Canyon ^a	2.5* (0.4)	3.3 (-) A	4.4 (0.2) A	1.2 (0.6) B
Little Green Valley (Control)	0.9 (0.3)	—	—	—
Kohl's Ranch ^b	0.9 (0.3) A	2.5 (-) B	5.3 (1.2) B	0.73 (0.1) A
Doubtful Canyon (Control)	1.6 (0.3)	—	—	—
Christopher Creek ^c	0.7 (-) A	4.1 (4.2) B	5.6 (2.2) B	1.1 (0.7) A
All^d	1.2 (0.2) A	3.5 (0.4) A, B	4.6 (0.7) B	1.2 (0.3) A

Note: Letters A and B denote pairwise comparisons obtained from Tukey test.

^a ANCOVA differences among reconstruction classes $F_{2,10} = 9.90$, $P = 0.003$.

^b ANCOVA differences among reconstruction classes $F_{3,7} = 5.25$, $P = 0.032$.

^c ANCOVA differences among reconstruction classes $F_{3,7} = 3.99$, $P = 0.050$.

^d ANCOVA differences among reconstruction classes $F_{3,45} = 14.73$, $P < 0.001$.

* Before-reconstruction mean from Dodd, Gagnon, Boe, et al. 2007; not used in this analysis.

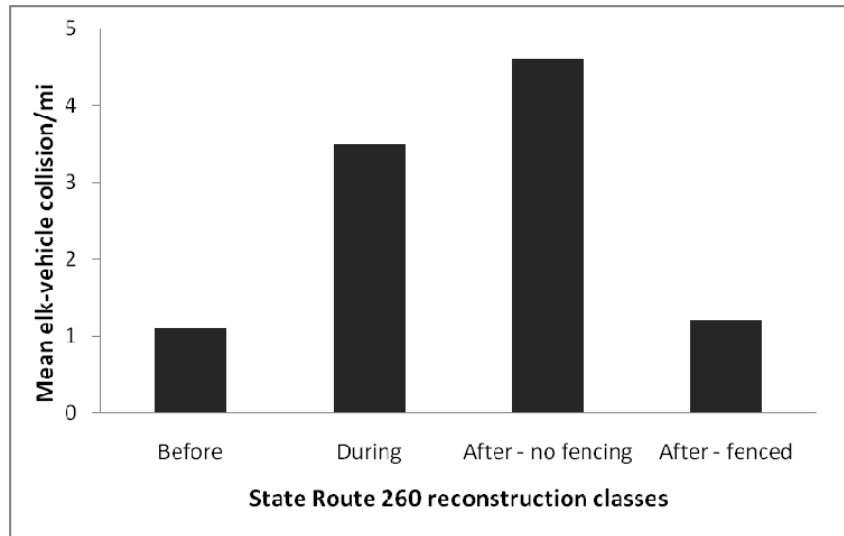


Figure 20. Mean Elk-Vehicle Collisions/mi by SR 260 Highway Reconstruction Class.

4.3.3 Economic Benefit of Reduced Elk-Vehicle Collisions

After AADT peaked at 8,700 vehicles/day in 2003, traffic volume remained relatively static (Table 15), ranging from 7,200 (in 2004) to 7,800 (in 2007 and 2008). Conversely, estimated elk population levels for GMUs 22 and 23 increased dramatically over the same period. From the estimated elk population level of 1,488 in 2003, the population more than doubled by 2007 to 3,015 and then dropped to 2,464 in 2008 (Table 15). With the increase in the elk population, the research team’s regression modeling of expected annual EVCs showed a corresponding increase from 31 in 2003 to a peak of 176 in 2007, whereas actual EVCs peaked at 69 in 2004 and steadily declined to 27 EVCs in 2008 (Table 15; Figure 21). Thus, the reduction in EVCs attributable to the reconstruction of highway sections grew from 26 in 2004 (one section reconstructed) to 138 in 2007 (three sections reconstructed), which is double the highest documented annual EVCs during the project. To assess the veracity of this modeled increase in the expected EVCs tied largely to the increased elk population, the research team considered EVC patterns on its research control sections over the corresponding period.

Between 2001 and 2004, before the elk population increased dramatically, the research team recorded a combined mean of 3.2 EVCs/yr on the Little Green Valley and Doubtful Canyon sections, which were the research controls for the project. Corresponding to the large increase in the elk population and the concomitant increase in the modeled expected EVCs, the combined mean EVCs on these sections showed a threefold increase to 11.0 EVCs/yr from 2005 to 2008 and corresponded closely to the elk population estimate trends (Figure 22). The 2001–2008 control EVC was strongly associated with elk population estimates ($r = 0.922$, $r^2 = 0.850$, $P < 0.001$, $n = 8$). The EVC pattern for control sections was consistent with the expected EVC pattern derived from the regression model, and therefore, the research team was confident in using this data to calculate the economic benefit of reduced SR 260 EVCs.

With the increasing elk population, the annual economic benefit from reduced EVCs approached \$2 million in 2006 and 2008 and exceeded \$2.5 million in 2007, substantially exceeding that predicted by Dodd et al. (2006) and Dodd, Gagnon, Boe, et al. (2007). The net economic benefit from reduced EVCs from 2001 to 2008 totaled nearly \$6.5 million, or nearly \$1 million/year (Table 15).

Table 15. Annual Number of Actual and Expected Elk-Vehicle Collisions (from Modeling of AADT and Elk Population Estimates) and Economic Benefit from Reduced Elk-Vehicle Collisions.

Year	AADT	Elk Population Estimate	Actual EVCs (A)	Expected EVCs (B)	Economic Benefit from Reduced EVCs ^a
2001	4,500	1,716	22	33	—
2002	6,300	1,587	34	29	-\$95,385
2003	8,700	1,488	39	31	-\$142,474
2004	7,200	1,685	69	43	-\$480,173
2005	7,500	2,243	47	99	\$971,000
2006	7,600	2,646	41	139	\$1,824,695
2007	7,800	3,015	38	176	\$2,570,142
2008	7,800	2,464	27	122	\$1,772,056
Total	—	—	317	674	\$6,419,860

Note: AADT = average annual daily traffic; EVC = elk-vehicle collision.

^a The research team determined the economic benefit of reduced EVCs associated with highway reconstruction by subtracting actual EVCs (A) from expected EVCs (B) and multiplying the difference by the cost of each EVC (using Huijser et al.'s 2007 cost of \$18,561/EVC).

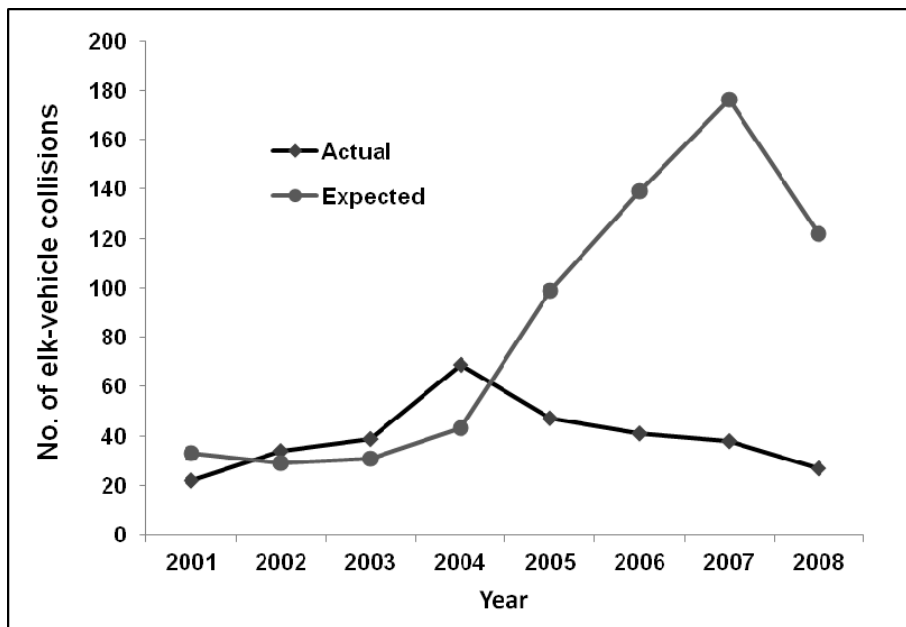


Figure 21. Annual Number of Actual and Expected Elk-Vehicle Collisions along SR 260, 2001–2008.

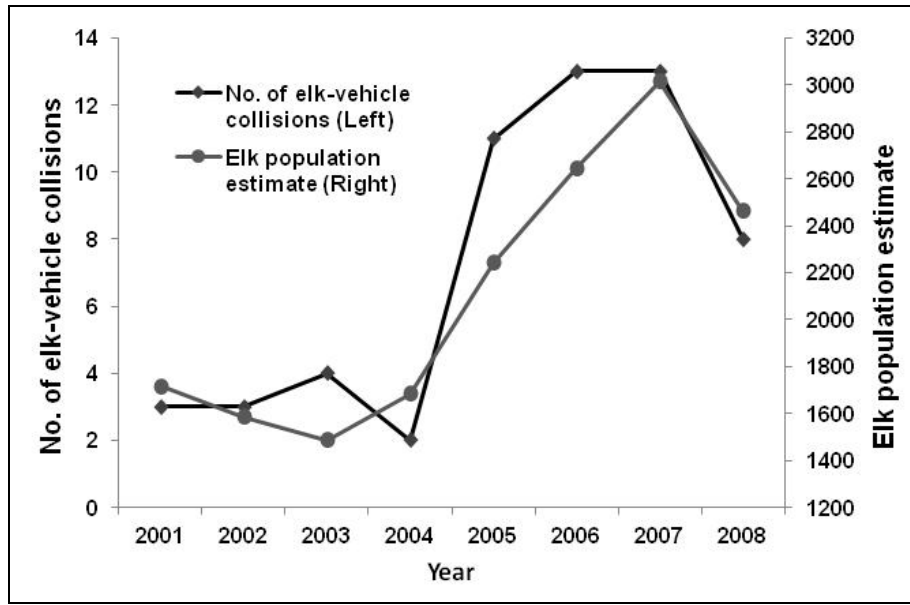


Figure 22. Annual Number of Documented Elk-Vehicle Collisions along SR 260 Control Sections and Corresponding Annual Elk Population Estimates for Game Management Units 22 and 23.

4.4 DISCUSSION

The mean EVC rate on unfenced SR 260 sections after reconstruction (4.6/mi/yr) far exceeded any EVC rates reported in previous studies in North America, including Alberta (Gunson and Clevenger 2003), British Columbia (Sielecki 2004), and New Mexico (Biggs et al. 2004). Yet with the addition of ungulate-proof fencing that funneled animals toward UPs (Dodd, Gagnon, Boe, et al. 2007; Dodd et al. 2007b), the mean SR 260 EVC rate was 76 percent lower and was comparable to the mean before-reconstruction rate. These results clearly pointed to the integral role that fencing plays in achieving highway reconstruction objectives for minimizing WVCs and promoting highway safety, as well as promoting wildlife permeability (Dodd, Gagnon, Boe, et al. 2007; Dodd et al. 2007b; see Chapter 4 of this report). Romin and Bissonette (1996a); Forman et al. (2003), and others have stressed the important role of fencing in conjunction with passage structures. Furthermore, the empirical basis for fencing's role in reducing WVCs has continued to grow, with reductions in WVCs of anywhere from 80 percent (Lavsund and Sandegren 1991; Clevenger et al. 2001b) to over 90 percent (Ward 1982; Woods 1990).

The Preacher Canyon section is the best example of the ineffectiveness of a limited-fencing approach in reducing the WVC rate. At that highway section, EVC rates incrementally increased from before reconstruction to during reconstruction to after reconstruction—before fencing (Table 14), and the proportion of accidents involving wildlife after reconstruction climbed to as high as 60 percent (at Preacher Canyon in 2005, Table 13). Since the entire highway section was fenced in 2007, EVC incidence dropped 97.2 percent (Gagnon et al. 2010) and the proportion of wildlife-related accidents declined to a mean of 0.1 EVC/mi.

The strategic fencing approach employed under adaptive management (Dodd et al. 2007a) fared somewhat better than the limited-fencing approach (especially given the increased elk population since 2005), though the results from the reconstructed Christopher Creek and Kohl's Ranch sections yielded mixed results. On the Christopher Creek section, where nearly half the section was fenced to intercept 89 percent of GPS telemetry-determined elk crossings (Dodd et al. 2007a), EVCs decreased 83 percent between the year before and after fencing (Dodd et al. 2007b). Considering the full four years since the installation of fencing, the EVC rate averaged 2.5 EVCs/mi/yr, compared to 4.1 EVCs/mi/yr during reconstruction and 0.7 EVCs/mi/yr before reconstruction.

However, of the after-reconstruction EVCs from 2005 to 2007 ($n = 33$), 15 EVCs (45 percent) occurred along a 0.2-mi gap at the east entrance to Christopher Creek, which remained unfenced until late 2007 due to the high cost of cattle guards (Dodd, Gagnon, Boe, et al. 2007; Dodd et al. 2007b). Upon completion of fencing at the gap, no EVCs were recorded at that location. However, in early 2008, floods created multiple breaks in the fence along a 0.2-mi stretch to the east, which remained unrepaired for nearly nine months. In that time, 5 of the 12 EVCs reported that year (42 percent) occurred near the unrepaired fence breaks, which points to the importance of fence maintenance. Excluding those EVCs that accounted for 44 percent of the total along only 5 percent of the section, the after-reconstruction EVC rate averaged 1.4 EVCs/mi/yr, and the research team anticipates that a similar EVC rate will be maintained into the future with secured fencing.

On the Kohl's Ranch section, fence installation extended beyond that planned under the original limited-fencing approach to encompass the eastern third of the section; the research team projected that the fencing would intercept 60 percent of the elk crossings. Here, however, only limited fencing was extended westward from the peak crossing area associated with the Indian Gardens UP. After reconstruction, the incidence of EVCs west of the UP nearly doubled from 1.3 to 2.4 EVCs/mi/yr, which likely reflects the increase in elk population and possibly indicates the creation of an end-run effect (Feldhamer et al. 1986; Woods 1990; Clevenger et al. 2001b; Parker et al. 2008). These results suggest that no benefit occurred from after-reconstruction implementation of passage structures and fencing, since there was insufficient fencing erected to intercept crossing elk and prevent the end-run effect. Under continued adaptive management, the majority of the eastern portion of the Kohl's Ranch section will receive ungulate-proof fencing once scheduled reconstruction begins in the Little Green Valley section.

The research team did not realize the full extent of highway safety and economic benefit from including UPs and fencing in the SR 260 reconstruction project until it compared the actual EVCs to expected EVCs derived from regression modeling. It also did not realize the utility of the SR 260 control sections in validating the results of the regression model that showed a link between expected EVCs and increased elk population, confirming the importance of research controls as stressed by Roedenbeck et al. (2007). The research team's regression model (Dodd et al. 2006; Dodd, Gagnon, Boe, et al. 2007), with AADT and elk population as joint independent variables predicting EVCs, is consistent with other research in which traffic volume has been reported as a factor

contributing to WVCs for a wide range of wildlife (Inbar and Mayer 1999; Joyce and Mahoney 2001; Forman et al. 2003).

Other studies have linked traffic volume and relative animal abundance to the incidence of WVCs (Fahrig et al. 1995; Romin and Bissonette 1996b; Philcox et al. 1999; Seiler 2004), including elk in Alberta (Gunson and Clevenger 2003). The research team's analysis indicated that as many as 138 EVCs were prevented due to highway reconstruction, which represents a significant benefit in highway safety, especially with the increased highway design standard on reconstructed sections. It is likely that this reduction in EVCs reduced the potential for human injury and even death to occur had the incidence of EVCs doubled over documented peak levels.

As reported by Dodd et al. (2006) and Dodd, Gagnon, Boe, et al. (2007), 2006 was the first year in which actual EVCs were lower than expected, yielding an economic benefit of nearly \$1 million and corresponding to the time when reconstruction of the Preacher Canyon and Christopher Creek sections were completed, with half of the latter section fenced in late 2004. Since then, with the continued benefit of these two sections and the completion of the Kohl's Ranch section reconstruction, the annual estimated benefit has averaged over \$2 million. Thus, over a 20-year period, the economic benefit from reduced EVCs with static AADT and elk population levels would exceed \$35 million in current U.S. dollars, or an amount that exceeds the cost of constructing all SR 260 wildlife UPs and fencing. That the economic benefit from reduced EVCs and improved highway safety can more than cover the cost of wildlife UPs and fencing is an extraordinary fact and serves to help justify the cost of implementing such measures (Huijser et al. 2007).

Few studies have investigated the incidence of WVCs during various stages of highway construction. Reilly and Green (1974) found that the reconstruction of Interstate 75 in Michigan resulted in a fivefold increase in white-tailed deer-vehicle collisions, which subsequently declined over time as deer became familiar with the upgraded highway even as traffic volume increased. Parker et al. (2008) reported an immediate decrease in Florida Key deer-vehicle collisions of 73 percent to 100 percent following the deer-proof fencing of a widened highway stretch with UPs. Conversely, these studies, like the SR 260 study, found that collisions increased 40 percent along the unfenced stretch of highway, and a record number of deer were killed two years after reconstruction. Also similar to the SR 260 study, they found no difference in overall before- and after-reconstruction deer-vehicle collisions (regardless of the presence or absence of fencing), though their results too were tempered by increasing deer populations. When Parker et al. (2008) controlled for the effects of increasing deer density and traffic volume, they concluded that highway reconstruction decreased the net risk of WVCs.

5.0 INFLUENCE OF PASSAGE STRUCTURES AND THEIR SPACING ON ELK HIGHWAY PERMEABILITY

5.1 INTRODUCTION

Highways constitute one of the most significant forces altering natural ecosystems (Noss and Cooperrider 1994; Trombulak and Frissell 2000; Farrell et al. 2002; Forman et al. 2003). Forman and Alexander (1998) estimated that highways affect more than 20 percent of the land area within the United States through habitat loss and degradation. Mortality from vehicle collisions has been recognized as a serious and growing problem for wildlife populations, as well as contributing to human injuries, deaths, and tremendous property loss (Reed et al. 1982; Farrell et al. 2002; Schwabe and Schuhmann 2002). Even more pervasive impacts of highways on wildlife are indirect barrier and fragmentation effects resulting in diminished habitat connectivity and permeability (Noss and Cooperrider 1994; Forman and Alexander 1998; Forman 2000; Forman et al. 2003; Bissonette and Adair 2008). Highways act as barriers to free movement of wildlife, fragmenting and isolating habitats, limiting juvenile dispersal (Beier 1995), and reducing genetic interchange (Epps et al. 2005; Riley et al. 2006). Long-term fragmentation and isolation increases population susceptibility to stochastic events (Swihart and Slade 1984; Forman and Alexander 1998; Trombulak and Frissell 2000).

Though numerous studies have alluded to highway barrier effects on wildlife, few have yielded quantitative data relative to animal passage rates, particularly in an experimental (e.g., before and after construction) context with research controls (Hardy et al. 2003; Roedenbeck et al. 2007; Dodd et al. 2007a; Olsson 2007). The degree of roadway barrier effects varies by species, highway type and standard, and traffic volume (Jaeger et al. 2005). Many studies have focused on efficacy of passage structures in maintaining permeability (Clevenger and Waltho 2003; Ng et al. 2004).

Dodd, Gagnon, Manzo, et al. (2007) stressed the value of a quantifiable metric of permeability and calculated elk-highway passage rates from GPS telemetry to conduct a before-after-control reconstruction comparison of permeability. Elk-highway crossing rates did not differ among treatments, though the number of times elk attempted to cross did differ (and hence so did passage rates), suggesting that crossing rate was not a useful metric in assessing permeability along SR 260. Olsson (2007), however, used crossing rates to assess moose permeability in a GPS telemetry-based before-during-after reconstruction study in Sweden and documented an 89 percent decrease in the moose crossing rate between before- and after-reconstruction levels, and a 67 percent decrease between during- and after-reconstruction levels.

Permeability for other wildlife varies by species and highway standard (Jaeger et al. 2005). Paquet and Callaghan (1996) reported that passage rates for wolves averaged 0.93 along a low-traffic highway but 0.06 along the Trans-Canada Highway. To assess permeability, Waller and Servheen (2005) compared the highway-crossing frequency of grizzly bears determined by GPS telemetry to simulated random walk analyses; the observed crossing frequency was 31 percent of the simulated frequency.

Dyer et al. (2002) compared actual road crossing rates to simulated road network crossing rates for caribou; their analysis revealed that caribou crossed actual roads less than 20 percent as frequently as they crossed simulated networks. Pronghorn are strongly affected by highway barrier effects, and during extensive VHF-telemetry studies in northern Arizona, Ockenfels et al. (1994) and Van Riper and Ockenfels (1998) documented very few pronghorn crossings of paved roadways.

Integration of structures designed to promote wildlife passage across highways has increased, as have insights showing them to be effective—particularly large bridges (e.g., underpasses or overpasses) designed specifically for large animal passage (Foster and Humphrey 1995; Clevenger and Waltho 2003; Gordon and Anderson 2003; Dodd, Gagnon, Manzo, et al. 2007). Wildlife passage structures have shown a benefit in promoting passage for a variety of species (Farrell et al. 2002; Clevenger and Waltho 2003; Dodd, Gagnon, Manzo, et al. 2007), and in conjunction with fencing, have reduced the incidence of WVCs and promoted permeability along highways (Clevenger et al. 2001b; Dodd et al. 2007b).

While fencing is often regarded as an integral component of effective passage structures (Romin and Bissonette 1996a; Forman et al. 2003), some studies have reported mixed results in reducing WVCs (Falk et al. 1978; Feldhamer et al. 1986; Woods 1990; Clevenger et al. 2001b). Fencing is costly and requires substantial maintenance (Forman et al. 2003), contributing negatively to the cost-benefit evaluations required of transportation agencies when considering any highway enhancement fencing.

On SR 260, ADOT's general model for integrating 8-ft ungulate-proof fencing with UPs was to erect limited (<300 ft) wing fences outward from each UP and most bridge abutments to funnel animals toward the structures. ADOT has embraced an adaptive management approach to reconstruction when data from prior research phases have been used to make modifications to UP design (Dodd, Gagnon, Manzo, et al. 2007) and the strategic placement of fencing to intercept crossing wildlife as determined from GPS telemetry (Dodd et al. 2007a). A key aspect of the research team's efforts was to evaluate the efficacy of the limited-fencing approach employed along SR 260 in promoting elk permeability.

Dodd et al. (2007a) found that the elk passage rate along the Christopher Creek section of SR 260 with seven passage structures (0.6-mi mean spacing) averaged 0.79 crossings/approach during reconstruction. Once reconstruction was completed, but before ungulate-proof fencing was erected, the passage rate declined 32 percent to 0.52 crossings/approach and then increased 52 percent to 0.82 crossings/approach with ungulate-proof fencing in place. This pointed to the efficacy of passage structures in combination with fencing in promoting permeability, as well as achieving an 85 percent reduction in EVCs (Dodd et al. 2007b).

However, on the Preacher Canyon section (1.5-mi mean passage structure spacing) where Dodd et al. (2007a) reported an after-reconstruction elk passage rate of 0.43 crossings/approach, Gagnon et al. (2010) reported a 70 percent reduction in the

mean passage rate to only 0.09 crossings/approach after fencing. These dramatically different responses in elk permeability after reconstruction on the same highway raise questions about the influence of passage structure spacing on permeability and ultimately the effectiveness of passage structures in maintaining population and genetic viability (Corlatti et al. 2009).

Bissonette and Adair (2008) conducted an assessment of recommended passage structure spacing for several species tied to allometric scaling of home ranges. They used the home range distance metric $HR^{0.5}$ as a daily movement metric and passage structure spacing distance, which when used with other criteria (e.g., proximity to meadows, WVC hotspots) will maintain landscape permeability. Bissonette and Adair (2008) recommended spacing of 2.2 mi between passage structures for elk. Given the growing body of scientific evidence demonstrating that passage structures are effective (Farrell et al. 2002; Clevenger and Waltho 2003; Dodd, Gagnon, Manzo, et al. 2007), determining the appropriate spacing between structures has strong implications for promoting permeability as well as for reducing highway reconstruction costs.

The research team conducted extensive GPS-elk telemetry along SR 260 during the past seven years and has addressed an array of research objectives reported by Dodd, Gagnon, Boe, et al. (2007) and Dodd et al. (2007a, 2007b) and by Gagnon, Theimer, Dodd, and Schweinsburg (2007) and Gagnon et al. (2010). The team has been afforded the opportunity to conduct an assessment of after-reconstruction elk permeability on three highway sections with a range of passage structure spacing for a minimum of two years. The goal of this chapter is to provide an assessment of elk highway permeability among reconstruction classes, as well as an empirical assessment of elk permeability as a function of passage structure spacing. The objectives were to assess the following:

- Elk permeability across the SR 260 corridor, comparing highway reconstruction classes.
- The role of ungulate-proof fencing associated with passage structures and the limited-fencing approach in promoting elk permeability.
- The relationship of elk permeability on reconstructed highway sections to passage structure spacing.

5.2 METHODS

5.2.1 Elk Capture and GPS Collars

The research team captured elk at 12 sites spaced along the 17-mi length of SR 260. The research team primarily trapped elk in net-covered Clover traps (Clover 1954) baited with salt and alfalfa hay; all traps were located within 1,000 ft of the highway corridor (Figure 23). The team also used a 40-ft × 40-ft remote-triggered drop net to capture elk. The researchers physically restrained, blindfolded, ear tagged, and fitted the elk with GPS receiver collars (Figure 23). Trapping was timed to target resident elk to maximize yearlong acquisition of GPS fixes near the highway.

Elk were instrumented with two models of GPS receiver collars. The research team predominantly used TGW-3600 store-on-board collars programmed to receive a GPS relocation fix every two hours. The team also used a limited number of TGW-3680 collars that received fixes every four hours and had Argos satellite uplink capabilities for rapid data return used in the team's early adaptive management activities. All collars had VHF beacons, mortality sensors, and programmed release mechanisms to allow recovery.



Figure 23. Cow Elk Caught in a Clover Trap and Blindfolded (Left) and Fitted with a GPS Receiver Collar and Ear Tag (Right).

5.2.2 GPS Data Analysis of Elk Movements and Permeability

Researchers employed ArcGIS[®] Version 8.3 Geographic Information System (GIS) software (ESRI, Redlands, California) to analyze GPS data similar to that of Dodd et al. (2007a). The team divided the length of the SR 260 site into 190 sequentially numbered 0.1-mi segments (Figure 24), which corresponded to the units used by ADOT for tracking WVCs and highway maintenance; these segments were identical to those used by Dodd et al. (2007a). The number and proportion of GPS relocations within 0.15 and 0.60 mi of SR 260 were calculated for each elk.

To determine highway crossings, the research team drew lines connecting all consecutive GPS fixes. The team inferred highway crossings where lines between fixes crossed the highway through a given segment (Figure 24). Animal Movement ArcView[®] Extension Version 1.1 software (Hooge and Eichenlaub 1997) was used to assist in elk crossing determination. The research team compiled crossings by individual animal, highway segment, associated distance between and distance from the highway for the two consecutive crossing fixes, direction of travel, date, and time. The team calculated crossing rates for individual elk by dividing the number of crossings by the days a collar was worn.

The researchers calculated passage rates for collared elk, which served as a relative measure of highway permeability (Dodd et al. 2007a). The researchers considered an approach to have occurred when an elk traveled from a point outside the 0.15-mi buffer zone to a point within 0.15 mi of SR 260 (Figure 24), determined by successive GPS fixes. The approach zone corresponded to the road-effect zone where elk were affected by traffic-related disturbance (Rost and Bailey 1979; Forman et al. 2003) and the zone adjacent to highways avoided by elk (Witmer and deCalesta 1985). The research team treated successive GPS fixes within 0.15 mi of SR 260 as a single approach. Elk that directly crossed the highway from a point beyond 0.15 mi were counted as an approach and a crossing. The research team calculated passage rates for each elk as the proportion of highway crossings to approaches during the period elk were fitted with GPS collars.

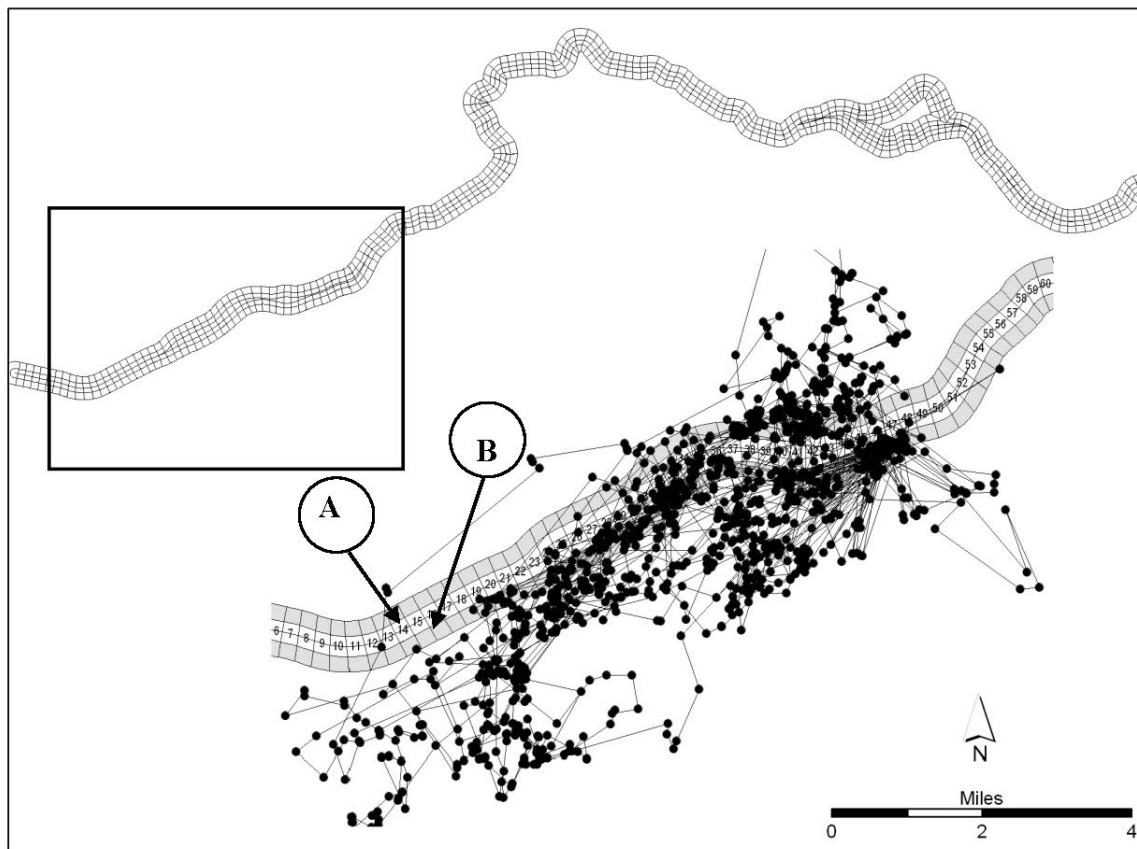


Figure 24. GPS Locations and Lines between Successive Fixes to Determine Highway Approaches and Crossings in 0.1-mi Segments.

Note: The expanded section shows GPS locations and lines between successive fixes to determine highway approaches (shaded band) and crossings. Example A denotes an approach with a highway crossing, while Example B denotes an approach without a highway crossing.

5.2.3 Elk Permeability by Highway Reconstruction Classes

The team employed ANOVA to test the hypothesis that there were no differences among mean elk passage rates by highway reconstruction classes. The ANOVA compared elk passage rates among four reconstruction classes to determine the degree to which permeability was affected by highway reconstruction under both the limited (after reconstruction–before fencing) and strategically located (after reconstruction–after fencing) ungulate-proof fencing approaches. The research control class included elk-GPS telemetry that occurred during the before-reconstruction period on the Kohl’s Ranch section.

For significant ANOVA results, the researchers performed post hoc pairwise comparisons using Tukey tests for unequal sample sizes to assess differences in mean passage rates among reconstruction classes. They transformed all proportion data (passage rates) before ANOVA with arcsin transformations. Results were considered significant at $P \leq 0.05$. Mean values were reported with ± 1 SE. Coefficients of variation (CVs) were calculated for highway reconstruction classes as a relative measure of variation among highway section means in each class.

5.2.4 Elk Permeability by Passage Structure Spacing

To assess the influence of passage structure (wildlife UPs and bridges) spacing on the three reconstructed sections, the research team employed ANOVA to compare mean elk passage rates among the three reconstructed sections where ungulate-proof fencing was erected to funnel elk toward passage structures and limit at-grade highway crossings (Dodd et al. 2007b):

- Preacher Canyon—1.5-mi mean spacing between passage structures (two structures in 3.0 mi); due to the proximity of the East and West Little Green Valley UPs (<750 ft apart), they were treated as a single structure.
- Kohl’s Ranch—1.3-mi mean spacing (three structures in 4.0 mi).
- Christopher Creek—0.6-mi mean spacing (seven structures in 4.5 mi).

The research team used linear regression analysis (Neter et al. 1996) to assess the association between elk passage rates and mean passage structure spacing on the three reconstructed highway sections.

5.3 RESULTS

5.3.1 GPS Data Analysis of Elk Movements and Permeability

The research team equipped and tracked 100 elk (79 females, 21 males) with GPS receiver collars from May 2002 to September 2008; 96 elk were trapped in Clover traps and 4 were caught under a drop net. Elk wore GPS collars for an average of 421.5 days (± 29.5), during which time the collars accrued 432,669 GPS fixes for a mean of

4,326.7 fixes/elk (± 398.1). Of the GPS fixes, 210,091 (48.5 percent) were recorded within 0.6 mi of SR 260, and 34,247 (7.9 percent) of the relocations were made within 0.15 mi.

5.3.2 Elk Permeability by Highway Reconstruction Classes

GPS-collared elk crossed SR 260 11,052 times, or a mean of 110.5 crossings/elk (± 16.6), at a rate of 0.26 crossings/day (± 0.04). Overall, the elk passage rate averaged 0.50 crossings/approach (± 0.03 ; Table 16). Mean elk passage rates among highway reconstruction classes ranged from 0.67 crossings/approach for the control class to 0.40 crossings/approach for the after-reconstruction–before-fencing class (Table 16). The ANOVA comparison of mean elk passage rates found significant differences among highway reconstruction classes ($F_{3, 131} = 7.20, P < 0.001$; Table 16). Among classes, the mean elk passage rate for the control class was higher than the mean passage rate for the after-reconstruction class, both before ($P = 0.007$) and after fencing ($P = 0.011$). The mean elk passage rate for the during-reconstruction class was higher than the after-reconstruction–before-fencing passage rate ($P = 0.044$).

Table 16. Mean Elk Passage Rates (Crossings/Approach) by Highway Section and Coefficients of Variation of Means by SR 260 Reconstruction Class, Determined from GPS Telemetry, 2002–2008.

Reconstruction Class	Highway Section	Elk (<i>n</i>)	Mean Passage Rate (\pm SE)	CV of Section Mean (%)
Before reconstruction (control sections)	Little Green Valley	5	0.61 (0.01)	
	Kohl's Ranch	5	0.71 (0.08)	
	Doubtful Canyon	11	0.71 (0.06)	
	All (A)^a	26	0.67 (0.05)	8.8
During	Kohl's Ranch	8	0.46 (0.07)	
	Christopher Creek	13	0.75 (0.05)	
	All (A, B)^a	19	0.64 (0.06)	32.0
After–before fencing	Preacher Canyon	35	0.35 (0.07)	
	Christopher Creek	12	0.53 (0.07)	
	All (C)^a	47	0.40 (0.05)	27.3
After–after fencing	Preacher Canyon	17	0.09 (0.02)	
	Kohl's Ranch	7	0.27 (0.04)	
	Christopher Creek	17	0.81 (0.09)	
	All (B, C)^a	41	0.42 (0.05)	96.2
All	All	135	0.50 (0.03)	44.4

Note: ANOVA = analysis of variance; CV = coefficient of variation.

^a Letters A, B, and C associated with the mean passage rates for all highway sections denote differences among means for reconstruction classes determined by ANOVA. ANOVA differences among reconstruction classes $F_{3, 131} = 7.20, P < 0.001$.

Mean elk passage rates for the control and during-reconstruction classes (0.64 crossings/approach) were similar (Table 16), with traffic limited to the narrow two-lane roadway for both classes. Permeability declined with highway reconstruction; mean elk passage rates for both after-reconstruction classes combined was 39 percent lower than the control and 36 percent lower than that the during-reconstruction class means. And though the mean passage rates for the two after-reconstruction classes were similar, there was considerably more variation among means for the highway sections within the after-fencing class, ranging from 0.09 to 0.81 crossings/approach; the CV for this class (96.2 percent) was three times higher than any other class (Table 16).

5.3.3 Elk Comparison of Permeability by Passage Structure Spacing

The research team suspected that the high variation within the after-reconstruction–after-fencing class reflected the range in passage structure spacing present on the three reconstructed SR 260 sections. The ANOVA comparison of mean elk passage rates among highway sections with differing passage structure spacing indeed found differences among the sections ($F_{2, 37} = 34.94, P < 0.001$; Table 17). The mean Christopher Creek section passage rate (0.6-mi mean spacing between structures; 0.81 crossings/approach) was higher than those for the Preacher Canyon section (1.5-mi spacing; 0.09 crossings/approach; $P < 0.001$) and the Kohl’s Ranch section (1.3-mi spacing; 0.27 crossings/approach; $P < 0.001$). There was no significant difference between mean passage rates for the Preacher Canyon and Kohl’s Ranch sections.

The research team’s correlation analysis between mean elk passage rate and passage structure spacing among the fenced reconstructed sections yielded a strong inverse association in which passage structure spacing accounted for 72 percent of the variation in mean elk passage rate ($r = -0.847, r^2 = 0.718, P < 0.001, n = 40$).

Table 17. Mean Elk Passage Rates for After-Reconstruction–After-Fencing Class, Determined from GPS Telemetry, 2002–2008.

Highway Section	Mean Passage Structure Spacing (mi)	Elk (<i>n</i>)	Mean Passage Rate (crossings/approach) ^a	± SE
Preacher Canyon	1.5	17	0.09 A	0.02
Kohl’s Ranch	1.3	7	0.27 A	0.04
Christopher Creek	0.6	17	0.81 B	0.06
All	1.0	41	0.44	0.05

^a Letters associated with the mean passage rates denote differences among means for mean passage structure spacing determined by analysis of variance (ANOVA). ANOVA differences among reconstruction classes $F_{2, 37} = 34.94, P < 0.001$.

5.4 DISCUSSION

The research team's application of GPS telemetry was central to the assessment of elk highway permeability along the SR 260 corridor under the various phases of reconstruction. This assessment represents one of the most comprehensive ever conducted in North America, from the standpoint of the number of GPS-collared animals, project duration, and application of a before-after-control experimental design (Hardy et al. 2003; Roedenbeck et al. 2007). Few studies have used a comparable and quantitative metric of highway permeability (Forman et al. 2003), such as the highway passage rate metric developed by Dodd et al. (2007a) and relied on for this permeability assessment.

Dodd et al. (2007a) calculated and reported both passage and crossing rates to measure permeability among SR 260 sections under different stages of highway reconstruction, but they found that crossing rates were subject to bias associated with non-highway-related factors that influence the proportion of time animals spend in proximity to the highway corridor, thus influencing crossing rates. Crossing rates also did not account for the number of unsuccessful crossing attempts that increased with traffic volumes (Gagnon, Theimer, Dodd, and Schweinsburg 2007), leading to increased energy expenditure, nor were they as sensitive to highway reconstruction impact on permeability as were passage rates (Dodd et al. 2007a).

5.4.1 Impact of Highway Reconstruction on Elk Permeability

Jaeger et al. (2005) modeled wildlife highway avoidance behavior associated with highway barrier effects and reduced highway permeability relative to highway type and standard. Their modeling differentiated small and large roads with similar high traffic levels, with the greatest level of highway avoidance caused by large roads. Observed SR 260 passage rate differences among reconstruction classes were consistent with this highway avoidance model, as mean elk passage rates for both after-reconstruction classes were lower than the mean passage rate for the narrow two-lane control sections.

The Jaeger et al. (2005) model also explains the similarity in elk permeability between control and during-reconstruction classes. Even though reconstruction activities extended across the entire four-lane highway corridor while SR 260 was under reconstruction, traffic was confined to two lanes and the highway remained a functional relatively small road. This suggests that the presence of traffic on all four lanes of the reconstructed sections contributes more to the barrier effect than the physical footprint or size of the highway, also consistent with Jaeger et al. (2005).

The research team found a 39 percent difference in elk permeability between SR 260 control and reconstructed sections. This level of impact on permeability was not as dramatic as that documented in other studies comparing wildlife permeability between two-lane and four-lane divided highways. Olsson (2007) reported that moose crossing rates determined from GPS telemetry declined 89 percent after reconstruction of a 3.7-mi stretch of highway in Sweden that incorporated three passage structures and fencing. Paquet and Callaghan (1996) reported a 97 percent lower passage rate for wolves along

the Trans-Canada Highway compared to a low-volume two-lane highway. Dodd et al. (2007a) reported that elk permeability was 50 percent lower (0.43 crossings/approach) on the first reconstructed SR 260 section (Preacher Canyon) compared to control sections. Thus, the comparatively low reduction in elk permeability across SR 260 with three reconstructed sections now completed reflects the benefit associated with passage structures and fencing on reconstructed sections.

5.4.2 Comparison of Elk Permeability by Passage Structure Spacing

Though the research team was limited to three reconstructed sections with differing mean distances between passage structures (Table 17) in which to assess the relationship to elk permeability, this assessment nonetheless provides valuable insights into spacing necessary to maintain permeability. Other factors may also have contributed to differences in elk permeability across sections, including topography and proximity to meadow habitats. Dodd et al. (2007b) documented the importance of ungulate-proof fencing in conjunction with wildlife UPs in promoting elk permeability. The results of this assessment also point to the importance of passage structure spacing on elk permeability and raise questions about the adequacy of the 2.2-mi spacing reported by Bissonette and Adair (2008) to maintain permeability for elk. Using the mean SR 260 elk home ranges of 28.2 mi² ($n = 33$) reported by Dodd et al. (2007a), the SR 260-specific allometric spacing ($HR^{0.5}$) equals 1.6 mi between passage structures, which is less than that recommended by Bissonette and Adair (2008) but still greater than the spacing distance on any of the three SR 260 reconstructed sections.

The 0.6-mi average spacing of passage structures on the Christopher Creek section, in conjunction with ungulate-proof fencing, resulted in a mean elk passage rate of 0.81 crossings/approach; this level of permeability exceeded even the mean during-reconstruction permeability (0.75 crossings/approach). After reconstruction but before fencing was erected, the mean elk passage rate was 0.53 crossings/approach; fencing resulted in a 53 percent increase in permeability. The team attributes this recovery in the elk passage rate with the fencing that funneled elk toward UPs and bridges. Funneling presented below-grade opportunities for elk crossings that ameliorated the road avoidance resistance to crossing a large roadway at grade (Jaeger et al. 2005) and the traffic-associated impact reported by Gagnon, Theimer, Dodd, Manzo, et al. (2007) and Gagnon, Theimer, Dodd, and Schweinsburg (2007). In this case, strategic fencing of half the section resulted in a significant increase in elk permeability and an 83 percent reduction in EVCs (Dodd et al. 2007b). These findings provide some of the most conclusive evidence to date documenting the efficacy of passage structures in restoring pre-reconstruction levels of elk permeability. However, the Preacher Canyon and Kohl's Ranch reconstructed sections produced less dramatic results in promoting elk permeability.

On the Preacher Canyon section, after the entire section was fenced, mean elk permeability declined 86 percent to only 0.09 crossings/approach. At the same time, EVCs were reduced 97.2 percent with fencing (Gagnon et al. 2010). The average 1.5-mi distance between passage structures seems to have been insufficient in maintaining elk

permeability once the entire corridor was fenced to preclude continued at-grade crossings. The barrier effect associated with fencing apparently exacerbated the barrier effect associated with the reconstructed highway. In this instance, there appears to be a tradeoff in benefits with fencing in improved highway safety against a reduction in elk permeability, a conflict that has long presented a challenge to transportation agencies (Forman et al. 2003).

On the Kohl's Ranch section, the combination of strategic fencing of one-third of the section and mean passage structure spacing of 1.3 mi proved ineffective in promoting highway safety or elk permeability; EVCs increased 85 percent (see Chapter 5 of this final report) and elk permeability declined 62 percent. The remaining length of this section will be fenced when the adjacent Little Green Valley section is reconstructed in the near future. While this fencing is anticipated to improve highway safety, given the results from the Preacher Canyon section with similar passage structure spacing, it is doubtful that elk permeability will be improved substantially on the Kohl's Ranch section due to the relatively large spacing between passage structures.

So what is the appropriate, or optimum (Olsson et al. 2008), spacing distance for passage structures to accommodate elk permeability? Answering this question depends on defining the desired level of permeability to be maintained. In the absence of studies that relate permeability to long-term population persistence and genetic viability, as advocated by Corlatti et al. (2009) to evaluate and justify wildlife passage structures, it is difficult to arrive at a biologically supported level of permeability. In developing their allometric spacing guidelines for wildlife passage structure placement, Bissonette and Adair (2008:486) did not specify a target level of permeability other than stating that spacing based on linear home-range distances ($HR^{0.5}$) are the "best" approach to "insure [sic] the health of large mammal populations." Permeability targets could range between the extremes of maintaining full before-reconstruction levels of permeability (e.g., 0.6-mi spacing) and providing for permeability just adequate enough to accommodate the one-migrant-per-generation minimum (Mills and Allendorf 1996) needed to ensure genetic viability (e.g., no less than 1.5-mi spacing), as depicted in Figure 25.

For SR 260, the level of elk permeability (0.44 crossings/approach) attained with the mean passage structure spacing of 1.0 mi across all three reconstructed sections was intermediate along the permeability scale documented for the individual highway sections (Table 17; Figure 25); this level represents a preferred target to that recommended by Bissonette and Adair (2008). However, the research team, like Bissonette and Adair (2008), recognizes that passage structures are a costly proposition to plan and implement during highway reconstruction. As such, the research team vigorously concurs with Bissonette and Adair's recommendation of placing passage structures in proximity to WVC "hotspots" and key areas, such as migration corridors or meadows (Manzo 2006), where these animals frequently cross highways (Dodd et al. 2007b).

Prioritizing the strategic placement of passage structures at such locales will likely lead to higher levels of permeability than spacing an equivalent number of structures evenly over the same distance. Lastly, elk are a relatively adaptable species in terms of highway

permeability and crossing patterns (Dodd et al. 2007a), with a propensity to readily learn, as evidenced by UP habituation results presented in Chapter 4. The research team's assessment of SR 260 permeability was conducted over a relatively short (two-year) period after highway reconstruction and/or fencing was completed on each section. Elk permeability levels on the Preacher Canyon and Kohl's Ranch sections could well increase over time as elk habituate to passage structures and fencing.

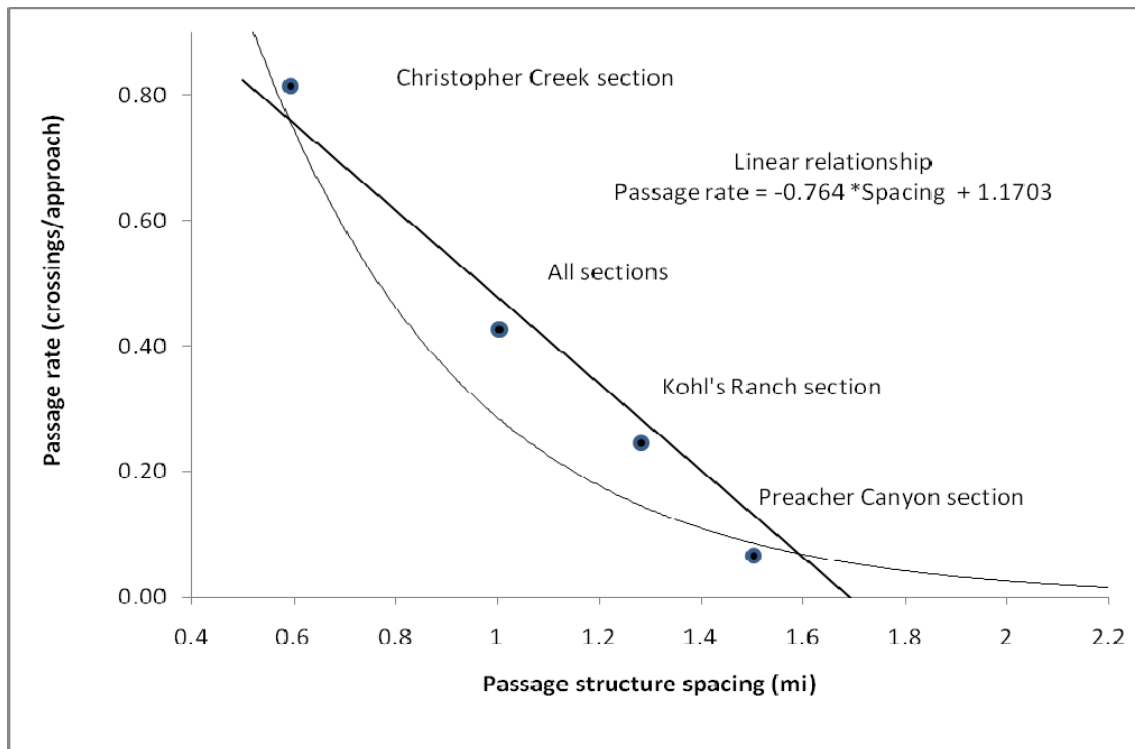


Figure 25. Relationships between Mean Elk Passage Rates and Mean Passage Structure Spacing on Three Reconstructed Sections along SR 260.

6.0 INFLUENCE OF UNDERPASSES AND TRAFFIC VOLUME ON COUES WHITE-TAILED DEER HIGHWAY PERMEABILITY

6.1 INTRODUCTION

As described in Chapter 5, the degree of highway barrier effects varies by wildlife species, traffic volume, and highway standard (Jaeger et al. 2005). With increased scientific understanding of highway impacts over the past decade, efforts to minimize the impacts on wildlife permeability during highway construction projects have also increased. Implementation of structures designed to promote passage across highways is increasing and is proving to be effective for a variety of wildlife species (Foster and Humphrey 1995; Farrell et al. 2002; Clevenger and Waltho 2003; Gordon and Anderson 2003; Dodd et al. 2007a). The SR 260 research project has contributed to this body of knowledge. However, SR 260 GPS-telemetry assessments of permeability have been limited to elk, which is considered a relatively adaptable species (Dodd et al. 2007a).

The SR 260 assessments have yielded quantitative data relative to animal passage rates in an experimental (e.g., before and after reconstruction) context with research controls (Roedenbeck et al. 2007) and have provided insights on the influence of highway reconstruction (Dodd et al. 2007a) and ungulate-proof fencing (Dodd et al. 2007b) on permeability. Gagnon, Theimer, Dodd, and Schweinsburg (2007) found that increasing vehicular traffic volume decreased the probability of at-grade crossing patterns by elk and shifted their distribution away from the highway. Theoretical models (Mueller and Berthoud 1997) suggest that highways averaging 4,000–10,000 vehicles/day present strong barriers to wildlife and would repel animals away from the highway, as noted by Gagnon, Theimer, Dodd, and Schweinsburg (2007). Conversely, Gagnon, Theimer, Dodd, and Schweinsburg (2007) found that traffic levels do not influence elk passage rates during below-grade UP crossings, likely accounting for the benefit of UPs and fencing in promoting permeability; fences funnel elk to UPs where traffic has minimal effect compared to what elk encounter when crossing at grade during high traffic volumes (Dodd et al. 2007b).

White-tailed deer account for the majority of WVCs in North America (Conover 1997; Schwabe and Schuhmann 2002), yet little is known about the impact of highways and traffic on deer permeability and habitat fragmentation. Killmaster et al. (2006) assessed the impact of traffic volume on deer in Georgia and reported that traffic had a disruptive effect on deer movements. Rost and Bailey (1979) found that mule deer avoided the areas less than 650 ft from roads and exhibited greater avoidance of roads than did elk. Deer exhibited lower densities within an avoidance zone of 330–1,000 ft associated with well-traveled roads in the western United States (Forman et al. 2003). Feldhamer et al. (1986) reported a portion of radio-collared deer using both sides of an interstate highway in Pennsylvania, of which half was fenced to limit deer access, with some animals crossing frequently, especially males. Carbaugh et al. (1975) made numerous observations of white-tailed deer along another Pennsylvania interstate, observing only 4 percent of deer crossing the highway relative to other activities confined to one side or the other.

In Arizona, the Coues subspecies of white-tailed deer is considered very sedentary and has limited home ranges (Ockenfels et al. 1991). The research team hypothesized that this species would respond differently than elk relative to the impact of highway barrier effects and increasing traffic volume. As such, the team sought to assess white-tailed deer-highway relationships and compare them to those previously determined for elk along SR 260. The objectives were to assess, for white-tailed deer:

- Highway crossing patterns and permeability on reconstructed highway and control sections to determine the influence of wildlife passage structures, compared to those reported for elk by Dodd et al. (2007a, 2007b).
- Passage relationships to traffic volume when crossing the highway at grade, compared to those reported for elk by Gagnon, Theimer, Dodd, and Schweinsburg (2007).
- Passage relationships to traffic volume when crossing the highway below grade through UPs, compared to those reported for elk by Gagnon, Theimer, Dodd, Manzo, et al. (2007).

6.2 METHODS

6.2.1 Deer Capture and GPS Telemetry

The research team trapped white-tailed deer at six sites along four sections of SR 260; all capture sites were located within 1,000 ft of the highway. The team captured deer in net-covered Clover traps (Clover 1954) baited with sweet feed (Figure 26) and with a 30-ft × 30-ft remote-triggered drop net over bait. Researchers physically restrained, blindfolded, ear tagged, and fitted deer with GPS receiver collars (Figure 26). The deer were outfitted with Telonics model TGW-3500 GPS receiver collars programmed to receive a fix every two hours. All collars had VHF mortality sensors and programmed release mechanisms for recovery. Collar battery life was 11 months.

6.2.2 GPS Data Analysis of Deer Movements and Permeability

The research team employed the same GPS data analysis and permeability calculation methods described in Section 5.3.2 for elk for this analysis of white-tailed deer GPS data. The team calculated individual deer minimum convex polygon (MCP; from connecting the outermost fixes) home ranges comprising all GPS fixes (White and Garrott 1990).

The research team compared mean white-tailed deer crossing and passage rates between two SR 260 reconstruction classes: the two experimental control sections and the three reconstructed sections that included wildlife UPs (Table 18). The team derived values for individual deer approaching and crossing on each highway section and pooled them by highway reconstruction class. Consistent with Dodd et al. (2007a), *t*-tests for independent samples were used to test the hypotheses that no differences in deer crossing and passage rates existed as a function of highway condition class. The research team

applied an arcsine transformation to raw crossing and passage rate data to allow comparison of proportions (Neter et al. 1996). All means are reported with ± 1 SE.

6.2.3 Traffic Volume and Deer At-Grade Highway Crossings

The research team estimated traffic volume using a permanent traffic counter programmed to record hourly traffic volumes (Table 18). ADOT’s Data Management Section helped the team to install the traffic counter in 2003 at the center of the SR 260 study area, on the Little Green Valley section. No major roads branched off the highway along the studied length, and vehicles could move from either end of the study area to the traffic counter in no more than 10 minutes. Thus, the team assumed that traffic recorded by the counter accurately represented levels present along that stretch of highway during any 1-hr interval.



Figure 26. Female White-Tailed Deer Caught in a Clover Trap (Left) and Male Deer Fitted with a GPS Receiver Collar (Right) along SR 260.

Table 18. SR 260 Reconstruction Status and Number of White-Tailed Deer Caught and Relocated by Highway Section, 2004–2007.

Highway Section	Reconstruction Status	Wildlife Passages		No. of Deer	
		Underpass	Bridge	Caught	Using Section
Preacher Canyon	Completed 2001	2	1	1	1
Little Green Valley	Control	1	0	0	2
Kohl’s Ranch	Completed 2006	1	2	4	6
Doubtful Canyon	Control	3	0	5	7
Christopher Creek	Completed 2004	4	3	3	4
	All	11	6	13	13

Similar to Gagnon, Theimer, Dodd, and Schweinsburg's (2007) elk analysis, the research team combined traffic and GPS data by assigning traffic volumes for the previous hour to each deer GPS location using ArcGIS Version 9.1. This allowed the team to correlate the traffic volume each deer experienced in the hour before movement to a particular point, regardless of deer distance traveled.

The research team examined how the proportion of deer relocations at different distances from the highway varied with traffic volume by calculating the proportion of relocations in each 330-ft distance band, out to a maximum of 2,000 ft (Gagnon, Theimer, Dodd, and Schweinsburg 2007). To avoid bias due to differences in the number of relocations for individual deer, the proportion of relocations occurring in each distance band for each animal was used as the sample unit, rather than total relocations. The team then calculated a mean proportion of deer relocations for all deer within each 330-ft distance band at varying traffic volumes: <100, 101–200, 201–300, 301–400, 401–500, 501–600, and >600 vehicles/hr (Gagnon, Theimer, Dodd, and Schweinsburg 2007).

For each of the seven traffic volume classes above, the research team calculated traffic-specific deer highway crossing passage rates. The team used the following rate calculation: number of crossings that occurred when traffic in the hour preceding the crossing fell within the traffic volume class divided by number of approaches that also occurred when traffic volume in the hour preceding the crossing fell within the same traffic volume class. The research team used linear regression to determine the relationships between deer passage rates and traffic volume, calculating separate relationships for deer approaches and crossings that occurred on reconstructed highway sections and control sections.

To investigate how traffic volume influenced the probability of deer crossing SR 260, the research team used a multiple logistic regression approach (Agresti 1996) and assigned a binomial response to two different behaviors: (1) movement that resulted in successive relocations on opposite sides of the highway (crossing occurred) and (2) movement near the highway when two successive GPS relocations indicated that deer had entered the 0.15-mi zone adjacent to the highway from beyond that distance (noncrossing occurred). The 0.15-mi zone was chosen to provide results comparable to those derived for elk by Gagnon, Theimer, Dodd, and Schweinsburg (2007). The research team identified four factors that potentially influence ungulate movement near roads or that were incorporated into its modeling based on prior studies:

1. Traffic volume (Rost and Bailey 1979; Witmer and deCalesta 1985; Rowland et al. 2000; Wisdom et al. 2005; Killmaster et al. 2006; Olsson et al. 2008)
2. Highway reconstruction class (Paquet and Callaghan 1996; Jaeger et al. 2005; Dodd et al. 2007a; Olsson et al. 2008)
3. Season (Bruinderink and Hazebroek 1996; Gunson and Clevenger 2003; Dodd et al. 2007a; Gagnon, Theimer, Dodd, and Schweinsburg 2007)
4. Time of day (Bruinderink and Hazebroek 1996; Haikonen and Summala 2001; Dodd et al. 2007a)

The research team defined four seasons based on local climatic conditions and white-tailed deer behavioral patterns, consistent with Gagnon, Theimer, Dodd, and Schweinsburg (2007): winter (December–February), spring (March–May), summer (June–August), and fall (September–November). The time of day analysis associated with deer highway movements differed from Gagnon, Theimer, Dodd, and Schweinsburg (2007), which limited modeling to movements that occurred between dusk and dawn. Deer, though more active during these periods, were nonetheless active at all hours; Dodd et al. (2007b) reported deer-vehicle collisions that occurred during daytime hours. The team partitioned time of day into four periods: evening (1600–2159 hr), which included dusk/sunset; nighttime (2200–0359 hr); morning (0400–0959 hr), which included dawn/sunrise; and daytime (1000–1559 hr).

The sex of the animal was not used in the modeling due to the disproportionately high proportion of male deer collared in our study. Also, the research team excluded the presence of adjacent riparian-meadow habitat within 0.6 mi of SR 260, important in modeling the probability of elk crossing (Gagnon, Theimer, Dodd, and Schweinsburg 2007) and in predicting crossing and elk-vehicle collision peaks (Manzo 2006; Dodd et al. 2006), from the deer modeling. It was excluded from analysis to limit potential bias associated with the confined movements of deer and the capture of most deer (70 percent) at or in proximity to riparian-meadow habitats.

The research team used Akaike’s Information Criterion (AIC) (Burnham and Anderson 2002) to select the most parsimonious model that included up to three-way interactions among parameters. All models with interactions inherently included lower-order terms and interactions, contributing to the total number of parameters (k). AIC values were adjusted for small sample size using the small sample AIC calculation (AIC_c).

6.2.4 Traffic Volume and Deer Below-Grade Underpass Crossings

The research team used video surveillance systems consisting of four cameras triggered by infrared beams (Dodd, Gagnon, Manzo, et al. 2007; Figure 9) to simultaneously monitor traffic and behavior of deer that approached within 150 ft of six UPs along SR 260 (Table 18). The team used two methods to determine traffic levels associated with white-tailed deer approaches and crossings. First, they calculated traffic volume by counting vehicles recorded by the camera aimed at the roadway and then dividing that count by the amount of time deer spent in the UP area until either crossing or leaving the field of view (Gagnon, Theimer, Dodd, Manzo, et al. 2007). The team defined approach as deer that crossed the highway ROW fence (approximately 150 ft from the roadway) and then moved toward the UP.

The research team derived passage rates by dividing the number of successful crossings by the number of approaches. The team also assigned traffic volumes from the permanent traffic counter for the previous hour to each deer UP approach and crossing. This allowed the team to directly compare passage rates associated with both at-grade highway and below-grade UP crossings, as well as to directly compare deer and elk along the same stretch of roadway.

To examine the overall effect of traffic levels on deer passage rates, the research team compared the proportion of animals that successfully crossed at each of five traffic volume levels to the proportion of successful crossings expected based on the relative amount of time deer experienced each traffic level during attempted crossings (Gagnon, Theimer, Dodd, Manzo, et al. 2007). For a consistent comparison to elk behavior documented at these same UPs (Gagnon, Theimer, Dodd, Manzo, et al. 2007), traffic volume classes included 0, 0–2, 2–4, 4–6, and >6 vehicles/min. Due to their herding nature, groups of one or more deer were used as the sampling units for this analysis. The research team used a chi-squared contingency table to test the hypothesis that traffic levels had no influence on crossings (Agresti 1996).

As deer entered UPs they could not see vehicles passing overhead; as such, sound and vibration may be more important factors determining successful crossings (Gagnon, Theimer, Dodd, Manzo, et al. 2007). Therefore, the type of vehicle passing overhead (e.g., cars versus commercial vehicles) could have a differential impact on successful UP crossings. To determine whether vehicle type affected deer passage through UPs, the team assessed the number and proportion of individual deer that exhibited a retreat-flight response at the moment a particular vehicle type passed overhead, thereby leading to an unsuccessful crossing. To test the hypothesis that there was no relationship between vehicle type and crossings, the research team compared the retreat-flight response of deer during crossings when commercial vehicles or passenger cars passed overhead, both within the same and at different traffic volumes (<4 and >4 vehicles/min), using chi-square goodness-of-fit tests.

To compare to traffic-specific highway crossings determined from GPS telemetry, the research team calculated UP passage rates using the number of deer group crossings that occurred when traffic volume in the hour preceding the crossing fell within the traffic volume class, divided by the number of approaches that also occurred when traffic volume in the hour preceding the UP crossing fell within the same traffic volume class. The team used the same traffic volume classes as those used in its at-grade crossing analysis: <100, 101–200, 201–300, 301–400, 401–500, 501–600, and >600 vehicles/hr.

6.3 RESULTS

6.3.1 Deer Capture and GPS Data Analysis of Movements and Permeability

Researchers fitted 13 white-tailed deer (3 female, 10 male) with GPS receiver collars between July 2004 and December 2007; five were caught in Clover traps and eight under the drop net. Deer wore the GPS collars an average of 202.2 (\pm 36.1) days (range = 36–346 days). The collars accrued a total of 28,646 GPS fixes, representing a 96.8 percent fix success, with a mean of 2,203.5 (\pm 356.5) fixes per deer (range = 420–4,177).

The deer were located within 0.15 mi of SR 260 on 6,008 occasions (25.3 percent of total fixes) with a mean of 462.1 (\pm 121.3) fixes/deer. The team recorded 21,446 fixes within 0.6 mi of the highway (79.3 percent) and a mean of 1,649.7 (\pm 314.5) fixes/deer. On average, deer traveled 142.3 (\pm 8.9) ft between successive 2-hr GPS relocations. The

distance that deer traveled during at-grade highway crossings ($\bar{x} = 623.2 \pm 9.3$ ft, $n = 241$) was similar to the distance traveled during noncrossing movements ($\bar{x} = 639.9 \pm 1.8$ ft, $n = 6,235$). Deer MCP home ranges averaged $8.46 (\pm 5.72)$ mi^2 for all 13 animals, though one male had a home range of 76.9 mi^2 . Excluding this animal, the home ranges averaged $2.7 (\pm 0.4)$ mi^2 (Figure 27).

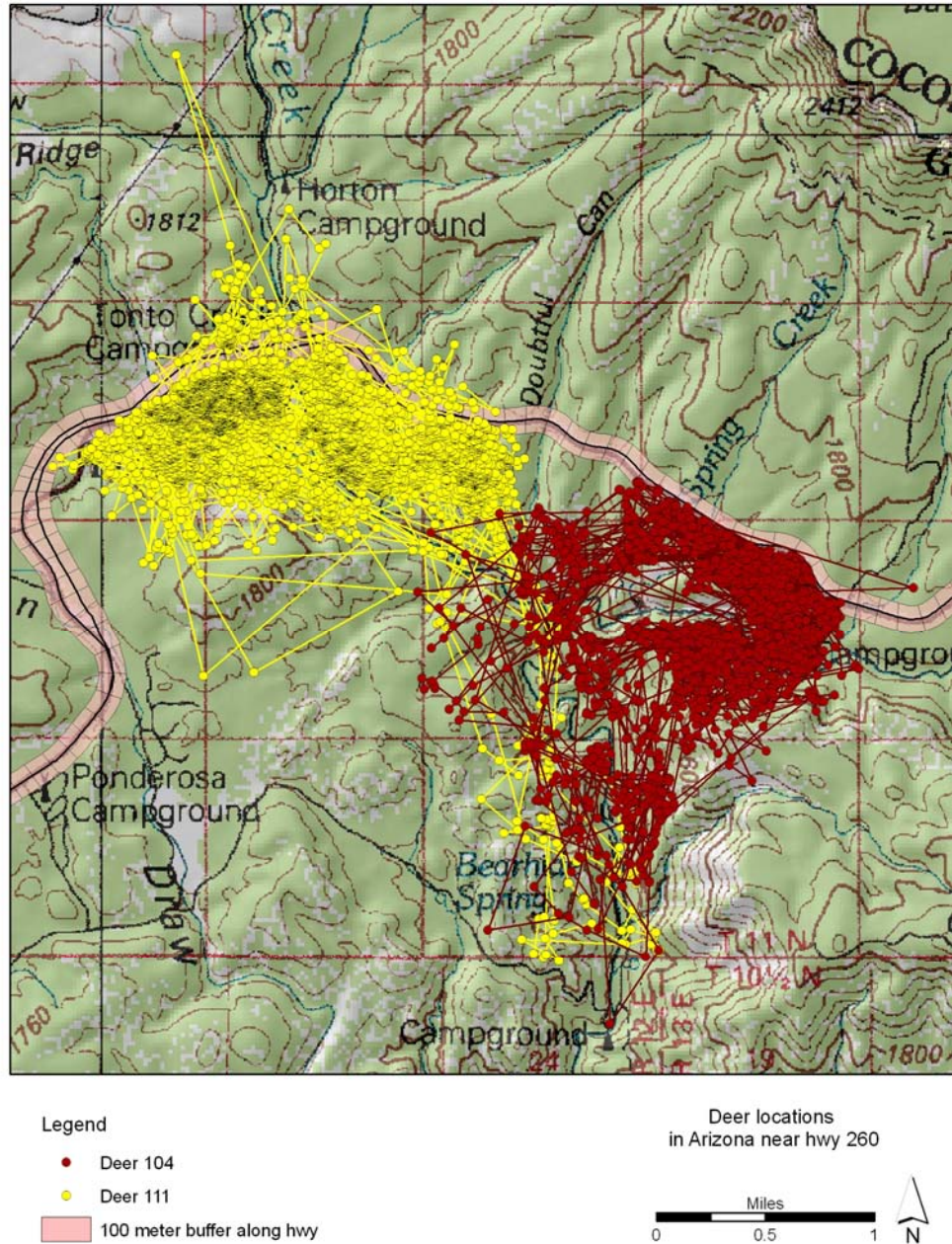


Figure 27. GPS Relocations for Male White-Tailed Deer 104 (Red) and 111 (Yellow), Determined from GPS Telemetry Conducted along SR 260, 2004–2007.

Of the 13 deer, 11 crossed SR 260 one or more times (ranging from 2 to 131 crossings), accruing 395 crossings and averaging 37.0 (\pm 13.2) crossings/deer. On the two control sections, the research team recorded an average of 0.02 (\pm 0.01) highway crossings/day by deer (n = 6). On the three reconstructed highway sections, the mean deer crossing rate averaged 0.28 (\pm 0.13) crossings/day (n = 9), which was nearly 15 times higher than that on the control sections (t_{13} = -2.35; P = 0.035; Table 19).

The calculated deer passage rate on the highway control sections averaged 0.03 (\pm 0.02) crossings/approach (n = 6). On the reconstructed highway sections, the mean passage rate was 0.16 (\pm 0.06) crossings/approach (n = 9), which was five times higher than the mean passage rate for the control sections (t_{13} = -2.43; P = 0.030; Table 19).

Table 19. Mean Highway Crossing and Passage Rates for White-Tailed Deer on Control and Reconstructed Sections of SR 260, 2004–2007.

Reconstruction Class	Crossing Rate (crossings/day)		Passage Rate (crossings/approach)	
	Deer (n)	Mean (\pm SE) ^a	Deer (n)	Mean (\pm SE) ^a
Control	6	0.02 (0.01) A*	6	0.03 (0.02) A**
Reconstructed	9	0.28 (0.13) B*	9	0.16 (0.06) B**

^a Different letters (A and B) denote significantly different means for crossing and passage rates between highway reconstruction classes determined from t -tests.

* t_{13} = -2.35; P = 0.035

** t_{13} = -2.43; P = 0.030

6.3.2 Traffic Volume and Deer At-Grade Highway Crossings

Monthly traffic volumes along SR 260 for 2004–2007 ranged from 120,989 to 331,010 vehicles and totaled 9,540,413 vehicles. Hourly traffic volumes during the peak deer movement period, 1700–0800, ranged from 1 to 1,365 vehicles/hr and averaged 185.0 vehicles/hr. Traffic volumes were highest during daytime hours when passenger cars accounted for 81.4 percent of all vehicles; commercial vehicles contributed 18.6 percent of the traffic volume but often exceeded 40 percent during nighttime hours (Figure 6).

The distribution analysis was based on 15,920 GPS locations recorded within 0.6 mi of SR 260. Frequency distributions of combined probabilities showed minimal shift in distribution away from the highway at increasing traffic volume, with the mean probability of a deer occurring within 660 ft of the highway remaining constant from approximately 32 percent at <100 vehicles/hr to 28 percent when traffic was more than 600 vehicles/hr (Figure 28). The mean combined probability for male white-tailed deer occurring within 660 ft of the highway when traffic volume was less than 100 vehicles/hr (36 percent) was nearly twice that of female deer (19 percent); at >600 vehicles/hr, the mean probabilities were more comparable at 26 percent (male) and 28 percent (female).

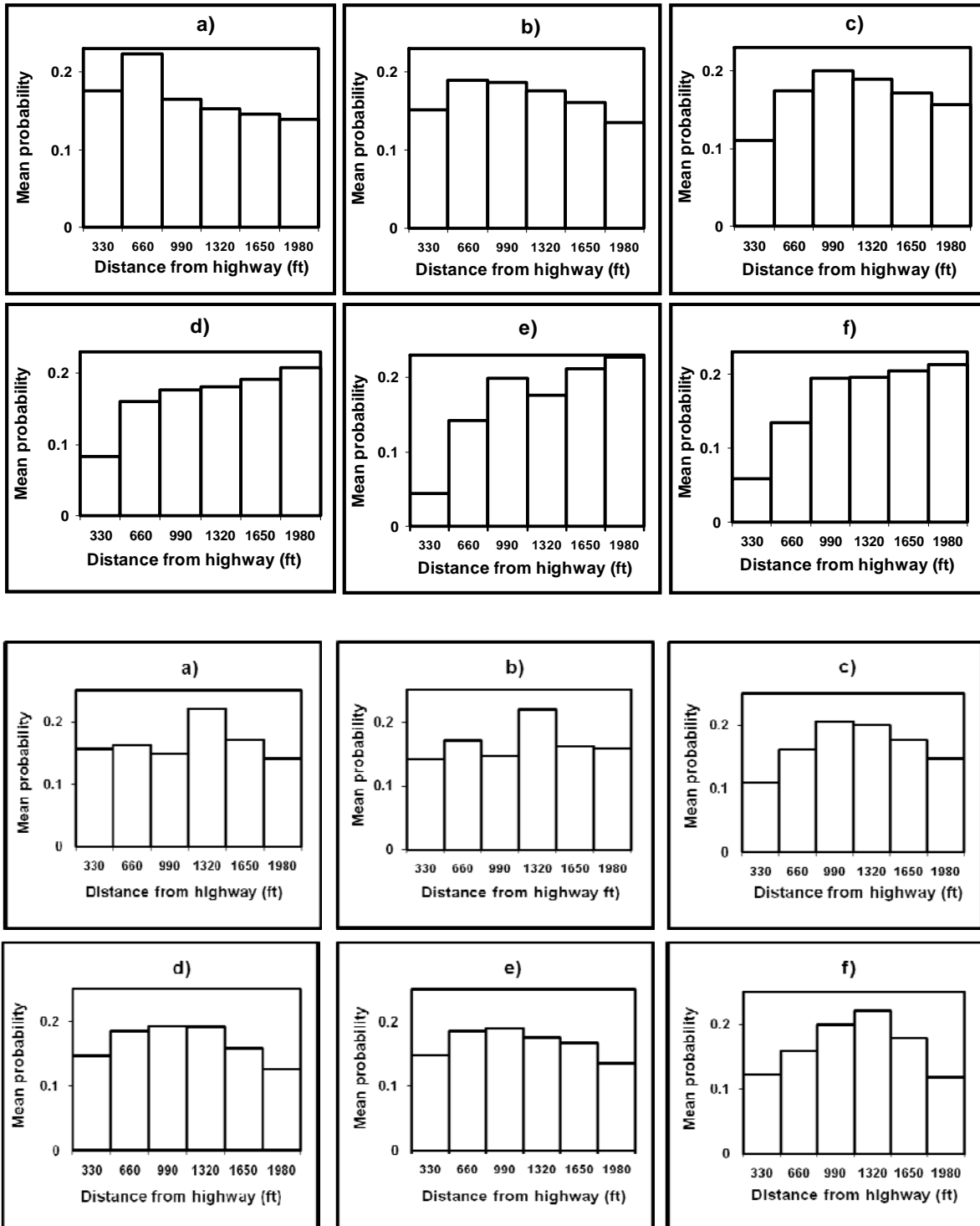


Figure 28. Mean Probability of GPS-Collared Elk (Top, A–F) and White-Tailed Deer (Bottom, A–F) Occurring within Each 330-ft Distance Band along SR 260 at Varying Traffic Volumes, between 2004 and 2007.

Note: (A) <100, (B) 100–200, (C) 200–300, (D) 300–400, (E) 400–500, and (F) >600 vehicles/hr.

Deer crossing passage rates related to traffic volume were all low (≤ 0.1 crossings/approach) and remained static across traffic volume classes, with passage rates varying from 0.08 crossings/approach at <100 vehicles/hr to 0.06 crossings/approach at >600 vehicles/hr (Figure 29). However, the linear regression analysis of deer passage rates and traffic volume for deer approaches and crossings that occurred on reconstructed highway sections and control sections yielded markedly different relationships (Figure 29). For reconstructed sections with passage structures present, the research team did not find a significant relationship between passage rate and increasing traffic volume ($r = -0.390$, $r^2 = 0.152$, $P = 0.445$, $n = 6$; Figure 30). On control sections without passage structures, the team noted a strong negative relationship between deer passage rate and increasing traffic volume ($r = -0.881$, $r^2 = 0.657$, $P = 0.050$, $n = 6$; Figure 30).

Logistic regression modeling yielded 15 different models predicting the probability of white-tailed deer at-grade crossings of SR 260 (Table 20). The AIC model selection yielded four models that were supported under the AIC criteria ($\Delta AIC_c < 10$; Table 20). The three best models included variations of three-way interactions among time of day (all three models), traffic volume (two models), season (two models), and highway reconstruction class (two models), while the remaining model included the two-way interaction of season and time of day (Table 20).

Among the models that contained individual factors, time of day was the most influential in determining crossing probability, though this factor alone was not supported under the model selection process ($\Delta AIC_c = 10$; Table 20); the observed frequency of crossings differed from the expected frequency ($\chi^2 = 35.1$, $df = 3$, $P < 0.001$), because >40 percent of deer crossings occurred in the evening. The model with traffic volume as an individual factor was the poorest in predicting deer highway crossings ($\Delta AIC_c = 21$). The highest proportion of deer highway crossings occurred during fall (0.36) compared to other seasons, and the observed frequency of crossings by season differed from the expected frequency ($\chi^2 = 17.4$, $df = 3$, $P < 0.001$).

6.3.3 Traffic Volume and Deer Below-Grade Underpass Crossings

The research team analyzed approximately 306 hours of white-tailed deer behavior and documented 865 groups, accounting for 1,419 individual deer recorded on surveillance videotape from May 2003 to June 2007. Of these, 270 groups consisting of 731 individuals crossed the ROW fence and came within the 150-ft zone constituting an approach to the six UPs. When combined across all UPs, traffic levels determined from video surveillance counts did not have an effect on deer passage rates ($\chi^2 = 5.25$, $df = 5$, $P = 0.391$); passage rates were static across all traffic volume classes (Table 21).

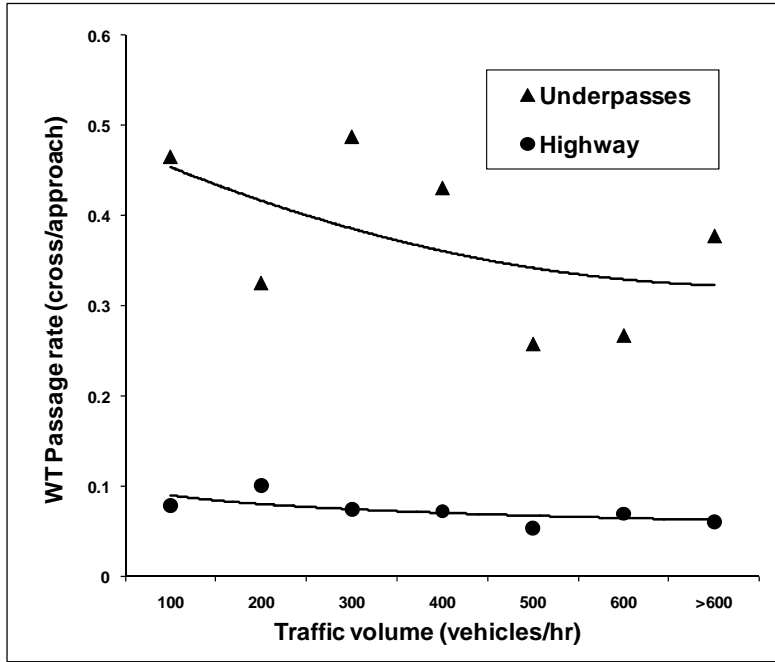
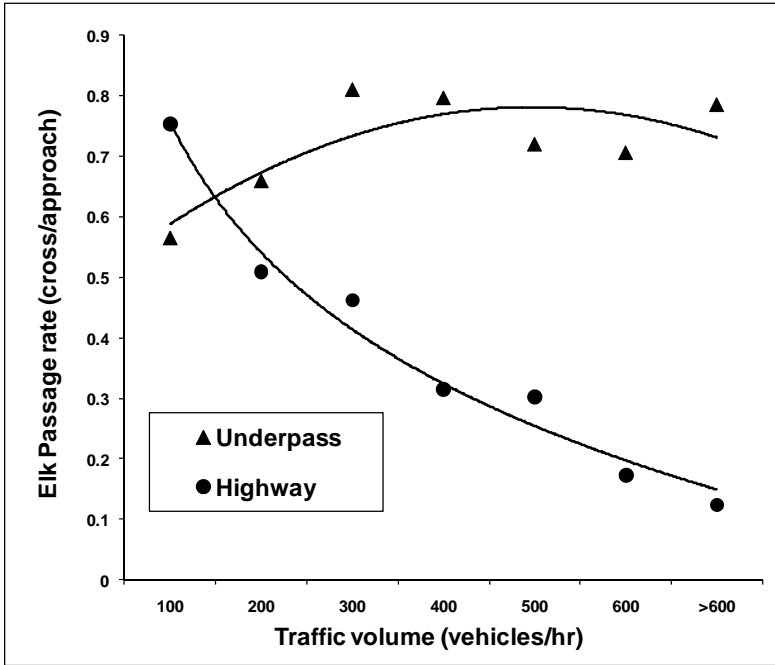


Figure 29. Comparison of At-Grade Highway and Below-Grade Underpass Passage Rates for Elk (Top) and White-Tailed Deer (Bottom) at Varying Traffic Volume Levels along SR 260, 2003–2007.

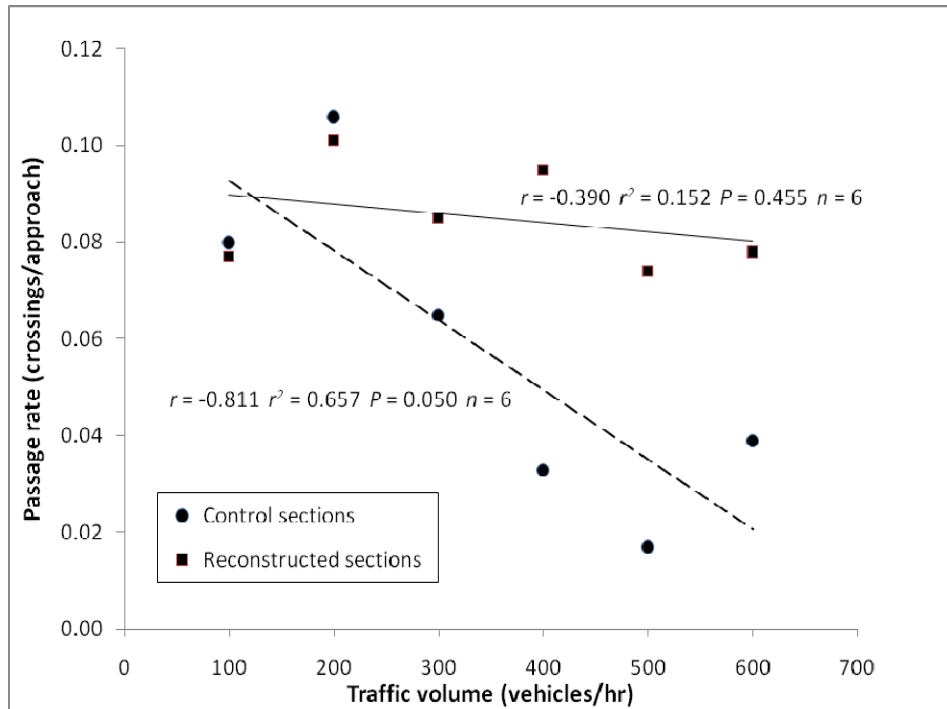


Figure 30. Linear Regression Analyses for Association between White-Tailed Deer Highway Crossing Passage Rates and Traffic Volume along SR 260, 2004–2007.

Table 20. Parameters for the Best Four Models Supported by Akaike’s Information Criterion of the Probability of 13 White-Tailed Deer Crossing SR 260.

Model	-2 Log Likelihood	k	AIC _c	ΔAIC _c	w _i
Supported Models					
Season + time + reconstruction	1,517	4	764	0	1.000
Time + reconstruction + traffic	1,523	4	767	3	0.235
Season + time + traffic	1,527	4	769	5	0.064
Season + time	1,534	3	771	7	0.022
Individual Factor Models					
Time of day	1,551	2	778	10	<0.001
Season	1,553	2	779	16	<0.001
Reconstruction class	1,564	2	784	20	<0.001
Traffic	1,565	2	784	21	<0.001
Null model	1,564	1	783	20	<0.001

Note: Models compared to individual factors and to the null model; k = number of parameters, ΔAIC_c = Akaike’s Information Criterion difference, w_i = Akaike weight. In total, 15 models were developed from deer GPS telemetry and traffic counting conducted along SR 260 from 2004 to 2007.

Table 21. Number of Successful and Unsuccessful White-Tailed Deer Crossings and Passage Rates at Five Wildlife Underpasses along SR 260, 2003–2007.

Parameter	Traffic Volume Level (Vehicles/Min)				
	0	1–2	2–4	4–6	>6
Successful Underpass Crossing	5	25	25	16	22
Unsuccessful Underpass Crossing	13	49	38	44	33
Passage Rate	0.28	0.34	0.40	0.27	0.28

Vehicles passed directly overhead of individual white-tailed deer during 116 UP crossings, with 91 deer flight responses involving passenger vehicles and 26 flight responses involving commercial trucks (Table 22). Across both traffic volume classes, commercial vehicles were associated with deer flight from the six UPs 39 percent of the time deer entered UPs, while passenger vehicles caused flight 16 percent of the time ($\chi^2 = 5.81$, $df = 1$, $P = 0.016$). While commercial trucks were associated with a higher proportion of deer flight responses (0.58) than were passenger vehicles (0.12) at traffic levels <4 vehicles/min ($\chi^2 = 5.86$, $df = 1$, $P = 0.021$; Table 22), both vehicle types elicited nearly the same proportion of flight responses at a traffic volume >4 vehicles/min.

Table 22. Number of Individual White-Tailed Deer Exhibiting Flight Responses at Six Wildlife Underpasses along SR 260 with Varying Overhead Traffic Levels, 2003–2007.

Vehicle Type	Traffic Volume Level					
	<4 Vehicles/Min			>4 Vehicles/Min		
	Flight	Total Deer	Proportion	Flight	Total Deer	Proportion
Passenger	6	49	0.12	9	42	0.21
Commercial Truck	7	12	0.58	3	14	0.23
All	13	61	0.21	12	55	0.22

The proportion of passenger vehicles associated with deer flight from UPs did not differ by traffic volume classes ($\chi^2 = 1.39$, $df = 1$, $P = 0.239$), but for commercial vehicles, the proportion was higher at traffic levels <4 vehicles/min ($\chi^2 = 3.72$, $df = 1$, $P = 0.050$).

Deer UP passage rates declined with increasing traffic volume determined from our permanent traffic counter (Figure 30). Passage rates ranged from 0.46 crossings/ approach at <100 vehicles/hr to 0.27 crossings/ approach at 600 vehicles/hr.

6.4 DISCUSSION

6.4.1 Deer Movements and Highway Permeability

This study points to the degree to which even the relatively narrow, two-lane experimental control sections constituted a substantial barrier to deer passage across SR 260, especially when compared to elk. While Dodd et al. (2007a) reported a negligible barrier effect on elk associated with the SR 260 control sections (0.88 crossings/approach), deer appeared considerably more sensitive to the highway barrier effect with a very low mean passage rate (0.03 crossings/approach) along these same sections. The deer control passage rate was even lower than the passage rates reported by Paquet and Callaghan (1996) for wolves along the Trans-Canada Highway (0.06) and elk along the Preacher Canyon section (0.09 crossings/approach), both of which are four-lane divided and fenced highways with anticipated barrier effects as predicted by Jaeger et al. (2005).

The apparent sensitivity of white-tailed deer to this barrier effect is further illustrated in comparing their mean crossing rate to that of elk. Though Dodd et al. (2007a) found that the elk passage rate on reconstructed SR 260 was half that of control sections, they found no difference in highway crossing rates among reconstruction classes (0.22 and 0.26 crossings/day for control and reconstructed sections, respectively). Elk appeared sufficiently adaptable to maintain constant crossing rates across all reconstruction classes regardless of passage rate, requiring more effort in approaching the highway or crossing later in the evening when traffic volume was lower (Gagnon, Theimer, Dodd, and Schweinsburg 2007). White-tailed deer crossing rates differed greatly between control (0.02 crossings/day) and reconstructed (0.28) highway classes, and deer apparently did not exhibit the same capacity as elk to maintain constant crossing rates across reconstruction classes. Rather, they showed a propensity to increase their movement across the highway corridor in the presence of passage structures.

6.4.2 Deer Response to Highway Reconstruction with Passage Structures

Just as Dodd et al. (2007a, 2007b) reported a benefit to elk permeability associated with the combined influence of wildlife UPs and ungulate-proof fencing along SR 260, the research team noted an even more dramatic benefit to both white-tailed deer crossing and passage rates on reconstructed highway sections: 1,300 percent and 433 percent higher than on control sections, respectively. These benefits constitute tangible evidence of the efficacy of wildlife passages along SR 260 in promoting deer permeability. And where the results of passage structures and fencing benefit in promoting elk permeability along SR 260 have been mixed (e.g., Dodd et al. 2007a, 2007b versus Gagnon et al. 2010), the spacing between passage structures to facilitate passage may be a factor. Bissonette and Adair (2008) recommended 2.2-mi spacing between passages for elk, which is greater than the spacing found on all three reconstructed SR 260 sections. Their recommendation for elk may be insufficient to promote a high level of elk permeability, as discussed in Chapter 5.

Moose in Sweden showed a similar response, and Olsson et al. (2008) believed that far-ranging movements of moose contributed to reduced ability to encounter and habituate to passage structures compared to less-mobile species such as deer. Assessments by Olsson et al. (2008) and Gagnon et al. (2010) may also point to the need for additional time for animals to habituate to passage structures; regardless, both studies concluded that even the relatively low permeability may be sufficient to maintain gene flow given the animals' wide-ranging movements (Mills and Allendorf 1996). For white-tailed deer, Bissonette and Adair (2008) recommended that passages be spaced 0.9 mi apart to promote permeability for this less-mobile species. The spacing of passage structures associated with the three reconstructed SR 260 sections where the research team documented increased permeability averaged 0.88 mi (13 passage structures in 11.5 mi), thus providing an empirical validation of Bissonette and Adair's (2008) recommendation for white-tailed deer.

6.4.3 Influence of Traffic Volume on Deer Movements and Permeability

Compared to prior SR 260 assessments of traffic volume influence on elk at-grade highway crossings (Gagnon, Theimer, Dodd, and Schweinsburg 2007), the influence of traffic on white-tailed deer crossings superficially does not appear as great. Compared to the dramatic shift in elk distribution across 330-ft distance bands with increasing traffic, including a greater than 50 percent reduction in the probability of elk occurring within 660 ft of the roadway as traffic increased from <100 to 600 vehicles/hr, the distribution remained static for white-tailed deer (Figure 28).

Likewise, while the elk passage rate for at-grade crossings showed a dramatic drop with increasing traffic, deer passage rates remained nearly constant across traffic levels, albeit very low (Figure 29). Although traffic volume was the most influential single-parameter model in the logistic regression modeling in determining elk crossing probability (Gagnon, Theimer, Dodd, and Schweinsburg 2007), it proved to be the weakest of the single-parameter models for white-tailed deer along SR 260; it was nevertheless incorporated into two models with other parameters. In spite of these measures that suggest limited differential white-tailed deer response to increasing traffic volume or relative importance in modeling, the research team nonetheless believes that deer along SR 260 were influenced by traffic to an equal or even greater degree than elk.

First, deer are considerably more restricted in their movements along SR 260 than elk. While only 13.6 percent of elk GPS relocations occurred within 0.15 mi (approximately 800 ft) of SR 260 (Dodd et al. 2007a), white-tailed deer were relocated within 0.15 mi twice as often (25.3 percent). And nearly 80 percent of white-tailed deer relocations were recorded within 0.6 mi of SR 260 compared to 45 percent for elk (Dodd, Gagnon, Boe, et al. 2007). Deer home ranges averaged (excluding one far-ranging male) less than one-tenth of those of elk along SR 260 (Dodd et al. 2007a). GPS-collared deer were thus considerably more confined in their movements and proximity to the highway and were constantly exposed to the impact of nearby traffic.

The research team hypothesizes that deer movements were influenced to a constant degree across all 330-ft distance bands by increasing traffic volume, especially compared to elk. This phenomenon, combined with the overall constant influence of increasing traffic volume on passage rates when deer crossed the highway at grade (Figure 30), may have accounted for the lower influence traffic volume played in modeling the probability of deer crossings. Along with the low passage rates for deer along highway control sections, the dramatic response by deer to the presence of passage structures on reconstructed sections illustrates both the constant influence of traffic and benefit from passage structures in promoting permeability (Figure 30).

The research team compared findings by Gagnon, Theimer, Dodd, and Schweinsburg (2007) for at-grade UP elk crossings and those of Gagnon, Theimer, Dodd, Manzo, et al. (2007) for below-grade UP elk crossings (summarized in Figure 29; Dodd et al. 2007b); the team found that UPs promoted elk passage and that elk passage rates remained constant across traffic volume levels when animals crossed below grade. The same phenomenon occurred for white-tailed deer, given the relatively high passage rates for animals recorded on videotape at the UPs (Figure 29). The UP passage rates reported in this SR 260 study are conservative, since they reflect relatively low passage rates at the two Preacher Canyon section UPs (<0.08 crossings/approach) due to limited cover habitat on the south side of the UPs (Dodd, Gagnon, Manzo, et al. 2007), compared to the passage rates for the other four UPs that averaged above 0.54 (Dodd, Gagnon, Boe, et al. 2007).

The linear regression model comparing passage rates on reconstructed highway sections with passage structures and control sections without passage structures provided the most conclusive evidence of the influence of traffic volume on GPS-collared deer passage rates (Figure 30). On control sections, increasing traffic volume had a strong negative association with passage rate, similar to the relationship for elk at-grade crossings and traffic volume reported by Gagnon, Theimer, Dodd, and Schweinsburg (2007). Where UPs were present, the association between deer passage rate and increasing traffic volume was more static and consistently higher across traffic levels. This was similar to the influence of UPs on elk passage rates reported by Gagnon, Theimer, Dodd, Manzo, et al. (2007). Even at high traffic volumes, deer continued to cross SR 260 through UPs and bridges, as did elk (Gagnon, Theimer, Dodd, Manzo, et al. 2007).

Though traffic was the poorest of the research team's individual-factor logistic regression models, half of the selected models predicting probability of white-tailed deer at-grade crossings nonetheless included traffic. All four selected models included time of day, since a disproportionate number of deer crossings occurred during evening hours. Other studies have suggested that evening is a peak time for deer activity, particularly as reflected in deer-vehicle collision patterns (Allen and McCullough 1976; Danielson and Hubbard 1998). Haikonen and Summala (2001) reported a large peak in deer-vehicle collisions within three hours after sunset tied to circadian rhythms associated with light, which included 37 percent of white-tailed deer collisions. Dodd et al. (2006) reported an even more dramatic peak in deer-vehicle collisions within three hours after sunset when 64 percent of deer collisions occurred along SR 260.

Three of the four selected models included season, with a disproportionately high number of deer crossings during fall. Romin and Bissonette (1996b), Hubbard et al. (2000), and Puglisi et al. (1974) all noted and attributed increased deer-vehicle collisions in fall to increased movements associated with breeding and the impact of sport hunting. Gagnon, Theimer, Dodd, and Schweinsburg (2007) found that elk crossing probability was highest in fall and spring and interacted strongly with proximity to riparian-meadow habitats that were important for foraging and water. Such open habitats are not considered as important for white-tailed deer feeding, partly explaining why crossings in fall were higher than in spring when riparian-meadow habitats provide their highest quality forage (Dodd et al. 2007a); this further supported the research team's exclusion of proximity of riparian-meadow habitat from its logistic regression analysis.

The influence of commercial vehicles in eliciting a flight response from deer crossing through UPs when traffic volumes were relatively low (<4 vehicles/min) was nearly five times as great as that for passenger cars, and it was over twice as great as commercial trucks passing when traffic volume was >4 vehicles/min. These results mirrored those for elk UP use (Gagnon, Theimer, Dodd, Manzo, et al. 2007). At relatively low, intermittent traffic levels the overall increase in sound and vibration appears to have a greater impact than a higher and more continuous flow of traffic and associated sound and vibration.

The influence of commercial vehicles is probably due to the sound created by larger vehicles, since the noise of passing large trucks is approximately 10 decibels (A-weighted scale) more than that of passing passenger vehicles (Lee and Fleming 1996). Though a relatively small proportion of videotaped white-tailed deer crossings resulted in a flight response due to traffic passing overhead (21 percent), the high proportion of commercial trucks traveling on SR 260 during nighttime hours when traffic volume is lowest (Figure 6) has the potential to limit successful deer passage via UPs.

In conclusion, the research team found that even the narrow highway control sections constituted a significant barrier to white-tailed deer passage across SR 260, with traffic volume contributing to this barrier effect. Passage structures dramatically improved deer crossing and passage rates along reconstructed sections. Traffic volume had a much lower impact on deer when crossing through UPs compared to when crossing SR 260 at grade. Passage structures have been demonstrated as being effective in promoting permeability for both a far-ranging, migratory ungulate species such as elk (Dodd et al. 2007a; Gagnon, Theimer, Dodd, Manzo, et al. 2007) and a nonmigratory, relatively sedentary species such as white-tailed deer (Ockenfels et al. 1991). These structures effectively serve to maintain sufficient genetic flow to maintain long-term population viability for these species (Mills and Allendorf 1996).


7.0 CONCLUSIONS AND RECOMMENDATIONS

The research team integrated and synthesized the findings from all phases of SR 260 research conducted in 2001–2008 to develop the following conclusions and recommendations, including results from Phase I and II of the project (Dodd, Gagnon, Boe, et al. 2007). In several instances, the research team derived similar conclusions from independent research methodologies, adding to the power of such findings. Though conclusions were specific to SR 260, the research team’s recommendations are more generic in nature and thus potentially applicable to other highways and locales.


Recommendations are identified by this symbol: 

7.1 HIGHWAY PLANNING AND MONITORING


- The research underscored the ability to fully integrate transportation and ecological objectives into highway construction activities, yielding tangible benefits to both highway safety and wildlife permeability.
- The combined application of phased construction, adaptive management, and effective monitoring and evaluation of measures to reduce WVCs and promote permeability were instrumental to jointly achieving transportation and ecological objectives.

 The research team recommends a phased, adaptive management approach to highway construction and monitoring, when and where possible.

- ADOT prioritized the reconstruction of the five SR 260 sections based on the historic incidence of WVCs, especially EVCs. Our WVC monitoring and GPS telemetry research validated this prioritization; the strong association between EVCs and highway crossings underscored the utility and value of WVC data in planning wildlife mitigation measures ranging from passage structures to ungulate-proof fencing.

 ADOT and other agencies should continue committed efforts to collect and archive spatially accurate WVC data throughout Arizona, using a standardized interagency collision reporting system. Such an effort will provide valuable information for future highway planning and design.

- Though expensive to conduct, monitoring of wildlife mitigation measures and WVCs yielded significant benefit in improving the efficacy of these measures.

 ADOT and other agencies should consider funding and incorporating an effective monitoring system as part of construction projects, which will add to the body of knowledge on wildlife collision mitigations and contribute to the “toolbox” of potential measures for application on highways elsewhere.

7.2 WILDLIFE UNDERPASSES

- Wildlife UPs on SR 260 were highly effective in promoting below-grade wildlife crossings, with two-thirds of over 15,000 animals recorded during video surveillance having crossed through UPs. These UPs were instrumental in improving highway safety through reduction of WVCs and promoting wildlife permeability.
 - The distance between wildlife passage structures, including both UPs and bridges over streams, averaged 1.0 mi and ranged from 0.6 mi on the Christopher Creek section to 1.5 mi on the Preacher Canyon section. This spacing is important to promote elk and white-tailed deer permeability.
 - The close (0.6-mi) spacing of structures promoted a high level of after-reconstruction elk permeability (0.81 crossings/approach), while spacing that was only twice the distance (1.3 mi; Kohl's Ranch section) promoted only one-third the level of permeability (0.27). The 1.5-mi spacing resulted in one-tenth the permeability (0.09).
- ☞ The research team recommends that passage structure spacing not exceed 1.0 mi in order to accommodate elk, as well as deer, permeability. Passage structures should be prioritized for placement in areas exhibiting high incidence of WVCs or near important habitat areas such as meadows or known travel corridors.
- ☞ For the most part on SR 260, constructed passage structures were large, open-span bridges that are relatively expensive, especially when implemented elsewhere at the same average spacing of SR 260 and the above recommendation. Though this project confirmed that these passage structures have a high degree of effectiveness, the research team recognizes the cost of constructing such structures at a spacing distance of 1.0 mi. The research team recommends that ADOT investigate and consider other accepted and cost-effective passage structure designs (e.g., large metal multiplate arched culverts) in an appropriate mix with large, open-span bridge structures to reduce cost while promoting permeability.
- Structural design characteristics and placement of UPs are important in maximizing their efficacy in promoting wildlife passage. The researchers found UP structural characteristics to be the most important factor in determining the probability of achieving successful crossings by both elk and deer.
 - As reported in other studies, UP openness is important to achieving high probability of successful crossings by wildlife. The SR 260 data suggest that UP length, the distance that animals must travel through a UP, is an especially important factor in maximizing UP efficacy.

- ☞ UP length should be minimized in designing any wildlife UP, where possible, given terrain and other factors. Atria between UP bridge spans contribute to openness, especially for UPs exhibiting longer lengths.
- Researchers found that elk avoided a UP where concrete mechanically stabilized earth retaining walls were erected for soil stabilization. Concrete walls contributed to a “tunnel effect,” and created a ledge atop the walls (which the elk seemed to perceive as a place for potential lurking predators). The walls also may contribute to adverse noise propagation.
 - ☞ The application of concrete walls in wildlife UPs should be avoided where possible.
- Visibility through UPs should be maximized, especially in UP design for divided highways with atria between bridges.
 - ☞ The research team recommends that the bridges be placed in line to maximize animal visibility through the structures. Offset UP bridges should be avoided; where offset bridges are necessary, the use of fill material that limits animal visibility should be minimized.
- UP placement was particularly important for white-tailed deer, given that passage rates associated with UPs with cover on one side and open meadow on the other were low compared to UPs with cover on both sides.
 - ☞ To accommodate use by multiple species, that the research team recommends that UP approaches be situated within or adjacent to cover habitats (versus open meadows where deer may avoid use), where possible. This will also help reduce the impact of noise associated with vehicular traffic in open habitats.
- Daytime human presence and disturbance (e.g., hiking) at UPs appeared to have limited impact on wildlife use of UPs.
 - ☞ Wildlife UP placement should avoid concentrated areas of human disturbance or places where humans congregate during nighttime hours.
- Video camera surveillance constituted an effective means to quantify and compare wildlife use of UPs, provided bias-free measures of wildlife use (passage rate, probabilities of successful passage), allowed researchers to quantify animal behavioral response to UPs and supported modeling of factors influencing UP efficacy. Long-term monitoring will provide valuable insights on changes in wildlife use patterns.

7.3 INFLUENCE OF TRAFFIC VOLUME ON WILDLIFE

- Traffic levels along SR 260 fluctuated greatly on an hourly, daily, and seasonal basis through our study area, averaging between 7,000 and 8,500 AADT, which was considerably higher on weekends and during the peak tourist/recreation summer months. Theoretical models suggest that highways above 10,000 AADT become near-total barriers to movement for many species. Traffic volumes on SR 260 were considered moderately high, to the degree that elk permeability was not generally precluded but was high enough to yield meaningful insights into temporal highway crossing and distribution patterns.
- Researchers found that traffic volume influenced elk and white-tailed deer crossing patterns and distribution at highway grade. With increasing traffic levels, the team found reduced probability of successful elk highway crossings at grade, crossings occurred later in the evening when volume levels abated, and elk moved away from the highway as volumes increased. Unsuccessful attempts (repels) by elk to cross SR 260 typically coincided with high traffic volume. Deer seldom crossed at grade regardless of traffic volumes.
- At monitored wildlife UPs, traffic volume on SR 260 overhead generally did not have an effect on both elk and deer approaching and successfully crossing through the UPs. This finding was of paramount importance to understanding the efficacy of UPs in promoting wildlife permeability.
- Researchers noted limited impact of traffic volume on elk at UPs during very high AADT levels (>9,000 vehicles/day). However, increasing traffic could have increased impact in the future, to the degree that measures may be necessary to mitigate the impact of vehicle noise associated with high AADT (e.g., rubberized asphalt on bridges and approaches, sound walls). At very high traffic levels, such measures could create “quiet zones” that attract crossing animals and/or improve the likelihood of successful crossings.

7.4 WILDLIFE PERMEABILITY RELATIONSHIPS

- GPS telemetry afforded an unprecedented opportunity to assess and compare wildlife permeability among highway reconstruction classes, as well as to assess permeability before and after the erection of ungulate-proof fencing. The research team’s use of passage rate as a comparable metric for permeability facilitated these assessments. The long-term duration of telemetry research and the number of animals fitted with GPS collars (100 elk, 13 white-tailed deer) makes this one of the most comprehensive highway studies ever conducted.

☞ When possible, GPS telemetry should be used to evaluate the need for passage structures and to identify the best possible structure locations. The goal is to promote permeability, particularly for those species that do not readily cross highways and for which limited WVC data exist (e.g., pronghorn).

- The reconstruction of SR 260 from a two-lane to four-lane highway reduced wildlife permeability. The mean passage rate measured on three reconstructed sections regardless of fencing status was 0.41 crossings/approach—39 percent lower than the mean passage rate of the control sections, which was 0.67 crossings/approach. This difference in permeability with highway reconstruction is considerably less than other reported studies and reflects the benefit of passage structures.
 - Permeability on reconstructed sections with and without ungulate-proof fencing was similar, with passage rates averaging 0.40 and 0.41 crossings/approach, respectively. However, on the three reconstructed sections after fencing, there was considerably more variation in passage rates, which ranged from 0.09 to 0.81 crossings/approach. This variation in passage rates was likely related to the spacing of passage structures; researchers found a strong inverse relationship between permeability and passage structure spacing. Spacing thus has an influence on elk permeability as reflected in the recommendation above.
- ☞ Fencing was critical to achieving a high level of elk permeability and should be considered an integral component of passage structures in promoting permeability. Fencing must extend outward from passages a distance sufficient to funnel animals and prevent at-grade crossings. Short-wing fences extending out from passage structures (e.g., 250–300 ft) under a limited-fencing approach will not promote permeability or highway safety. Conversely, fencing alone to address highway safety without effective passage structures will not promote permeability.
- Even the narrow control sections constituted a barrier to deer passage, where passage rates averaged only 0.03 crossings/approach. Permeability was improved significantly with passage structures and fencing, and passage rates averaged 0.16 crossings/approach on the reconstructed sections, which is a 433 percent increase in permeability. These findings for a relatively sedentary species complemented the findings for elk, further underscoring the permeability benefits from UPs and fencing for multiple wildlife species.

7.5 HIGHWAY SAFETY AND WILDLIFE-VEHICLE COLLISIONS

- With three of the five SR 260 sections reconstructed to date integrating UPs and ungulate-proof fencing, 2006 was the first year that the incidence of actual EVCs dropped below the level predicted from modeling based on AADT and elk population levels. Reconstructed highway sections without substantial ungulate-proof fencing had the highest EVC rates recorded for North America (4.6 EVCs/mi) and reflect the inability of the limited-fencing approach to mitigate WVCs with reconstruction. Conversely, after the erection of additional fencing based on GPS telemetry-informed adaptive management, EVC rates were reduced to before-reconstruction levels (1.2 EVCs/mi), and a reduction of 96 percent was achieved on the Preacher Canyon section that was entirely fenced.

- With three highway sections now reconstructed for at least three years, the economic benefit realized from reduced EVCs associated with UPs and fencing (when modeled against EVCs without these mitigations) has averaged \$2 million/year for the last three years. Therefore, along with the benefit in reducing WVCs and promoting highway safety and wildlife permeability, highway reconstruction with effective wildlife UPs and fencing also yields significant economic benefit.

7.6 ROLE OF UNGULATE-PROOF FENCING

- In addition to playing an instrumental role in promoting permeability and highway safety from reduced EVCs, ungulate-proof fencing was crucial to achieving effective use of UPs, especially those not located in proximity to meadow habitats. Without fencing, elk and deer continued to cross SR 260 at grade immediately adjacent to UPs. With fencing, elk and deer passage rates and probabilities of successful crossing through UPs increased dramatically while at-grade crossings decreased.
 - ☞ Fencing was critical to achieving significant reductions in EVCs and should be considered an integral component of wildlife mitigation measures to promote highway safety in concert with effective passage structures. As with promoting permeability, sufficient fencing is needed to prevent at-grade highway crossings and to funnel animals to UPs.
- Through the adaptive management process with SR 260 reconstruction, the research team used elk-GPS telemetry crossing data to recommend strategic placement of ungulate-proof fencing in order to intercept elk at peak crossing zones; planned application of fencing was limited due to high cost, maintenance requirements, and impact on visual quality. This strategically placed fencing approach was effective on the Christopher Creek section, where 50 percent of the section that was fenced was projected to intercept 89 percent of elk crossings; the EVC rate dropped 83 percent in the year after fencing. On the Kohl's Ranch section where only the eastern third of the section was fenced, this approach did not yield the desired results, given that EVCs on the western portion of the section actually increased (though this increase is partly attributable to an increase in the elk population).
- Researchers found that the benefit of ungulate-proof fencing in promoting wildlife use of UPs was particularly important for relatively marginal passage structures. For UPs that received limited wildlife use before fencing, the installation of fencing at those UPs led to a proportionally greater improvement in the probability of successful wildlife crossings. This finding has potential implications for retrofitting structures not specifically designed for wildlife passage that might be considered marginal; fencing can funnel and “force” animals to such structures.

- Though beneficial in reducing WVCs, maximizing UP use by wildlife, and promoting permeability, fencing nonetheless requires constant maintenance and attention to maintain its integrity.
 - ☞ Ungulate-proof fencing along SR 260 should be checked and maintained to ensure its long-term integrity and continued benefit in promoting a safe highway. Adequate funding is needed for ADOT to accomplish effective maintenance of fencing and UPs as these measures are increasingly applied on Arizona’s rural highways in the future. Inadequate maintenance funding could limit the potential application of new fencing and jeopardize the long-term effectiveness of existing fencing.

7.7 FUTURE SR 260 RECONSTRUCTION SECTIONS

- Compared to the first three reconstructed sections, the Little Green Valley and Doubtful Canyon sections exhibited relatively few WVCs or elk-GPS crossings (with the exception of the R-C Scout Ranch area of the latter section, where riparian-meadow habitat is located near the highway). However, in the past three years when elk populations increased, so did the incidence of EVCs.
 - ☞ On the Little Green Valley section, the research team recommends that fencing be erected from the western abutments of the single planned wildlife UP westward to the existing Preacher Canyon section fencing that terminates at the eastern end of the Little Green Valley meadow complex. This will eliminate most WVCs that occur beyond the end of the Preacher Canyon section fence, funneling all animals that encounter the fence to a UP. The team recognizes that funding for such fencing may be limited.
 - ☞ The research team recommends that the western portion of the Kohl’s Ranch section be fenced to eliminate the end-run effect. Here, modification of the existing ROW fence similar to that done on the Preacher Canyon section (Gagnon et al. 2010) presents a viable and cost-effective option.
- On the Doubtful Canyon section, three wildlife UPs are planned.
 - Dodd, Gagnon, Boe, et al. (2007) recommended that priority be given to ungulate-proof fencing associated with the UP in the R-C Scout Ranch area, where considerable WVCs and elk-GPS highway crossings were documented. They recommended that this fencing be extended so that potential end runs are avoided. Furthermore, at the other two planned UPs near Doubtful Canyon, Dodd, Gagnon, Boe, et al. (2007) recommended fencing along the limited distance between the two UPs to connect them and to funnel all animals that encounter the fence to a UP.

☞ Based on the insights gained during this phase of research, particularly for the Kohl's Ranch section, the research team now recommends that ungulate-proof fencing be considered for the entire 4.0-mi Doubtful Canyon section to maximize UP effectiveness by linking all UPs together, thus preventing the potential for future end-run issues and increased incidence of WVCs. By the time appropriate lengths of fencing are erected in association with the three UPs to funnel animals to them, the additional fencing required to fence the entire section and prevent end runs at gaps in the fence may be minimal.

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