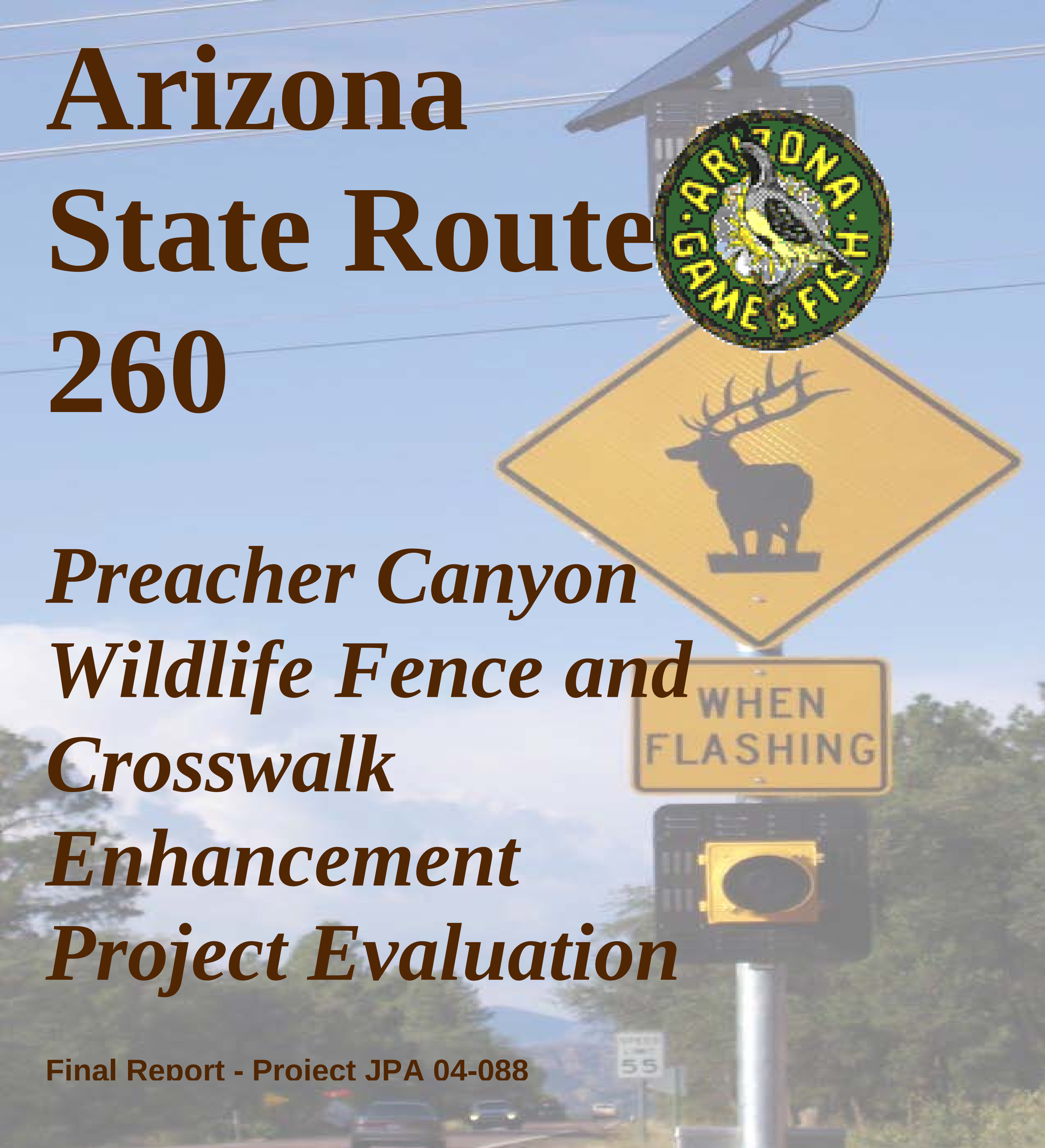
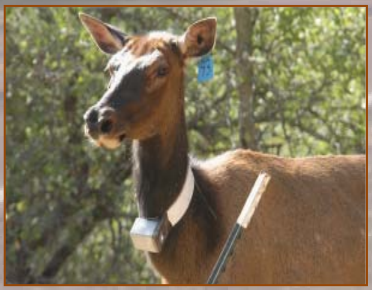
Arizona State Route 260

Preacher Canyon Wildlife Fence and Crosswalk Enhancement Project Evaluation



Final Report - Project JPA 04-088




PREACHER CANYON WILDLIFE FENCE AND CROSSWALK ENHANCEMENT PROJECT EVALUATION

State Route 260

Final Report - Project JPA 04-088

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FUNDING FOR THE PROJECT

AGFD, in cooperation with the ADOT Prescott District, submitted an enhancement project proposal in July 2003, through the Transportation Equity ACT of the 21st Century (TEA-21) application process. Our project proposal fell under Category 11: Reduce Vehicle Caused Wildlife Mortality While Maintaining Habitat Connectivity, and was Arizona's first project proposal ever submitted under this category. The project was approved in early 2004, comprehensive project planning was completed in 2005, and full project implementation was accomplished by February 2007. Many people acknowledged above contributed to making this one of the quickest implementations of an enhancement grant in Arizona. AGFD received additional funding from ADOT to conduct the research evaluation of the effectiveness of the different fence designs, the RADS and crosswalk, and all other elements of the project. Amendment No. 1 to the Interagency Agreement for ADOT Project No. TEA-260-B(008)A (JPA 04-088) was executed on June 13, 2006, and stipulated that the research evaluation would be conducted and that AGFD would "… recommend to the State

(ADOT) the need to continue the Project in conjunction with the State by providing to the State an up-to-date summary of the effectiveness of all fences and RADS.” This report addresses the findings of the funded research evaluation.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS AND ABBREVIATIONS

AADT	average annual daily traffic
ADOT	Arizona Department of Transportation
AGFD	Arizona Game and Fish Department
CC	Christopher Creek (section)
DVC	deer-vehicle collision(s)
EVC	elk-vehicle collision(s)
ft	foot/feet
FHWA	Federal Highway Administration
GPS	Global Positioning System
hr(s)	hour(s)
LS	Lion Springs (section)
mi	mile(s)
min	minute(s)
MP	milepost
mph	miles per hour
PC	Preacher Canyon (section)
RADS	roadside animal detection system
ROW	right-of-way
SR	State Route
TNF	Tonto National Forest
VCR	videocassette recorder
WVC	wildlife-vehicle collision(s)

LIST OF SPECIES

Animals

Black bear	*Ursus americanus*
Deer	*Odocoileus* spp.
Elk	*Cervus elaphus*
Gray fox	*Urocyon cineroargenteus*
Javelina	*Tayassu tajacu*
Moose	*Alces alces*
Mountain lion	*Puma concolor*
Mule deer	*Odocoileus hemionus*
Pronghorn	*Antilocapra americana*
Raccoon	*Procyon lotor*
Roe deer	*Capreolus capreolus*
Coues white-tailed deer	*Odocoileus virginianus couesi*

Plants

Juniper	*Juniperus* spp.
Live oak	*Quercus* spp.
Manzanita	*Arctostaphylos pungens*
Pinyon pine	*Pinus edulis*
Ponderosa pine	*Pinus ponderosa*

1.0 EXECUTIVE SUMMARY

We evaluated the efficacy of 2.5 mi of retrofit fencing using three different designs integrated with a roadside animal detection system (RADS) intended to reduce wildlife-vehicle collisions (WVC) while maintaining permeability across State Route (SR) 260. Right-of-way (ROW) fence modifications to raise the existing fence were installed to funnel wildlife to two wildlife underpasses and Preacher Canyon Bridge, located along the reconstructed Preacher Canyon (PC) section. The RADS was intended to alert motorists with a series of signs when wildlife approached the highway through a "detection zone." Implementation of all fencing and RADS was completed in February 2007.

The primary goal of the Preacher Canyon wildlife crosswalk and fencing enhancement project was to reduce the incidence of elk and other wildlife at-grade highway crossings along the PC section, thus reducing the frequency of WVC, promoting highway safety, and maintaining wildlife permeability by:

1) Implementing various types of ungulate-proof fencing, including retrofits of existing right-of-way fence and associated escape mechanisms.
2) Retrofitting existing bridges with funnel fencing to limit at-grade crossings by wildlife and force them to cross SR 260 below-grade through the bridges.
3) Providing a RADS at the western terminus of the fence to address a potential end run by wildlife and provide an alternative to wildlife crossing structures.

Baseline WVC data and Global Positioning System (GPS) elk movement data were collected during prior phases of research before the fencing was modified, allowing for later comparison. The primary objectives of our research were to evaluate the effectiveness of the above experimental components of the Preacher Canyon elk crosswalk and wildlife fencing enhancement project, including:

1) Comparison of WVC incidence on the fenced PC and adjacent Lion Springs sections, including the crosswalk location, before- and after-fencing modification.
2) Evaluation of the effectiveness of the RADS in modifying motorist behavior at the wildlife crosswalk.
3) Evaluation of the operational reliability of the RADS.
4) Evaluation of wildlife use of the crosswalk and west Little Green Valley underpass following fencing modification.
5) Assessment of the impact of fencing on wildlife permeability across the Preacher Canyon section highway corridor.
6) Development of recommendations for the future implementation and applications of fencing and RADS.

The findings for each of the research objectives are reported in separate sections or chapters in the report, and are summarized below.

1.1 COMPARISON OF THE INCIDENCE OF WILDLIFE-VEHICLE COLLISIONS BEFORE- AND AFTER-FENCING MODIFICATION

Because of the risk of injury and even death to motorists and wildlife, the ultimate measure of any WVC mitigation, including fencing and RADS, is the ability to reduce the incidence of WVC. All other factors, including system reliability and altered motorist behavior, are moot if the incidence of WVC is not reduced. Achieving a reduction in WVC with raised fencing along the SR 260 PC section was the primary focus of this enhancement project. With the long-term (>15 years) Arizona Department of Transportation (ADOT) roadkill database and our research project database maintained since 2000, we had solid before-fencing WVC data to use in assessing the effectiveness of fencing modifications and RADS in reducing the incidence of WVC.

We documented all WVC along the PC section for six years prior and three years following completion of the enhancement project by compiling collisions by 10th-mile segments. We documented monthly and annual frequency of elk-vehicle collisions (EVC) and deer-vehicle collisions (DVC) using our WVC records identified by periodic searches for animals, Arizona Department of Public Safety Highway Patrol accident report records, and ADOT maintenance roadkill records. In addition, we used ADOT crash records to determine the proportion of single-vehicle accidents that involved wildlife before and after project implementation.

Since completion of fencing there have been only four WVC recorded along the fenced portion of the PC section. One involved an elk, the others a black bear and two white-tailed deer. The bear and two white-tailed deer were killed along the stretch of highway with raised barbed-wire fence that is considered semi-permeable to passage by animals other than elk, especially those that can cross over or under the fence (e.g., deer, bears). The lone EVC occurred in March 2007, soon after the ElectroBraid™ fence extension was completed. This animal could possibly have been trapped in the fenced corridor during the erection of fencing. In the 32 months since, no EVC have been recorded along the PC section within the modified fencing limits. Thus, the documented incidence of after-fencing EVC represents a 97% reduction compared to the 2001–2006 The proportion of all single-vehicle accidents that involved wildlife dropped from a mean of 0.47 (2001–2006) to 0.17 (2007–2008), or an overall reduction of 64%. We documented a decrease of 42.5% in EVC on the adjacent unfenced SR 260 Lion Springs section, indicating that there was no displacement of EVC to this section from the fenced PC section. The success of the fencing and associated components along the PC section in reducing EVC by 97% warrants the continued operation of the RADS and fencing. ElectroBraid Fence, Inc. did record an EVC just to the west of the crosswalk, on November 11, 2007, where an elk standing on the centerline was simultaneously hit by vehicles traveling in both directions. The motorist alert signs were not activated as the elk entered the roadway outside the detection zone, and it appeared that minimal damage to the vehicles occurred, although the elk was killed. One white-tailed deer was also struck at the crosswalk in August 2009.

1.2 EVALUATION OF THE EFFECTIVENESS OF THE ROADSIDE ANIMAL DETECTION SYSTEM IN MODIFYING MOTORIST BEHAVIOR

Central to reducing or eliminating WVC with RADS is its ability to elicit modified driver behavior. If driver behavior is not modified, WVC in the vicinity of the RADS will likely not decrease. Two components of driver response to RADS can be measured: 1) increased driver alertness, and 2) lowered vehicle speed. Modified motorist response to RADS in turn can result in either avoiding a collision altogether, or hitting the animal at a slower speed thus reducing the risk of injury to both the animal and vehicle occupants. To determine the effectiveness of our RADS, we assessed motorist response before and at the crosswalk by conducting paired sampling with and without activating the variable message and crosswalk flashing signage. Using a permanent traffic counter, we determined average vehicle speeds during paired 15-min sampling periods. To assess braking (our surrogate measure for motorist alertness), we hid and observed the proportion of vehicles braking during 15-min sampling periods.

Motorist speeds were reduced by 14.6% (8 mph) in the westbound lane and 18.2% (10 mph) in the eastbound lane when the signs were activated. In the westbound lane, 76% of motorists braked when the signs were activated versus only 8% when the signs were off. In the eastbound lane, 58% of motorists exhibited a braking response when the signs were activated versus only 8% when the signs were off. Overall, the RADS and associated warning signs met the objective of modifying driver behavior, thereby reducing the risk of collision with wildlife.

1.3 EVALUATION OF THE OPERATIONAL RELIABILITY OF THE ROADSIDE ANIMAL DETECTION SYSTEM

Although secondary to the overall importance of reducing WVC, the operational reliability of our RADS can likewise influence its ultimate success. If motorists are frequently exposed to activated signs when animals are not present, or “false positives,” they may become complacent and ultimately ignore the system when animals are present. Worse is the presence of wildlife without the RADS being activated, or “false negatives,” leading to unaware motorists potentially encountering wildlife in the detection zone.

We used two methods to assess RADS reliability: 1) periodic field visits, and 2) video surveillance of wildlife entering and passing through the detection zone. Periodic visits were made to the crosswalk site where warning sign operational status was noted (e.g., activated, not activated, system under repair). To determine if signs were activated when wildlife was present we used a 4-camera video surveillance system that allowed simultaneous determination of animal presence and warning sign status.

Between May 2007 and December 2009, we conducted 275 test visits, including days when traffic and braking counts were conducted. We encountered few instances when the RADS and signs were inoperable; overall, the crosswalk system performed properly on 93% of our test visits We recorded 168 groups of elk and 65 groups of white-tailed deer entering the RADS detection zone from the camera monitored side of the road and coming within 50 ft of the roadway during video surveillance. Motorist warning signs activated 98% of the time for both species at some point following the presence of animals in the detection zone.

Overall, the system exhibited a relatively minimal amount of false positives or false negatives; following final modifications to the system, the amount of time the system was not operable was negligible.

1.4 EVALUATION OF WILDLIFE USE AT THE CROSSWALK AND WEST LITTLE GREEN VALLEY UNDERPASS FOLLOWING IMPLEMENTATION OF FENCING

Although RADS have been implemented in various locations throughout the world, wildlife behavior associated with at-grade crossings has not been thoroughly investigated. Wildlife interaction with the roadway and associated traffic volume may be an important indication of the viability of RADS under certain scenarios. We used a 4-camera video surveillance system to: 1) calculate passage rates of animals that approached the highway through the detection zone and ultimately crossed the highway, 2) document the incidence of animals that crossed around the end of the crosswalk fencing and traveled along the side of the highway within the ROW, and 3) evaluate traffic volume associated with elk and deer at-grade crossings that occurred at the crosswalk. To determine passage rates at the crosswalk, we used methods similar to calculations made for wildlife underpasses along SR 260 in previous research, calculating the proportion of highway crossings to approaches through the detection zone. This allowed for a direct comparison of passage rates at the crosswalk and underpasses, and provided insight as to the efficacy of the crosswalk as a potential alternative to costly constructed crossing structures.

The west Little Green Valley Underpass was located at the east end of the 2.5-mile stretch of modified ungulate-proof fencing. We began our video surveillance monitoring here in late 2002 during previous research along SR 260. Our objective of continued monitoring of the west underpass was to determine changes in wildlife use and/or passage rates with the increase in the length of impermeable fencing that funneled animals toward the underpass.

Through December 2009, the system recorded a total of 801 animals on videotape (523 elk, 157 white-tailed deer, 57 javelina), and 64 animals of various other species, including, mule deer, mountain lion, black bear, raccoon, and gray fox. Of the 523 elk recorded on videotape (255 groups) that approached the crosswalk from the camera (south) side, 32% successfully crossed the highway while 20% went around the end of the electric fence and into the highway corridor. In contrast, only 10% of deer successfully crossed while 21% entered the gap into the highway corridor The probability of an elk crossing the highway once it approached the detection area was 0.25 when traffic volumes were low (<1 vehicle/min) and dropped 92% to 0.02 as traffic volumes increased to 12 vehicles/min. Deer showed an even greater avoidance of increased traffic volume with only six highway crossings at a maximum traffic volume of

1.8 vehicles/min, or approximately 108 vehicles/hr. All wildlife crossings occurred between 2000 and 0800 with 86% occurring during the hours when traffic volumes were at their lowest (2300–0400 hr). Average hourly traffic volumes during this four-hour period averaged 32 vehicles/hr, whereas the average hourly traffic volume for the entire 24-hr period along this same stretch of highway was 308 vehicles/hr between 2004 and 2009.

Although elk showed no difference in use of the west underpass and maintained a >80% passage rate, white-tailed deer showed a dramatic increase in underpass use following construction of ungulate-proof fencing. Overall, 61 deer used this structure in the year following completion of fencing versus a total of six crossings dating back to the installation of our video system in 2002. The odds of a successful crossing for deer following completion of fencing was 38:1 of that prior to fencing.

1.5 ASSESSMENT OF FENCING ON WILDLIFE PERMEABILITY ACROSS THE PREACHER CANYON SECTION HIGHWAY CORRIDOR

Although reducing WVC along the PC section was the primary objective of the project, we also evaluated the effect of modified fencing on elk permeability, or their ability to cross SR 260. Very few studies have documented the effect of highway reconstruction on wildlife permeability along the same stretch of roadway, controlling for location differences under a before-during-after experimental scenario as was afforded on SR 260. To evaluate the impact of fence modification on elk movement, we compared elk permeability on the PC section immediately before and after the section was fenced to preclude elk crossings at-grade.

Of 28 elk tracked with GPS collars from 2006 to 2008, 26 crossed the highway along the PC section. Following installation of elk-proof fencing, the number of approaches did not differ from before-fencing levels, with elk entering the 0.15 mi buffer constituting an approach 342.7 times/elk prior to fencing versus 283.7 times/elk following fencing. However crossings/elk over this similar length of time dropped almost 65% from 129.8 prior to fencing to 47.4 crossings/elk following fencing. The mean passage rate (our metric for permeability) following modification of fencing dropped to 0.09 crossings/approach, or a 70% reduction in the mean passage rate from 0.29 crossings/approach prior to the modification of fencing.

A dramatic shift in distribution of elk crossings occurred along the length of the PC section after fencing was modified. While there were numerous peaks in crossing distribution along the highway prior to fence modification, crossings were strongly concentrated near the Preacher Canyon Bridge and Little Green Valley underpasses following fence modification. A relatively small peak in crossing distribution also occurred at the elk crosswalk, indicating that a majority of the crossings occurred at the existing crossing structures, rather than showing an excessive end-run effect, pointing to the success of these bridge type passage structures in conveying wildlife across the highway.

Although elk permeability was reduced, the enhancement project met its objective of funneling elk to the existing crossing structures without creating an end-run effect around the fence. This indicates the success of site selection to end the fence where animals were not regularly crossing the highway according to our GPS crossing and EVC patterns. Levels of permeability, although reduced, still should allow for sufficient passage of individuals to maintain levels of gene flow and prevent complete genetic isolation of sub-populations (Mills and Allendorf 1996).

1.6 OVERALL CONCLUSIONS AND RECOMMENDATIONS

Almost two years after implementation, this enhancement project appears to be well on track toward meeting its objectives, particularly in reducing the incidence of EVC by >95%. Further, the experimental RADS and crosswalk systems performed reliably and effectively in detecting animals and alerting motorists to crossing wildlife. Motorists responded both by reducing speed and displaying alertness in response to the warning signs and crosswalk. Currently, EVC are reduced to a level where the reduction on the PC section has yielded a >$600,000 economic benefit in its first three years; this rate will exceed initial project costs within the next year or two and show a benefit of close to $1 million over the next 10 years if such reductions in EVC are maintained. We recommend that the system (fencing and crosswalk) remain in place and operational to continue to reduce costs to motorists and wildlife.

2.0 INTRODUCTION

As roads are expanded to safely accommodate increasing numbers of motorists and movement of goods and services throughout the world, measures to reduce WVC while maintaining wildlife permeability across the highway corridor are essential to the safety of motorists and viability of many wildlife species (Forman et al. 2003). WVC are responsible for numerous human injuries and deaths, and tremendous property loss (Reed et al. 1982, Schwabe and Schuhmann 2002). Estimates of annual vehicle collisions involving deer alone in the U.S. have ranged as high as 1.5 million (Conover 1997). Attempts to reduce WVC include using warning signs (Pojar et al. 1975, Sullivan et al. 2004), reflectors (Waring et al. 1991, Reeve and Anderson 1993, Ujvari et al. 1998, D'Angelo et al. 2006), acoustic road markings (Ujvari et al. 2004), warning whistles (Romin and Dalton 1992), lighting (Reed 1981), fencing (Falk et al. 1978, Feldhamer et al. 1986, Clevenger et al. 2001), crosswalks (Lehnert and Bissonette 1997) , wildlife passage structures (Foster and Humphrey 1995, Clevenger and Waltho 2005, Dodd et al. 2007*a*, Olsson 2007), and animal detection systems (Ward et al. 1980, Huijser and McGowen 2003, Gordon et al. 2004).

Wildlife passage structures (i.e., underpasses and overpasses) are becoming a frequent and successful method to provide safe passage across roadways for many wildlife species when combined with appropriate fencing and other measures to funnel small and large animals benefit from these efforts (Foster and Humphrey 1995; Clevenger and Waltho 2000, 2005; Dodd et al. 2007*a–d*, Olsson et al. 2008*a,b*). The use of ungulate-proof fencing ranging in height from 6.5 to 8 ft appears to be the single most effective method proven to reduce collisions with large ungulates, especially when used in conjunction with properly located and designed wildlife passage structures (Ward 1982; Foster and Humphrey 1995; Romin and Bissonette 1996; Clevenger and Waltho 2000, 2005; Forman et al. 2003; Dodd et al. 2007*a–d,* Olsson 2007, 2008*a,b*). Ward (1982) reported >90% reduction in vehicular collisions with mule deer where underpasses and fencing were applied in Wyoming, though modifications to the original fencing were needed to achieve this reduction in WVC. Woods (1990) reported 94−97% reductions in WVC involving several species in Alberta with passages and fencing. Dodd et al. (2007*a,d*) documented a >85% reduction in elk-vehicle collisions (EVC), following completion of fencing that connected a series of wildlife underpasses along the Christopher Creek section of State Route (SR) 260, approximately 10 mi east of this study area.

In some cases wildlife crossing structures may not be feasible due to high costs or topography. If fencing is used, options to allow wildlife to continue crossing the road for daily and seasonal movements are essential. Ideally, existing bridges and culverts that are adequate to accommodate wildlife passage may suffice as a substitute for constructing new structures specifically for wildlife passage. In these cases there may be options to "retrofit" highways to accommodate wildlife passage and improve highway safety by fencing between existing culverts and bridges.

Wildlife "crosswalks" are a combination of fencing and gaps in the fence that allow animals to cross roadways in designated areas, thus providing options for wildlife passage. Crosswalks have been minimally tested, though Lehnert and Bissonette (1997) reported moderate effectiveness of crosswalks along two- and four-lane highways in Utah. These crosswalks constituted designated crossing areas with static or continuously activated signs warning motorists of crossing animals, primarily mule deer. Stripes were painted on the highways to simulate cattle guards. Although they documented minimal motorist response, likely due to motorists becoming accustomed to static or continuously activated signs, there was still an overall decrease in mule deer mortality.

RADS may also provide an alternative to expensive wildlife crossing structures, and have shown positive results in reducing WVC (Ward et al. 1980; Huijser and McGowen 2003, 2004; Gordon et al. 2004; Huijser et al. 2006*a*,*b*, 2009). The purpose of RADS is to modify driver behavior using flashing signs to warn motorists when animals are adjacent to or within the roadway. Wildlife are detected through either "break-the-beam" or "area coverage" type systems (see Huijser 2009 for details) that send a signal to activate warning signs, providing the opportunity for motorists to reduce their speeds and avoid collisions altogether or hit animals at a slower speed, reducing the chance of injury (Huijser et al. 2009). This technology provides less opportunity for motorists to become accustomed to static or continuously activated signs.

Huijser and McGowen (2003) identified 47 current, previous, and planned RADS (including the SR 260 system we evaluated) and animal warning systems in Europe and North America; however, only the Swiss systems included the reduction in WVC as their ultimate measure of success. RADS applications in Switzerland yielded a dramatic decrease (82%) in WVC following installation (Huijser et al. 2007*a*).

Although rarely given credit, Ward et al. (1980) was nearly 20 years ahead of today's scientists and engineers in the application of RADS. They documented the first promising results of this method with a reduction in accidents and as high as a 15-mph decrease in motorist speed when signs were activated. Gordon et al. (2004) documented a minimal reduction in speeds, overall about 4 mph with the RADS that they evaluated in Wyoming. However, when a deer decoy was visible to approaching motorists in combination with the flashing lights, speeds decreased by up to 20%.

Huijser et al. (2006*a*) recognizes that many of these systems have not been adequately evaluated and remain experimental. Huijser et al. (2004, 2009) conducted one of the most extensive evaluations to date of various RADS, testing several different systems in a controlled environment. They evaluated all systems under the same conditions allowing for a direct comparison of reliability. Most RADS applications have been applied and tested in Europe, with relatively little RADS testing and evaluation done in North America in field settings (Ward et al. 1980, Gordon et al. 2004, Huijser et. al. 2006*b*). In many cases these systems cover relatively large stretches of road. In areas where the roadside varies in topography or the road regularly curves, the number of detection devices can increase dramatically, simultaneously increasing maintenance requirements. Excess vegetation can also compromise the integrity of the systems by blocking beams or constantly activating signs when wind blows vegetation.

Another major drawback of RADS and crosswalks is the requirement for wildlife to continue to cross highways at-grade, risking collision with vehicles or being subject to the barrier effect created by high traffic volumes. Gagnon et al. (2007*a*) documented that elk crossing frequencies at-grade were deterred by increasing traffic volumes; conversely, elk crossing rates showed no effect from traffic volumes while crossing below-grade through wildlife underpasses (Gagnon et al. 2007*b*). Species that exhibit sensitivity to road-associated impact (e.g., traffic, noise) may not benefit from the installation of RADS if traffic volumes are high, as these animals likely will not attempt at-grade road crossings.

2.1 PROJECT NEED

Wildlife-highway research tied to the phased reconstruction of the highway has been ongoing along SR 260 since 2001 (Dodd et al. 2007*a–d*, 2009). The first phase of this study took place on the PC section, approximately 3.0 mi in length, and was the first of five highway sections reconstructed along a 17-mi stretch (Figure 3.1). Reconstruction of the PC section from a two-lane roadway to a four-lane divided highway was completed in 2001. In late 2001, we began our first phase (2002–2004) of a research project that evaluated the incidence of WVC and movement of wildlife through the two underpasses located along the PC section at Little Green Valley. Simultaneously, we collared elk with Global Positioning System (GPS) telemetry collars along the PC section as well as a section under reconstruction [Christopher Creek (CC) section] and along three control sections (Little Green Valley, Kohl's Ranch, and Doubtful Canyon) to evaluate highway permeability during different phases of reconstruction. Dodd et al. (2007*b,c*) evaluated permeability by documenting the number of crossings that occurred once elk approached the highway and documented significantly lower permeability on the completed PC section (0.43 crossings/approach) compared to control sections (average of 0.86 crossings/ approach), indicating a barrier effect to elk passage associated with the reconstructed highway.

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 underpass and most bridge abutments. As research showed this approach to be inadequate, fencing was later guided by an adaptive management approach where data from prior phases of research was used to identify strategic placement of fencing to intercept crossing wildlife as determined from GPS telemetry (Dodd et al. 2007*c*).

During the second phase of SR 260 research (2004–2006), Dodd et al. (2007*d*) documented a similar effect of highway reconstruction on elk highway permeability along the CC section. However, following completion of fencing that tied several underpasses together, the average elk passage rate increased 53% higher than was documented after reconstruction but before fencing was erected, while also realizing an 87% reduction in EVC in the year following fencing. In addition to playing an instrumental role in promoting permeability and reducing collisions, ungulate-proof fencing was crucial to achieving effective use of underpasses, especially those not located in proximity to meadow habitats. Without fencing, elk and deer continued to cross SR 260 at-grade adjacent to underpasses. Gagnon et al. (2007*a,b*) evaluated the influence of traffic volume on elk movement during at-grade and below-grade crossings and determined elk permeability at-grade was reduced as traffic volumes increase, while there was no association with traffic as elk crossed below-grade, explaining why fencing constitutes an integral component of wildlife mitigations in promoting permeability.

Along the 5-mi CC section, there were seven passage structures with an average spacing of 0.7 mi. Our research not only demonstrated the importance of funneling animals to passage structures where traffic volume did not affect their crossing the highway, but provided a comparison to the PC section where minimal fencing was incorporated to funnel animals to passage structures. Furthermore, passage structure spacing on the PC section (1.5 mi) was approximately twice that of the CC section, allowing for an empirical assessment of passage structure spacing needed to facilitate elk movement across highways (Bissonette and Adair 2008).

Our first two phases of SR 260 research determined that a high number of crossings and WVC occurred within the unfenced portion of PC section (Dodd et al. 2006, 2007*d*). In fact, following reconstruction that included only 0.4 mile of ungulate-proof fencing along the section near the two wildlife underpasses opening into Little Green Valley, the incidence of EVC did not change from before-reconstruction levels, likely due to the increase in traffic volumes during the evaluation period. In all cases along SR 260, adequate ungulate-proof fencing was the essential component to reducing WVC while maximizing the effectiveness of the wildlife passage structures. Thus, with the limited original application of fencing on the PC section and continued incidence of WVC, there was a need to incorporate and evaluate the addition of ungulate-proof fence. To determine the potential benefit of ungulate-proof fencing in intercepting and funneling elk to the existing passage structures on the PC section, we employed an approach similar to that used for the CC section. Here we projected an 89% interception of GPS-determined highway crossings with only 50% of the roadway fenced that ultimately resulted in a >85% reduction in EVC (Dodd et al. 2007*b,c*). Our first phase of research found that the original fencing intercepted only 24% of the GPS-telemetry determined elk crossings along the PC section. Using GPS telemetry data, we projected that fencing the entire PC section would intercept an additional 75% of elk crossings (Figure 2.1).

Standard woven-wire ungulate-proof fencing is costly, potentially contributing to reluctance on the part of transportation managers to fencing extensive stretches of highways. And while fencing is often regarded as an integral component of effective passage structures (Romin and Bissonette 1996, Forman et al. 2003), limited data or guidelines exist for the application of fencing in conjunction with wildlife passages. Due to the high cost associated with standard woven wire ungulate-proof fence, options to modify the existing ROW fence were implemented along the PC section to reduce cost and evaluate retrofit options for current and future projects. Less expensive retrofit options for fencing will provide increased opportunities for wildlife/highway managers to address WVC in areas where funding is limited or where new woven-wire fencing is not feasible. Therefore, there is a need to evaluate cost-effective retrofit alternatives compared to costly woven-wire ungulate-proof fence.

Passage structures built specifically for wildlife are costly and in some cases not immediately feasible due to budgets, topography, or construction schedules. RADS can provide a valuable alternative to expensive passage structures. Because fencing is a proven method to reducing WVC, the combination of fencing and RADS may simultaneously address WVC and connectivity issues for some wildlife species under certain scenarios. Our study employs a hybrid of the delineated crosswalk described by Lehnert and Bissonette (1997) and area cover type RADS (Huijser et al. 2009) to address potential end-run effects at the fencing terminus.

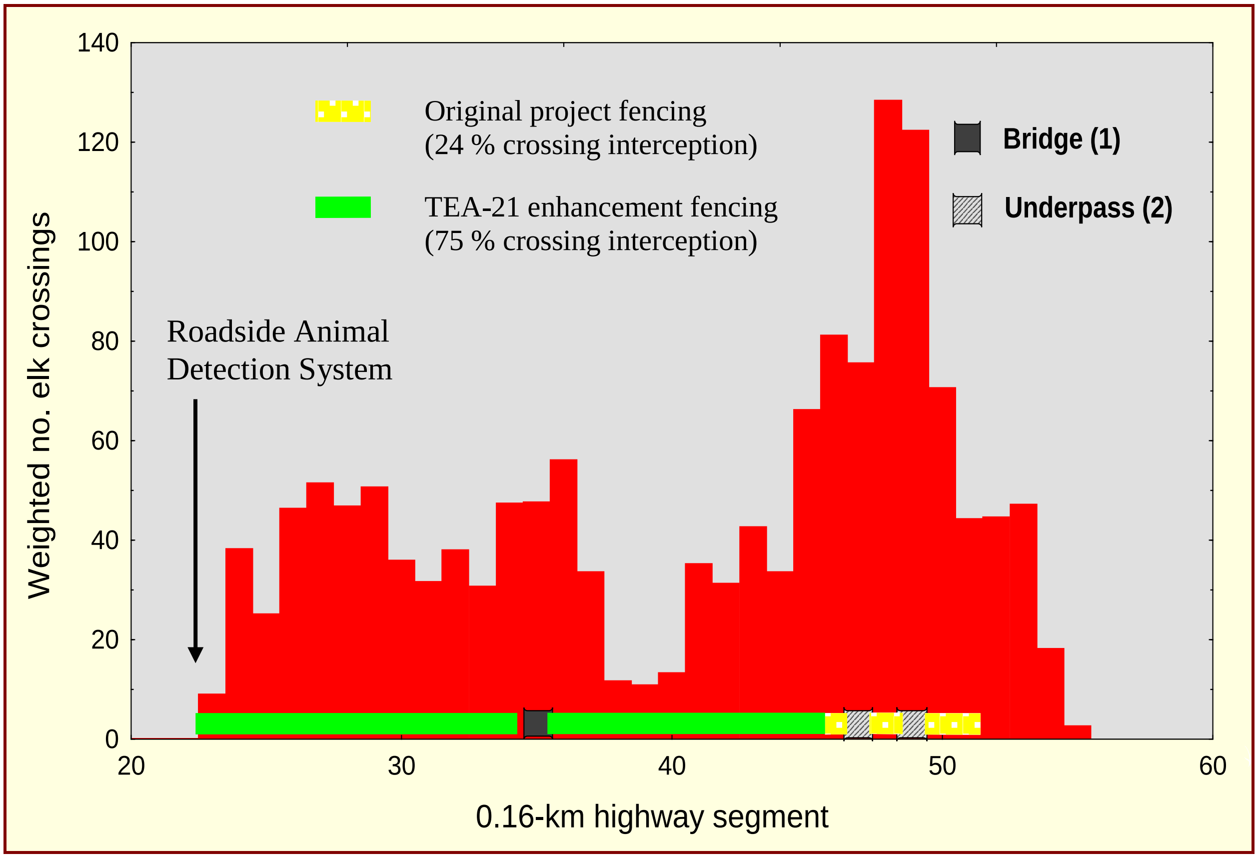


Figure 2.1. Distribution of SR 260 crossings by GPS-collared elk along the Preacher Canyon section from 2002 to 2004 in relation to the location of the original extent of ungulate-proof fencing (yellow) erected during highway reconstruction and location of additional proposed enhancement fencing (green) to intercept and funnel elk to the Preacher Canyon Bridge, Little Green Valley underpasses, and RADS.

This combination may prevent habituation by motorists who become accustomed to continuous or static warning signage (Lehnert and Bissonette 1997). This type of hybrid system has not been thoroughly evaluated as an alternative to costly wildlife passage structures. Furthermore, an evaluation of this system in a field setting will allow for documentation of responses by motorists and local wildlife, providing insight for future similar opportunities.

2.2 ENHANCEMENT AND RESEARCH PROJECT OBJECTIVES

The primary goal of this enhancement project was to reduce the incidence of elk and other wildlife at-grade highway crossings along the PC section, thus reducing the incidence of WVC, promoting highway safety, and maintaining wildlife permeability by:

1) Implementing various types of ungulate-proof fencing, including retrofits of existing ROW fence and associated escape mechanisms.
2) Retrofitting existing bridges with funnel fencing to limit at-grade crossings by wildlife and force them to cross SR 260 below-grade through the structures.
3) Establishing a RADS at the western terminus of the fence to address the potential end run by wildlife and provide an alternative to wildlife crossing structures.

As part of this project, existing ROW fence along approximately 2.5 mi of the highway was modified and raised to 7.5–8 ft to make the fence impermeable to elk and to funnel animals toward the Preacher Canyon Bridge and two underpasses. At the west end of the PC section, no passage structure or impassable topographical feature (e.g., canyon, steep rock wall) existed where we could effectively terminate the fence. Therefore, we installed a RADS to prevent WVC as wildlife passed around the end of the fence.

The primary objectives of the research component of our study were to evaluate the effectiveness of the above experimental components of the wildlife fencing enhancement project, including:

1) Comparison of WVC incidence on the fenced PC and unfenced adjacent Lion Springs sections, including the crosswalk location, before- and after-fencing modification.
2) Evaluation of the effectiveness of the RADS in modifying driver behavior at the wildlife crosswalk.
3) Evaluation of the operational reliability of the RADS.
4) Evaluation of wildlife use of the crosswalk and west Little Green Valley underpass following fencing modification.
5) Assessment of the impact of fencing on wildlife highway permeability on the PC section.
6) Development of recommendations for the future implementation and application of the fencing and RADS.

Achieving a reduction in WVC with extended fencing along the PC section of SR 260 was the primary focus of the enhancement project. With the long-term (>15 years) ADOT collision database and our research project database maintained since 2001, we have a solid before-fencing baseline from which to assess the effectiveness of fencing in reducing the incidence of WVC. Fencing was primarily intended to limit animal access to the highway at-grade by funneling animals to the existing wildlife underpasses; our RADS was used solely to prevent collisions with wildlife at the western terminus of the fence versus as an alternative to fencing as done by Huijser et al. 2006*b*. The success of the entire package of fencing and RADS is predicated on the project's ability to reduce or eliminate EVC along the PC section.

Although this project will benefit multiple species, elk were a primary focus of our research for several reasons. First, elk accounted for >80% of all collisions between vehicles and wildlife in this area (Dodd et al. 2006, 2009) and the vast majority of property loss and human injuries associated with WVC. Second, elk are large animals that readily support GPS telemetry collars, allowing the collection of long-term data on movements in relation to the highway corridor.

3.0 STUDY AREA

Our study area lies east of Payson, Arizona along a 3-mi stretch of highway (milepost [MP] 260–263) within the bounds of our ongoing 17-mi SR 260 research project study area (MP 260–277; Dodd et al. 2007*d*; Figure 3.1).

Vegetation adjacent to this stretch of SR 260 was predominantly mixed pinyon pine, juniper, live oak, and other chaparral species such as manzanita, with sparse ponderosa pine. Little Green Valley, an approximately 150-acre riparian-meadow habitat, lies along the highway corridor at the east end of the project area. Two streams flow adjacent to portions of the highway, including the perennial Little Green Valley Creek and ephemeral Preacher Canyon Wash. Terrain is relatively steep and ranges from 5,000 to 6,300 ft within a mile of the highway.

Reconstruction of the PC section was completed in November 2001 and included two bridged wildlife underpasses and a large bridge over Preacher Canyon (Figures 3.2 and 3.3). Originally, only 0.4 mi (13%) of the highway was fenced with 8-ft ungulate-proof fencing linking the two underpasses near Little Green Valley with the Preacher Canyon Bridge.

3.1 STATE ROUTE 260 TRAFFIC CHARACTERISTICS

Because our wildlife crosswalk required animals to cross the highway at-grade, risking collisions with vehicles, understanding traffic patterns and its associated influence on wildlife behavior and movements provided insights on the efficacy of our system and its applicability to other highways. During our first phase of research in 2004, we installed a permanent traffic counter at the center of our study area to compare GPS-collared elk and white-tailed deer movements to traffic volumes as well as movements through several wildlife underpasses (Gagnon et al. 2007*a,b*). We continue to collect traffic data at this counter and documented 11,713,281 vehicles from January 2004 to July 2008; yearly traffic volumes did not change dramatically and averaged 2.7 million vehicles/year. The traffic counter relays hourly counts, average speeds, and vehicle type data via a cell phone modem. During the first year of the Preacher Canyon enhancement project study, we documented 2.69 million vehicles.

Over the past 4.5 years, traffic volumes varied by month, day, and hour. During summer, we documented higher traffic volumes, particularly in June and July (256,033 and 250,152, respectively) while February had the lowest traffic volume (averaging <140,000 vehicles/month) (Figure 3.4). Overall average annual daily traffic (AADT) levels were relatively consistent over that period (mean = 7,140 vehicles ±73 SE). Traffic level varied by day, with a >30% increase in AADT on weekends (Fri–Sun; mean = 7,569 vehicles) than on weekdays (Mon–Thu; mean = 5,125). On holiday weekends, traffic volume exceeded 18,000 vehicles/day (Figure 3.4). Hourly traffic volume dropped during the night and early morning hours, and averaged below 50 vehicles/hr (2400−0400), in contrast to averaging close to 600 vehicles/hr during midday (1200−1600; Figure 3.5).

Commercial vehicles travel SR 260 regularly, with a higher proportion during the times that passenger vehicle volumes are at their lowest (2400–0400; Figure 3.5). The proportion of commercial to passenger vehicles average as much as 0.40 from 0200–0300. Commercial vehicle collisions with elk are a common occurrence along SR 260; although gaps in the "moving fence" (Bellis and Graves 1978) increased during these late hours, the ability of a commercial vehicle to slow to avoid an EVC is less than that of a passenger vehicle.

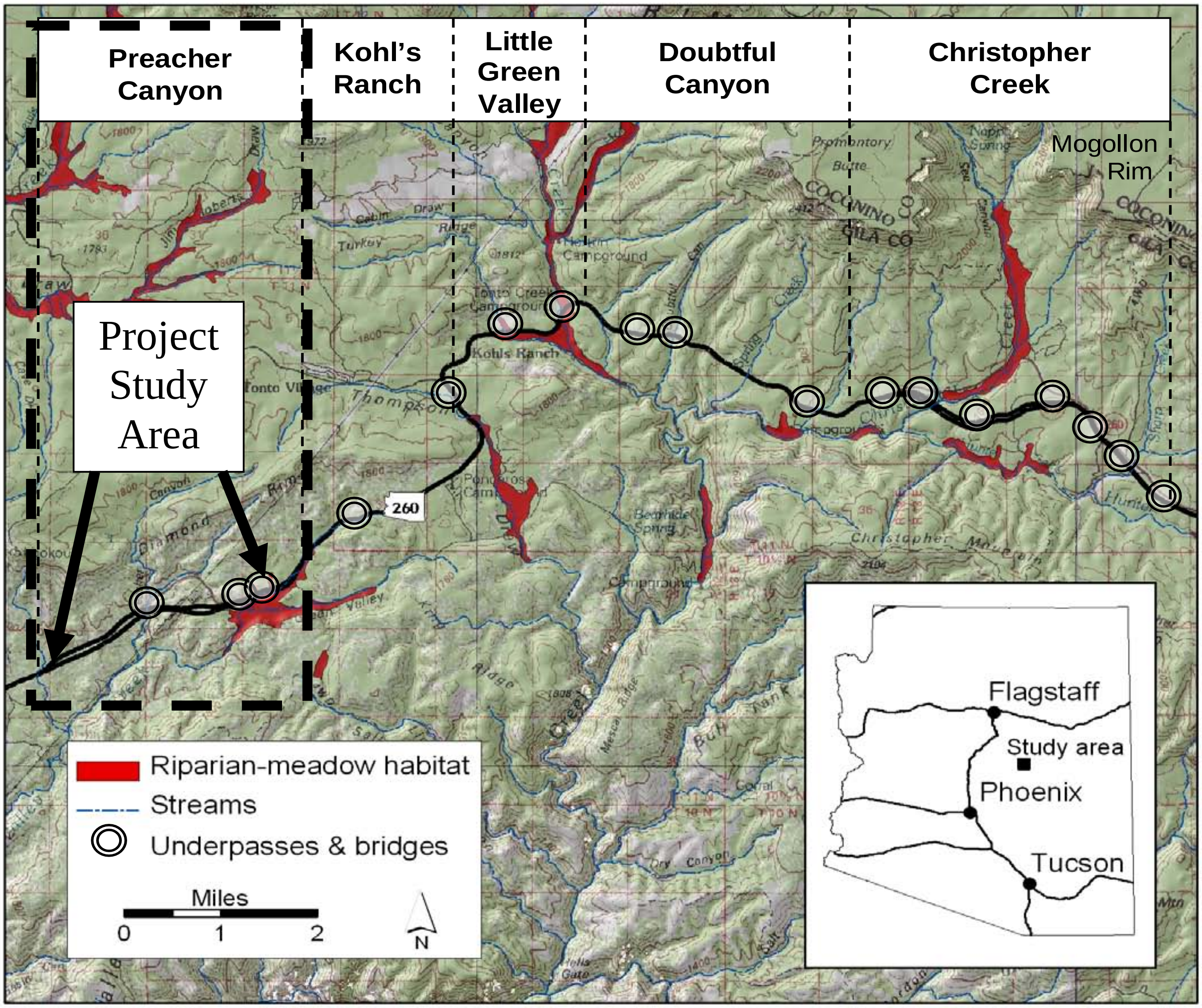


Figure 3.1. Location of the 3-mi PC section study area along the 17-mi SR 260 five-phased reconstruction project, and the location of wildlife underpasses and bridges. The shaded areas correspond to riparian-meadow habitats located adjacent to the highway

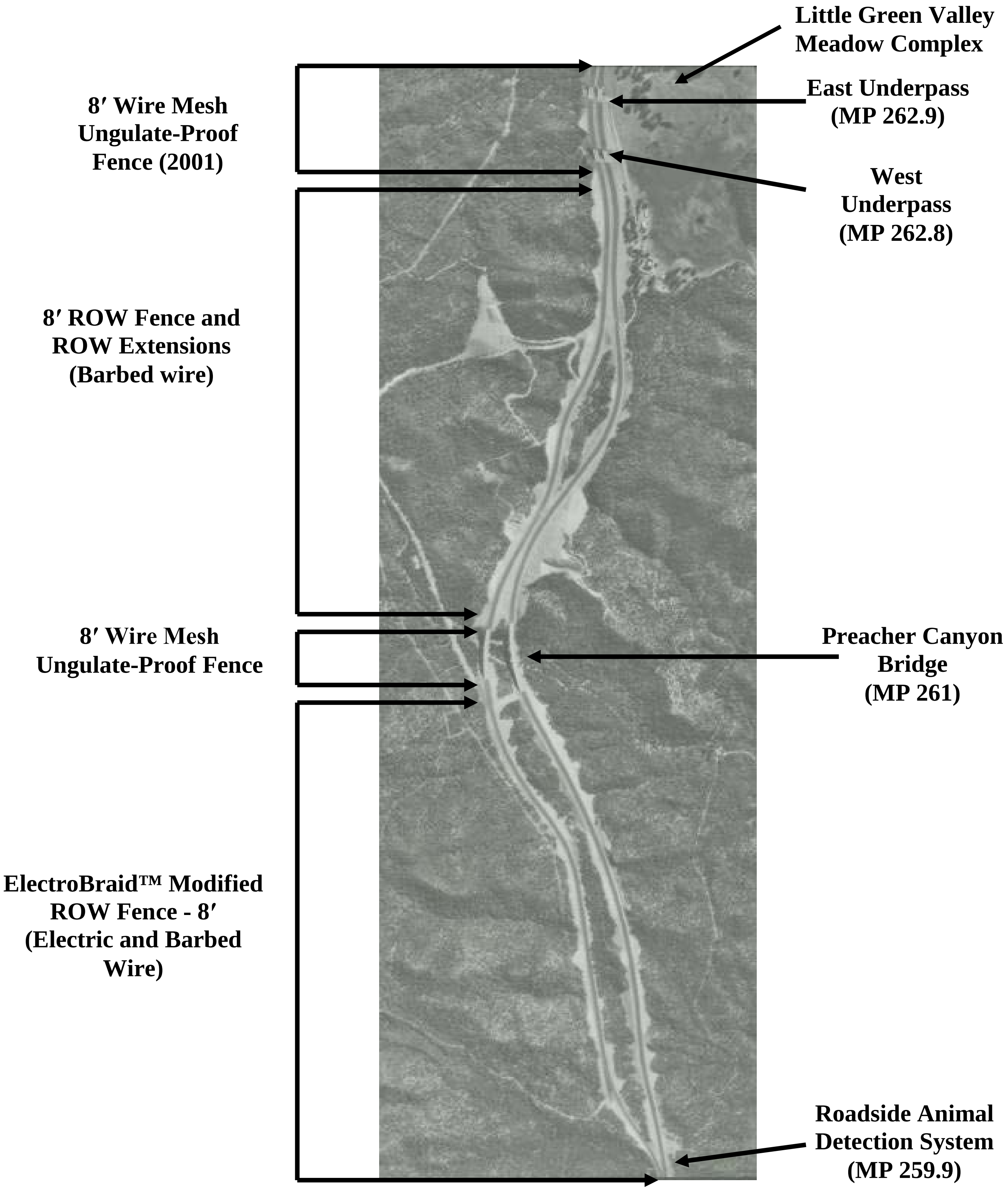


Figure 3.2. Aerial photograph of the PC study area along SR 260 showing the locations of different fencing types, wildlife underpasses and Preacher Canyon Bridge, and the RADS and crosswalk.

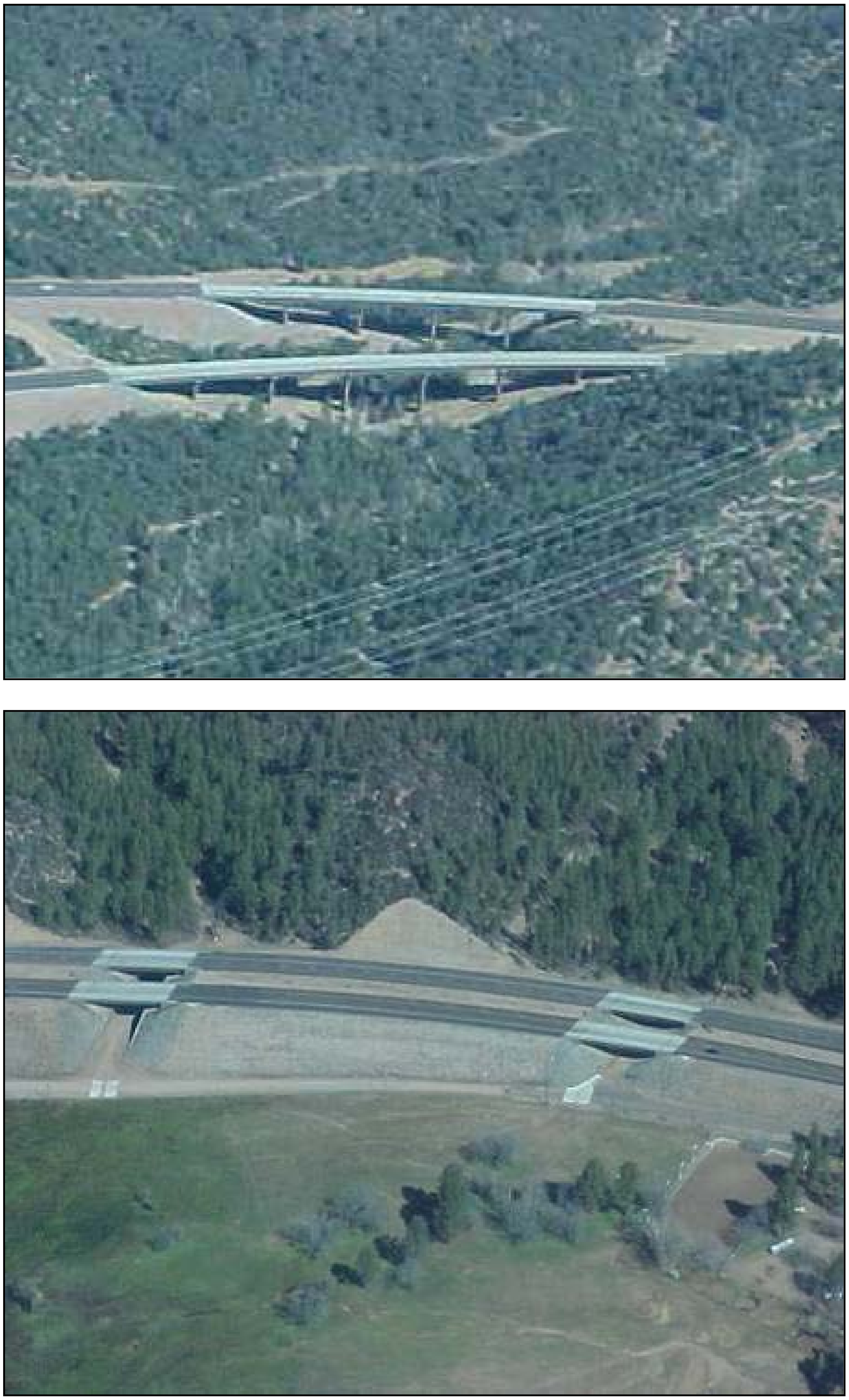


Figure 3.3. Aerial photographs of the Preacher Canyon Bridge (top) and the west and east underpasses at Little Green Valley along the PC section.

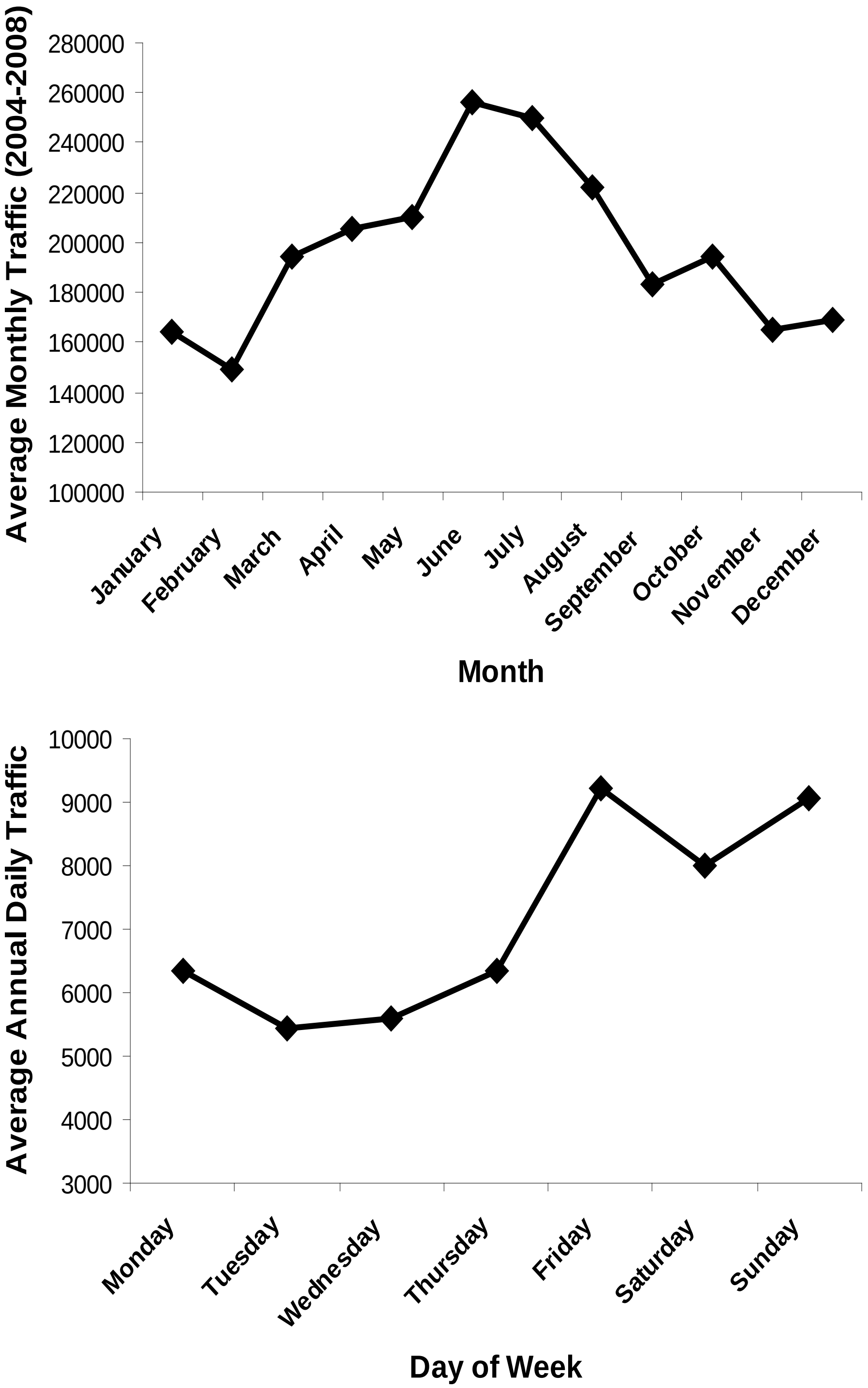
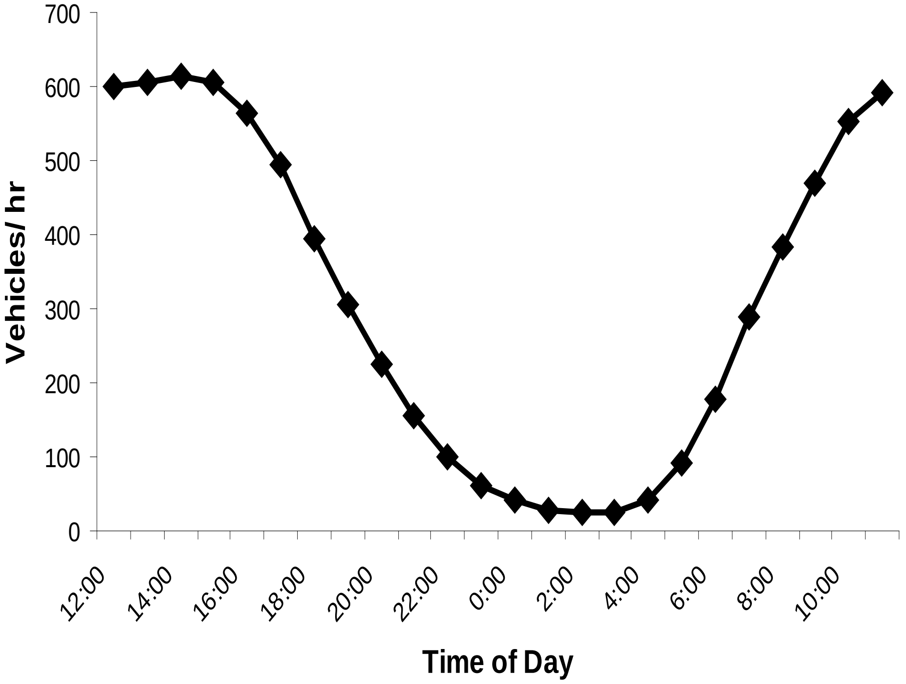


Figure 3.4. Mean monthly (top) and daily (bottom) traffic volumes along SR 260 from 2004 to 2009.



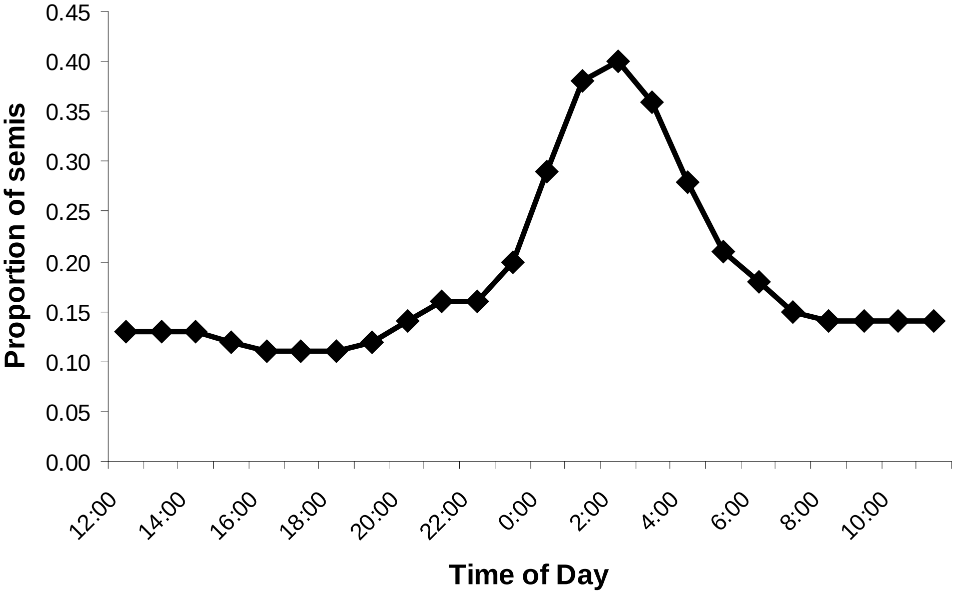


Figure 3.5. Mean hourly traffic volumes (top) and proportion of commercial vehicles to total vehicles (bottom) along SR 260 from 2004 to 2009.

4.0 PROJECT COMPONENTS AND IMPLEMENTATION

This enhancement project incorporated several components designed to intercept large animals, primarily elk, crossing SR260 along the PC section and funnel them to existing bridges, wildlife underpasses, and a RADS located on the west end of the project.

4.1 FENCING TYPES

Our research evaluated the efficacy of three retrofit fencing designs to guide animals to the underpasses and the crosswalk: 1) existing ROW fence raised to 8 ft high with 10-ft T-posts and barbed-wire, 2) existing ROW fence raised to 7.5 ft high with T-post sleeve extensions and barbed-wire, and 3) existing ROW fence raised to 7.5 ft high with ElectroBraid™ braided rope electric fence (Seamens and VerCauteren 2006) affixed to fiberglass poles and with a "kicker" attached to the ROW fence T-posts (Figure 4.1). These cost-effective (compared to ADOT's standard woven wire ungulate-proof fence) retrofit fencing designs were integrated into the existing ROW fence for possible future modification or removal and to evaluate their effectiveness on other highways where reconstruction and installation of new ungulate-proof fence is not planned.

Figure 4.1. Types of retrofit fencing used to funnel animals to existing passage structures and the crosswalk along SR 260, including 10-ft T-posts and barbed-wire (top left), T-post sleeve extensions and barbed-wire (top right), and ElectroBraid™ electric fence modifications to extend the existing ROW fence to 7.5–8 ft.

4.2 WILDLIFE ESCAPE MECHANISMS

In the event that animals breached the fenced corridor and became trapped within the ROW, measures to allow them to escape were installed. These mechanisms include: 1) escape ramps, 2) “slope jumps” in the fencing, 3) one-way gates (Reed et al. 1974), and 4) a pair of experimental animal-activated self-opening electronic gates. The electronic gates were opened with a break-beam photo sensor situated along the fence far enough in advance of the gate so animals did not see movement of the gates as they opened; the gates closed automatically after two minutes (Figure 4.2).

Figure 4.2. Right-of-way wildlife escape mechanisms incorporated into the project in the event elk entered the ungulate-proof fenced right-of-way along the Preacher Canyon section, State Route 260, Arizona. These mechanisms include three engineered escape ramps (top two and middle left photos), “slope jumps” installed in corners of the fencing (middle right photo), one-way gates (bottom left photo) and a pair of animal-activated electric gates (bottom right).

4.3 LATERAL ACCESS ROAD ACCOMMODATION

Two lateral side roads intersected the fenced highway corridor. To alleviate the potential ramifications of gates being left open and allowing animals into the fenced corridor, two systems were evaluated: 1) a dual cattle guard wide enough to prevent elk from jumping across, and 2) an electrified ElectroBraid™ ElectroMat, an alternative to a cattle guard (Figure 4.3).

Figure 4.3. Dual cattle guard (left) and ElectroBraid™ ElectroMat (right) designed to allow lateral road access for vehicles while preventing wildlife from entering the fenced SR 260 ROW.

4.4 ROADSIDE ANIMAL DETECTION SYSTEM

At the western terminus of the extended ROW fence, ADOT contracted with ElectroBraid Fence, Inc. to design and implement a RADS-integrated “crosswalk.” This system was intended to alert motorists to wildlife entering the RADS detection zones. The crosswalk consisted of an infrared camera detection system integrated with military-grade target acquisition software to detect wildlife movement (Figure 4.4). This software was sensitive to both movement and size of the moving object such that small animals (e.g., rabbits) would not trigger the signs. Once an animal was detected, radio signals were relayed to activate signs alerting approaching motorists of the presence of animals within the crossing area (Figure 4.5). The RADS was configured such that a defined wildlife “crosswalk” was created with fencing (Figure 4.6). An adjacent undivided 2-lane section of the highway was selected to minimize the complexity of the detection system and the potential for animals to enter the highway ROW when they used the crosswalk. Motorists were presented with a series of signs: 1) a static sign reading “Test Area-Elk Crossing – 1500 ft ahead, 2) a variable message board that was activated by the RADS when wildlife were present displaying “Caution – Elk – Detected,” and 3) a RADS-activated warning sign at the crosswalk with flashers that displayed the silhouette of an elk (Figures 4.5 and 4.6). The system was operational 24 hrs a day.

Figure 4.4. Tower-mounted infrared detection camera (left) and images of elk captured on target acquisition software (right).

The westbound approach to the SR 260 RADS and crosswalk occurred just beyond where the reconstructed four-lane divided PC section narrows to two lanes at a curve; most vehicles exceed the posted 55 mph speed limit attempting to pass each other and gain position as the lanes narrow to a single westbound lane. The westbound variable message sign is visible to motorists approximately 250 ft from the point where the westbound lanes narrow down to one lane, whereas eastbound traffic traverses a single lane that winds gradually uphill toward the crosswalk from Star Valley; the variable message sign here is first visible to eastbound motorists >750 ft in advance of the sign.

Because RADS was new technology to Arizona, the research team evaluated the degree to which it remained operational as well as its ability to elicit a change in driver behavior (e.g., reducing motorist speed). This study therefore integrated and evaluated the efficacy of several new technologies, including different fence designs and mechanisms to maintain the integrity of the fenced corridor, as well as assessing the utility of the RADS and crosswalk as a potential alternative to costly wildlife passage structures. The crosswalk is a hybrid of RADS, similar to those evaluated by Gordon et al. (2004) and Huijser et al. (2006*b*) combined with a defined crossing area as evaluated by Lehnert and Bissonette (1997). Also similar to the crosswalks described by Lehnert and Bissonette (1997), an unfenced gap existed between the shoulder of the roadway and the end of fencing. This gap provided access for wildlife to move within the fenced ROW, risking WVC until they returned via the same gap or left through an escape mechanism. Lehnert and Bissonette (1997) documented entry through similar gaps even with obstructive cobble fields laid in the gaps and painted lines, simulating cattle guards.

Figure 4.5. Array of signs presented to motorists as they approach the SR 260 wildlife crosswalk. A static sign (top) alerts motorists that the detection area lies ahead, while the variable message board (middle) and the flashing lights on the elk silhouette sign (bottom) are only activated when animals were detected by the RADS.

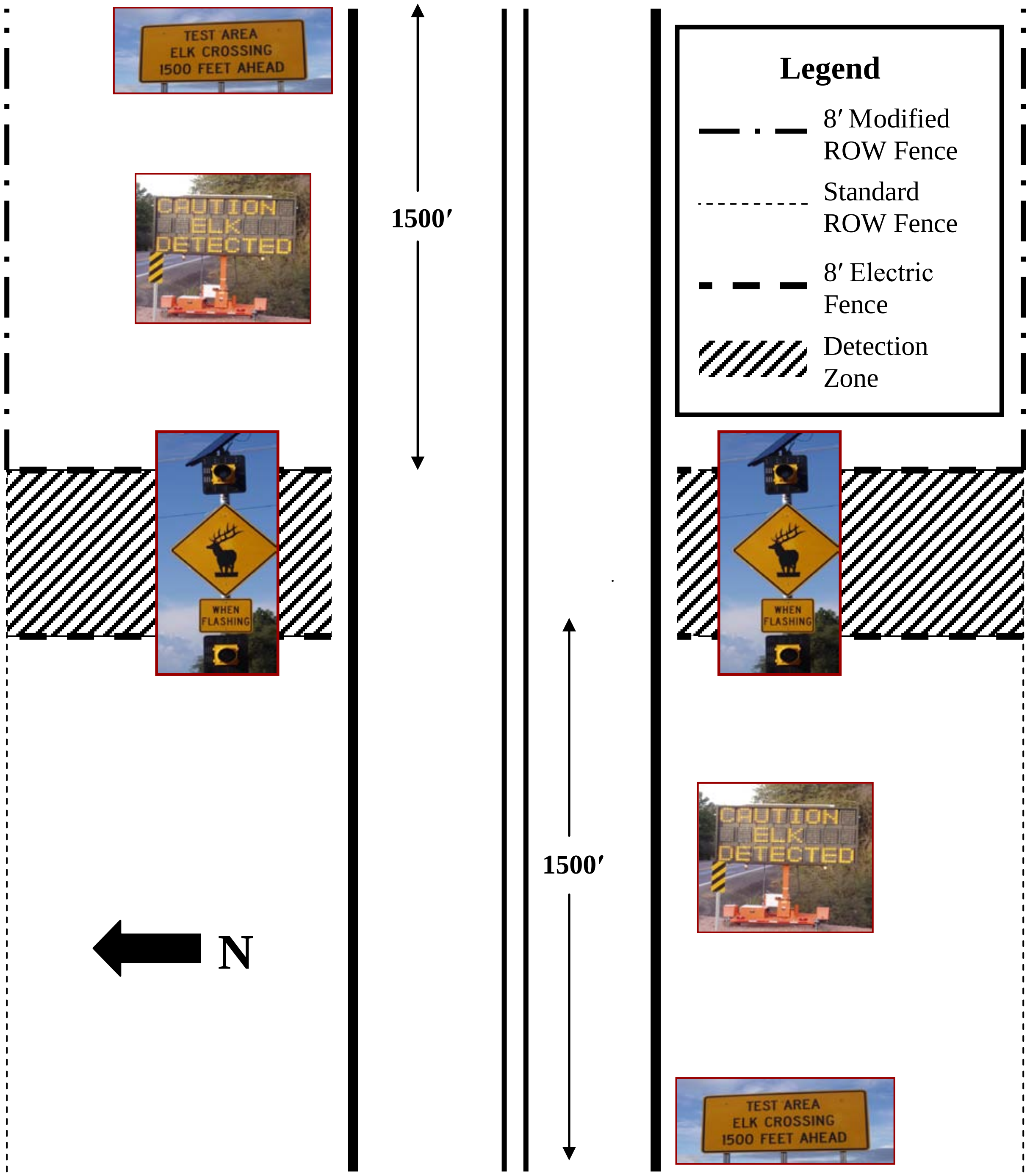


Figure 4.6. Layout of the array of signs designed to alert motorists of animals on or near SR 260 at the wildlife crosswalk. Motorists are informed of the presence of animals at the wildlife crosswalk a minimum of 1500 ft prior to entering the defined detection zone (striped area).

5.0 COMPARISON OF THE INCIDENCE OF WILDLIFE-VEHICLE COLLISIONS BEFORE- AND AFTER-FENCING MODIFICATION

5.1 INTRODUCTION

Because of the risk of injury or death to motorists and wildlife, the ultimate measure of any WVC mitigation, including RADS, is the ability to reduce the incidence of WVC. All other measures or metrics of success including system reliability and altered motorist behavior are moot if the incidence of WVC is not reduced.

Collisions with elk along this section of highway averaged almost 12/year from 2001 to 2006. Substantial reductions in EVC were expected to deem this enhancement project a success and without seeing a displaced increase in WVC on the adjacent Lion Springs (LS) section.

5.2 METHODS

The study documented all WVC per 0.1-mile segments along the PC and LS sections, as per Dodd et al. (2006, 2007*d*) for six years before and two years after the erection of ungulate-proof fencing. The research team used fixed search and reporting method for WVC before and after modification of the fencing and implementation of the RADS (Huijser et al. 2006a). We compared the incidence of WVC before fencing was modified to that after fencing was modified by: 1) documenting numbers of WVC by species and 2) using ADOT crash data to determine the proportion of single-vehicle accidents that were wildlife related.

We assessed and compared the frequency and distribution of WVC in relation to the type of fencing adjacent to the 0.1-mile segment where collisions occurred. This allowed the researchers to compare the efficacy of each type of fencing in preventing WVC. The team assessed the effectiveness of the RADS at the west fence terminus in reducing the potential presence of an “end-run effect” by tracking WVC at the RADS, as well as on the adjacent LS section to the west (mileposts 258–259).

5.3 RESULTS

Since completion of fencing there have been only four WVC recorded along the PC section within the fenced section. One involved an elk, the others a black bear and two white-tailed deer. The bear and two white-tailed deer were killed along the stretch of highway with raised barbed-wire fence that is considered semi-permeable to passage by animals other than elk, especially those that can cross over or under the fence (e.g., deer, bears). The lone EVC occurred in March 2007, soon after the ElectroBraid™ fence extension was completed. This animal could possibly have been trapped in the fenced corridor during the erection of fencing. In the 32 months since, no EVC have been recorded along the PC section within the modified fencing limits. Thus, the documented incidence of after-fencing EVC represents a 97% reduction compared to the 2001–2006 mean (11.7 EVC/year; Figure 5.1 and Table 5.1). By comparison elsewhere along SR 260, the incidence of WVC on two SR 260 experimental control sections (Little Green Valley and Doubtful Canyon) combined averaged 5.2 EVC/year 2001–2006 (Dodd et al. 2007*a*) but doubled to a combined 10 EVC/year in 2007–2008 (Dodd et al. 2009). The proportion of wildlife-related single-vehicle accidents within the fenced PC section dropped from a before-fence modification mean of 0.47 (±0.05) to an after-fence modification mean of 0.25, or an overall reduction 47.0% (Table 5.1).

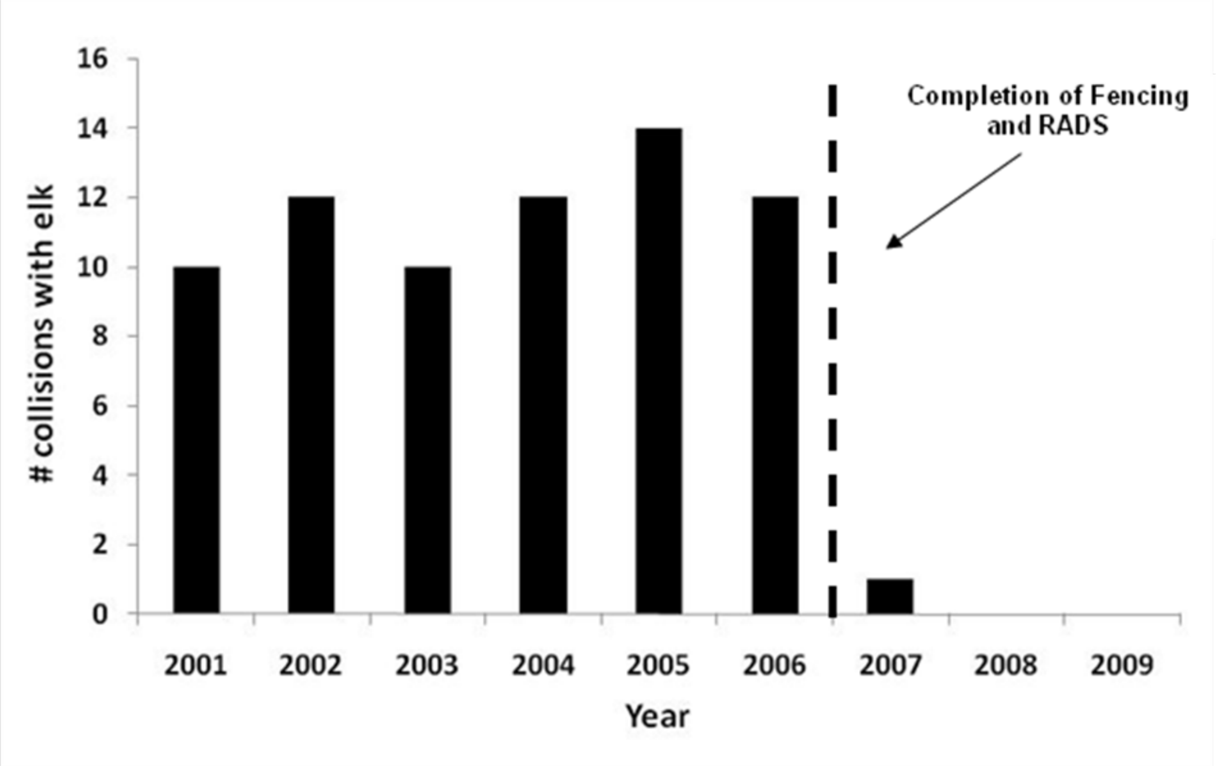


Figure 5.1. Number of EVC before (2001–2006) and after (2007–2009) completion of fencing and animal detection system along the PC section.

Along the LS section west of the crosswalk, five (three in 2007 and two in 2008, respectively) EVC occurred since the completion of the crosswalk and fencing project (including one documented by ElectroBraid Fence, Inc. personnel); this is below the 2001−2006 mean of 4.7 EVC/year. In the two years following completion of fencing we documented a decrease of 65% in EVC on the LS section indicating that there was not a displaced end-run effect by animals from the fenced PC section or an increase in EVC (Table 5.2).

ElectroBraid Fence, Inc. did record an EVC just to the west of the crosswalk, on November 11, 2007, where an elk standing on the centerline was simultaneously hit by vehicles traveling in both directions. The motorist alert signs were not activated as the elk entered the roadway outside the detection zone, and it appeared that minimal damage to the vehicles occurred, although the elk was killed. Though an isolated incident, it nonetheless points to the potential for animals to cross the highway outside the crosswalk detection zone. One white-tailed deer was also struck at the crosswalk in August 2009.

Table 5.1. Frequency of elk- and deer-vehicle collisions along the Preacher Canyon section and the adjacent Lion Springs section before and after completion of fencing and a roadside animal detection system along the Preacher Canyon section, 2001-2009, State Route 260, Arizona.

	Preacher Canyon Section			Lion Springs Section		
Year	Elk VC	Deer VC	Proportion Wildlife-related Single-vehicle Accidents	Elk VC	Deer VC	Proportion of Wildlife-related Single-vehicle Accidents
Before Fence Modification and RADS						
2001	10	0	0.36	3	0	1.00
2002	12	1	0.56	2	0	0.33
2003	10	2	0.45	4	1	0.67
2004	12	2	0.27	9	1	1.00
2005	14	1	0.60	7	0	0.67
2006	12	1	0.60	3	0	0.40
Mean	11.7	1.2	0.47	4.7	0.3	0.68
After Fence Modification and RADS						
2007	1	0	0.33	3	0	0.33
2008	0	1	0.17	2	0	0.33
2009	0	1	NA*	0	1	NA*
Mean	0.33	0.66	0.25	1.67	0.33	0.33

*Available 2010

Table 5.2. Difference in mean number of EVC on the Preacher Canyon and Lion Springs sections before (2001−2006) and after (2007−2009) modification of fencing and implementation of RADS.

	Preacher Canyon Section			Lion Springs Section		
	Before Fence Modified	After Fence Modified	Mean Changes in EVC	Before Fence Modified	After Fence Modified	Mean Change in EVC
Mean EVC	11.70	0.33	-97.2%	4.70	1.67	-51.1%

5.4 DISCUSSION

With the 97% reduction in WVC in the two years since this enhancement project was implemented, the project has successfully promoted highway safety along the PC section without an increase in the incidence of WVC at the fencing terminus or on the adjacent LS section.

One important measure of any WVC mitigation effort is the cost:benefit tradeoffs of installation and maintenance versus magnitude of WVC reduction. Applying an economic assessment similar to that done by Dodd et al. (2007*d*) for elsewhere along SR 260, which used the cost associated with EVC reported by Huijser et al. (2007*b*:35), the reduction in EVC on the PC section exceeded $600,000 in just its first three years; longer-term benefits will exceed the project costs within a year or two years if such a reduction in EVC are maintained. Long-term monitoring will determine if the combination of fencing, crossing structures, and RADS continue to be effective over time.

One major difference of the RADS used on this enhancement project, compared to most other RADS applications, is the use of the system in conjunction with wildlife underpasses, allowing animals the opportunity to cross the highway below-grade in other locations. Had there not been alternative opportunities for wildlife to cross the highway, the results at the crosswalk likely would have differed. Animals that need to make daily and seasonal movements would have been forced to cross the highway at-grade, if underpasses were not provided as an alternative means of crossing, thus increasing the potential for WVC.

6.0 EVALUATION OF THE EFFECTIVENESS OF THE ROADSIDE ANIMAL DETECTION SYSTEM IN MODIFYING MOTORIST BEHAVIOR

6.1 INTRODUCTION

An important measure of success of any RADS is its ability to elicit modified motorist behavior. Without this key result, collisions with wildlife along the area where a RADS is located will likely not be reduced. Success of the PC section enhancement project is predicated upon achieving both a response from wildlife by modifying highway-crossing patterns associated with fencing and crossing structures, while simultaneously eliciting a response from motorists to animal-activated warning signs when animals approach and cross through the crosswalk. These two measures largely determine the effectiveness of the RADS in preventing EVC at the terminus of the fencing. In assessing motorist response to the RADS and motorist alert signs, the research team employed the model of potential motorist response developed by Huijser et al. (2006*a*, 2009) whereby two driver responses can occur: 1) increased driver alertness, and 2) lowered vehicle speed. These responses in turn can ultimately lead to motorists either avoiding collisions altogether, or hitting animals at slower speeds, reducing the risk of injury. These measures of motorist response are the primary metrics to the effectiveness of the RADS and motorist alert signs on achieving modified motorist behavior associated with this project.

6.2 METHODS

To determine the effectiveness of the overall array of motorist warning signs, we assessed the response of motorists to the signs at the crosswalk by conducting paired sampling with and without the variable message board and crosswalk flashing signs activated (by toggle switch), using 15-min sampling periods.

6.2.1 Evaluation of Traffic Counters

During the course of the study it proved necessary to assess the accuracy of the various traffic speed monitoring devices used to determine motorist speeds. We documented speeds of individual vehicles and number of vehicles during each 15-min sampling period. To accomplish this sampling, a radar gun was used to determine mean speeds and conducted manual vehicle counts to allow for a direct comparison to the output received from each traffic counting device. In the event vehicles were equipped with radar detectors, these results were used solely for validation of the speed monitoring devices and not for evaluation of motorist response.

We used three different types of traffic counters: 1) a permanent "Groundhog" traffic counters (Nu-Metrics, Inc.), 2) a permanent Measurement Specialties, Inc. piezo loop electric sensor system installed during the second year of the project, and 3) temporary downloadable "card counters" (Nu-Metrics, Inc.). Data from both permanent counters provided traffic data retrieval via phone modem. All counters were programmed to collect speed, volume, and vehicle class data in 15-min increments, allowing for a comparison by paired 15-min intervals when signs were activated and not activated.

6.2.2 Comparison of Average Motorist Speeds

To determine changes in average motorist speed, the research team compared data collected with the traffic counters with paired T-tests consisting of vehicle speeds during paired 15-min intervals with and without motorist warning signs activated. These values were reported as means (± SE).

6.2.3 Comparison of Motorist Alertness

To assess differences in motorist braking response with and without motorist warning signs activated, the surrogate measure of motorist alertness, we determined the proportion of vehicles braking during paired 15-min sampling periods from each direction as they approach the RADS and crosswalk. We conducted counts for each lane individually at a point beyond where motorists first encountered the variable message signs. The team alternated between eastbound and westbound directions, and observers remained hidden from motorist view to prevent bias. Along with calculating proportions of motorists exhibiting a braking response, we used a general linear model with a logit link (Agresti 1996) to calculate the odds of motorists exhibiting a braking response with and without the signs activated. To control for environmental parameters (i.e., weather, full moon, sunrise and sunset times), the paired sampling periods were alternated randomly and occurred throughout the year and at all times of the day, though the preponderance of sampling occurred at times when elk are active and typically cross SR 260 (e.g., within 2 hrs of sunset and sunrise; Dodd et al. 2006, 2007*a*).

SR 260 traffic generally consists of a higher proportion of local traffic on the weekdays and an influx of tourists or motorists traveling to second homes or campsites in the higher elevations on the weekends, particularly in the summer. The research team hypothesized that exposure to the RADS-activated signs likely differed among weekends and weekdays, with the potential that either local motorists may become complacent or alternatively that weekend motorists may be less likely to be aware of the location and function of the system (Huijser et al. 2006*a*). We determined odds and proportions for each lane individually and combined, and for weekend days (Fri–Sun) and weekdays (Mon–Thu). To evaluate motorist response over time and determine if motorists became habituated to or ignored the signs, the research team evaluated and compared the proportion and odds of braking responses with and without the signs activated between the first and second years of the project evaluation.

6.3 RESULTS

6.3.1 Evaluation of Traffic Counters

The project team collected vehicle speed and counts for 44 15-min sampling intervals, accounting for 2,209 vehicles. All three different traffic counters recorded speeds higher than those recorded by radar validation by 0.1 to 8.3 mph on average (Table 6.1).

Table 6.1. Comparison of three different traffic counters and their relationship to radar-gun speeds for calibration of the traffic counters used to evaluate motorist response.

Traffic Counter Type	Average Traffic Speed (mph)		Difference from Radar (±SE)	
	Eastbound	Westbound	Eastbound	Westbound
Nu-metrics Card Counter	55.0	63.1	+1.3 (0.31)	+8.35 (0.44)
Nu-metrics Groundhog	53.7	58.1	+0.06 (0.81)	+3.44 (0.58)
Measurement Specialties Piezo Strip	51.6	55.9	+1.29 (0.39)	+3.46 (0.55)

6.3.2 Motorist Speed

Following evaluation of the traffic counter data, we calibrated the data to reflect radar gun-determined detection speeds. We conducted 256 paired 15-minute sampling periods for our analysis. We recorded 22,064 vehicles (11,584 eastbound and 10,480 westbound) during these sampling periods. We documented a reduction in speeds of 14.6% in the westbound lane and an 18.2% reduction in the eastbound lane when motorist alert signs were activated. Overall, speeds were reduced significantly in both lanes when the signs were activated ($t = 1.97$, df = 256, $P < 0.001$; Table 6.1 and Figure 6.1).

Average speeds did not differ significantly between weekdays and weekends. Weekday speeds were slightly higher, both with the signs not activated (0.9 mph) and when signs were activated (0.4 mph); average speeds when warning signs were activated were 0.5 mph higher during weekdays compared to weekends (Table 6.3).

Table 6.2. Difference in speeds when warning signs were activated or not at the PC section crosswalk.

Warning Signs	Average Traffic Speed (mph)		
	Eastbound Lane	Westbound Lane	Both Lanes
Not Activated (off)	53.6	52.7	53.2
Activated (on)	43.6	45.0	44.3
Difference mph (%)	-10.0 (18.7%)	-7.7 (14.6%)	-8.9 (16.7%)

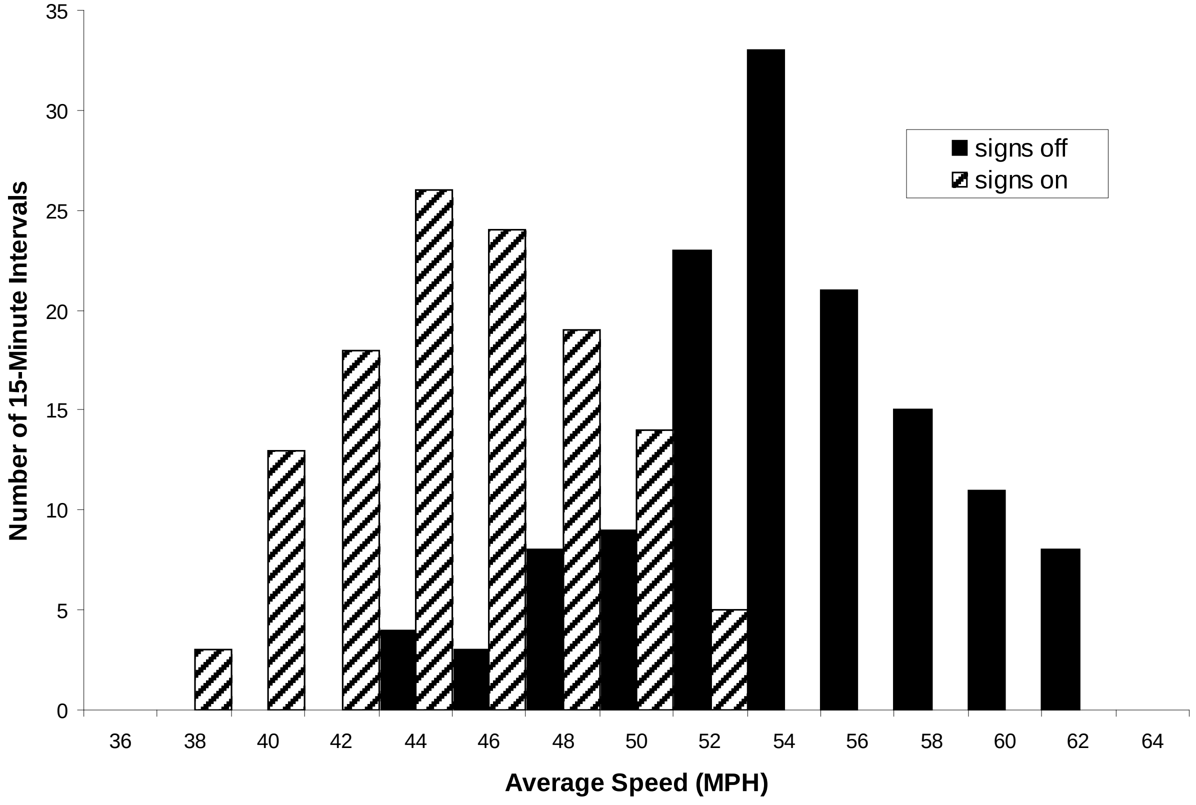


Figure 6.1. Distribution of average vehicle speeds during 15-min sampling periods with motorist alert signs not activated (black bars) and with signs activated (striped bars) at the PC section crosswalk.

Table 6.3. Reduction (difference) in average vehicle speeds (mph [%]) during weekends and weekdays from 2007-2009 at the PC section crosswalk.

Warning Sign Status	Average traffic speed (miles/hour)	
	Weekend	Weekday
Not activated (off)	52.6	53.5
Activated (on)	44.1	44.5
Difference (%)	-8.5 (16.2%)	-9.0 (16.8%)

6.3.3 Motorist Alertness

To assess differences in motorist braking response, the research team observed vehicles during 286 paired 15-min sampling periods accounting for 71.5 sampling hours and a total of 8,098 vehicles (3,607 eastbound, 4,491 westbound). Traffic levels in each lane during our 15-min sampling periods ranged from 1 to 101 vehicles and averaged 33 vehicles (SE ±2.5). Overall, the odds of motorists exhibiting a braking response were 21:1 when approaching the crosswalk with warning signs activated compared to when they were not activated (95% CI; 19:1 – 24:1; $\chi 2=3206$, df = 1, $P < 0.001$; Table 6.4). When warning signs were activated, motorists traveling in the westbound direction where the signs were encountered in a shorter distance from the crosswalk showed a higher braking response (76%) than those traveling eastbound (58%). The odds of motorists exhibiting a braking response in the westbound lane when the signs were activated (34:1) was almost three times that of the eastbound lane (13:1) where the array of signs could be seen for up to 0.5 mile from the crosswalk, apparently allowing motorists to slow down by deceleration versus braking.

During the first year of the study (2007), 65% of all motorists exhibited a braking response to the activated signs and the odds of motorists braking were 25:1 (95% CI; 20:1–31:1; $\chi 2=1151$, df = 1, $P < 0.001$) when the signs were activated. During the second year of the study (2008), we did not observe a reduction in the proportion of motorists exhibiting a braking response, as 67% of motorists exhibited a braking response though the odds of motorists braking with the signs activated were slightly lower in the second year (20:1; 95% CI: 17:1–23:1; $\chi 2=2058$, df = 1, $P < 0.001$; Table 6.5)

Table 6.4. Proportion of motorists exhibiting a braking response with and without the motorist alert signs activated in the eastbound, westbound, and both lanes combined at the PC section crosswalk.

Warning Sign Status	Eastbound Lane		Westbound Lane		Both Lanes	
	Total Vehicles	Proportion Braking	Total Vehicles	Proportion Braking	Total Vehicles	Proportion Braking
Not Activated (off)	1,758	0.08	2,183	0.08	3,941	0.08
Activated (on)	1,849	0.58	2,308	0.76	4,157	0.68
Difference (%)		+0.50 (725%)		+0.64 (950%)		+0.48 (850.0%)

Table 6.5. Proportion of motorists exhibiting a braking response with and without motorist alert signs activated during the first (2007) and second (2008) years of evaluation at the PC section crosswalk.

Warning Sign Status	Year 1		Year 2	
	Total Vehicles	Proportion Braking	Total Vehicles	Proportion Braking
Not Activated (off)	1,315	0.10	2,632	0.09
Activated (on)	1,458	0.65	2,693	0.67
Difference (%)		+0.55 (550.0%)		+0.58 (640.0%)

Traffic volume levels during the times we normally sampled had minimal influence on proportion of motorists exhibiting a braking response. However, during the Labor Day weekend where traffic volumes were very high (mean = 261 vehicles/15-min sampling period), our warning signs caused traffic to backup approximately 0.5 mi; thus all vehicles at that time exhibited a braking response. As such, sampling periods for this weekend were removed from the analyses to prevent a bias in the data. This observation indicates that excessive traffic volumes may increase the incidence of braking response by motorists, as one vehicle slowing can cause a chain reaction with the vehicles that follow. This may indicate why the proportion of vehicles braking on the weekend (0.70) slightly exceeded those on the weekdays (0.63; Table 6.6). Alternatively, this difference may reflect the local traffic on the weekdays becoming habituated to the crosswalk

RADS, whereas, weekend traffic may be more reflective of tourists that respond to the novel warning signage.

Table 6.6. Proportion of motorists exhibiting a braking response with and without motorist alert signs activated during weekends (Fri–Sun) and weekdays (Mon–Thu) at the PC section crosswalk.

Days Sampled	Signs Not Activated (off)		Signs Activated (on)	
	Total Vehicles	Proportion Braking	Total Vehicles	Proportion Braking
Weekends	2,148	0.09	2,200	0.70
Weekdays	1,799	0.10	1,951	0.63
Difference		+0.01		-0.07

6.4 DISCUSSION

The results indicate that the SR 260 crosswalk motorist warning signs were successful in eliciting the desired response from motorists relative to reduced speeds and increased awareness. The research team documented a 15–19% reduction in average speeds and a high proportion of braking response with the signs activated (0.58–0.76) versus when signs were not activated (0.08) indicating increased awareness among motorists. Both responses in motorist behavior have contributed to the success of the crosswalk and lack of WVC associated with animals crossing the highway at-grade at the crosswalk.

Gordon et al. (2004) documented a 6% decrease in speed and questioned the cost:benefit aspects of warning systems in reducing WVC. Although this project experienced a higher reduction in speed than that reported by Gordon et al. (2004), even minimal vehicle slowing by motorists in combination with increased motorist alertness due to warning signs may enhance reaction time and lead to reduced incidence of WVC. This increased alertness can reduce the vehicle stopping distance by 68 ft at 55 mph (Huijser et al. 2006*a*, 2009), the posted speed limit along the stretch of SR 260 encompassing our RADS and crosswalk.

The ability of our RADS and motorist alert signs to reduce speeds by as much as 19% may also be attributable to a greater percentage of local traffic and motorist awareness of the system, as described by Gordon et al. (2004). Prior to and during this study, various media events occurred that helped educate the public about the function and importance of the RADS and associated signs. Unlike Gordon et al. (2004), the SR 260 RADS also funneled animals to a discrete location that allowed motorists to focus their attention on an identified crossing zone and reducing the potential for motorists to encounter large ungulates outside of the detection zone. Huijser et al. (2006*a*) also reported the potential importance of local exposure and knowledge of RADS. They further pointed to the importance of a reliable system in these cases so as not to reduce the responsiveness of motorists that are presented with activated signs when no animals are present.

Although the SR 260 RADS performed well under the traffic volumes and speeds we evaluated, the use of RADS on highways with considerably higher traffic volumes or higher speeds may not be appropriate having potential increase in risk of injury to motorists through vehicular collisions. The response of motorists at the PC crosswalk to the warning signs during periods of high traffic volume on a holiday weekend, causing a backup of a 0.5 mi, demonstrates one limitation of such a system.

Motorists exhibited similar responses to the signs in the first and second year of evaluation. As they become increasingly aware of the system, it will be important to evaluate the long-term effectiveness of the RADS and crosswalk in reducing speeds and eliciting increased awareness to determine if motorists become complacent or habituated over time. In this instance where signs are activated only when wildlife are present, such potential is reduced assuming the RADS and signs continue to operate reliably in the future.

7.0 EVALUATION OF THE OPERATIONAL RELIABILITY OF THE ROADSIDE ANIMAL DETECTION SYSTEM

7.1 INTRODUCTION

Although secondary to the overall importance of reducing WVC, the operational reliability of a RADS can determine its overall success. If motorists are regularly and repeatedly exposed to activated signs that occur in the absence of wildlife (false positives), they may become complacent and begin to ignore the activated signs. A worse scenario is wildlife occurring in the detection zone without the system being activated, or false negatives, leaving unsuspecting motorists with a reduced opportunity to slow down to completely avoid a collision or strike an animal at a slower speed, thus leading to potentially greater accident severity (Huijser et al. 2007*a*). RADS should also be subject to minimal downtime as this may have the same repercussions as that of a false negative. If signs are left activated during substantial RADS downtime (our default setting when the RADS become inoperable in the early stages), this can lead to the perception of false positives and the potential for motorists to ignore the system in the future.

RADS are typically complex systems integrating sophisticated electrical components that require proper design, integration, implementation, and maintenance. RADS are also subject to a full range of environmental factors that also may affect their reliability, ranging from snow and ice, extreme heat and cold, roadside vegetation, and a multitude of other factors. Often such systems are prone to inherent operational limitations that can affect system reliability, as described by Huijser et al. (2006*b,* 2009). Many RADS, such as that used on SR 260, include radio signaling features that trigger warning sign activation that also are subject to technological limitations. . The PC section crosswalk RADS was no exception, however over a short time period (about 4 months) known problems were identified and corrected.

7.2 METHODS

To assess RADS reliability, we used two primary evaluation methods: 1) periodic field status visits, and 2) video surveillance of RADS activation performance when wildlife entered and passed through the detection zone. Periodic visits were made to the crosswalk site during which warning sign operational status was noted from the highway (e.g., signs activated, not activated, default message “system under repair” when the system was inoperable). When signs were encountered in an activated status, especially during daytime hours, an effort was made to determine whether an animal had been present; if no evidence of animals having been present existed, such an event was categorized as a false positive. On each status visit, an observer entered the detection zone to see if the warning signs subsequently activated.

Operational status and RADS reliability was also monitored independently by the vendor (ElectroBraid Fence, Inc.) that designed, implemented, and was responsible for maintenance of the system via a combination of regular site visits and remote monitoring. This monitoring allowed them to immediately resolve problems, either through remote troubleshooting or contacting on-site staff. In most cases the vendor was already aware of problems and in the process of resolution to minimize downtime, false positives, and false negatives prior to our visits.

To determine if motorist warning signs were activated when animals were present in the RADS detection zone, the researcher team installed a 4-camera video surveillance system that allowed documentation of false negatives (Dodd et al. 2007*a*, also detailed in section 8.2). Because activation of both the RADS and video surveillance systems occurred only when wildlife were present, this allowed for documentation of false negatives only and not false positives. The research team evaluated the frequency of occasions where the motorist warning signs were activated when animals entered the detection zone and came within 50 ft of the roadway by orienting one camera such that it allowed the viewer to determine if the warning signs were flashing. As the camera systems were installed to detect wildlife well before they reached the detection zone, and the 50 ft distance from the highway, the viewers were able to determine at what instant the signs were activated as wildlife passed through the zones. We documented three possible outcomes relative to sign activation: 1) signs activated immediately, 2) signs activated after animals came within 50 ft of the roadway, but not immediately, and 3) signs never activated while the animal was within 50 ft of the roadway. The researchers compared the proportion of times that each of these outcomes occurred when animals entered the detection zone. We also recorded the number of occasions the signs activated properly but went off prior to animals leaving the detection zone.

7.3 RESULTS

7.3.1 Evaluation of False Positives and RADS Downtime

The crosswalk RADS, though fully functional by February 2007, coinciding with ElectroBraid™ ROW fence modification, required troubleshooting and refinements by the contractor, including replacement of faulty components outside their control. As such, the research team did not begin the reliability test visits until the system was fully functioning in May 2007. Between May 2007 and December 2009, the team logged 275 test visits including days when traffic and braking counts were conducted. There were few instances when the system exhibited false positives or when the RADS and signs were inoperable (Table 7.1). Overall, the crosswalk system performed properly on 93% of the test visits (Table 7.1). During three of the false positives encountered, weeds had grown to 5 ft in height in the detection zone and apparently caused activation of the system. Once the weeds were trimmed, the system functioned normally thereafter.

Table 7.1. Number of total test visits made from 2007−2009 to the SR 260 RADS and the number of visits where the system was operating properly, displaying false positives, or when the system was inoperable.

RADS Test Visits	Visits RADS Operating (%)	Visits with False Positives (%)	Visits RADS Inoperable (%)
275	270 (98.0%)	12 (4.0%)	6 (2.0%)

7.3.2 Evaluation of False Negatives

We recorded 168 groups of elk and 65 groups of white-tailed deer entering the RADS detection zone from the video camera monitored side of the road and coming within 50 ft of the roadway during video surveillance. Motorist warning signs activated 98% of the time for both species at some point following the presence of animals in the detection zone (Table 7.2). On 15 occasions however, warning signs deactivated for some time during the animals' presence in the detection zone but reactivated once the animals began moving again.

Table 7.2. Number of elk and white-tailed deer that entered the SR 260 RADS detection zone from the south side of the road and approached within 50 ft of the roadway (2007−2009) and the number of times that motorist warning signs were activated, activated late, or did not activate (false negative).

Species	Total Groups 50 ft from Roadway	Signs Activated*	Signs Activated Late	No Activation (false negatives)	% of Time Signs Activated
Elk	168	137	28	3	98%
White-tailed deer	65	59	5	1	98%
Total	233	196	33	4	98%

* On 15 total occasions, signs deactivated for some time period and reactivated prior to animals leaving the detection zone.

7.4 DISCUSSION

Overall, the SR 260 RADS and associated motorist warning signs exhibited relatively low incidence of false positives or false negatives once most issues were resolved by May 2007. Following final modifications to the system by the contractor, operational downtime of the system was minimal. The system reliability combined with the reduction of EVC and modified driver behavior appears to provide a complete package that proved effective in preventing a spike in WVC at the crosswalk. One concern was the occasional times that the signs deactivated while animals were still in the detection zone due to the programmed RADS software turnoff time after the system was activated. These instances were a few seconds in duration, and warning signs were reactivated as animals milled about in the detection zone.

The diligence of ElectroBraid Fence, Inc. personnel in keeping the RADS, motorist warning signs, and electric fencing operational by remote monitoring and repair and by site visits allowed for immediate repair and regular maintenance of the system. The contractor was extremely responsive to any problems that arose with the system and acted in a timely manner.

For the first three-year duration of the study, the evaluation found the RADS to be reliable and functional. Long-term monitoring will allow for the evaluation of maintenance needs and costs, as well as the reliability of the system to continue reducing the incidence of WVC.

8.0 EVALUATION OF WILDLIFE USE AT THE CROSSWALK AND WEST LITTLE GREEN VALLEY WILDLIFE UNDERPASS FOLLOWING FENCING MODIFICATION

8.1 INTRODUCTION

Although RADS have been implemented in various locations throughout the world (Huijser and McGowen 2003), wildlife behavior associated with use of at-grade crossings has not been thoroughly documented. Wildlife interactions with roadways and associated traffic may be an important determinant of the utility of RADS under various scenarios. Gagnon et al. (2007*a*) determined that elk along SR 260 were deterred by traffic levels when crossing the highway at-grade. However, elk were not influenced by traffic volume when crossing the highway below-grade via wildlife underpasses at the traffic volumes they evaluated (Gagnon et al. 2007*b*). This finding may provide insight into applicability of at-grade crossings such as crosswalks integrated with RADS. Larger ungulates such as elk pose an increased safety threat to motorists due to their large body size. Implementation of wildlife crossing structures that accommodate these species simultaneously allow them to access resources such as food and water, while reducing the risk of human casualties associated with WVC. Understanding of how large ungulates utilize at-grade crossings and their reaction to traffic at these locations will help to determine situations where at-grade crossings are a viable alternative to costly passage structures including underpasses and overpasses.

Similar to the crosswalks described by Lehnert and Bissonette (1997), an unfenced gap existed between the roadway shoulder and the end of fencing. This gap provided access for wildlife to move within the fenced ROW, risking WVC until they returned via the same gap or left through an escape mechanism. Lehnert and Bissonette (1997) documented entry through similar gaps even with obstructive cobble fields laid in the gaps between the shoulder of the road and the fence combined with painted lines, simulating cattle guards.

The west Little Green Valley wildlife underpass lies at the far eastern end of 2.5 mi of newly modified ungulate-proof fencing (Figures 3.2 and 3.3). The research team began video monitoring the west underpass in late 2002 during the initial study along SR 260 (Dodd et al. 2009). They documented 2,445 animals using the west underpass, primarily elk (n = 2,179), along with eight other species. After reconstruction in 2001, the west underpass had minimal wing fencing (<1/4 mi) to funnel animals toward the underpass. Under this enhancement project, an 8-ft high barbed-wire fence linked the west underpass to the Preacher Canyon Bridge, located approximately a mile to the west (Figures 3.2 and 3.3). With this increase in funnel fencing length, the researchers sought to determine changes in wildlife use, if any, at the west underpass

Video data from previous studies (Dodd et al. 2007*a*, 2009) showed reluctance by elk to use the west underpass for the first few years. Videos showed elk fixated on the concrete retaining wall ledges above them, apparently for fear of lurking predators (Dodd et al. 2007*a*). In an attempt to increase use of the west underpass, the wing-fences on the east side of the underpass were tied directly into the abutments, allowing animals to use the side-slope above the eastern ledge if desired as an alternative to crossing lower through the underpass (Figure 3.3).

8.2 METHODS

On the south side of the SR 260 crosswalk, the research team installed an integrated video surveillance system comprised of four low-lux, high-resolution black and white video cameras linked to a quad-screen splitter with a feed to a videocassette recorder (VCR) with alarmed input. To illuminate the area covered by the cameras, we installed nine infrared illuminators. The researchers used infrared photo-beam triggers to detect animals and initiate VCR recording. The system was operated on 120-volt AC power converted to 12-volt DC power for distribution to all equipment via buried wiring. Following troubleshooting and repair of the RADS as well as the video system, the camera system was operational from May 2007 to November 2009, providing more than a year and a half of system monitoring and testing.

The four cameras were situated atop two 15-ft poles to record animals crossing the ROW fence, entering the RADS detection zone, and crossing the highway. One camera was oriented toward the highway to record passing traffic and to monitor the activation of motorist alert signs. The cameras simultaneously recorded wildlife approaching or crossing the highway. Photo-beam triggers were placed approximately 1.5 ft above ground oriented such that animals could not approach the highway within the detection zone without interrupting one or more triggers. To avoid recording delays, we operated all components continuously so that the VCR began recording immediately once triggered, with all cameras recording simultaneously. We programmed the VCR alarm to record for two minutes each time animals successively interrupted a trigger. This video surveillance system allowed viewers to determine the following:

1) The number and proportion of animals in the RADS detection zone that crossed the highway or turned back (passage rate).
2) The number and proportion of animals in the RADS detection zone that walked around the end of the crosswalk fencing via the gap and traveled along the side of the highway.
3) Traffic volumes associated with elk and white-tailed deer crossings or repels from the highway.

To calculate passage rate at the crosswalk, we calculated the proportion of animal crossings to the number of approaches (Dodd et al. 2007*d*). This allowed a direct comparison of the crosswalk passage rates to those determined at SR 260 underpasses. For analysis, an approach was defined as an animal crossing the highway ROW fence (approximately 150 ft from the roadway) and travelling into the RADS detection zone toward the highway.

We simultaneously monitored traffic and crossings by elk and deer that approached within the RADS detection zone. Traffic levels were determined by counting vehicles passing by the crosswalk that were recorded by the camera aimed at the roadway divided by the amount of time elk or deer spent in the area until either crossing, going around the end of the fence into the ROW, or leaving the area. We used a general linear model with a logit link (Agresti 1996) to evaluate the relationship of varying traffic volumes to elk and deer highway crossings and end of fence use and converted converted the log odds model derived from JMP 7.0 (SAS Institute 2008) into probabilities using:

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

This can be interpreted as the probability of a successful crossing under a given scenario versus that of a failure (1 – probability) once an elk or deer approaches the road at the crosswalk. The α and β terms represent the intercept and log odds respectively, derived from logistic regression modeling. For ease of interpretation, these probability equations were used to create a graphical model of the probability of elk or deer crossing the highway or breaching the ROW via the roadway as traffic volumes fluctuated.

Monitoring of the west underpass continued following erection of modified fencing, which allowed a direct comparison of use by animals with the same video surveillance system that had been in place since 2002 (Dodd et al. 2007*a*,*d*). The purpose of continued monitoring of the underpass was two-fold: 1) to determine the change, if any, in wildlife underpass use and passage rate following modification of fencing, and 2) to evaluate use of the side-slope crossing area above the concrete retaining wall ledge following tying fencing directly into the bridge abutments.

To compare seasonal differences in use of the west underpass before and after fencing modification, the research team documented the number of months elk and deer were captured on film at the underpass and compared it to wildlife use of an identical time period. We compared crossings/day, passage rates, and calculated odds of a successful crossing before and after fencing modification. We used Mann-Whitney *U*-tests to compare crossing and passage rates between treatments (before and after fence modification) and a general linear model with a logit link to determine odds of a successful crossing before and after fencing modification.

8.3 RESULTS

8.3.1 Elk Crosswalk Video Surveillance

Like the crosswalk RADS, the video surveillance system required troubleshooting after installation as we encountered initial sporadic data collection until the system was fully operational. Through December 2009, the system recorded a total of 801 animals on videotape (523 elk, 157 white-tailed deer, 57 javelina), and 64 animals of various other species, including, mule deer, mountain lion, black bear, raccoon, and gray fox. Of the 523 elk recorded on videotape (255 groups) that approached the crosswalk from the camera (south) side, 32% successfully crossed the highway while 20% went around the end of the electric fence and into the highway corridor (Table 8.1). In contrast, only 10% of deer successfully crossed while 21% entered the gap into the highway corridor (Table 8.1). Passage rates for elk and deer were 0.29 crossings/approach and 0.09 crossings/approach respectively.

Table 8.1. Number of individuals and groups of wildlife recorded on videotape, the number of times they entered the crosswalk, and percentage of times they crossed the highway or went around the end of the fence once they approached the highway at the PC section crosswalk.

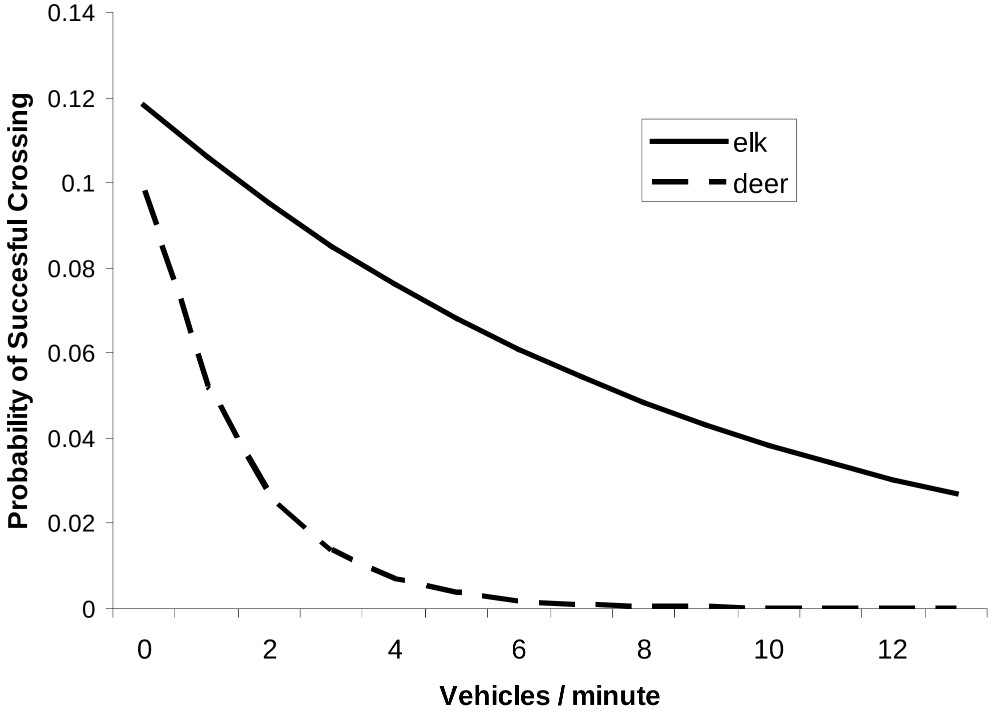
Species	Total Groups (Individuals) Recorded	No. Groups (Individuals) Approaching Roadway	No. Groups (Individuals) Crossing Highway	% of Groups (Individuals) Crossing Highway	% of Groups (Individuals) Around End of Fence
Elk	255 (523)	233 (471)	68 (152)	29% (32%)	20% (20%)
White-tailed deer	118 (157)	105 (138)	10 (11)	9% (10%)	17% (21%)
Javelina	12 (57)	3 (6)	1(1)	33% (17%)	0% (0%)
Other	49 (64)	19 (17)	0 (0)	0% (0%)	0 (0%)
Total	434 (801)	360 (632)	79 (164)	22% (26%)	18% (19%)

Similar to the relationship of at-grade crossings and traffic volume documented for elk (Gagnon et al. 2007*a*) and white-tailed deer (Dodd et al. 2009) along SR 260, increases in traffic volume reduced the probability of a successful highway crossing at the crosswalk by elk and deer. The probability of an elk crossing the highway after approaching was 0.21 when traffic volumes were low (<1 vehicle/min) and dropped to 0.02 as traffic volumes increased to 12 vehicles/min. Deer showed an even greater avoidance response in highway crossings with increased traffic volume, as only six animals crossed the highway at a maximum traffic volume of 1.8 vehicles/min, or approximately 108 vehicles/hr (Figure 8.1).

The crossing of animals around the end of the crosswalk fence into the ROW was also influenced by increasing traffic volumes. Once an elk approached the highway, the probability of it moving through the gap at the roadway was as high as 0.25 at low traffic volumes, but dropped off as traffic volumes increased (Figure 8.1). Deer showed a similar response and tended to use this gap to enter the ROW more often than elk (Figure 8.1).

Although both crossings and fence gap use by elk and deer showed a negative relationship to increasing traffic volumes, traffic volume was not a significant parameter in the logistic regression model for either species. This may be reflective of the low number of crossings for each species.

All wildlife crossings occurred between 2000 and 0800 with 86% occurring during the hours when traffic volumes were at their lowest (2300–0400 hr). Traffic volumes during this four-hr period (2300−0400 hrs) averaged 32 vehicles/hr, whereas the average hourly traffic volume for the entire 24-hr period along this same stretch of highway from 2004–2008 was 308 vehicles (Figure 8.2).



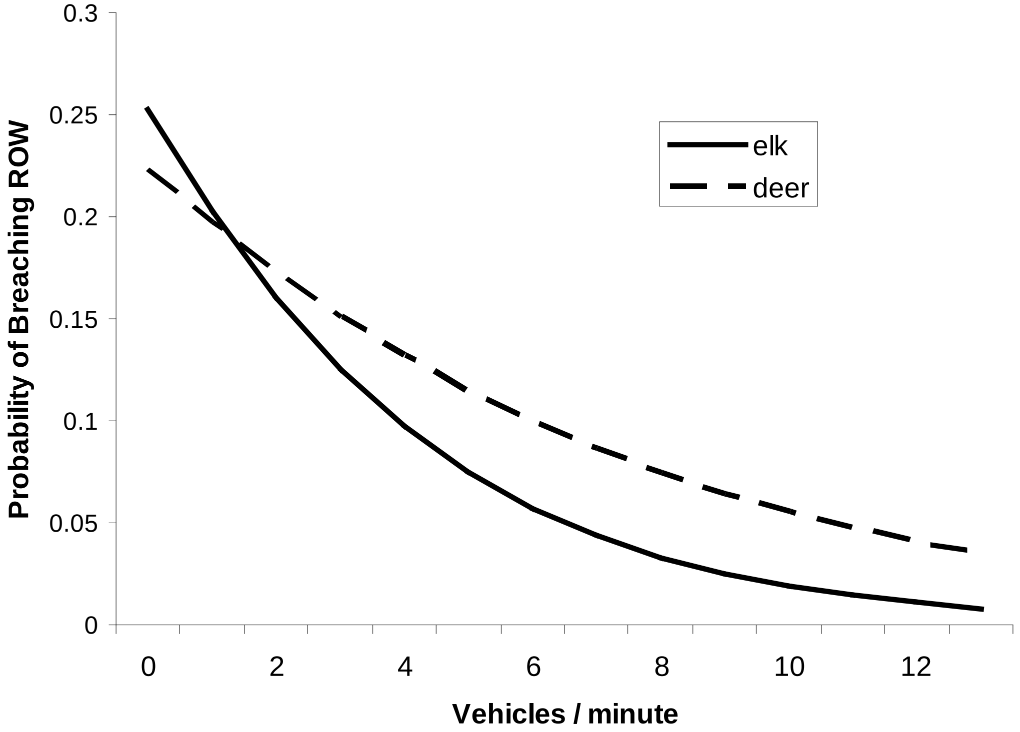


Figure 8.1. Probability of successful at-grade highway crossings (top) and use of the gap in the crosswalk fencing and shoulder of the road (bottom) as traffic volumes increased from 2007 to 2009.

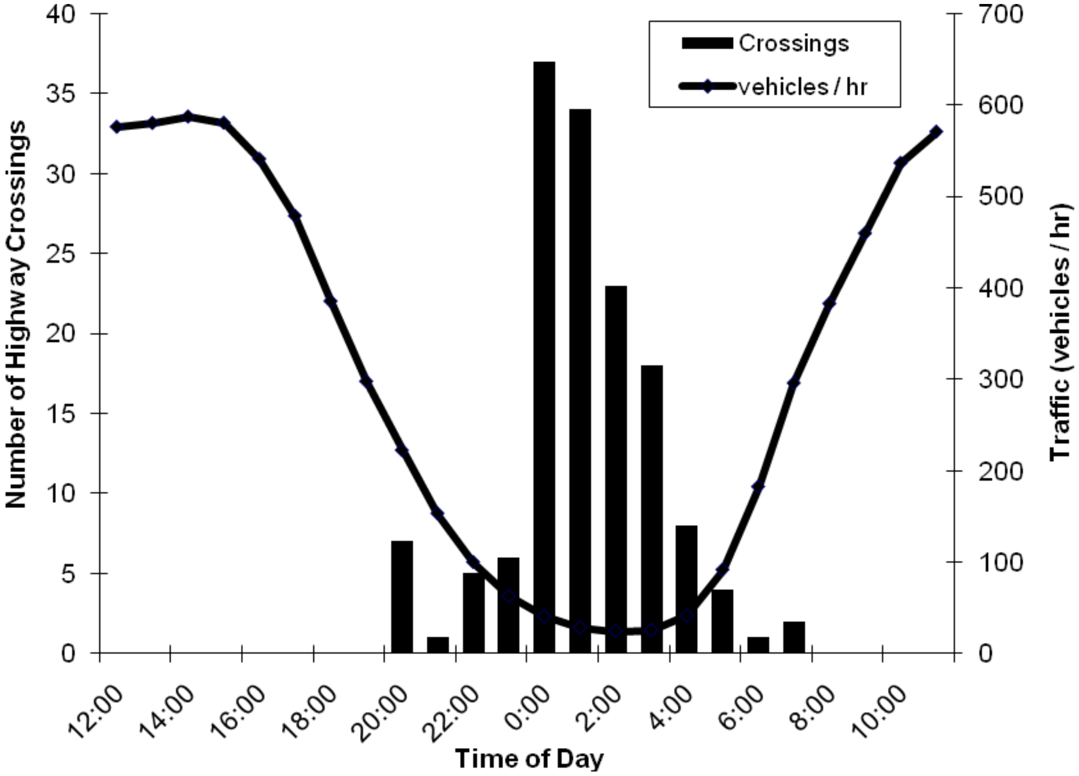


Figure 8.2. Hourly at-grade crossings (black bars) and traffic volume (vehicles/hr; black line) determined from video surveillance, 2007−2009, at the PC section crosswalk.

8.3.2 Use of West Underpass

The research team compared elk and deer use of the west Little Green Valley underpass the full year prior to and following modification of ungulate-proof fencing along the PC section. Elk approached the highway through the west underpass 479 times prior to fencing and crossed 268 times, or a passage rate of 0.86. Following fencing modification, elk approached the underpass 452 times and crossed 277 times (0.82 crossings/approach). There was no significant difference in passage rate before and after fencing modification ($U = 0.16$, df = 1, $P = 0.70$; Table 8.2). The odds of a successful elk crossing also did not differ significantly between treatments (1.24 to 1).

White-tailed deer passage rate and use of the west underpass, however, showed a dramatic increase following lengthening of the extent of ungulate-proof fencing. In the year prior to fencing, we only documented use of the west underpass by 1 deer out of 35 approaches, a passage rate of 0.04. This low passage rate was consistent with long-term monitoring since 2002 (Dodd et al. 2009). Monitoring following fencing modification recorded 118 approaches and 32 crossings for a passage rate of 0.30, or an increase of 750% (Table 8.2). Overall, 61 deer crossings were documented in the year following completion of fencing versus six crossings since video surveillance began in 2002 until the modification of the fencing (Figure 8.3). The odds of a successful deer crossing following completion of fencing were 38:1 versus prior to fencing.

Table 8.2. Differences in mean crossing and passage rate at the west Little Green Valley underpass for elk and white-tailed deer one year before (2006) and one year following (2007) the modification of fencing along the PC section.

	Mean Value by Behavior Class			
Species	Before-Fencing	After-Fencing	Difference (%)	Mann-Whitney *U*-test Comparison of Means
Elk				
No. Crossings/Day	0.69	0.71	+0.02 (+2.9)	*U* = 1.0, *P* = 0.32
Passage Rate (Crossings/Approach)	0.86	0.84	-0.02 (-2.3)	*U* = 0.16, *P* = 0.70
White-tailed deer		.		
No. Crossings/Day	<0.01	0.18	+0.18 (+6,000.0)	*U* = 10.5, *p* = 0.001*
Passage Rate (Crossings/Approach)	0.04	0.30	+0.26 (+750.0)	*U* = 6.14, *P* = 0.01*

*Statistically significant

8.3.3 Use of the Slope above the West Underpass Retaining Wall

Of the 277 elk crossings recorded on videotape since ungulate-proof fencing was erected, elk used the area above the concrete retaining wall ledge to cross through the west underpass on only two occasions. This may be reflective of the amount of time the crossing was in place (5 years) prior to this modification.

8.4 DISCUSSION

Consistent with the enhancement project objective of using the crosswalk integrated with RADS to alleviate a potential end-run effect, the research team placed the system at an area where crossings and collisions were not as prevalent as other areas along the PC section. It was not placed at a primary crossing area for elk and white-tailed deer; therefore, use of the crosswalk was relatively low (152 and 11 crossings, respectively). The RADS successfully detected crossing elk and deer, activated the warning signs, reduced driver speed, and increased alertness. Although the number of successful crossings was low, we documented 471 elk in the detection zone, and many of those fed on the shoulder of the roadway in the crosswalk or along the ROW after breaching the end of the fence. We documented several occasions where animals were on the roadway or the shoulder itself as vehicles slowed their approach thus avoiding potential collisions with animals.

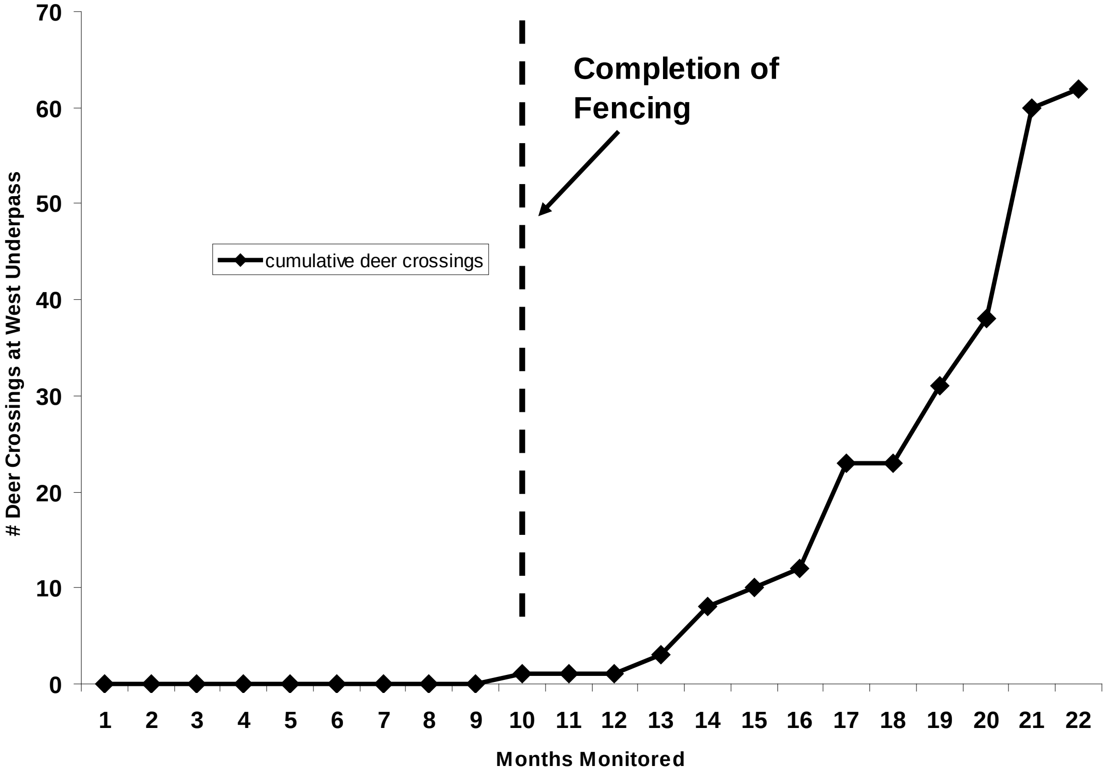


Figure 8.3. The number of white-tailed deer crossing the highway below-grade through the west Little Green Valley underpass before and after the modification of fencing in early 2007.

A high proportion (19%) of animals breached the end of the ungulate-proof fencing at the crosswalk and entered the ROW. This gap remains a significant limitation of the SR 260 system. Lehnert and Bissonette (1997) incorporated cobbled-rock areas up to the roadway edge combined with painted lines simulating a cattle guard to address a similar problem in Utah, but documented continued use of the gap by mule deer. This propensity to use the gap to access the ROW could lead to WVC outside the RADS area associated with warning signs not being activated. Options to “seal” off the end of the fence preventing wildlife movement into the fenced ROW should be explored, including ElectroBraid Fence, Inc.’s ElectroMat™ installed across the highway that is being tested in New Mexico and Alaska and shows promise to prevent animal movement around the end of the fence in these situations (pers. comm. ElectroBraid Fence, Inc.)

Passage rates at the crosswalk for elk (0.29) and deer (0.09) were lower expectedly lower than those for wildlife underpasses monitored by Dodd et al. (2007*d*, 2009) where elk and deer passage rates averaged 0.61 and 0.39 respectively. Dodd et al. (2009) documented white-tailed deer resistance to crossing SR 260 at-grade, even on a two-lane highway. Following installation of below-grade passage structures and associated fencing, deer highway crossings increased dramatically even on the newly upgraded and expanded four-lane highway, increasing permeability and hence genetic interchange and resource access. With the lack of crossings by white-tailed deer at the crosswalk, this suggests a potential for minimal success of at-grade crossings for some species, particularly in high traffic volume situations. However, even minimal success of at-grade crossings for species with high traffic avoidance can contribute to continued population persistence. Mills and Allendorf (1996) indicate that a handful of individuals per generation can provide sufficient genetic interchange to maintain population viability.

Traffic volume appeared to have the same impact on wildlife crossings at the crosswalk as reported for at-grade crossings elsewhere along SR 260 (Gagnon et al. 2007*a*) exhibiting a reduced probability of a successful crossing as traffic volumes increased. Elk passage rates under varying traffic volume at the crosswalk were similar to those reported by Gagnon et al. (2007*a*) for at-grade. Increased traffic volumes also appeared to reduce the probability of an elk or deer breaching the fenced crosswalk via the gap.

The reduction in traffic volumes during late night and early morning hours was essential to the success of the crosswalk as an at-grade crossing opportunity for wildlife. If traffic volumes remained relatively high throughout the night it is likely that elk and deer would not have risked crossing the road at the crosswalk location. Primarily diurnal species may be exposed to higher traffic volumes than nocturnal species along the same stretch of roadway, reducing their potential for a successful crossing, whereas nocturnal species that can wait to cross at lower traffic volumes at night (Gagnon et al. 2007*c*). Other wildlife species, such as pronghorn in Arizona, may also be more susceptible to high traffic levels and therefore avoid the roadway altogether. In these cases, even with designated at-grade crossings, high traffic volumes may impede these species from crossing, potentially risking habitat fragmentation and ultimately population persistence (Jaeger et al. 2005).

Based on the traffic volume levels along SR 260 during our evaluation (e.g., 8,700 AADT) and the hindrance it appeared to have on crossing elk and especially deer, this traffic volume is probably near the upper limit of acceptable traffic volume under which a similar RADS and crosswalk application are appropriate.

9.0 ASSESSMENT OF THE EFFECT OF FENCING MODIFICATION ON ELK PERMEABILITY ACROSS THE HIGHWAY CORRIDOR

9.1 INTRODUCTION

Although reducing WVC along the SR 260 PC section was the primary objective of the enhancement project, the researchers felt it necessary to simultaneously evaluate the effect of fencing on the ability of elk to successfully cross the highway (permeability) and at what level, if any, permeability changed following fencing installation. Very few studies have documented the effect of reconstruction on wildlife permeability along the same stretch of roadway, controlling for location and under a before-during-after reconstruction context (Dodd et al. 2007*b,d*; Olsson 2007). During their first phase of SR 260 GPS telemetry (2002−2004), Dodd et al. (2007*d*) found that the mean elk passage rate across the reconstructed PC section was half (0.43 crossings/approach) that of experimental control sections (0.88) and those where reconstruction was ongoing (0.84). This reduced level of permeability was tied to the barrier created by the widened highway and associated traffic.

In the second phase of GPS telemetry tracking (2005−2006), Dodd et al. (2007*c*) found that on the Christopher Creek section of SR 260, the elk passage rate dropped from 0.79 crossings/approach during reconstruction to 0.54 after reconstruction; this was before ungulate-proof fencing was erected. Once fencing was in place, the mean passage rate rebounded over 50% to 0.82. Fencing promoted permeability because it likely funneled elk toward wildlife underpasses where Gagnon et al. (2007*b*) found that traffic volume had minimal effect on permeability compared to at-grade crossing success (Gagnon et al. 2007*a*). The CC section had a high density of wildlife passage structures (1 structure/0.7 mi) compared to the PC section (1 structure/1.5 mi). Thus, this evaluation provided an opportunity to assess the impact that fence modifications on the PC section had on permeability compared to that of the CC section. Olsson (2007) conducted a similar before-during-after construction study of moose in southwestern Sweden and documented a reduction in crossing rate, his measure of permeability.

Though the degree to which spacing of structures influences permeability is uncertain, we hypothesize that the increase in elk permeability coincident with fencing underpasses documented in Dodd et al. (2007*d*) is partly attributable to the spacing of passage structures along the CC section. Bissonette and Adair (2008) applied isometric scaling principles to estimate spacing distance between passage structures to promote wildlife permeability. They hypothesized that highest permeability would be attained where passage structure spacing is based on a species' linear home range distance; in the case of elk, the optimum spacing distance was estimated at 2.2 mi between structures, compared to the lower 0.7 mi spacing on the CC section and intermediate 1.5 mi spacing on the PC section of SR 260. Our objective was to determine if the lower density of crossing structures along the PC section was adequate to maintain permeability in a manner similar to that of the CC section (Dodd et al. 2007*d*).

9.2 METHODS

To evaluate the impact of fence modification on elk permeability, the researcher team conducted GPS telemetry tracking similar to earlier phases of the ongoing SR 260 research (Dodd et al.

2007*c*). The team captured elk in net-covered Clover traps (Clover 1954) baited with salt and alfalfa hay at five sites spaced evenly along the 3-mi length of the PC section; all traps were located within 1,000 ft of the highway. The elk were physically restrained, blindfolded, ear tagged, and fitted with GPS receiver collars (Figure 9.1). The timing for the trapping targeted resident elk to maximize yearlong acquisition of GPS fixes near the highway.

Figure 9.1. Cow elk captured in Clover trap (left) and fitted with a GPS tracking collar and ear tag (right) to gather movement data to evaluate the modification of fence along the PC section.

We compared elk permeability and elk movements, crossing patterns, and passage rates across the PC section immediately before and after the retrofit types of ROW fence were installed (Dodd et al. 2007*c*, 2009). Passage rates were considered the best measure of highway permeability, and could be directly related to permeability measures obtained along the same stretch of highway three years earlier. An approach occurred when an elk moved (determined by successive GPS fixes) within 0.15 mi of SR 260; successive fixes within 0.15 mi of SR 260 were treated as a single approach. This approach zone corresponded to the road-effect distance in which 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). We calculated passage rates for each elk as the proportion of highway crossings to approaches during the same period before and after ungulate-proof fencing was erected.

To determine highway-crossing distributions, all consecutive GPS fixes were connected, and crossings were inferred where lines between fixes crossed the highway. We used Animal Movement ArcView Extension Version 1.1 software (Hooge and Eichenlaub 1997) to assist in elk crossing determination.

We compared crossings, approaches, and passage rates before and after fencing using Mann-Whitney *U* tests (Sokal and Rohlf 1995). We removed those animals from our analysis that did not approach the highway at least 20 times and calculated crossing rates for individual elk by dividing the crossings by the days a GPS collar was worn(Dodd et al. 2007*d*). In the instance that elk wore collars both before and after fencing was erected, we evaluated crossing rates separately and tested the null hypothesis that no differences occurred between crossing and passage rates before and after fencing. We compared the frequency and distribution of crossings that occurred along the PC section and their relationship to crossing structures and the crosswalk.

9.3 RESULTS

Of 28 elk instrumented with GPS satellite tracking collars, 26 crossed the highway along the PC section. Elk wore GPS collars an average of 306 days before fence erection and 300 days after. Elk crossed the highway 3,627 times (mean = 139.5 crossings/elk). Prior to fencing, 21 elk crossed the highway 2,726 times (mean = 129.8 crossings/elk), and after 19 elk crossed SR 260 901 times (mean = 53.0 crossings/elk; Table 9.1).

In the 10 months before fencing, elk (*n* = 21) approached the highway an average of 342.7 (±77.6) times and crossed the highway a mean of 129.8 times (±36.2). The average passage rate for all elk was 0.31 (±0.04) crossings/approach. Following installation of elk-proof fencing, the number of approaches did not differ significantly, with a mean of 283.7 (±59.6; *n* =19) approaches within the 0.15-mi buffer. However, crossings per elk over this similar length of time dropped almost 65% to 47.4 (±11.2). Passage rates on the PC section following implementation of fencing dropped to an average of 0.09 crossing/approach, showing a 70% reduction in passage rate compared to the before-fencing average (Table 9.1).

Interestingly, cow elk #4 was collared from 2002 to 2004 during the first phase of the SR 260 project and crossed the highway 686 times, averaging 1.03 crossings/day. She was recaptured in 2005 prior to fencing of the PC section and crossed the highway an additional 573 times, for a near identical crossing rate of 1.08 crossings/day before fencing was erected. Once fencing was erected however, her crossing rate decreased to 0.56 crossings/day. Her highway passage rate declined from 1.0 crossings/approach during the first research phase to 0.61 in the two years prior to fencing, and to only 0.26 crossings/approach following the erection of fencing (74% reduction from the first phase).

A marked shift in the distribution of GPS-collared elk highway crossings occurred along the PC section before and after fencing (Figure 9.2). Although there were slight peaks in the crossing distribution prior to fencing coinciding with the locations of the Preacher Canyon Bridge and the two Little Green Valley underpasses, elk crossed throughout the entire section, thus contributing to the occurrence of EVC along the entire highway section. These peaks at the structures increased in concentration after implementation of fencing, indicating increased use in areas where existing passage structures were available and pointing to their efficacy in conveying wildlife across the highway. A relatively small peak in elk crossing distribution occurred at the crosswalk after fencing reflecting a minimal end run effect (Figure 9.2).

9.4 DISCUSSION

Although elk permeability was reduced, we met our enhancement project objective of funneling a majority of elk crossings to the existing crossing structures rather than creating an unsafe end-run effect where the fencing ended. This validated using GPS crossing data and WVC patterns in selecting the crosswalk site in a place where animals were not regularly crossing the highway prior to fencing modification.

Table 9.1. Comparison of elk highway crossings, approaches, and passage rates along the SR 260 PC section before and after modification of fencing, 2005−2008.

Parameter	Mean (±SE)			Mann-Whitney *U*-Test Comparison of Means
	Before-Fencing[a]	After-Fencing[b]	Difference (%)	
No. highway crossings/elk	129.8 (36.2)	47.4 (11.2)	-82.0	*U* = 2.18, *P* = 0.14
Highway crossings/day/elk	0.35 (0.06)	0.21 (0.07)	-0.13	*U* = 3.65, *P* = 0.04*
Highway approaches/elk	342.7 (77.6)	283.7 (59.6)	+58.9	*U* = 0.18, *P* = 0.14
Highway approaches/day/ elk	0.96 (0.12)	1.07 (0.16)	+0.08	*U* = 0.01 *P* = 0.95
PC passage rate (crossings/ approach)	0.29 (0.03)	0.09 (0.07)	-0.20	*U* = 13.9, *P* <0.001*

[a] n = 21 [b] n = 19 *Statistically significant (α = 0.05)

Following the completion of fencing on the PC section, permeability dropped 70% where crossing structures were spaced approximately 1.5 mi apart versus the CC section where crossing structures were 0.7 mi apart. This finding indicates that distance between passage structures on the PC section was not adequate to maintain before-fencing levels of permeability as it was on the CC section. Olsson (2007) documented a similar reduction in permeability (89% reduction in crossing frequency) for moose in Sweden with three crossing structures over a 3.7 mi stretch of highway, or 1.23 mi spacing on average. This suggests that maintaining permeability at levels comparable to those prior to construction would require passage structures to be much closer, however, Olsson (2007) indicated that enough moose crossed this stretch of highway to maintain gene flow between otherwise isolated sub-populations

Based on the documentation of decrease in passage rate, we recommend that crossing structures for elk be located <1 mi apart when possible (as did Dodd et al. 2009), although this standard is likely unattainable in many cases due to high costs of wildlife passage structures. Since passage structures are expensive, spacing them at distances similar to those recommended by Bissonette and Adair (2008), based on linear home range distance may be adequate to maintain gene flow (Mills and Allendorf 1996) for highly mobile species such as elk. Research similar to that conducted on SR 260 for elk (Dodd et al. 2007*d*) and in Sweden for moose and roe deer (Olsson 2007) should be conducted to determine actual permeability rates following implementation of passage structures. An understanding of baseline levels of permeability is essential to determining changes following spacing of passage structures. Bissonette and Adair (2008:486) also suggested that structures placed "in hotspot areas where these animals cross the road frequently and are often hit by vehicles, would certainly improve highway safety and help insure ease of movement, improving landscape permeability for >71% of the species" they evaluated (*n* = 102). These recommendations to strategically place wildlife crossing structures in hotspots will likely lead to higher levels of permeability than an equivalent number of structures evenly spaced over the same distance, as environmental factors (migration routes) or preferred resources (riparian-meadows, water sources) may increase the potential of animals to cross in certain areas (Dodd et al. 2007*a*, Gagnon et al. 2007*a*)

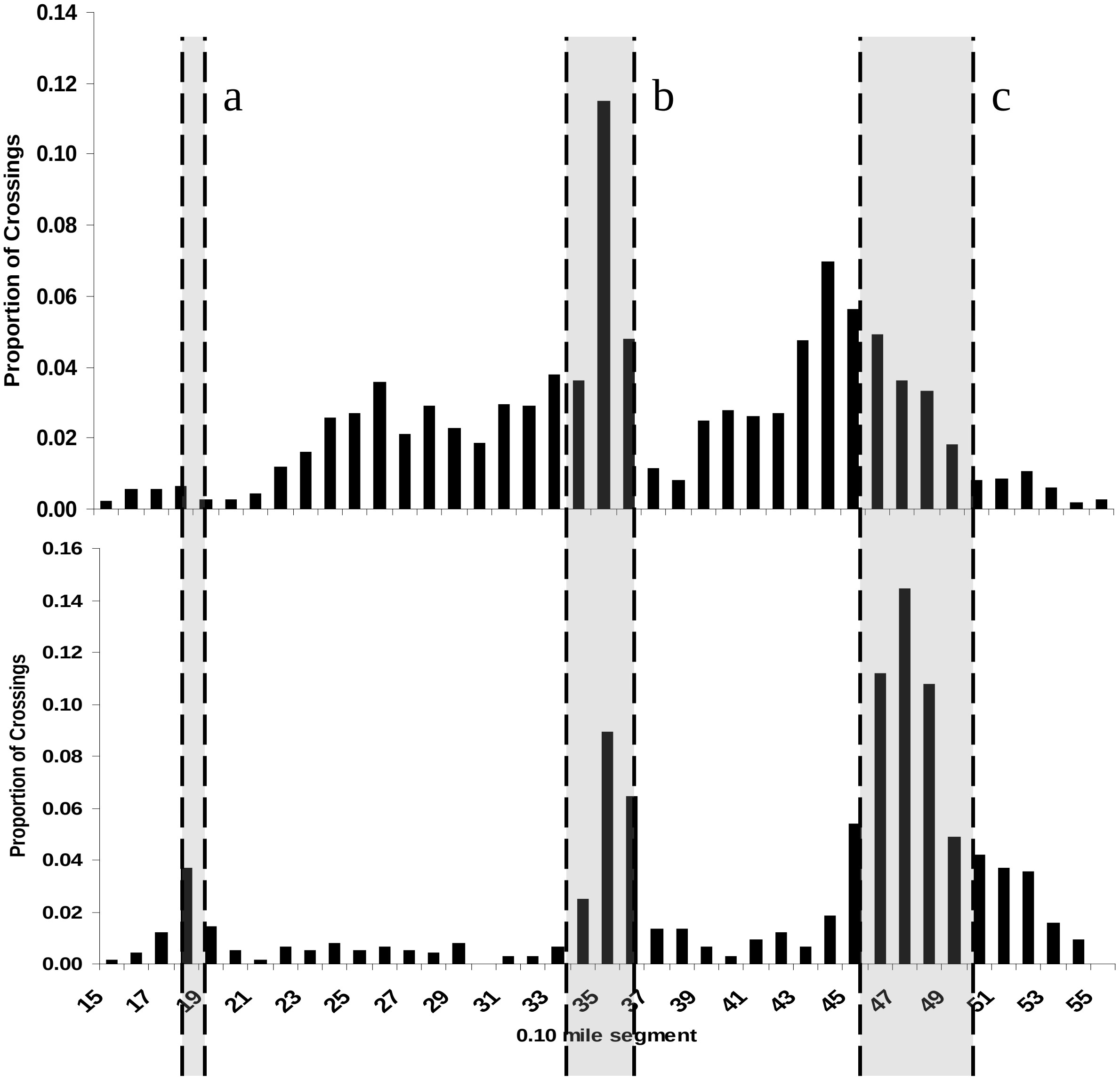


Figure 9.2. Frequency distribution of elk highway crossings by 0.1-mi segment along the SR 260 PC section, before (top) and after (bottom) fence was modified. Light gray shading denotes the locations of the wildlife crosswalk (a), Preacher Canyon Bridge (b), and the West and East Little Green Valley underpasses (c).

A couple of alternative explanations for the dramatic reduction in elk passage rates following the erection of fencing should be noted: 1) the presence of a severe drought during the first phases of the SR 260 projects, increasing the need for elk to cross the highway to obtain resources (e.g., water), and 2) the elimination water retention basins located within the highway median once the PC section corridor was fenced. Another aspect to be considered is the potential learning required for animals to adapt to the newly erected fencing over time, as the evaluation occurred immediately after the fence was modified. Passage rates could increase over time with additional learning on the part of elk and other species.

One major difference of the RADS used in this study, compared to many animal detection systems, was the use of the system in conjunction with wildlife underpasses, allowing animals to cross the highway in other locations below-grade. Had there not been alternative crossing opportunities, the results at the crosswalk likely would have differed, as animals that are required to make daily or seasonal movements to survive would likely have been forced to cross at-grade. Alternatively, the lack of crossing structures for the 3-mi stretch of highway may have provided a barrier that effectively blocked some animals from crossing the highway, contributing to population fragmentation. Fragmentation threatens population persistence, particularly for species that exhibit high roadway or traffic avoidance (Jaeger and Fahrig 2004, Jaeger et al. 2005). Along the SR 260 study location, elk would have likely crossed the highway at the crosswalk or unfenced portion of the highway, risking collision. However, animals that are more sensitive to traffic levels may not be to find a way around fencing and may not have crossed at-grade. Thus, wildlife crossing structures continue to be the most effective means of reducing WVC while maintaining highway permeability.

10.0 PROJECT CONCLUSIONS AND RECOMMENDATIONS

10.1 CONCLUSIONS

Two years after implementation, this enhancement project appears to be meeting its objectives, particularly in reducing the incidence of EVC by >90% along the PC section without an increase in the incidence of EVC at the fencing terminus or on the adjacent LS section. Given the complexities of achieving full integration of the experimental RADS and crosswalk components, these systems performed reliably and effectively in detecting animals and alerting motorists to crossing wildlife. Motorists responded by reducing speed and displaying alertness in response to the warning signs and crosswalk concept.

Long-term monitoring of the fencing and RADS will determine the ability of the system to continue to modify driver behavior over time, or if motorists ultimately become habituated to the system. This is unlikely if the system continues to be reliable and activates primarily when wildlife is on, or near, the roadway. If driver behavior continues to show a reduction in speed and increased alertness over time, then EVC should remain at lower levels than before-fencing modification levels. Evaluation of project components including fencing and RADS system maintenance over a longer period will help determine the long-term value of the project. Applying a cost associated with EVC reported by Huijser et al. (2007*b*:35) in an economic assessment similar to that done by Dodd et al. (2007*a*) for SR 260 suggests that the reduction in EVC on the PC section yielded a >$600,000 in benefit in just its first three years. The benefits will exceed the project costs within within the next year or so, and if the system continues to work in this manner over the long-term one can expect a benefit, above and beyond the cost of the project, of approximately $1 million in reduced EVC over 10 years.

The crosswalk system and RADS was a hybrid of a “typical” system, which generally covers a larger area, combined with a crosswalk zone defined by fencing, has met all of the metrics for success of the enhancement project. However, one problematic aspect is the movement of animals around the crosswalk fence, allowing them to enter the ROW outside the crosswalk detection zone via the gap in the fence, as was similarly documented in Utah by Lehnert and Bissonette (1997). Overall, 20% of the elk captured on the videotape breached the crosswalk by passing around the end of the fence. Opportunities to close this gap are being explored, and an ElectroMat™ (electrified cattle-guard) is planned for installation in spring 2010.

In many cases underpasses or overpasses are not a feasible option due to topographic and cost limitations. In these cases, RADS may provide a cost-effective alternative to wildlife passage structures. Huijser and McGowen (2004) and Huijser et al. (2006*b*) evaluated the reliability of several different RADS under a controlled environment in a field setting. Other studies have also evaluated systems in field settings (Ward et al. 1980, Huijser and McGowen 2003, Gordon et al. 2004). This combined knowledge along with continued testing and evaluation of RADS methods will provide valuable insight into the efficacy, reliability, and applicability of these systems under different scenarios.

In the case of SR 260, the combined crosswalk and RADS proved to be a viable alternative to a wildlife passage structure. However, increased traffic volume reduced the passage rate and probability of an animal successfully crossing the road at-grade. When animals attempt highway crossings at high traffic volumes, three outcomes can occur: 1) a successful crossing, 2) mortality by collisions with vehicles, or 3) avoid crossing altogether or attempt to cross again when traffic volumes reach lower levels (Gagnon 2006; Figure 10.1). The success of many large ungulates in crossing highways at-grade is often predicated on traffic volume. As volumes increase the probability of successfully moving through a "gap" in the traffic is reduced and the potential for mortality is increased (Langevelde and Jaarsma 2004, Waller et al. 2006).

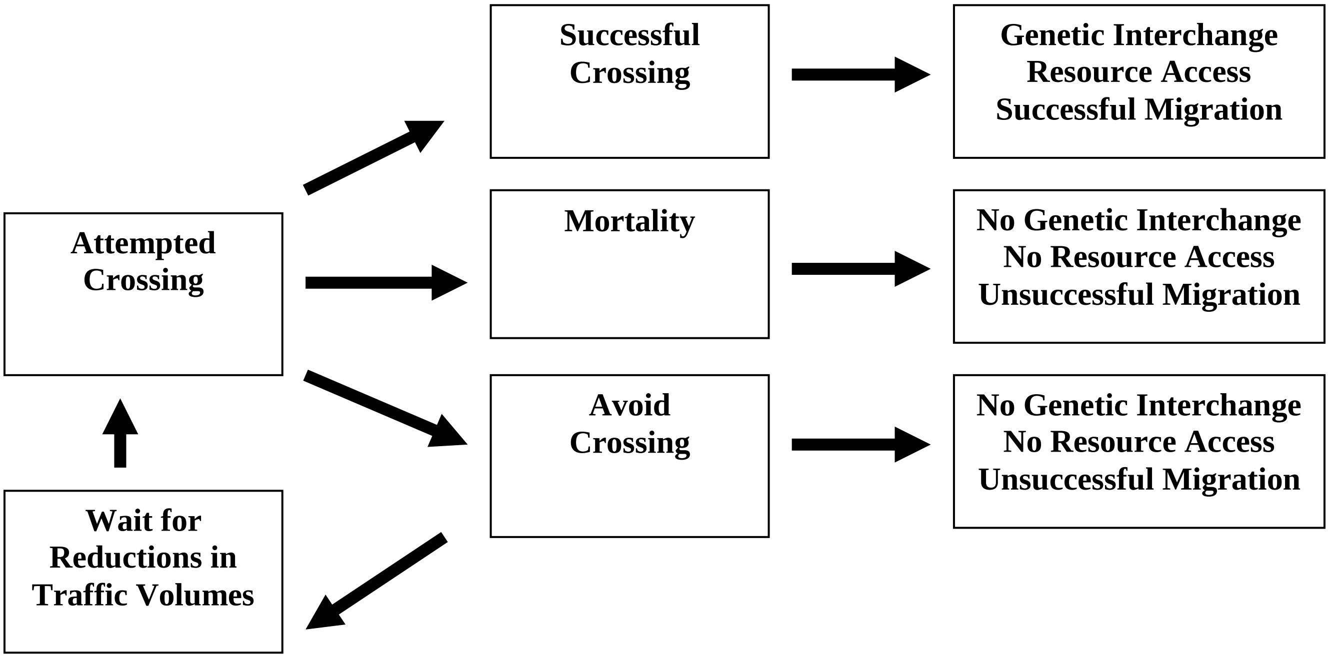


Figure 10.1. Model depicting outcomes for at-grade highway crossing attempts of large ungulates at high traffic volumes.

Because increases in traffic volume reduce the probability of a successful crossing for many wildlife species, the efficacy of at-grade crossings such as crosswalks and RADS in promoting wildlife passage are inherently limited to highways with relatively low to moderate traffic volumes. Along highways where traffic volumes reach levels that significantly reduce the probability of a successful crossing, adequately spaced wildlife underpasses or overpasses are required to simultaneously reduce WVC while maintaining acceptable levels of permeability (Clevenger and Waltho 2000, 2005; Olsson 2007; Dodd et al. 2007*b,d*; Bissonette and Adair 2008; Bissonette and Cramer 2008). Gagnon et al. (2007*a,b*) documented a substantial decrease in at-grade elk crossings on SR 260 as traffic levels increased; however, they found no relationship in traffic levels and the success of below-grade wildlife underpass use (Figure 10.2). This finding, along with many other studies worldwide, points to the success of well designed and placed wildlife crossing structures and associated fencing as an overall answer to reducing WVC and maintaining permeability.

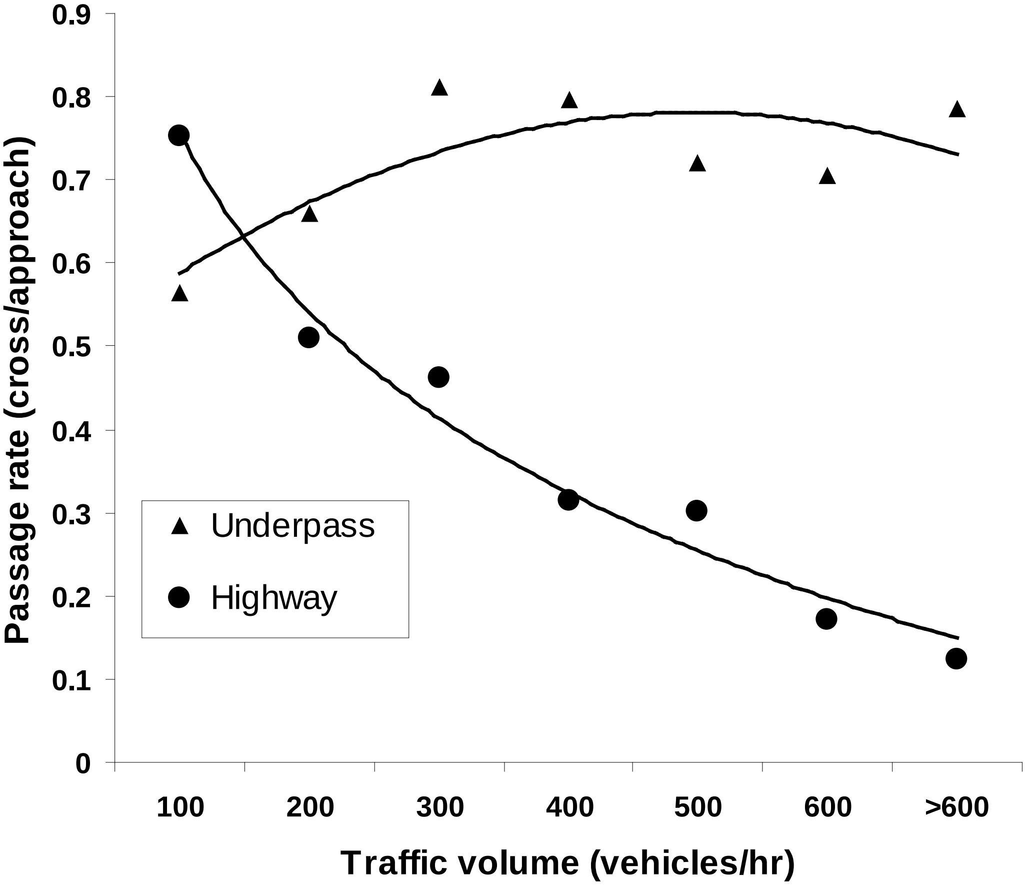


Figure 10.2. Passage rates of at-grade (circles) and below-grade (triangles) crossing attempts at varying traffic volumes during identical periods along SR 260 from 2003 to 2007 (Gagnon et al. 2007*a–c,* Dodd et al. 2009).

10.2 RECOMMENDATIONS

Safety for motorists is the most important measure of effectiveness of this experimental enhancement project. An average reduction in WVC of >97% was attained over the past three years on the PC section, without an increase in WVC along the adjacent LS section to the west of the crosswalk. This indicates that the combination of modified fencing between existing wildlife passage structures and the crosswalk were effective in reducing WVC and promoting highway safety.

> ☞We recommend that the fencing and RADS remain in place until the reconstruction of the LS section, at which time comprehensive alternatives to address reductions in WVC and promote permeability can be explored.

Modifications to the ROW fence along this project appear to be effective in keeping elk off of the roadway while requiring minimal maintenance over the period and environmental conditions experienced during the project. Furthermore, these modifications appear to serve as an effective and relatively inexpensive “retrofit” of new or existing ROW fencing and present cost-effective options for funnel fencing for other roadways. The RADS also proved to be effective in reducing EVC through modification of motorist behavior. Ongoing monitoring of the system components, incidence of EVC, and motorist response over time will provide further insights into the long-term effectiveness of the overall project.

> ☞We recommend that long-term monitoring of the fence and RADS components, incidence of EVC, and motorist response continue in order to evaluate the effectiveness of the system over time (recently approved to continue monitoring until 2015).

The study documented a relatively high proportion of elk and white-tailed deer entering the fenced ROW through the gap in the fence by the roadway. Although WVC data to date does not warrant the sealing of this gap, a proactive approach may reduce the potential for future accidents. ElectroBraid Fence, Inc. has proposed the experimental application and evaluation of an “ElectroMAT™” tied into crosswalk fencing on each side of the highway to prevent animals from entering into the fenced highway corridor. This application as an alternative to a large cattle guard may be a good option to “seal” the fencing project and reduce the risk of motorists encountering large ungulates in areas without warning signs.

> ☞We recommend that an ElectroMAT™ be considered at the west terminus of the fencing along the PC section to eliminate the ability of animals to enter the fenced ROW via the gap at the roadway. This will increase the potential for interaction with vehicles in areas where warning signs are not installed. This application, if pursued, should be evaluated for effectiveness and potential for application elsewhere (planned installation of ElectroMAT™ in spring 2010)

Although the crosswalk performed well and was effective along SR 260, this is likely not an option for higher volume, higher speed highways. Implementation along interstate highways, for example, would potentially exhibit a higher risk in safety from the sudden reduction in speed at the RADS detection zone and crosswalk location.

> ☞We recommend that animal detection systems be used in areas with traffic volumes and speeds similar or lower than those on SR 260 (e.g., < 8,700 AADT, 55 mph posted speeds) and not on roads with substantially higher traffic volumes or higher speed roadways.

Permeability for elk was reduced during this project, however, we believe it was maintained at a level that will still promote adequate genetic interchange across the highway, thus population viability will be maintained. In order to maximize permeability, passage structure spacing should be closer than evaluated on the PC section.

> ☞We recommend that future wildlife passage structures for elk and deer be spaced at a maximum of 1.5 mi apart to maintain permeability at levels to allow sufficient genetic interchange. However to promote permeability, the structures should be spaced < 1 mi apart.

Fencing continues to be a proven method of successfully reducing incidence of WVC and maintaining highway permeability when combined with crossing opportunities. ROW fencing retrofits provide a less expensive option to complete replacement of ROW fencing and can effectively link adequate existing structures together to function as wildlife passage structures and promote permeability.

> ☞We recommend that opportunities to retrofit or replace ROW fencing to link adequately spaced existing bridges and culverts be evaluated statewide, particularly in areas where WVC regularly occur.

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