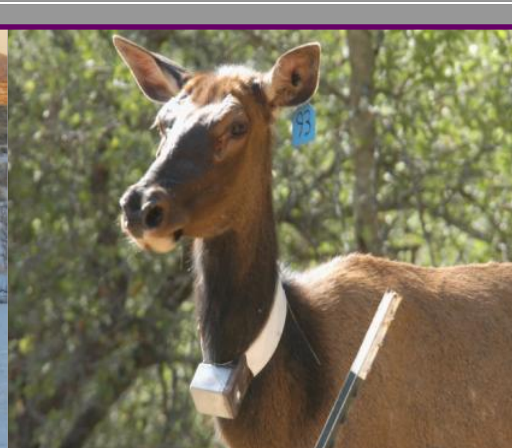
# Wildlife Accident Reduction Study and Monitoring: Arizona State Route 64

Final Report 626
November 2012



Arizona Department of Transportation
Research Center

# Wildlife Accident Reduction Study and Monitoring:

## Arizona State Route 64

Final Report 626
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# Technical Report Documentation Page

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16. Abstract


The research team assessed elk (*Cervus elaphus*), mule deer (*Odocoileus hemionus*), and pronghorn (*Antilocapra americana*) movements and vehicle collision patterns from 2007 through 2009 along a 57 mi stretch of State Route (SR) 64 to develop strategies to improve highway safety and wildlife permeability. This study followed the SR 64 2006 *Final Wildlife Accident Reduction Study* that recommended nine wildlife passage structures and further monitoring to determine the best locations for passage structures and fencing. Research objectives were to:

- Assess wildlife movements, highway crossing patterns, and permeability across SR 64.
- Assess relationships of wildlife crossings and distribution to vehicular traffic volume.
- Investigate wildlife-vehicle collision spatial and temporal incidence and patterns.
- Determine use of Cataract Canyon Bridge by wildlife for below-grade passage.
- Develop recommendations to enhance highway safety and wildlife permeability.

The team tracked 23 elk, 11 deer, and 15 pronghorn with Global Positioning System (GPS) receiver collars, yielding mean passage rates of 0.44, 0.54, and 0.004 crossings/approach, respectively. In total, 167 wildlife-vehicle collisions were analyzed. Traffic volume influenced permeability and wildlife-vehicle collision patterns. The team recommended 11 passage structures, including Cataract Canyon Bridge, which had modest current wildlife use, along with wildlife fencing to reduce collisions and promote permeability for elk, deer, and pronghorn.


| | | | | |
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# SI* (MODERN METRIC) CONVERSION FACTORS

## APPROXIMATE CONVERSIONS TO SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | 25.4 | millimeters | mm |
| ft | feet | 0.305 | meters | m |
| yd | yards | 0.914 | meters | m |
| mi | miles | 1.61 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 645.2 | square millimeters | $mm^2$ |
| $ft^2$ | square feet | 0.093 | square meters | $m^2$ |
| $yd^2$ | square yard | 0.836 | square meters | $m^2$ |
| ac | acres | 0.405 | hectares | ha |
| $mi^2$ | square miles | 2.59 | square kilometers | $km^2$ |
| | | **VOLUME** | | |
| fl oz | fluid ounces | 29.57 | milliliters | mL |
| gal | gallons | 3.785 | liters | L |
| $ft^3$ | cubic feet | 0.028 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.765 | cubic meters | $m^3$ |
| | | NOTE: volumes greater than 1000 L shall be shown in $m^3$ | | |
| | | **MASS** | | |
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2000 lb) | 0.907 | megagrams (or "metric ton") | Mg (or "t") |
| | | **TEMPERATURE (exact degrees)** | | |
| $^oF$ | Fahrenheit | 5 (F-32)/9 or (F-32)/1.8 | Celsius | $^oC$ |
| | | **ILLUMINATION** | | |
| fc | foot-candles | 10.76 | lux | lx |
| fl | foot-Lamberts | 3.426 | candela/$m^2$ | cd/$m^2$ |
| | | **FORCE and PRESSURE or STRESS** | | |
| lbf | poundforce | 4.45 | newtons | N |
| lbf/$in^2$ | poundforce per square inch | 6.89 | kilopascals | kPa |

## APPROXIMATE CONVERSIONS FROM SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.039 | inches | in |
| m | meters | 3.28 | feet | ft |
| m | meters | 1.09 | yards | yd |
| km | kilometers | 0.621 | miles | mi |
| | | **AREA** | | |
| $mm^2$ | square millimeters | 0.0016 | square inches | $in^2$ |
| $m^2$ | square meters | 10.764 | square feet | $ft^2$ |
| $m^2$ | square meters | 1.195 | square yards | $yd^2$ |
| ha | hectares | 2.47 | acres | ac |
| $km^2$ | square kilometers | 0.386 | square miles | $mi^2$ |
| | | **VOLUME** | | |
| mL | milliliters | 0.034 | fluid ounces | fl oz |
| L | liters | 0.264 | gallons | gal |
| $m^3$ | cubic meters | 35.314 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.307 | cubic yards | $yd^3$ |
| | | **MASS** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.202 | pounds | lb |
| Mg (or "t") | megagrams (or "metric ton") | 1.103 | short tons (2000 lb) | T |
| | | **TEMPERATURE (exact degrees)** | | |
| $^oC$ | Celsius | 1.8C+32 | Fahrenheit | $^oF$ |
| | | **ILLUMINATION** | | |
| lx | lux | 0.0929 | foot-candles | fc |
| cd/$m^2$ | candela/$m^2$ | 0.2919 | foot-Lamberts | fl |
| | | **FORCE and PRESSURE or STRESS** | | |
| N | newtons | 0.225 | poundforce | lbf |
| kPa | kilopascals | 0.145 | poundforce per square inch | lbf/$in^2$ |

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AADT | average annual daily traffic |
| ADOT | Arizona Department of Transportation |
| AGFD | Arizona Game and Fish Department |
| ATR | automatic traffic recorder |
| BLM | Bureau of Land Management |
| DPS | Department of Public Service |
| ft | foot or feet |
| GCNP | Grand Canyon National Park |
| GMU | Game Management Unit |
| GPS | Global Positioning System |
| hr | hour(s) |
| I-40 | Interstate 40 |
| MCP | minimum convex polygon |
| mi | mile(s) |
| MP | milepost |
| mph | miles per hour |
| NF | National Forest |
| ROW | right(s)-of-way |
| SDI | Shannon diversity index |
| SE | standard error |
| SR | State Route |
| U.S. | United States |
| US 89 | U.S. Route 89 |
| US 93 | U.S. Route 93 |
| US 180 | U.S. Route 180 |
| VHF | very high frequency |
| WVC | wildlife-vehicle collision |

# LIST OF SPECIES

## Animals

| | |
|---|---|
| Badger | *Taxidea taxus* |
| Black bear | *Ursus americanus* |
| Black-tailed jackrabbit | *Lepus californicus* |
| Caribou | *Rangifer tarandus* |
| Coyote | *Canis latrans* |
| Desert cottontail rabbit | *Sylvilagus audubonii* |
| Elk | *Cervus elaphus* |
| Gray fox | *Urocyon cinereoargenteus* |
| Grizzly bear | *Ursus arctos horribilis* |
| Moose | *Alces alces* |
| Mountain lion | *Puma concolor* |
| Mule deer | *Odocoileus hemionus* |
| Pronghorn | *Antilocapra americana* |
| Raccoon | *Procyon lotor* |
| Squirrel | *Spermophilus variegatus* |
| Striped skunk | *Mephitis mephitis* |
| White-tailed deer | *Odocoileus virginianus couesi* |
| Wolf | *Canis lupus* |

## Plants

| | |
|---|---|
| Apache plume | *Fallugia paradoxa* |
| Big sagebrush | *Artemisia* spp. |
| Black grama | *Bouteloua eriopoda* |
| Blue grama | *Bouteloua gracilis* |
| Cliffrose | *Cowania mexicana* |
| Galleta | *Pleuraphis jamesii* |
| Gambel oak | *Quercus gambelii* |
| Needle-and-thread grass | *Hesperostipa comata* |
| One-seed juniper | *Juniperus monosperma* |
| Pinyon | *Pinus edulis* |
| Ponderosa pine | *Pinus ponderosa* |
| Rabbitbrush | *Ericameria nauseosa* |
| Winterfat | *Ceratoides lanata* |

# ACKNOWLEDGMENTS

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Many individuals at ADOT provided support and guidance in this project. The research team commends Roadway Predesign Section for its commitment to developing preliminary strategies for resolution of wildlife-highway conflicts. Estomih Kombe of the ADOT Research Center provided project oversight and coordination. The team thanks John Harper and Chuck Howe of the Flagstaff District for their tremendous support and innovative management. Doug Eberline and Jennifer Toth of the Multimodal Planning Division provided traffic data support. The team also thanks Todd Williams and Justin White, of the Office of Environmental Services as well as Bruce Eilerts and Siobhan Nordhaugen, formerly with the same office, for their commitment to the project and overall efforts to address wildlife permeability.

AGFD Flagstaff Region personnel played a crucial role in supporting the project, including Ron Sieg, Tom McCall, Carl Lutch, and David Rigo. The outstanding capture support provided by Larry Phoenix was vital to the success of pronghorn capture and the project. The research team also is indebted to the capable pilots of Papillion Helicopters. Kari Ogren, Rob Nelson, and Chad Loberger of the AGFD Research Branch provided invaluable field support, data collection, and analysis.

Highway patrol officers with the Arizona Department of Public Safety (DPS) Flagstaff District made an outstanding effort to record all wildlife-vehicle collisions along State Route (SR) 64. They collected and recorded information that was important to the research project beyond what was required on accident reports. The research team is particularly grateful to Matt Bratz for his coordination of accurate accident data collection by DPS and his valuable input into the 2006 *Wildlife Accident Reduction Study*.

The Kaibab National Forest (NF) provided invaluable logistical support during the project. In particular, Jeffrey Waters provided project guidance and coordination, as well as assistance with pronghorn capture.

The Arizona Antelope Foundation, the Rocky Mountain Elk Foundation, the Arizona Elk Society, the Arizona Deer Association, and the Mule Deer Foundation were crucial in helping to meet matching funding requirements for the project. Their interest and commitment to efforts to promote wildlife permeability are sincerely appreciated.

The Technical Advisory Committee (TAC) provided many suggestions toward improving the project's effectiveness and applicability. Its tremendous support, oversight, and commitment throughout the project are appreciated.

# EXECUTIVE SUMMARY

The ADOT Research Center funded this study through a funding allocation from the Federal Highway Administration (FHWA) State Planning and Research Program (SPR). The Arizona Game and Fish Department was assigned the lead role in the execution of the study and making recommendations based on the results. This partnership was made possible with a joint project agreement (JPA) between the two state departments. The study would concentrate on a 57 mile stretch of SR 64 beginning at the southern end, which is the junction with Interstate 40. The focus would be a thorough evaluation of the movement of elk, mule deer, and pronghorn in relation to highway and habitat characteristics, traffic volumes, wildlife related accidents, and existing highway assets like bridges.

The incidence of wildlife vehicle collisions along State Route 64 (SR 64) in Arizona has been on the rise and thus a growing safety issue. Data collected over a ten year period ending in 2008 showed 42 percent of single vehicle accidents in the study area involved wildlife. The national average for wildlife related accidents is only five percent. In addition, on a five mile stretch of highway at the north end of the study area wildlife related accidents accounted for 75 percent of all single vehicle accidents.

Apart from the safety issue, good wildlife management means that we need to pay attention to whether highway infrastructure may be creating a barrier to essential wildlife movement within its habitat. In the long term, for wildlife to flourish, it is important that man made barriers do not create scattered 'islands' of smaller and smaller animal populations. Such an unintended segregation of wildlife populations has the potential to result in diminished genetic strength and other weaknesses related to small numbers that ultimately leads to a slow death for the affected species. It is therefore important that efforts to address one issue (like wildlife vehicle collisions) are not done in a manner that worsens the situation with respect to another important consideration. Solutions need to be developed that strike a good balance between these needs.

**What the Data Shows**

For purposed of data collection and analysis, the designated length of highway for the study was divided into small sections one tenth of a mile long. This would enable researchers to clearly identify and chart out where within the proximity of the highway animals were located or seen to make successful crossings. Monitoring of animal movements was made possible by the use of Global Positioning System (GPS) collars on animals. Successful crossings by an animal were identified when two consecutive location coordinates for a collared animal matched locations on opposite sides of the highway.

In addition to the use of GPS collars to monitor animal movement and highway crossings, wildlife-vehicle collision data and traffic volume data were collected during the study as well as from other sources. Relevant evaluations by other researchers in prior years were also reviewed to see whether they were in agreement with or contradicted any of our results. The evaluation attempted to establish relationships between wildlife crossing levels and corresponding wildlife vehicle accidents and traffic levels for different highway segments.

Analysis of the data established a positive relationship between wildlife crossing figures and vehicle collisions for both elk and mule deer. No pronghorn crossings or accidents/collisions were documented. It is thought that the highway may constitute enough of a barrier that pronghorn will not venture to approach it. In comparison to highway approach and crossing data seen for elk and deer in other locations like State Route 260, the approach and crossing levels documented for SR 64 are considerably lower. This is thought to be explained in part by the absence of attractive wet meadow/riparian foraging habitat areas. Overall, high traffic volumes were associated with lower wildlife (in this case elk and mule deer) approaches to and crossings of highways. Where these high traffic volumes lasted only short durations, and thus could be considered temporary, animals could be expected to return to habitat close to the highway when the period of high traffic volume ended.

**Summary of Conclusions and Recommendations**

- For some wildlife (like elk and mule deer), wildlife vehicle accident data can be used reliably in the identification of locations where wildlife crossing assets can make a big impact. When possible, GPS tracking is useful for supplemental data.
- For animals like pronghorn which have a strong tendency to keep their distance from busy highways, GPS tracking studies are crucial for collecting the data necessary to identify potential solutions.
- Measures to reduce noise and negative visual impacts near wildlife crossing infrastructure have potential to enhance the effectiveness of these assets.
- Passage structure designs should consider some important characteristics, some specific to the main animal species of concern, noted in the report to maximize the use of these assets.
- Based on the full set of data collected and analyzed as part of this study, the research team identified a total of eleven potential wildlife passage locations. As opportunities arise, consideration should be made towards the implementation of some underpasses/overpasses or the retrofitting of bridges as the case may be. The specific details are provided for each of the potential locations.
- For existing or future wildlife passage structures, having a length of appropriate fencing to ‘channel’ animals to the point of crossing is an important part of achieving maximum benefits from what is typically a sizeable infrastructure investment.

# 1.0 INTRODUCTION

The research team assessed wildlife-highway relationships from 2007 through 2009 along a 57 mile stretch of State Route (SR) 64, the highway linking Interstate 40 (I-40) and Grand Canyon National Park (GCNP) in north-central Arizona. The incidence of wildlife-vehicle collisions (WVCs) involving elk and mule deer along this stretch of highway is a significant and growing concern, as is the ability of wildlife to cross the highway corridor, or permeability. This predominately two-lane highway will be reconstructed in the future to a four-lane divided highway to address growing traffic volume and the incidence of WVCs. The average annual traffic volume on SR 64 was 4275 vehicles per day during the study period, but traffic levels at night were low, averaging less than 10 vehicles per hour for a 4 hour period.

In a *Final Wildlife Accident Reduction Study (1991–2003)*, the Arizona Department of Transportation (ADOT) commissioned the development of a proactive assessment of WVCs and potential mitigation measures to reduce the incidence of WVCs along approximately 50 miles of SR 64 (185.5–235.4). This assessment (ADOT 2006) recommended that nine passage structures be integrated into future highway reconstruction of SR 64. It also recognized the need to conduct further field evaluation and monitoring to determine the best locations for wildlife passage structures and the extent of fencing needed to funnel animals to the structures.

The study called for assessing wildlife use of Cataract Canyon Bridge to determine whether its design is conducive to wildlife passage. The assessment addressed the potential barrier effect on pronghorn and recommended that this issue also be addressed with monitoring. As a result of these recommendations, this research project was initiated in 2007, with the following objectives:

- Assess elk (June 2007 through October 2009), mule deer (April 2008 through October 2009), and pronghorn (January 2008 through January 2009) movements, highway crossing patterns, and distribution relative to SR 64 and determine permeability across the highway corridor.
- Investigate the relationships of elk, mule deer, and pronghorn highway crossing and distribution patterns to SR 64 vehicular traffic volume (2007 through 2009).
- Investigate WVC patterns and relationships to elk, mule deer, and pronghorn movement and highway crossing patterns in relation to SR 64 (2007 through 2009).
- Assess the degree to which Cataract Canyon Bridge is used by wildlife for below-grade passage (July 2008 through December 2009).
- Develop recommendations to enhance elk, mule deer, and pronghorn highway permeability along SR 64 through the application of wildlife passage structures and ungulate-proof fencing.

## MOVEMENTS AND PERMEABILITY

The research team determined highway crossings and calculated the crossing and passage rates for elk, mule deer, and pronghorn using Global Positioning System (GPS) telemetry. Passage rates served as the team's relative measure of highway permeability, calculated as the number of times animals crossed SR 64 in proportion to the number of times animals approached to within 0.15 mi. The research team tracked 23 elk fitted with GPS collars and accrued 107,055 GPS relocations. Elk crossed the highway 843 times, an average of 0.12 times per day, with the highest proportion of crossings (60 percent) occurring during the driest season (April–July).

Travel to limited water sources likely influenced movement and crossing patterns. The elk passage rate averaged 0.44 crossings per approach, 52 percent lower than the rate found during previous research on SR 260 sections with similar highway standards (Dodd et al. "Evaluation of Measures," 2007). The elk crossing distribution was not random and exhibited several peak crossing zones, especially at the north end of the study area.

The research team tracked 11 mule deer fitted with collars and accrued 29,944 GPS fixes. Deer crossed SR 64 550 times, an average of 0.26 times per day—twice as frequently as elk. Seasonal deer crossings were more consistent than seasonal elk crossings, though 46 percent of crossings occurred during late summer and fall (August–November). The average deer passage rate was 0.54 crossings per approach, which was higher than the rate for elk. The mule deer crossing distribution did not occur in a random fashion. It exhibited two peak crossing zones at the north end of the study area, with 92 percent of the crossings occurring along a 3.2 mile stretch between Grand Canyon Airport and the GCNP, in the vicinity of Tusayan.

The research team tracked 15 pronghorn with GPS collars that amassed 56,433 GPS fixes. Only a single GPS-collared pronghorn crossed SR 64 (three times), for a crossing rate average of 0.001 crossings per day. The mean pronghorn passage rate was a negligible 0.004 crossings per approach, indicating that SR 64 is a near total barrier to pronghorn passage. Pronghorn approached the highway 4269 times, and the distribution was not random. The approach distribution exhibited three peaks along SR 64, with the largest peak near the south boundary of the Kaibab National Forest, north of Valle.

## TRAFFIC RELATIONSHIPS

In cooperation with ADOT, the research team measured traffic volume using a permanent automatic traffic recorder. The pattern of elk and mule deer distribution with fluctuating traffic was consistent with published models that indicated reduced "habitat effectiveness" near the highway.

The use of habitat within 990 ft of the highway, as measured by probability of presence of all three species, was clearly reduced at higher traffic volumes. The mean proportion for the three species occurring within 990 ft of SR 64 dropped nearly in half, from 0.34 at less than 100 vehicles per hr to 0.19 at 200 to 300 vehicles per hour. However, elk and deer returned to areas within 330 ft of the highway in proportions greater than 0.12 when traffic volumes were low. The impact to habitat effectiveness for these two species thus was temporary.

The highest levels of permeability for elk and deer (passage rates greater than 0.70 crossings per approach) occurred at night when traffic was lowest. Pronghorn, on the other hand, are diurnal and are active when traffic is heaviest. Along SR 64, pronghorn uniformly avoided habitats adjacent to the highway (within 330 ft), thus reflecting a permanent loss in habitat effectiveness.

Peak daytime traffic volumes along SR 64 approach 10,000 vehicles per day, a volume at which highways become strong barriers to wildlife passage. Pronghorn appeared more sensitive to traffic volume impact than elk and deer, and their avoidance of the area adjacent to the highway is problematic in terms of implementing effective passage structures to promote permeability.

## WILDLIFE-VEHICLE COLLISION RELATIONSHIPS

The incidence of WVCs along SR 64 is a growing highway safety issue, with an increase in collisions from that documented in the 2006 *Final Wildlife Accident Reduction Study* report (36.7 per year) to 52.0 per year during this study (ADOT 2006). The research team recorded 167 WVCs, with elk accounting for 59 percent of the accidents and mule deer accounting for 35 percent. SR 64 sections on Kaibab National Forest lands at the north and south ends of the study area had the highest incidence of elk and deer collisions, though the collision rate on the north end was more than twice the rate on the south end near I-40. No WVCs involving pronghorn were recorded during the study.

The spatial association between WVCs and GPS-determined crossings at the 1.0 mi scale was significant for elk and mule deer. From 1998 through 2008, 42 percent of all single-vehicle accidents in the study area involved wildlife, compared with the national average of just 5 percent. On the five miles at the north end of the study area, wildlife-related accidents accounted for more than 75 percent of all single-vehicle accidents.

The observed frequency of elk-vehicle collisions by time of day was different from our expectations, with the highest proportion of elk collisions (50 percent) recorded during evening hours. There was a negative association between elk-vehicle collisions and traffic volume by hour. Deer-vehicle collisions also varied by time of day, with 49 percent of accidents recorded during the evening. Accidents during the morning and midday, when traffic volume was highest, accounted for 43 percent of deer-vehicle collisions.

There was a significant difference in the observed versus expected frequency of elk-vehicle collisions by season. The driest season of the year, early spring–summer (April–July), accounted for 43 percent of all elk-vehicle collisions; late summer–fall accounted for another 38 percent. The association between elk collisions and mean monthly traffic volume was significant, which was not the case for deer. For mule deer, the incidence of collisions was relatively constant through much of the year, except for the late summer–fall season (August–November), when nearly half of all collisions occurred. The association between highway crossings and collisions by month was significant for elk and mule deer.

Using nationally accepted cost estimates associated with elk and mule deer collisions, and based on 2007–2009 WVCs, the annual cost associated with SR 64 vehicle collisions is estimated to be $612,513 for elk and $162,168 for deer, or a total of $774,681 per year; over 20 years, the total cost from WVCs would exceed $15.5 million (Huijser et al. 2007).

## CATARACT CANYON BRIDGE WILDLIFE USE

To quantify wildlife use of Cataract Canyon Bridge, the research team employed single-frame cameras in each of the four box-culvert cells; these self-triggering cameras provided infrared nighttime illumination to record animals crossing through the bridge at night. In total, 126 wildlife images were recorded by cameras, including 13 elk and 37 mule deer. In addition to wildlife, substantial human presence was documented at the bridge, with a total of 191 humans and 29 all-terrain vehicles passing under the structure.

Of the limited number of elk and mule deer that approached the bridge, 92 percent and 89 percent of these species, respectively, crossed through the bridge cells. The majority (89 percent) of deer use occurred from August through October. Elk use occurred only in October and December, with no approaches the rest of the year. Of all deer and elk bridge crossings, 64 percent occurred in the 4 hr period between 11:00 p.m. and 3:00 a.m..

Though the documented wildlife use of the bridge was nominal, the research team's expectation for significant use was also low because wildlife fencing to limit at-grade crossings and funnel animals to the bridge could not be accomplished as hoped. Despite the limited wildlife use recorded on the cameras, the research team nonetheless believes that the bridge has the potential to be a highly effective retrofitted wildlife passage structure due to the comparatively high rates of mule deer and elk that crossed through with minimal behavioral resistance.

The bridge exceeds all recommended structural and placement guidelines for effective elk and mule deer passage structures. The high level of human use should not significantly limit effective wildlife use of the structure because wildlife use occurs in the evening and nighttime hours; human use occurs during daylight hours.

## IDENTIFICATION OF PASSAGE STRUCTURE SITES

The research team used elk and mule deer highway crossings, WVCs, pronghorn approaches, and the proportions of animals crossing or approaching within each segment, among other criteria, to rate 95 0.6 mile segments for suitability as potential passage structure locations, this 57 mile area extends into GCNP and included all areas where elk, mule deer and pronghorn approached the highway and ranged outside of the area defined by ADOT (2006). Additional criteria included land ownership and topography that would support passage structure construction. The ratings ranged from 1 to 33 points on a 40-point scale and averaged 10.0 points per segment. The research team's ratings identified 11 priority wildlife passage structure locations; the 0.6 mile segments with these structures averaged a 20.7 rating.

Six sites were conducive to underpasses, and five were at sites where the terrain was conducive to overpasses and would promote pronghorn permeability. Of the nine wildlife underpass locations identified in the 2006 *Final Wildlife Accident Reduction Study* report, the research team's rating of potential passage structure sites corroborated that eight were warranted.

In addition to the passage structure sites recommended in the 2006 *Final Wildlife Accident Reduction Study* report, which were based largely on WVC records and sites where the topography could support a structure, the team identified three additional passage structures. One of these was an underpass at the Kaibab National Forest–GCNP boundary, and the other two structures are overpasses recommended for pronghorn passage in an area where no WVC was recorded during this study or documented in the 2006 *Final Wildlife Accident Reduction Study* report.

A variety of passage structure types can be considered for use along SR 64, including the single-span bridges used effectively along SR 260, cost-effective multi-plate arch underpasses, and pre-cast concrete arches. The 11 structures recommended by the team are spaced 1.5 to 2.3 mi apart, with this spacing generally consistent with guidelines for elk and pronghorn.

The situation for pronghorn is very different from that for elk and deer. For pronghorn, fencing in association with passage structures is not needed to preclude at-grade pronghorn crossings, but it is important in providing a visual cue as to a path across the highway barrier, provided no fencing is used at the mouth of the passages. For pronghorn, minimizing the impact of high daytime traffic may be more critical than fencing, especially given pronghorn avoidance of the habitats adjacent to SR 64. A comprehensive set of measures to reduce traffic-associated impact could create "quiet zones" along the highway corresponding to passage structures and could facilitate pronghorn permeability.

Wildlife fencing plays an integral role with passage structures in achieving objectives for reducing WVCs, promoting highway safety, and improving wildlife permeability, especially for elk and deer. Failure to erect adequate fencing in association with passage structures, even when spaced adequately, has been found to substantially reduce their effectiveness. The research team identified a 14.2 mile section of the highway where fencing would be needed to meet WVC reduction and permeability objectives.

# 2.0 LITERATURE REVIEW

## 2.1 BACKGROUND

Direct and indirect highway impacts have been characterized as some of the most prevalent and widespread forces altering ecosystems in the United States (Noss and Cooperrider 1994, Trombulak and Frissell 2000, Farrell et al. 2002). Forman and Alexander (1998) estimated that highways have affected more than 20 percent of the nation's land area through habitat loss and degradation.

It is estimated that as many as 1.5 million collisions involving deer occur annually in the United States (Conover 1997). Wildlife-vehicle collisions (WVCs) cause human injuries, deaths, and tremendous property loss (Reed et al. 1982, Schwabe and Schuhmann 2002). More than 38,000 human deaths attributable to WVCs occurred in the United States from 2001 through 2005, and the economic impact exceeds $8 billion a year (Huijser et al. 2007). The most pervasive impacts of highways on wildlife, however, are the barrier and fragmentation effects resulting in diminished habitat connectivity (Noss and Cooperrider 1994, Forman and Alexander 1998, Forman 2000).

Highways block animal movements between seasonal ranges or other vital habitats. This barrier effect fragments habitats and populations, reduces genetic interchange (Gerlach and Musolf 2000, Epps et al. 2005, Riley et al. 2006), and limits dispersal of young (Beier 1995), all disrupting viable wildlife population processes. Long-term fragmentation and isolation renders populations more vulnerable to the influences of catastrophic events and may lead to extinctions (Hanski and Gilpin 1997). Fencing that blocks wildlife and livestock access across highways without provisions for adequate passage may exacerbate barrier effects.

Though numerous studies have alluded to highway barrier effects on wildlife (e.g., Forman et al. 2003), relatively few have provided quantitative data relative to animal passage rates. Most studies have focused on the efficacy of passage structures in maintaining wildlife permeability, the ability of animals to pass across highways (Clevenger and Waltho 2003, Ng et al. 2004). Assessments of highway fragmentation effects on relatively small, less mobile mammals (Swihart and Slade 1984, Conrey and Mills 2001, McGregor et al. 2003) have proved easier to accomplish than assessments for larger, more mobile species that are limited by cost-effective techniques to measure permeability.

Paquet and Callaghan (1996) used winter track counts adjacent to highways and other barriers to determine passage rates by wolves. Very high frequency (VHF) radio telemetry has also been used to assess wildlife movements and responses to highways, often pointing to avoidance of highways and roads (Brody and Pelton 1989, Rowland et al. 2000).

Only a limited number of studies have addressed permeability in an experimental (e.g., before and after construction) context with research controls (Hardy et al. 2003; Roedenbeck et al. 2007; Olsson 2007; Dodd et al., "Evaluation of Measures," 2007).

Olsson (2007) documented an 89 percent decrease in the mean moose-crossing rate between before- and after-reconstruction levels along a highway in Sweden. Dyer et al. (2002) compared actual road to simulated road network crossing rates, where caribou crossed actual roads less than 20 percent as frequently as simulated networks.

Dodd et al. ("Assessment of elk," 2007) stressed the value of a quantifiable and comparable metric of permeability. They calculated elk highway passage rates from Global Positioning System (GPS) telemetry to conduct before-after-control reconstruction comparisons along SR 260. Dodd et al. ("Effectiveness of Wildlife," *in review)* reported that overall elk ($n$ = 100) passage rates averaged 0.50 crossings per approach. Among reconstruction classes, the mean elk passage rate for the before-reconstruction control class (0.67) was 39 percent higher than the mean after-reconstruction passage rate (0.41). They also calculated white-tailed deer passage rates along SR 260; the rates averaged only 0.03 crossings per approach on control sections. On reconstructed sections with passage structures, the passage rate was significantly higher (0.16 crossings per approach).

Along United States Route 89 (US 89), Dodd et al. ("Effectiveness of Wildlife," *in review*) used the same consistent methodology and found the mean pronghorn ($n$ = 31) passage rate to be negligible—0.006 crossings per approach. US 89 constitutes a near-total barrier to pronghorn passage.

In addition to the permeability insights gained from the previously discussed GPS telemetry studies, the SR 260 and US 89 studies furthered the understanding that traffic volume plays in the highway barrier effect. Theoretical models (Mueller and Berthoud 1997) suggest that highways averaging 4000 to 10,000 vehicles per day present strong barriers to wildlife and would repel animals from the highway. Gagnon et al. ("Traffic volume alters," 2007) found that increasing vehicular traffic volume decreased the probability of at-grade crossings by elk, which shifted their distribution away from the highway with increasing traffic volume, consistent with Mueller and Berthoud (1997) and Jaeger et al. (2005).

For white-tailed deer, Dodd and Gagnon (2011) found that at-grade SR 260 passage rates were consistently low (fewer than 0.1 crossing per approach) across all traffic volumes. Pronghorn also were consistently negatively impacted by traffic volume, even at low levels, and distribution remained constant among all distances from US 89 and across all traffic volumes up to 500 vehicles per hr (Dodd et al. "Effectiveness of Wildlife," *in review*). Whereas elk and deer highway crossings occur at night when traffic volume is lowest, pronghorn are diurnal and active when traffic volumes are typically at their highest (Gagnon et al. "Traffic volume alters,"2007) contributing to their low permeability.

Collectively, these Arizona studies using consistent, comparable methodologies and metrics have added substantially to the understanding of highway impact to wildlife permeability and traffic volume relationships for multiple species and highways exhibiting different traffic patterns. This understanding will further benefit from continued studies that assess permeability for additional species and on highways that expand the range of experimental conditions under which permeability is assessed (Jaeger et al. 2005).

Numerous assessments of WVC patterns have been conducted, most focusing on deer (Reed and Woodward 1981, Bashore et al. 1985, Romin and Bissonette 1996, Hubbard et al. 2000). Only recently have WVC assessments specifically addressed elk-vehicle collision patterns (Gunson and Clevenger 2003, Biggs et al. 2004, Dodd et al. "Effectiveness of Wildlife," *in review*, Gagnon et al. 2010). Insights gained from such assessments have been instrumental in developing strategies to reduce WVCs (Romin and Bissonette 1996, Farrell et al. 2002), including planning passage structures to reduce at-grade crossings and to maintain permeability (Clevenger et al. 2002).

Consistent tracking of WVCs constitutes a valuable tool to assess the impact of highway construction (Romin and Bissonette 1996) and the efficacy of passage structures and other measures (e.g., fencing) in reducing WVCs (Reed and Woodard 1981, Ward 1982, Clevenger et al. 2001, Dodd et al., "Evaluation of Measures," 2007).

Increasingly, structures designed to promote wildlife passage across highways are being implemented throughout North America, especially large bridges (e.g., underpasses or overpasses) designed specifically for large animal passage (Clevenger and Waltho 2000, Bissonette and Cramer 2008). Whereas early passage structures were typically approached as single-species mitigation measures to address WVCs (Reed et al. 1975), the focus today is more on preserving ecosystem integrity and landscape connectivity benefiting multiple species (Clevenger and Waltho 2000).

Transportation agencies are increasingly receptive to integrating passage structures into highways to address safety and ecological needs (Farrell et al. 2002). At the same time, there is increasing expectation that such structures will benefit multiple species and enhance connectivity (Clevenger and Waltho 2000), and that scientifically sound monitoring of wildlife response to these measures will occur to improve effectiveness (Clevenger and Waltho 2003, Hardy et al. 2003). Corlatti et al. (2009) argued for long-term monitoring of wildlife passages to evaluate their effectiveness in maintaining connectivity and promoting population and genetic viability, thus justifying their relatively high cost.

Wildlife passage structures have indeed shown benefit in promoting wildlife passage for a variety of wildlife species (Farrell et al. 2002; Clevenger and Waltho 2003; Dodd et al., "Assessment of elk," 2007; Gagnon et al. 2011). Dodd et al. ("Evaluation of Measures," 2007) found that elk passage rates along one section of SR 260 increased 52 percent to 0.81 crossings per approach once reconstruction was completed and ungulate-proof fencing linking passage structures was erected. This pointed to the efficacy of passage structures and fencing in promoting permeability, as well as achieving an 85 percent reduction in elk-vehicle collisions (Dodd et al., "Evaluation of Measures," 2007).

Gagnon et al. ("Effects of traffic," 2007) found that traffic levels did not influence elk passage rates during below-grade underpass crossings. This finding shows the benefit of underpasses and fencing in promoting permeability by funneling elk to underpasses where traffic has minimal effect compared with crossing at-grade during high traffic volumes (Gagnon et al. "Traffic volume alters,"2007). The fivefold higher white-tailed deer permeability along SR 260 after reconstruction with passage structures compared with controls suggests the efficacy of passage structures; like elk, deer passage rates were minimally affected by traffic on sections where passage structures facilitated below-grade passage (Dodd and Gagnon 2011).

Structural characteristics and placement of wildlife crossing structures are important to maximizing wildlife use (Reed et al. 1975; Foster and Humphrey 1995; Clevenger and Waltho 2000, 2003; Dodd et al., "Evaluation of Measures," 2007; Gagnon et al. 2011). Prior studies modeled structural factors accounting for differences in wildlife use (Clevenger and Waltho 2000, 2005; Ng et al. 2004). Gagnon et al. (2011) assessed five factors, of which structural design and placement characteristics had the greatest influence on elk use of SR 260 underpasses. However, given sufficient time for habituation, most structures became equally effective for elk, even in spite of structural or placement limitations.

The spacing between passage structures is also an important consideration (Bissonette and Adair 2008). Dodd et al. ("Effectiveness of Wildlife," *in review*) and Gagnon et al. (2010) found considerable variation in mean elk passage rates (ranging from 0.09 to 0.81 crossings per approach) on three reconstructed SR 260 sections, likely reflecting the corresponding variation in passage structure spacing ranging from 1.5 to 0.6 miles, with a strong negative association with increased distance between structures ($r$ = -0.847; Dodd et al. "Effectiveness of Wildlife," *in review*). Bissonette and Adair (2008) assessed recommended passage structure spacing for several species tied to isometric scaling of home ranges to define appropriate passage structure spacing distance. They hypothesized that when used with other criteria this approach will help maintain landscape permeability for a range of species.

Most assessments of wildlife passage structure use have been for newly constructed structures implemented as part of major highway reconstruction projects (Clevenger and Waltho 2000, 2005; Gagnon et al. 2011). However, some assessments have been of primarily drainage structures retrofitted to serve as wildlife passage structures with the erection of fencing to limit at-grade crossings and funnel animals to structures (Gordon and Anderson 2003, Ng et al. 2004).

In Arizona, such retrofitting has considerable promise as a cost-effective approach to minimizing WVCs and promoting permeability (Gagnon et al. 2010), particularly compared with costly highway reconstruction that may not occur on some highways for decades. As such, there is a need to better understand the potential effectiveness of existing structures for retrofitting applications, including structural design characteristics that may limit effectiveness.

## 2.2 RESEARCH JUSTIFICATION

The incidence of WVCs along SR 64 between I-40 and GCNP is a significant and growing concern. In the future, this predominantly two-lane highway will be reconstructed to a four-lane divided highway to address growing traffic volume and the incidence of WVCs.

To help address the WVC issue, ADOT commissioned the development of a proactive assessment of WVCs and potential mitigation measures to reduce their incidence along SR 64. In ADOT (2006) it was reported that 48 percent of 475 accidents recorded along SR 64 in the five-year period from October 1998 through September 2003 involved collisions with wildlife, primarily elk and mule deer (Table 1). This study developed and evaluated alternatives and associated mitigation measures for consideration in the planned feasibility study for the eventual reconstruction of SR 64.

Table 1. Vehicle Accidents Involving Collisions with Elk and Mule Deer along SR 64 from 1991 through 2003, Including the Mean Number of Collisions (per Year and per Mile).

| SR 64 section | Mileposts | Elk-vehicle accidents | | | Mule deer-vehicle accidents | | |
|---|---|---|---|---|---|---|---|
| | | Total | Mean (per year) | Mean (per mile) | Total | Mean (per year) | Mean (per mile) |
| A | 185.5–204.7 (19.2 mi) | 58 | 4.5 | 3.0 | 79 | 6.1 | 4.1 |
| B | 204.7–212.5 (7.8 mi) | 2 | 0.2 | 0.3 | 2 | 0.2 | 0.3 |
| C | 212.5–214.3 (1.8 mi) | 0 | 0.0 | 0.0 | 1 | 0.1 | 0.6 |
| D | 214.3–223.4 (9.1 mi) | 6 | 0.5 | 0.7 | 3 | 0.2 | 0.3 |
| E | 223.4–235.4 (12.0 mi) | 97 | 7.5 | 8.1 | 238 | 18.3 | 19.8 |
| All | 185.5–235.4 (49.9 mi) | 163 | 12.5 | 3.3 | 315 | 24.2 | 6.3 |

Source: *Final Wildlife Accident Reduction Study* (ADOT 2006)

The earlier study report (ADOT 2006) delineated five SR 64 sections (A–E) based on land ownership and habitat (Figure 1). This study developed two mitigation alternatives for three of the sections (Table 2) to address the past incidences of WVCs, including the construction of as many as seven wildlife underpasses and three overpasses, depending on the selected alternatives (Table 2; Figure 1). None of the passage structures were recommended along highway sections where American pronghorn were a focus (Sections B and D), partly because no WVC involving this species was recorded from 1991 through 2003. However, SR 64 likely constitutes a significant barrier to pronghorn passage similar to US 89 to the east, where no pronghorn-vehicle collisions were recorded either (Dodd et al. 2011).

Table 2. SR 64 Sections and Mileposts with Proposed Wildlife Mitigation Measures for Focal Wildlife Species Identified in the 2006 *Final Wildlife Accident Reduction Study*.

| SR 64 section | Mileposts | Mitigation alternative | Proposed wildlife mitigation measures | | | Focal wildlife species |
|---|---|---|---|---|---|---|
| | | | Underpass | Overpass | Fencing | |
| A | 185.5–204.7 (19.2 mi) | A(W)-1<br>A(W)-2 | 2[a]<br>1[a] | 0<br>1 | Yes<br>Yes | Elk, mule deer |
| B | 204.7–212.5 (7.8 mi) | None | 0 | 0 | No | Pronghorn |
| C | 212.5–214.3 (1.8 mi) | None | 0 | 0 | No | None; human development |
| D | 214.3–223.4 (9.1 mi) | D(W)-1<br>D(W)-2 | 1<br>0 | 0<br>1 | Yes<br>Yes | Elk, mule deer, pronghorn |
| E | 223.4–235.4 (12.0 mi) | E(W)-1<br>E(W)-2 | 4<br>4 | 0<br>1 | Yes<br>Yes | Elk, mule deer |

[a] Includes Cataract Canyon Bridge, which will be used as a passage structure

The same study (ADOT 2006) identified the need to conduct further field evaluation and monitoring to determine the best locations for wildlife passage structures and the extent of ungulate-proof fencing needed to funnel animals to passage structures. The report indicated that the focus of such monitoring should be from mile post (MP) 222.0 to MP 235.4, where the highest incidence of WVCs involving elk and mule deer has occurred in the past.

The report called for the monitoring of current and potential (e.g., with added funnel fencing) wildlife use of Cataract Canyon Bridge at MP 187.3; Section A to determine whether this multiple box culvert design is conducive to wildlife passage.

The report also addressed the potential barrier effect to pronghorn (especially along Section B) and recommended that this issue also be further evaluated with monitoring. In that report it was also recommended that a cooperative research project between ADOT and the AGFD be initiated in advance of the feasibility study and final design for highway reconstruction such that refined, site-specific information can be incorporated into the final reconstruction plans.

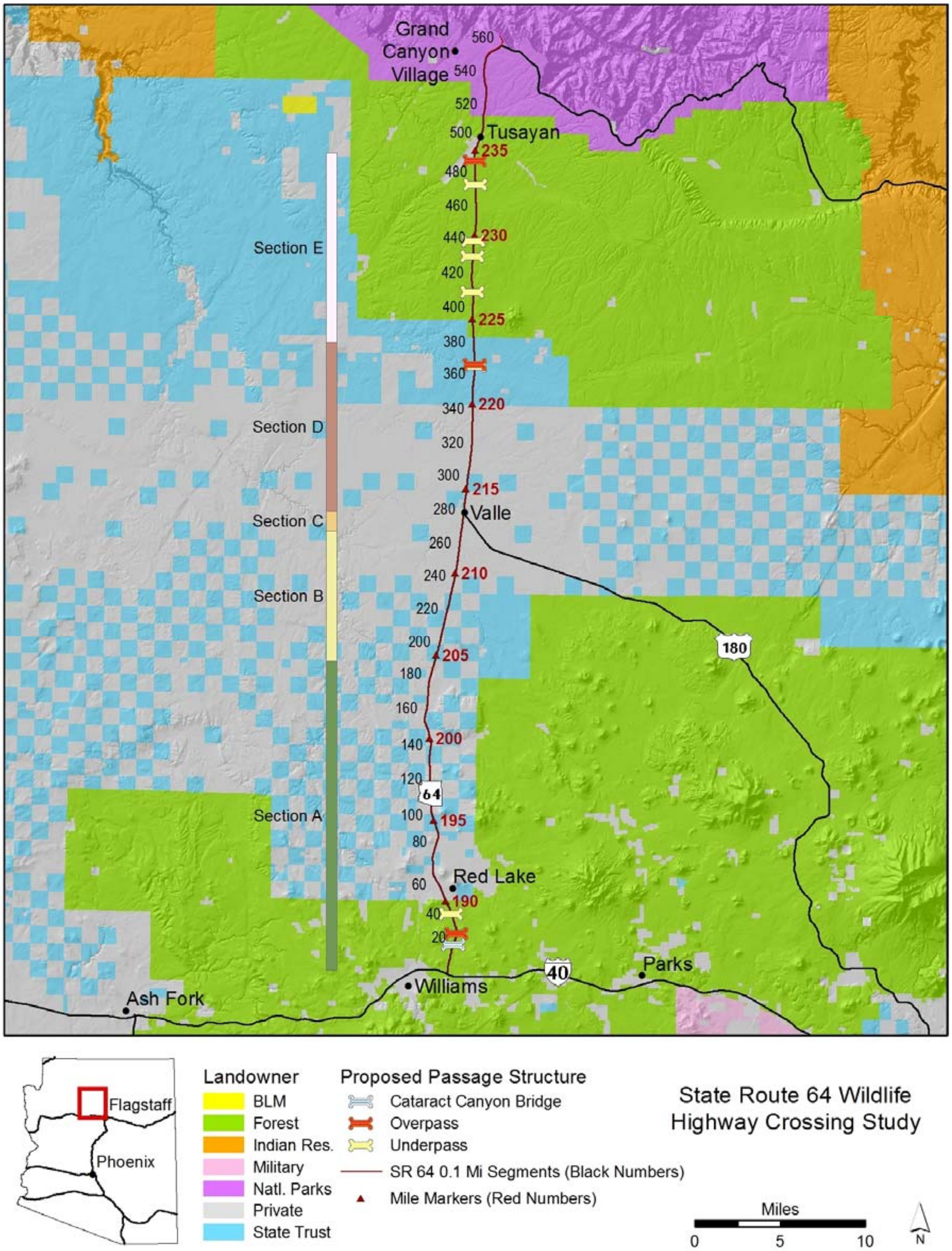



Figure 1. Landownership, Mileposts, 0.1 mi Segments, Highway Sections A–E, and Preliminary Wildlife Passage Structures in the SR 64 Study Area Identified by the Final Wildlife Accident Reduction Study (ADOT 2006).

In 2007, an interagency agreement between ADOT and the AGFD was executed for the SR 64 research project (Project JPA07-026T), with funding provided by the ADOT Research Center. This research project is significant from several perspectives.

The cited study (ADOT 2006) conducted for SR 64 represents the first assessment of its type in Arizona, forming the proactive basis from which to develop strategies to mitigate WVCs and obtain refined information with further monitoring and research.

The project also reflects the incremental process in addressing wildlife connectivity and permeability needs embodied in *Arizona's Wildlife Linkages Assessment* (Arizona Wildlife Linkages Workgroup 2006). General connectivity needs identified in the assessment (e.g., Linkage No. 12; Coconino Plateau–Kaibab National Forest) were also addressed in the 2006 *Final Wildlife Accident Reduction Study*, which called for further monitoring to assess site-specific needs and refined strategies for promoting permeability.

## 2.3 RESEARCH OBJECTIVES

Pursued largely as a result of the 2006 *Final Wildlife Accident Reduction Study*, this research project will add considerably to the understanding of wildlife movements in relation to highways and provide information to support data-driven design planning for the planned reconstruction of SR 64. Focusing on elk, mule deer, and pronghorn, this research project complements previous research on wildlife-highway permeability, traffic volume, and WVC relationships (Dodd et al. "Effectiveness of Wildlife," *in review*, 2011; Gagnon et al. "Traffic volume alters," 2007). The specific research objectives of this research project were to:

- Assess elk (June 2007 through October 2009), mule deer (April 2008 through October 2009), and pronghorn (January 2008 through January 2009) movements, highway crossing patterns, and distribution relative to SR 64 and determine permeability across the highway corridor.
- Investigate the relationships of elk, mule deer, and pronghorn highway crossing and distribution patterns to SR 64 vehicular traffic volume (2007 through 2009).
- Investigate WVC patterns and relationships to elk, mule deer, and pronghorn movement and highway crossing patterns in relation to SR 64 (2007 through 2009).
- Assess the degree to which Cataract Canyon Bridge is used by wildlife for below-grade passage (July 2008 through December 2009).
- Develop recommendations to enhance elk, mule deer, and pronghorn highway permeability along SR 64 through the application of wildlife passage structures and ungulate-proof fencing.

# 3.0 STUDY AREA

SR 64 is the highway connecting I-40 to Grand Canyon National Park (GCNP). It is classified as a rural principal arterial highway. The focus of this research project was a 57 mile stretch of highway starting at I-40, approximately 2 miles east of Williams (MP 185.5), and ending at the GCNP boundary (MP 237.0) just north of the community of Tusayan, Coconino County, Arizona (latitude 35º25'–35º99'N, longitude 112º12'–112º15'W; Figure 1). SR 64 runs north–south and intersects US 180 at Valle (MP 213.5); US 180 links SR 64 to Flagstaff, 40 miles to the southeast. The majority of SR 64 now is a two-lane highway, with occasional passing lanes.

## 3.1 NATURAL SETTING

The study area is at the southwest extent of the Colorado Plateau physiographic province. The south half of the study corridor lies within the San Francisco Peaks Volcanic Field (Hansen et al. 2004). The study corridor adjacent to SR 64 varies in elevation from 6000 ft between Red Lake and Valle to 6930 ft at the south end of the study area near Kaibab Lake, and 6600 ft elevation at Grand Canyon Airport in Tusayan. The topography is a mix of mesas, cinder cones, and broken terrain with rolling hills, ridges, and valleys interspersed with large, relatively flat grassland areas (Figures 1 and 2).

Land ownership adjacent to the highway includes U.S. Forest Service (Kaibab NF) lands (35 percent of the corridor), including 5 miles at the south end and 13 miles at the north end of the study area (Figure 1). In between, land ownership is a mix of interspersed Arizona State Trust (25 percent) and private lands (40 percent), with much of the private land subdivided for development (Figure 1). Existing development is concentrated near the communities of Red Lake, Valle, and Tusayan (Figure 1).

### 3.1.1 Climate

Generally, the climate is characterized as semiarid, dominated by hot summers and cool winters. At the south and north ends of the study area, near Williams and the Grand Canyon, respectively, the average maximum temperature is 64 °F, with July being the warmest month (mean = 84 °F); highs can approach 95 °F. Winter daily low temperatures average 35 °F at Williams and 32 °F at the Grand Canyon, with January being the coolest month (mean = 19 °F); winter lows at the Grand Canyon often dip below 0 °F.

Precipitation varies considerably along the length of the study area, with Williams averaging 21.6 inches annually, including an average snowfall accumulation of 69.3 inches. Precipitation drops off to the north along SR 64 at Valle, where it averages only 9.4 inches annually, with 4.8 inches of annual snow accumulation. Precipitation at Tusayan (Grand Canyon Airport) is greater than at Valle but is still less than the south portion of SR 64; annual precipitation averages 13.7 inches, with annual snowfall of 44.3 inches. Precipitation occurs primarily during intense and localized thunderstorms associated with the summer monsoon and more widespread frontal storms that pass through the state in the winter.

Figure 2. Great Basin Conifer Woodland Adjacent to SR 64 (Top) with Open to Dense Stands of Pinyon and Juniper and Cliffrose, Apache Plume, and Other Shrubs, and Plains and Great Basin Grasslands (Bottom) Dominated by Blue and Black Grama, Galleta, and Needle-and-Thread Grasses.

### 3.1.2 Vegetation

Vegetation is diverse and exhibits characteristics of the Petran Montane Conifer Forest, the Great Basin Conifer Woodland, and the Plains and Great Basin Grassland biotic communities (Brown 1994). Ponderosa pine dominates montane coniferous forests at the southernmost and northernmost portions of the study areas. Gambel oak occurs in the overstory. Big sagebrush, rabbitbrush, and cliffrose dominate the understory. Sagebrush is particularly prevalent at the drier north extent of the study area.

The ponderosa pine–dominated forest adjacent to SR 64 is interspersed with small openings in draws and flats vegetated by sagebrush, blue grama, and other grasses. Though these sites are dry, they nonetheless may correspond to WVC incidence hotspots as observed for wet meadow habitats adjacent to SR 260 by Dodd et al. ("Evaluation of Measures," 2007) and Manzo (2006). Sparse to dense pinyon and one-seed juniper dominate the overstory of extensive Great Basin conifer woodlands, with sagebrush, cliffrose, Apache plume, and other shrubs in the understory, along with blue grama and other grasses in openings (Figure 2). Conifer woodlands transition to Plains and Great Basin grasslands dominated by blue and black grama, galleta, and needle-and-thread grasses, with winterfat and sage interspersed with sparse junipers (Figure 2).

### 3.1.3 Wildlife Species

The focal species of this study were elk, mule deer, and pronghorn. SR 64 separates Game Management Units (GMUs) 7 and 10 south of Valle and bisects GMU 9 between Valle and Tusayan. Elk are found in moderate densities at the south end of the study area and at high densities at the north end of the study area, with low densities in between (Figure 3). During the project (2007 through 2009), the AGFD surveyed an average of 424 elk in GMU 9, with a robust ratio of bulls in relation to cows and calves (39 bulls : 100 cows : 32 calves). In GMU 7, an average of 355 elk were surveyed annually (22 bulls: 100 cows : 39 calves).

At the north extent of the study area, mule deer are commonly seen along the highway corridor and occur in high densities; they occur in moderate densities at the south extent and in low densities in between (Figure 3). During the study, an average of 303 mule deer were surveyed by the AGFD each year (17 bucks : 100 does : 42 fawns). In GMU 7, extending far east of SR 64, 151 deer were classified in surveys each year (25 bucks : 100 does : 37 fawns).

The pronghorn population levels in grassland and open woodland areas of GMUs 9 and 7 are considered average relative to other northern Arizona populations. However, pockets of habitat east of SR 64 in GMUs 7 and 9 hold high densities of pronghorn (Figure 3), and the population on the east side is larger than the population on the west. In GMU 9, an average of 119 animals were surveyed each year during this project (47 bucks : 100 does : 26 fawns). For GMU 7, an average of 247 pronghorn were surveyed each year (31 bucks : 100 does : 25 fawns).

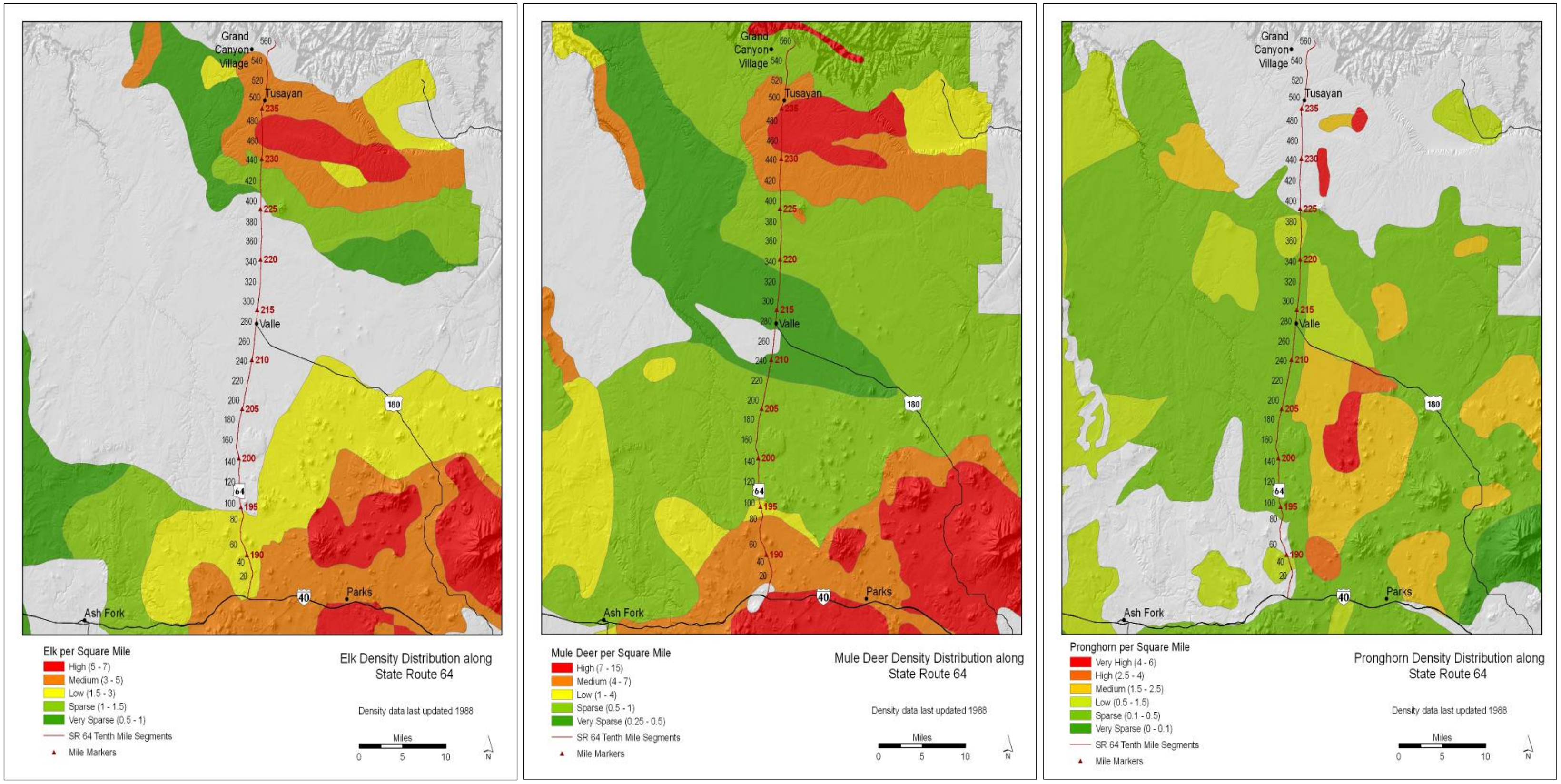



Figure 3. Density Distributions for the Three Target Species of Research along SR 64: Elk (Left), Mule Deer (Center), and Pronghorn (Right).

### 3.1.4 Cataract Canyon Bridge

Reflective of the generally rolling terrain along the highway corridor, Cataract Canyon Bridge at MP 187.3 near Kaibab Lake is one of the most substantial bridge structures along the 57 mi study area (Figure 4). This 44 ft wide reinforced concrete box-culvert bridge was constructed in 2001, with four 26 ft spans, for a total length of 104 ft. The bridge cells have a 16 ft vertical clearance. Due to the moderate to high elk numbers and moderate mule deer density in the vicinity of this bridge, there was an opportunity to evaluate existing wildlife use to document and better understand the efficacy of this structure type to serve as an effective wildlife crossing structures without fencing.

Dodd et al. ("Evaluation of Measures," 2007) stressed the need for ungulate-proof funnel fencing to guide animals toward passage structures to achieve desired wildlife use. Without fencing, animals continue to cross the highway at grade. Though ADOT was amenable to such fencing near Cataract Canyon Bridge and conducted a formal analysis, there were too many concerns to move forward with fencing to coincide with this research project. One of the foremost concerns related to addressing potential "end run" or forcing of elk to another location along SR 64 at the termini of the fencing, including immediately adjacent to I-40. As such, no fencing was erected in association with this bridge during the project.

Figure 4. Cataract Canyon Bridge on SR 64.

## 3.2 TRAFFIC VOLUME

Average annual daily traffic (AADT) volume on SR 64 was measured at 4343 vehicles per day in 2008 and 4208 vehicles per day in 2009, or an average of 4275 vehicles per day. Since late 2007, traffic volume has been continuously measured by a permanent automatic traffic recorder (ATR) installed near Valle. Traffic volumes were highest during daytime hours (Figure 5).

Compared with other study areas in central and northern Arizona, including SR 260 (Dodd et al. “Effectiveness of Wildlife,” *in review*), US 89 (Dodd et al. 2011), and Interstate 17 (Gagnon et al. “Elk Movements Associated,” *in review*), SR 64 is unique in that traffic is virtually nonexistent during the late nighttime hours, averaging less than 10 vehicles per hr for a 4 hr period (Figure 5). This reflects the predominant tourist destination nature of motorists traveling SR 64 to and from GCNP and not using this route for regional or interstate travel beyond GCNP at night. This is also reflected in the relatively small proportion of commercial vehicles traveling SR 64—only 0.07 percent during the day and 0.05 percent at night—compared with SR 260, where commercial traffic exceeded 40 percent at night (Dodd et al. “Effectiveness of Wildlife,” *in review*), and US 89, where commercial vehicles made up a third of the nighttime traffic (Dodd et al. 2011).

Peak annual traffic volume along SR 64 between 10:00 and 17:00 averaged 355 vehicles per hr, equivalent to an AADT volume of 8800 vehicles per day, though in summer it was considerably higher. Mean monthly traffic volume was highest during summer (June–August; 5710 AADT), when it was three times higher than volume during the lowest traffic months of December–February (1775 AADT). Traffic volume was highest on Saturdays—nearly 20 percent higher than during the rest of the week.

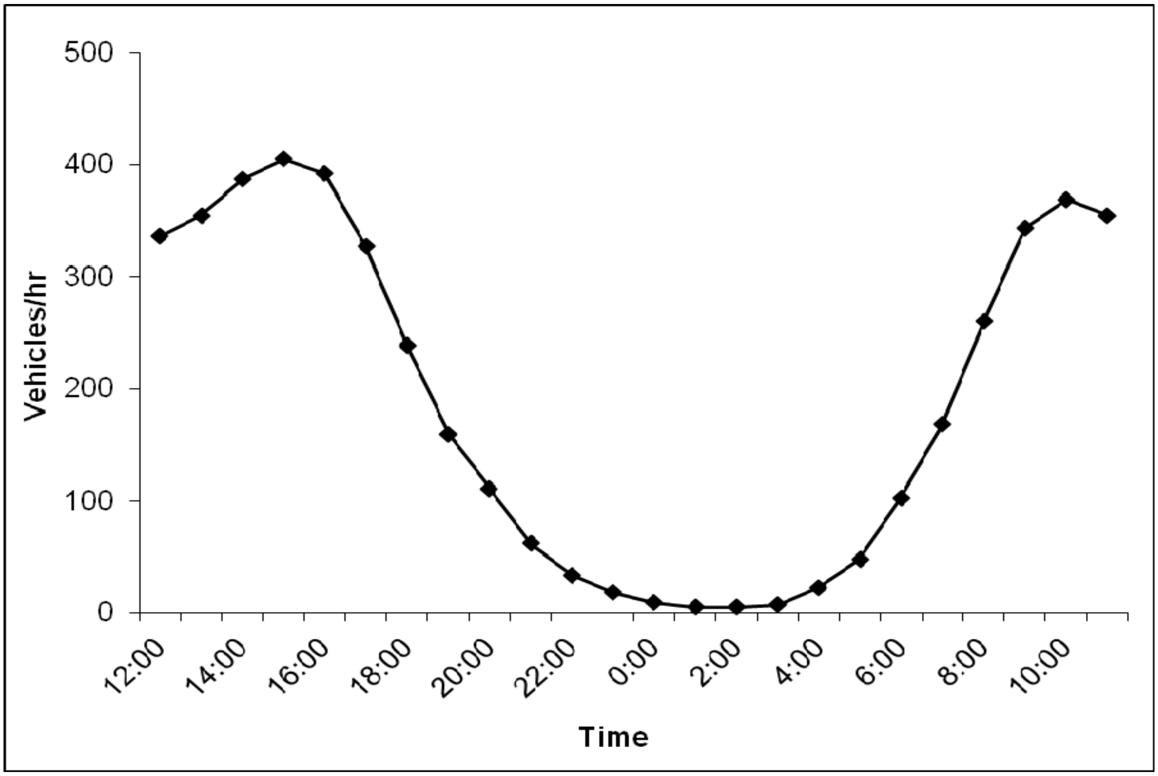


Figure 5. Hourly Traffic Volume (Vehicles per Hour) along SR 64, Arizona, from 2007 through 2009. Note the Low Volume of Traffic during Nighttime Hours (00:00–04:00).

# 4.0 METHODS

## 4.1 WILDLIFE CAPTURE, GPS TELEMETRY, AND DATA ANALYSIS

### 4.1.1 Elk Capture

The research team captured elk at 14 sites adjacent to SR 64, along Highway Sections A and E, at the north and south extremes of the study area; 11 sites were concentrated adjacent to Section E. Elk were trapped primarily in net-covered Clover traps (Clover 1954) baited with salt and alfalfa hay; all traps were within 0.5 mi of the highway corridor and near permanent water sources (Figure 6).

Elk were also captured by nighttime darting from a vehicle along the highway aided with a spotlight. The low volume of traffic late at night made such capture possible. Trapped animals were physically restrained, and all animals were blindfolded, ear-tagged, and fitted with global positioning system (GPS) receiver collars (Figure 6). Darted elk were administered a reversal drug when handling was complete. Elk were instrumented with Telonics, Inc., Model TGW-3600 store-on-board GPS collars programmed to receive a GPS relocation fix every two hours. All collars had very high frequency (VHF) beacons, mortality sensors, and programmed release mechanisms to allow recovery. Battery life for the GPS units was approximately two years.

### 4.1.2 Mule Deer Capture

The research team attempted to trap mule deer in small Clover traps baited with sweet feed and salt at five sites adjacent to Section E but had no success. Therefore, the team shifted to nighttime darting from a vehicle along or immediately adjacent to SR 64, aided by a spotlight. Again, the low volume of traffic late at night made such capture feasible. Deer were blindfolded, ear-tagged, and fitted with GPS receiver collars (Figure 6), and then administered a reversal drug. Most deer were fitted with Telonics, Inc. Model TGW-3500 GPS receiver collars (Figure 6) programmed to receive a fix every two hours, with a battery life of 11 months. Four deer were fitted with Telonics Generation IV GPS receiver collars that had a one-year battery life. All collars had VHF mortality sensors and programmed release mechanisms for recovery.

### 4.1.3 Pronghorn Capture

The research team captured pronghorn using a net gun fired from a helicopter (Firchow et al. 1986, Ockenfels et al. 1994, Dodd et al. 2011; Figure 6). A fixed-wing aircraft and numerous ground spotters using optics equipment were employed to search for pronghorn during capture to minimize helicopter searching. Pronghorn were captured during winter to minimize heat-related stress on animals as well as deleterious effects on females that could occur if captured later in their pregnancies.


Figure 6. Photographs of Capture Techniques Used for Elk, Mule Deer and Pronghorn along SR 64 and GPS-Collared Animals: Elk Captured with Net-Covered Clover Trap (Top), Darting to Immobilize Mule Deer (Middle), and Net-Gunning of Pronghorn from a Helicopter (Bottom).

The team's capture objectives were to:

- Instrument as nearly an equal number of pronghorn on each side of SR 64 as possible because the research team suspected that SR 64 would be a barrier similar to US 89 (Dodd et al. 2011).
- Spread the collars among as many different herds as possible along the length of the study area.
- Capture animals within 2 mi of SR 64.

Upon capture, pronghorn were immediately blindfolded and untangled from the capture net. Animals were fitted with a GPS collar and marked with a numbered, colored ear tag (Figure 6). Tissue samples were taken from animals' ears with a paper punch and preserved for future genetic analysis. The research team instrumented pronghorn with Telonics, Inc. Model TGW-3500 store-on-board GPS receiver collars programmed to receive 12 GPS fixes per day, with one fix every 90 minutes between 04:00 and 22:00. GPS units had a battery life of 11 months. All collars had VHF beacons, mortality sensors, and programmed release mechanisms to allow recovery.

### 4.1.4 GPS Analysis of Animal Movements

Once GPS collars were recovered and data downloaded, the research team employed ArcGIS® Version 8.3 Geographic Information System software (ESRI®, Redlands, California) to analyze GPS data similar to analyses done for elk by Dodd et al. ("Assessment of elk," 2007), white-tailed deer (Dodd and Gagnon 2011), and pronghorn (Dodd et al. 2011). The team calculated individual minimum convex polygon (MCP; connecting the outermost fixes) home ranges composed of all GPS fixes (White and Garrott 1990). Differences in means were assessed by analysis of variance, and means were reported with ±1 standard error (SE).

Crossings were compared among the following seasons:

- Late spring–summer (April–July).
- Late summer–fall (August–November).
- Winter–early spring (December–March).

### 4.1.5 Calculation of Crossing and Passage Rates

The team divided the entire length of SR 64 from I-40 to the Grand Canyon village into 570 sequentially numbered 0.1 mi segments corresponding to the units used by ADOT for tracking WVCs and highway maintenance, and identical to the approach used by Dodd et al. ("Evaluation of Measures," 2007, Figure 1). The number and proportion of GPS fixes within 0.15, 0.30, and 0.60 mi of SR 64 were calculated for each animal.

To determine highway crossings, the team drew lines connecting all consecutive GPS fixes. Highway crossings were inferred where lines between fixes crossed the highway through a given segment (Dodd et al. "Evaluation of Measures," 2007, Figure 7). Animal Movement ArcView Extension Version 1.1 software (Hooge and Eichenlaub 1997) was used to assist in animal crossing determination. The research team compiled crossings by individual animal by highway segment, date and time, and calculated crossing rates for individual elk, mule deer, and pronghorn by dividing the number of crossings by the days a collar was worn.

The research team calculated passage rates for collared animals, which served as its relative measure of highway permeability (Dodd et al., "Evaluation of Measures," 2007). An approach was considered to have occurred when an animal traveled from a point outside the 0.15 mi buffer zone to a point within 0.15 mi of SR 64, determined by successive GPS fixes (Figure 7). The approach zone corresponded to the road-effect zone associated with traffic-related disturbance (Rost and Bailey 1979, Forman et al. 2003) previously used for elk and white-tailed deer by Dodd et al. ("Evaluation of Measures," 2007, Dodd and Gagnon 2011). Animals that directly crossed SR 64 from a point beyond 0.15 mi were counted as an approach and a crossing.

The research team calculated passage rates as the ratio of recorded highway crossings to approaches. The research team tested the hypothesis that the observed spatial crossing distribution among 0.10 mi segments did not differ from a discrete randomly generated distribution using a Kolmogorov-Smirnov test (Clevenger et al. 2001; Dodd et al., "Assessment of elk," 2007), a test that is sensitive to the difference in ranks and shape of the distributions. The team used linear regression to assess the strength of associations between passage rates and traffic volume, as well as between the frequency of highway crossings and WVCs at the MP (1.0 mi) scale using WVC records from 1991 through 2009 on those highway stretches with elk or deer crossings.

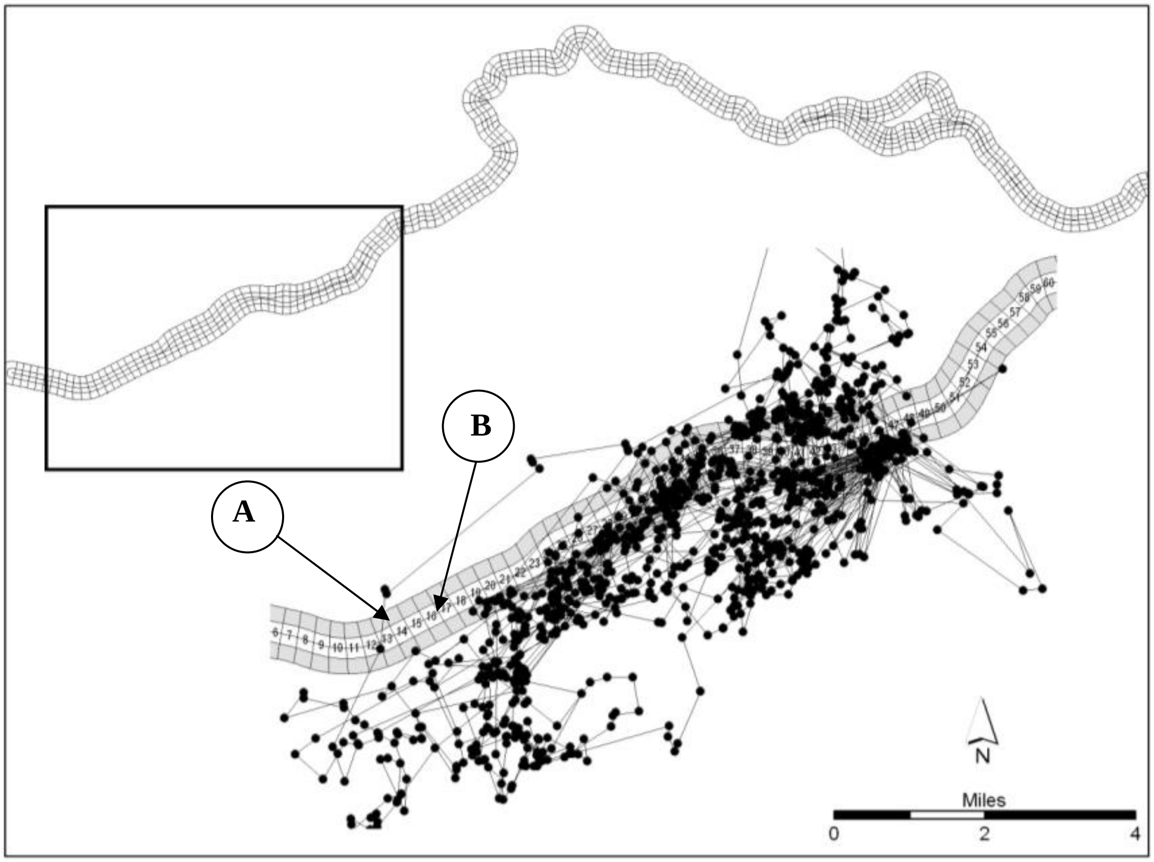



Figure 7. GPS Locations and Lines between Successive Fixes to Determine Highway Approaches and Crossings in 0.10 mi Segments. The Expanded Section Shows GPS Locations and Lines between Successive Fixes to Determine Approaches to the Highway (Shaded Band) and Crossings. Example A Denotes an Approach and Crossing; Example B Denotes an Approach without a Crossing.

#### 4.1.6 Calculation of Pronghorn Approaches

Based on previous northern Arizona pronghorn highway telemetry research (Ockenfels et al. 1997, van Riper and Ockenfels 1998, Bright and van Riper 2000, Dodd et al. 2011), the research team anticipated few pronghorn crossings or approaches to within 0.15 mi associated with crossings. As such, the team used the number of approaches by pronghorn to within 0.30 mi to determine the distribution of animals adjacent to SR 64 for the purposes of assessing the need for, and potential location(s) of, passage structures, as was done for the US 89 study (Dodd et al. 2011). Use of this greater approach distance also was deemed appropriate given the relatively open nature of pronghorn habitat, pronghorn reliance on visual stimuli in risk avoidance (Gavin and Komers 2006), and pronghorn mobility over long distances (Yoakum and O'Gara 2000) compared with other ungulates.

Pronghorn highway approaches were determined for animals approaching from each side of SR 64 and both sides combined. The research team tested the hypothesis that the observed spatial approach distribution among 0.10 mi segments did not differ from a discrete randomly generated approach distribution using a Kolmogorov-Smirnov test (Dodd et al. 2011).

### 4.1.7 Calculation of Weighted Crossings and Approaches

To account for the number of individual elk, deer, and pronghorn that crossed (and approached, in the case of pronghorn) each highway segment adjacent to SR 64, as well as evenness in crossing frequency among animals, the research team calculated Shannon diversity indexes (SDIs; Shannon and Weaver 1949) for each segment using this formula:

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

Thus, to calculate SDI (or $H'$) for each highway segment, the researchers calculated and summed all the $-(p_i \ln p_i)$ for each animal that had approaches in the segment, where each $p_i$ is defined as the number of individual collared elk and deer crossings and approaches for pronghorn within each segment divided by the total number of respective crossings or approaches in the segment. SDI were used to calculate weighted crossing or approach frequency estimates for each segment, multiplying uncorrected crossings or approach frequency by SDI. Weighted highway crossings and approaches better reflected the number of crossing and approaching animals and the equity in distribution among elk, deer, and approaching pronghorn (Dodd et al., "Evaluation of Measures," 2007).

## 4.2 TRAFFIC VOLUME AND ANIMAL DISTRIBUTION RELATIONSHIPS

The research team measured traffic volume using a permanent automatic traffic recorder (ATR) programmed to record hourly traffic volumes. ADOT's Data Team provided data collected from the ATR immediately north of Valle.

The research team examined how the proportion of elk, deer, and pronghorn GPS relocations at different distances from the highway varied with traffic volume by calculating the proportion of fixes in each 330 ft distance band, out to a maximum of 3300 ft. As done for elk (Gagnon et al. "Effects of traffic," 2007), white-tailed deer (Dodd and Gagnon 2011), and pronghorn (Dodd et al. 2011), the research team combined traffic and GPS data by assigning traffic volumes for the previous hour to each GPS location using ArcGIS® Version 9.1 and Microsoft® Excel® software.[1] This allowed the team to correlate the traffic volume each animal experienced in the hour prior to movement to a particular point, regardless of distance traveled.

To avoid bias due to differences in the number of fixes for individual animals, the proportion of fixes occurring in each distance band for each animal was used as the sample unit, rather than total fixes. The research team calculated a mean proportion of animals and fixes for all animals within each 330 ft distance band at varying traffic

[1] Microsoft and Excel are either registered trademarks or trademarks of Microsoft Corporation in the United States and/or other countries.

volumes: less than 100, 101–200, 201–300, 301–400, 401–500, and 501–600 vehicles per hr (Gagnon et al. "Effects of traffic," 2007).

The team compared elk, mule deer, and pronghorn distribution and highway impact along SR 64, and compared the species-specific distributions to those for elk (Gagnon et al. "Effects of traffic," 2007) and white-tailed deer on SR 260 (Dodd and Gagnon 2011) and pronghorn on US 89 (Dodd et al. 2011). The team also assessed and compared species-specific highway passage rates by time of day and associated traffic volume and used linear regression to assess the strength of associations between WVCs and traffic volume.

## 4.3 WILDLIFE-VEHICLE COLLISION RELATIONSHIPS

The research team documented the incidence of WVCs along all SR 64 sections using two methods. First, the research team relied on the submission of forms by agency personnel, primarily DPS highway patrol officers, to determine the incidence of WVCs during the study. DPS patrol officers made a concerted effort to record the species and sex of animals involved in WVCs where such could be determined. These records were augmented by regular searches of the highway corridor for evidence of WVCs by research personnel.

The database compiled from the consolidated (non-duplicate) records included the date, time, and location (to the nearest 0.1 mi) of the WVCs, the species involved, and the reporting agency. WVC records were compiled and summarized by highway section by year. Where duplicate reports of WVCs were made by DPS and research team searches, the locations were compared to determine their accuracy (Barnum 2003, Gunson and Clevenger 2003).

The research team used a database compiled by the ADOT Traffic Records Section which includes DPS accident reports to determine the proportion of single-motor vehicle accidents that involved wildlife along the respective highway sections. Huijser et al. (2007) reported that nearly all WVCs are single-vehicle crashes. The research team compared WVC incidence by season (using the same seasons for highway crossings), month, day, and time (2 hr intervals), and used chi-square tests to compare observed versus expected WVC frequencies.

## 4.4 WILDLIFE USE OF CATARACT CANYON BRIDGE

To quantify wildlife use of Cataract Canyon Bridge, the research team employed Reconyx™ professional model single-frame cameras installed within each of the four box-culvert cells (Figure 8). The encased cameras were mounted on wood strips attached to the culvert walls with glue, thus avoiding the need to make modifications to the walls that might impact their integrity. These self-triggering cameras provided infrared illumination to record animals crossing through the bridge at night. The cameras were programmed to record up to five frames per second, providing near-video-like tracking of animals as they approached and crossed through the bridge cells. Images were date, time, and temperature stamped (Figure 9), digitally stored, and periodically downloaded for analysis.

Figure 8. Reconyx™ Camera Mounted on a Wood Strip Glued to the Concrete Surface of Each SR 64 Cataract Canyon Bridge Culvert Cell to Monitor Wildlife Use.


Figure 9. Images of a Mule Deer Doe (Left) and Spike Bull Elk (Right) Recorded by Reconyx™ Cameras Mounted in the SR 64 Cataract Canyon Bridge Culvert Cells.

The research team analyzed camera data to determine the frequency of occurrence of animals by species (and people) that entered and then passed through the bridge cells. Though not able to determine underpass passage rates as done by Dodd et al. ("Video surveillance to assess," 2007) using video camera systems, the proportion of animals that entered the culvert cells and ultimately passed through provided some indication of the relative acceptance by animals to cross SR 64 below grade via Cataract Canyon Bridge.

## 4.5 IDENTIFICATION OF PASSAGE STRUCTURE SITES

Sawyer and Rudd (2005) identified several important considerations for locating the most suitable sites in which to place passage structures, primarily for pronghorn, though these criteria are applicable for other species. In this assessment of potential passage structure sites and to validate the preliminary findings in ADOT (2006), the research team considered each of the criteria identified by Sawyer and Rudd (2005) but recognized that the 0.1 mile segment length used was too small and cumbersome to discern and analyze differences among segments.

Dodd et al. ("Evaluation of Measures," 2007) reported that the optimum scale to address management recommendations for accommodating wildlife passage needs using GPS telemetry or WVC data was at the 0.6 mi scale. Making recommendations at this scale allows ADOT engineers latitude to determine the best technical location for passage structures along the segment. Thus, the team aggregated the 570 0.1 mi segments from MP 185.5 to MP 235.4 into 95 0.6 mi segments for analysis. The research team addressed passage structure needs for the entire highway study area as well as each individual highway section.

Sawyer and Rudd (2005) identified animal abundance as a primary criterion for the consideration of passage structure sites. The research team focused this criterion on the larger population levels adjacent to the entire study area versus by segment. For pronghorn, Sawyer and Rudd (2005) stressed that passage structures were more appropriate in linking populations with "abundant numbers (hundreds)" than small isolated populations that may not benefit to the same degree and exhibit a high likelihood of encountering passage structures. The pronghorn, elk, and mule deer populations adjacent to SR 64 indeed number well into the hundreds, with the herds for all three on both sides of the highway still viable and reproducing.

The team used the other segment-specific criteria identified by Sawyer and Rudd (2005) with some modifications to rate each of the 95 0.6 mi segments, considering GPS telemetry findings with other pertinent factors, as done for US 89 by Dodd et al. (2011). Because passage structures that have the potential to benefit permeability for multiple species are preferred (Clevenger and Waltho 2000), some ratings for elk, deer, and pronghorn were additive, thus weighting those sites that may yield benefit to multiple species. However, because pronghorn range largely did not overlap the higher-density portions of elk and mule deer ranges (Figure 3) and because few, if any, WVCs involving pronghorn were anticipated, the team made separate passage structure recommendations for this species.

The team's rating criteria/categories were as follows:

*Elk highway crossings* – Due to the anticipated availability of highway crossing data for elk, this rating was based on the proportion of SR 64 crossings made by GPS-collared elk within each aggregated 0.6 mi segment across the entire study area. The ratings for elk crossings were additive to mule deer crossings and pronghorn approaches. Categories used include:

| | |
|---|---|
| 0 | No crossings |
| 1 | 1–2% of total elk crossings |
| 2 | 3–4% of total elk crossings |
| 3 | 5–6 % of total elk crossings |
| 4 | 7–8% total elk crossings |
| 5 | >8% of total elk crossings |

*Mule deer highway crossings* – This rating was also based on the proportion of SR 64 crossings made by GPS-collared mule deer within each aggregated 0.6 mi segment. However, because deer were only captured adjacent to SR 64 Section E, rather than adjacent to a greater length of SR 64, the ratings reflect higher proportions of crossings. The ratings for mule deer crossings were additive to those for elk crossings and pronghorn approaches. Categories used include:

| | |
|---|---|
| 0 | No crossings |
| 1 | 1–2% of total crossings for the species |
| 2 | 3–4% of crossings for the species |
| 3 | 5–6 % of crossings for the species |
| 4 | 7–8% of crossings for the species |
| 5 | >8% of total crossings for the species |

*Pronghorn approaches* – This criterion was considered indicative of where animals potentially would approach and cross SR 64 via a passage structure and was based on the proportion of approaches to within 0.3 mi on both sides of the highway for aggregated 0.6 mi segments. This rating was additive with elk and mule deer crossing ratings where GPS-collared animals overlapped. Categories used include:

| | |
|---|---|
| 0 | No approaches |
| 1 | 1–3% of total pronghorn approaches |
| 2 | 3–5% of total pronghorn approaches |
| 3 | 5–15% of total pronghorn approaches |
| 4 | 15–25% of total pronghorn approaches |
| 5 | >25% of total pronghorn approaches |

*Elk, mule deer, and pronghorn distribution* – This rating was based on the number of different GPS-collared animals that crossed SR 64 for elk and deer and were relocated within the 0.3 mi approach zone for pronghorn. This rating was additive for each of the three species where data overlapped. Categories used include:

| | |
|---|---|
| 0 | No animals crossing or approaching |
| 1 | 1–2% of all animals crossing or approaching |
| 2 | 2–4% of all animals crossing or approaching |
| 3 | 4–6% of all animals crossing or approaching |
| 4 | 6–8% of all animals crossing or approaching |
| 5 | >8% of all animals crossing or approaching |

*Wildlife-vehicle collisions* – The number of non-duplicate WVCs recorded by 0.6 mi segment during the project (2007–2009) for elk, mule deer, pronghorn, and other large mammals such as mountain lion, black bear, badger, etc. categories used include:

| | |
|---|---|
| 0 | No WVC |
| 1 | 1–2 total WVCs |
| 2 | 3–4 total WVCs |
| 3 | 5–6 total WVCs |
| 4 | 7–8 total WVCs |
| 5 | >8 total WVCs |

*Land status* – This criterion reflected the ability to conduct construction activities on and outside the ADOT right-of-way (ROW), such as creating approaches with fill material for overpasses. Categories used include:

| | |
|---|---|
| 0 | Private |
| 1 | State Trust |
| 3 | National Park Service – GCNP (preservation and natural process focus) |
| 5 | Federal – U.S. Forest Service (multiple-use focus) |

*Human activity* – Ideally, no human activity should occur within the vicinity of a passage structure; however, road access, businesses, visitor pullouts, and other activities occur adjacent to US 89. Categories used include:

| | |
|---|---|
| 0 | Significant human activity (business, housing, etc.) |
| 1 | Moderate human activity (access road, visitor pullout) |
| 3 | Limited human activity |
| 5 | No human activity |

*Topography* – The ability to situate overpasses oriented along existing ridgelines that pronghorn, elk, or deer can traverse, or locate underpasses in association with wide gentle drainages is desirable. Categories used include:

| | |
|---|---|
| 0 | Terrain not suited for a passage structure (steep, broken) |
| 1 | Topography marginal for a passage structure (flat) |
| 3 | Topography could accommodate a passage structure (small drainage) |
| 5 | Topography ideally suited for passage structure (large drainage for underpass or ridgeline for overpass) |

In addition to the above criteria, the research team also considered other factors in its identification of potential passage structure sites. These factors included whether the 0.6 mile segments coincided with the preliminary sites recommended in ADOT *(2006)*, if the types of structures were suited for the site, and how the priority segments from this study relate to the minimum recommended passage structure spacing determined by Bissonette and Adair (2008).

# 5.0 RESULTS

## 5.1 WILDLIFE CAPTURE, GPS TELEMETRY, AND DATA ANALYSIS

### 5.1.1 Elk Capture, Movements, and Highway Permeability

From June 2007 through October 2009, the research team tracked and recovered data from 23 elk (13 females, 10 males) instrumented with GPS receiver collars; 17 elk were trapped in Clover traps and six were captured by darting with immobilizing drugs. Only three elk were captured at the far south end of the study area adjacent to Section A, while the remainder were captured at the north end adjacent to Section E (Figure 1).

GPS collars were affixed to elk for an average of 302.9 days (±33.4 SE), during which time the collars accrued 107,055 GPS fixes for a mean of 4654.6 fixes per elk (±322.6). Of the GPS fixes, 12,483 (11.6 percent) were recorded within 0.6 mi of SR 64, and 3796 (3.5 percent) of the fixes were made within 0.15 mi; the proportion of fixes near SR 64 were considerably lower than those for SR 260, where 48.5 percent occurred within 0.6 mi of the highway (Dodd et al. "Effectiveness of Wildlife," *in review*). Elk traveled an average of 1082.1 ft (±105.3) between GPS fixes. Males traveled slightly farther between crossings (1107.1 ft ±57.5) than females (1051.2 ft ±142.1). Elk minimum convex polygon (MCP) home ranges averaged 284.8 $mi^2$ (±56.3), and male home ranges (479.5 $mi^2$ ±165.5) which were significantly larger ($t_{21} = 2.45$, $P < 0.001$) than female home ranges (199.6 $mi^2$ ±17.8).

GPS-collared elk crossed SR 64 843 times, for a mean of 40.1 crossings per elk (±11.2). On average, elk crossed SR 64 0.12 time per day (±0.03), and ranged from 1 to 200 crossings per elk, though four elk never crossed SR 64. The highest proportion of crossings occurred in late spring–summer (April–July; 60 percent), followed by late summer–fall (August–November; 27 percent), and only 13 percent during winter–early spring (December–March). The overall elk passage rate averaged 0.44 crossing per approach (±0.07; Table 3). There was no significant statistical difference between mean passage rates for female and males elk (0.46 ±0.08 vs. 0.43 ±0.12 respectively).

The crossing distribution by elk among SR 64 0.1 mi segments was not random and exhibited several peak crossing zones (Figure 10), especially at the north end of the study area. The observed crossing distribution differed significantly from a random distribution (Kolmogorov-Smirnov $d = 0.309$, $P < 0.001$). The limited number of crossings at the southern area (Section A) reflects that only three elk were captured in this area and that these elk crossed SR 64 only an average of three times versus the study area average of 40.1 crossings per elk.

A total of 48 crossings occurred along Section D, with one apparent peak crossing zone, and 786 occurred along Section E, where several crossing peaks were registered by elk (Figure 10). The highest concentration of different crossing elk occurred between Segments 470 and 500, with seven animals (30.4 percent of all elk) and a mean of 3.2 different animals per 0.1 mi segment.

Weighted highway crossings reflect the frequency of elk crossings, the number of individual elk that crossed at each segment, and the evenness in crossing frequency among all collared animals. The weighted elk crossing pattern (Figure 11) was noticeably different than the uncorrected crossing distribution. Crossing peaks on Sections A and D were absent in the weighted crossing distribution due to the relatively small number of elk that crossed at these peak zones (Figure 10).

Table 3. Comparative Mean Values for GPS-Collared Animals by Species Determined from GPS Telemetry along SR 64.

| Parameter | Mean value per GPS-collared animal by species (±SE) | | |
|---|---|---|---|
| | Elk (*n* = 23) | Mule deer (*n* = 11) | Pronghorn (*n* = 15) |
| No. of highway crossings | 40.1 (11.2) | 55.0 (16.4) | 0.2 (0.2) |
| Highway crossings per day | 0.12 (0.03) | 0.26 (0.06) | 0.001 (0.001) |
| GPS fixes ≤0.6 mi of highway per year | 632.2 (164.4) | 1921.4 (637.7) | 791.0 (184.4) |
| GPS fixes ≤0.15 mi of highway per year | 346.6 (97.7) | 1054.9 (354.2) | 370.1 (84.1) |
| GPS fixes ≤0.06 mi of highway per year | 198.8 (63.2) | 522.4 (167.9) | 116.7 (21.4) |
| Highway approaches per day | 0.21 (0.04) | 0.58 (0.12) | 0.27 (0.16) |
| Passage rate (crossings per approach) | 0.44 (0.07) | 0.54 (0.08) | 0.004 (0.002) |
| MCP home ranges ($mi^2$) | 284.8 (56.3) | 141.1 (48.3) | 85.8 (21.1) |
| Distance traveled between GPS fixes (ft) | 1107.1 (57.5) | 942.2 (232.9) | 845.2 (46.6) |

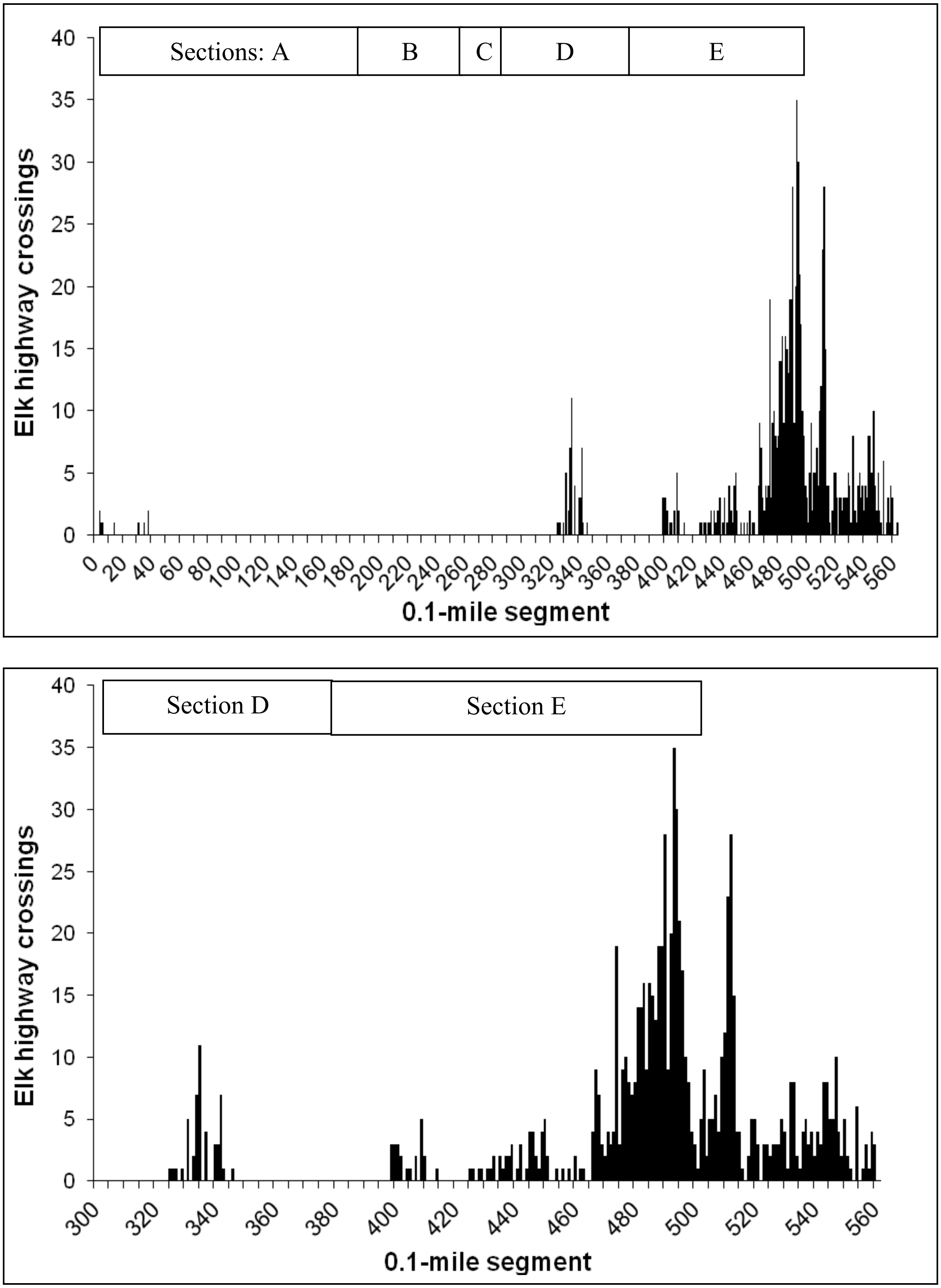



Figure 10. SR 64 Crossings by GPS-Collared Elk along the Entire Study Area (Top) and Sections A through E of the 2006 *Final Wildlife Accident Reduction Study* and Enlarged to Show Crossings along Sections D and E (Bottom).

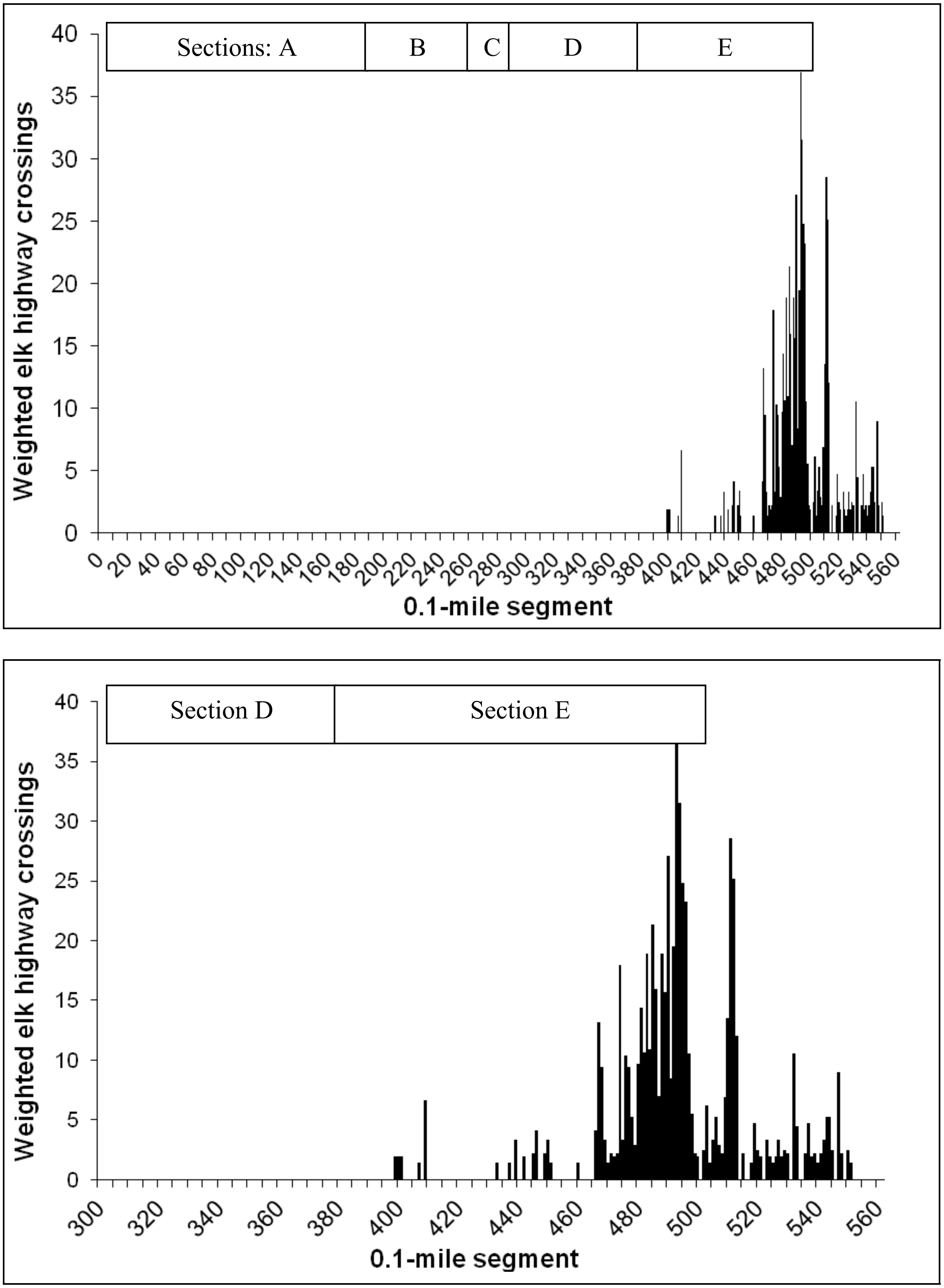



Figure 11. SR 64 Weighted Crossings by GPS-Collared Elk along the Entire Study Area (Top) and Sections A through E of the 2006 *Final Wildlife Accident Reduction Study* and Enlarged to Show Crossings along Sections D and E (Bottom).

### 5.1.2 Mule Deer Capture, Movements, and Highway Permeability

From April 2008 through October 2009, the research team tracked and recovered data from 11 mule deer (8 females, 3 males) instrumented with GPS receiver collars. Deer were captured adjacent only to Section E at the far north extent of the study area.

GPS collars were affixed to deer for an average of 207.9 days (±38.7), during which time they accrued 29,944 GPS fixes, for a mean of 5988.5 fixes per deer (±128.0). Deer were relocated near SR 64 more than elk, with 12,047 (57.2 percent) fixes recorded within 0.6 mi of SR 64, and 3796 (15.6 percent) of the fixes made within 0.15 mi of the highway. Mule deer traveled an average of 942.2 ft (±232.9) between GPS fixes. Males traveled slightly farther between crossings (1003.7 ft ±323.5) than females (820.9 ft ±155.2). Home ranges averaged 141.1 $mi^2$ (±48.3); male home ranges (189.8 $mi^2$ ±184.9) were not significantly different ($P = 0.343$) from female ranges (132.3 $mi^2$ ±51.4).

Five mule deer (two males, three females) captured along SR 64 exhibited extreme long-distance (more than 100 mi) movements away from SR 64 to the south, most independently of each other. All five followed the same travel corridor to an area northwest of Flagstaff and west of the San Francisco Peaks (Figure 12). The mean home range of these five deer (342.1 $mi^2$ ±41.9) was 22 times greater than those that did not make such movements (15.5 $mi^2$ ±3.6; $t_{11} = 10.0$, $P < 0.001$). The factors contributing to such movement patterns is being addressed in another study by the research team, but such movements point to the need to maintain landscape connectivity for far-ranging species.

Collared deer crossed SR 64 550 times, for a mean of 55.0 crossings per deer (±16.4). On average, deer crossed SR 64 twice as frequently as elk, or 0.26 times per day (±0.06). Deer crossings ranged from 2 to 147 crossings per deer, and one deer never crossed SR 64. Seasonal deer crossings were more consistent than elk, though 46 percent occurred during late summer–fall (August–November), followed by 28 percent in late spring–summer (April–July), and 26 percent in winter–early spring (December–March). The overall deer passage rate was higher than that for elk and averaged 0.54 crossing per approach (±0.08; Table 3). The mean passage rate for female deer (0.59 crossing per approach; ±0.08) was higher than that for male deer (0.34 ±0.34).

The deer crossing distribution by 0.1 mi segments did not occur randomly and exhibited two peak crossing zones; all crossings occurred along Section E beyond Segment 420 (Figure 13). The observed mule deer crossing distribution differed significantly from a random distribution (Kolmogorov-Smirnov $d = 0.281$, $P < 0.001$). The two crossing peaks occurred along a 3.2 mi stretch (Segments 480–512) between the entrances to Grand Canyon Airport and GCNP (Figure 13); 505 crossings (92 percent of total) occurred along this stretch of highway, though deer were captured along the length of Section E.

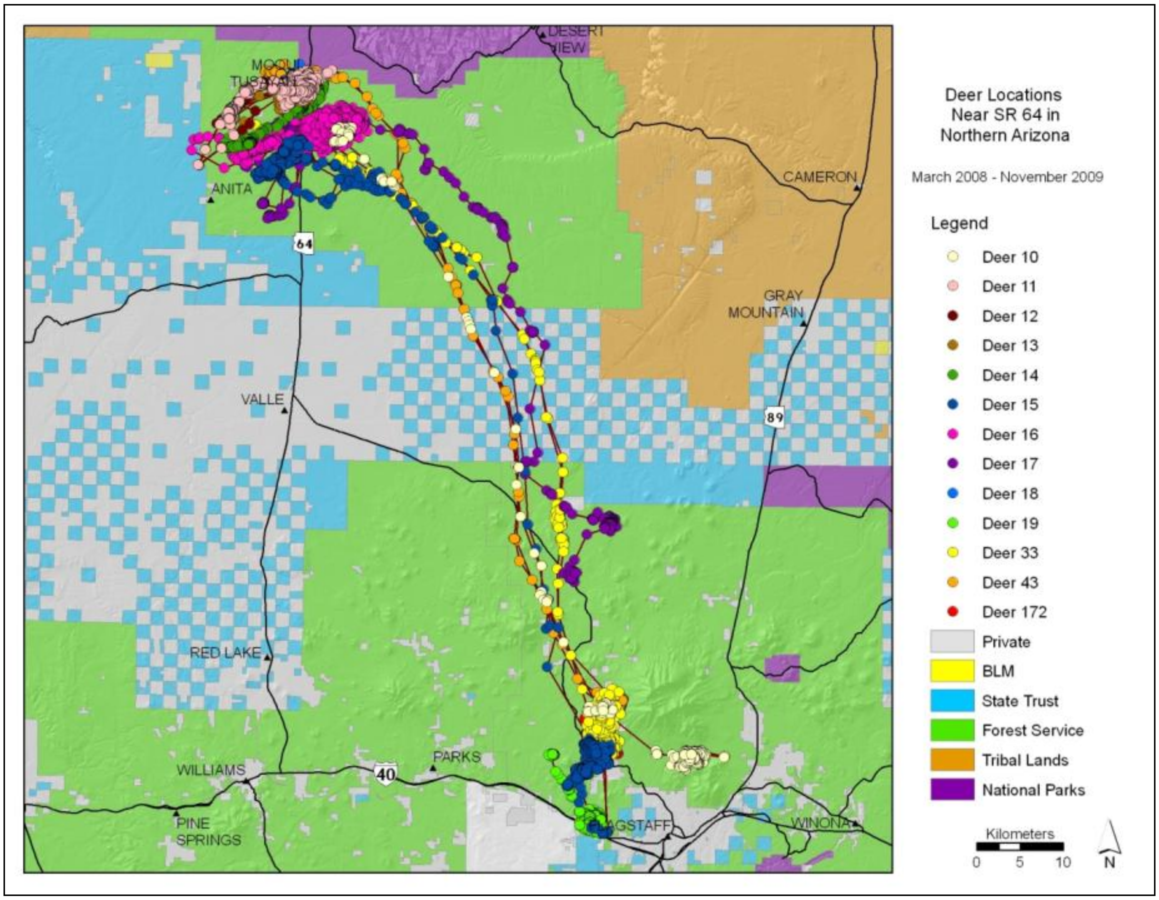


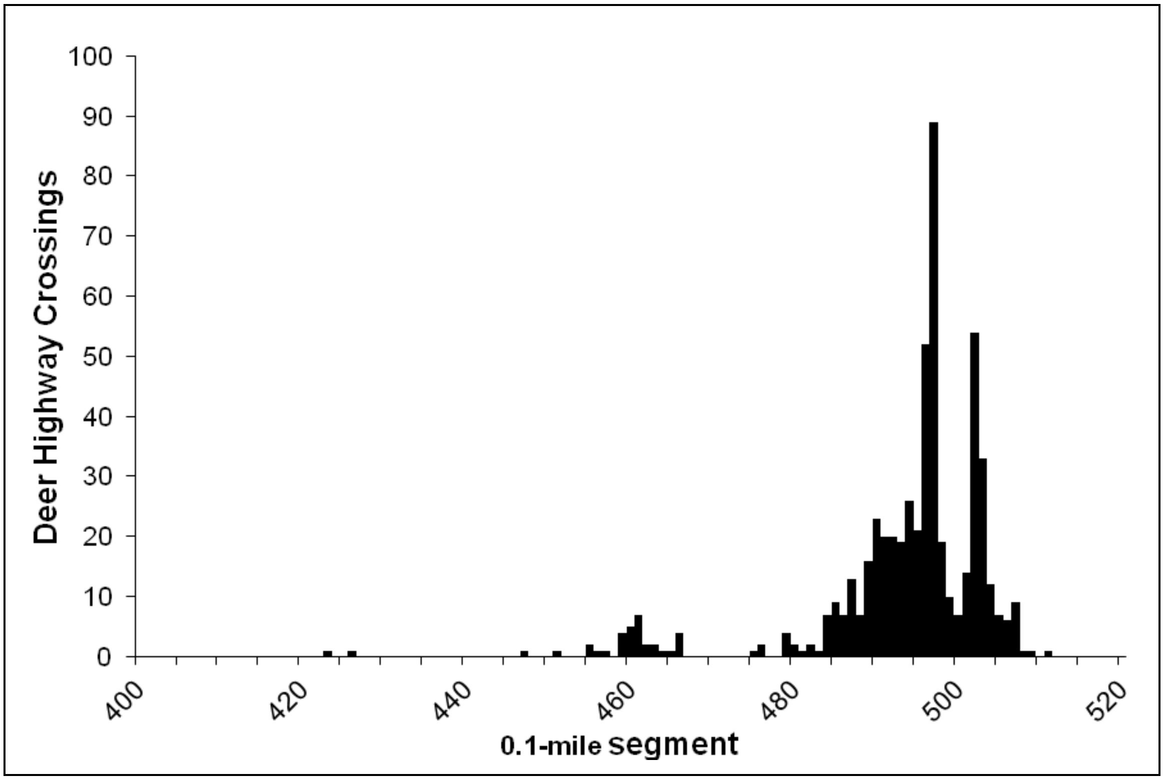

Figure 12. Mule Deer GPS Fixes along the SR 64 Study Area, as well as Fixes for Two Deer Captured North of Flagstaff (Numbers 43 and 172).

When considering the number of crossing mule deer in calculating weighted crossings, the same two peaks in the crossing distribution were even more apparent. Deer crossings between Segments 450 and 470 largely disappeared and were restricted to two segments when weighted crossings were calculated (Figure 13).

### 5.1.3 Pronghorn Capture, Movements, and Highway Approaches

The research team instrumented and tracked 15 pronghorn (10 females, 5 males) with GPS receiver collars from January 2008 through January 2009. Due to disparity in the distribution of pronghorn herds (Figure 3) adjacent to SR 64, coupled with the prevalence of closed private lands across much of the pronghorn range, the team was not able to achieve its objective of collaring an equal number of animals on each side of the highway; 10 were captured on the east side and five on the west.

GPS collars were affixed to pronghorn an average of 298.1 days (±29.6), during which time the collars accrued 56,433 GPS fixes for a mean of 3762.2 fixes per pronghorn (±339.0).



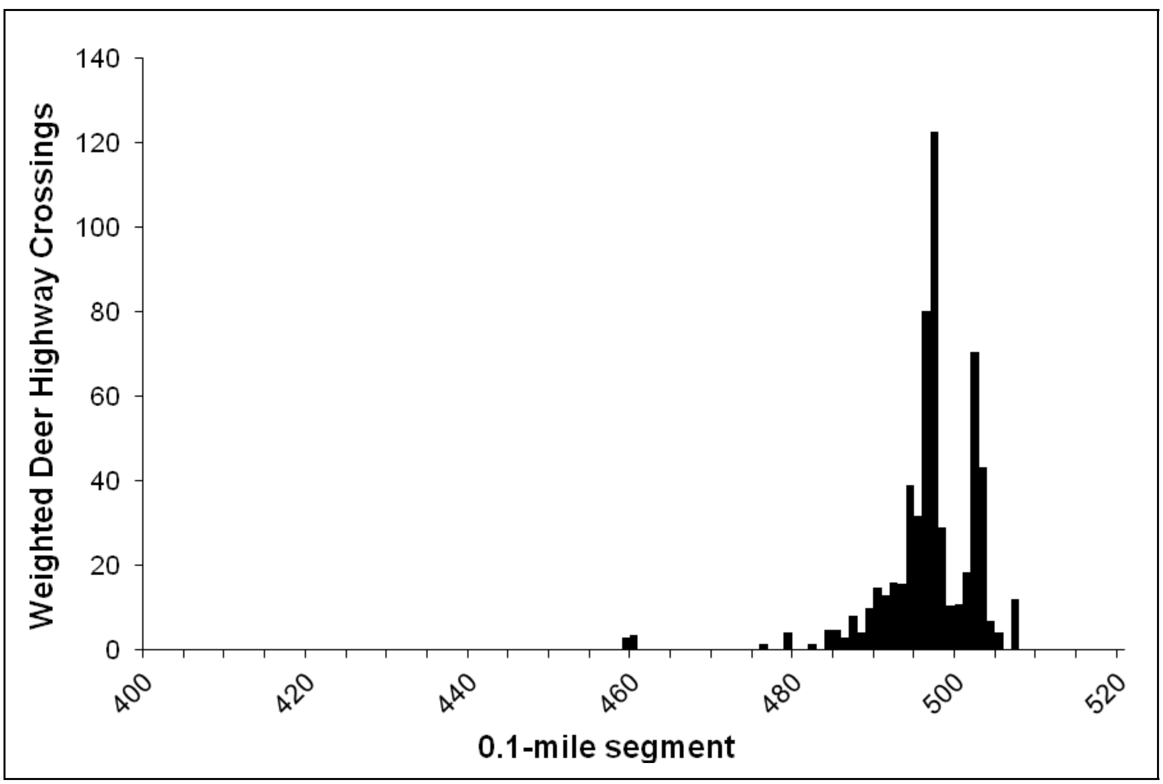




Figure 13. SR 64 Highway Crossings (Top) and Weighted Crossings (Bottom) by GPS-Collared Mule Deer along Highway Section E by 0.1 mi Segment.

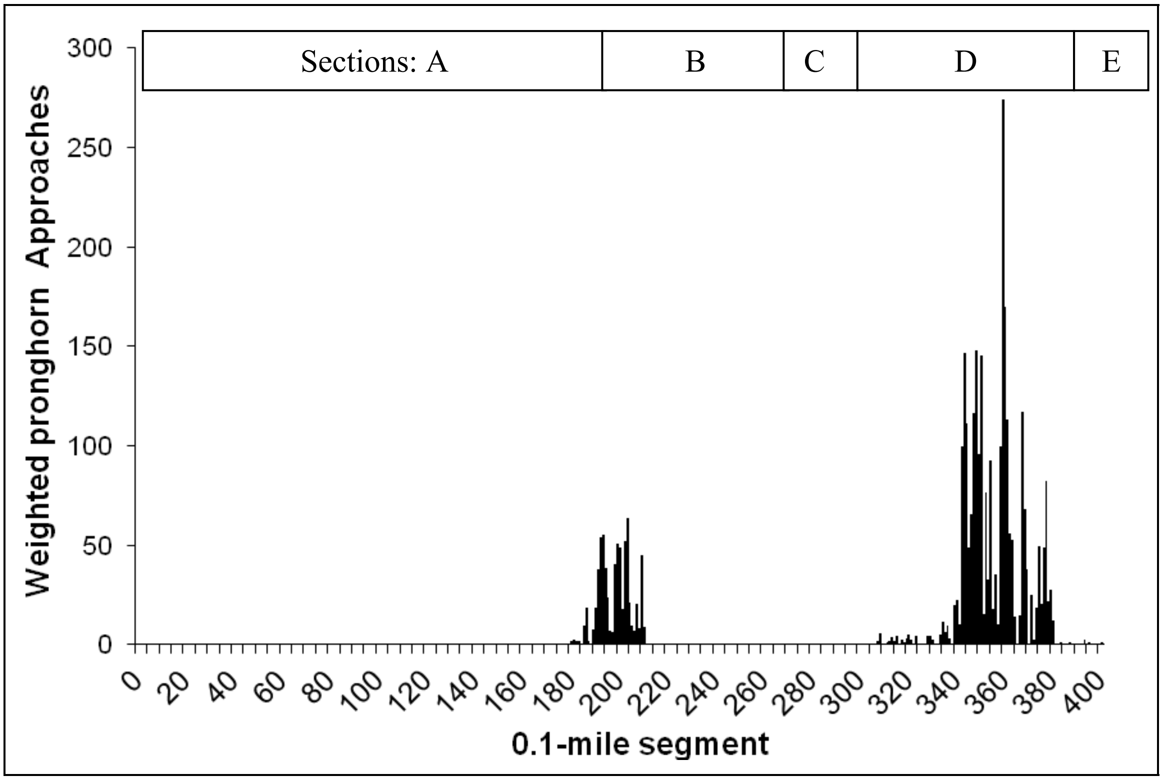
Of the GPS fixes accrued for pronghorn, 1426 (3 percent) occurred within 0.15 mi of SR 64, or an average of 95.1 (±26.1) fixes per animal; all but one pronghorn approached the highway to within 0.15 mi. All 15 pronghorn approached to within 0.60 mi of the highway, accruing 9729 GPS fixes (17 percent of all fixes), with a mean of 648.6 (±151.2) fixes per animal. During the duration of GPS tracking, pronghorn traveled an average of 845.2 ft (±46.6) between fixes (1.5 hr). Females traveled farther between fixes (905.5 ft ±44.6) than males (724.1 ft ±72.2). Pronghorn home ranges averaged 85.8 $mi^2$ (±21.1), and there was no difference between male (88.6 $mi^2$ ±29.6) and female (84.4 $mi^2$ ±34.5) home ranges ($P = 0.469$).

Only a single GPS-collared pronghorn crossed SR 64 during tracking—a female that crossed three times; none of the other 14 collared pronghorn crossed the highway. The pronghorn crossing rate averaged 0.001 crossings per day. The mean pronghorn passage rate was a negligible 0.004 crossings per approach (Table 3).

The frequency of approaches by pronghorn to within 0.30 miles of SR 64 yielded considerably more information than crossings for the determination of potential passage structure locations. Pronghorn approached the highway to within 0.30 miles 4269 times (Figure 14), for a mean of 284.6 (±69.0) approaches per animal and a range of 2 to 907 approaches.

The observed approach distribution did not occur in a random distribution (Kolmogorov-Smirnov $d = 0.883$, $P < 0.001$). Partly owing to the disparity in the number of collared animals on the east and west sides of SR 64, it is not unexpected that 3623 approaches were from the east and only 465 from the west. However, the approaches per animal were also dramatically different; 362.2 approaches per animal (±74.4) on the east side versus 91.2 approaches per animal (±121.3) from the west. All but two approaches to SR 64 between Segments 1 and 220 were made by pronghorn approaching from the east, though a limited number of animals were captured on the west side along this stretch.

Shannon diversity index (SDI)-weighted pronghorn approaches totaled 2756.7, and the distribution pattern changed considerably from the uncorrected approach distribution. The peak in crossings at the south end of the study area disappeared, owing to there being only a single male that approached here. The weighted distribution of approaches also showed an increased peak in approaches at the north extent of pronghorn range, between Segments 310 and 390. Between Segments 340 and 370, 11 different collared animals (73.3 percent of total) approached SR 64, with a mean of 6.9 different animals per 0.1 mile segment. The peak in approaches between Segments 180 and 220 at the center of the study area remained prevalent even after SDI-weighted approaches were calculated (Figure 14), though approaches here were attributable to just two pronghorn.



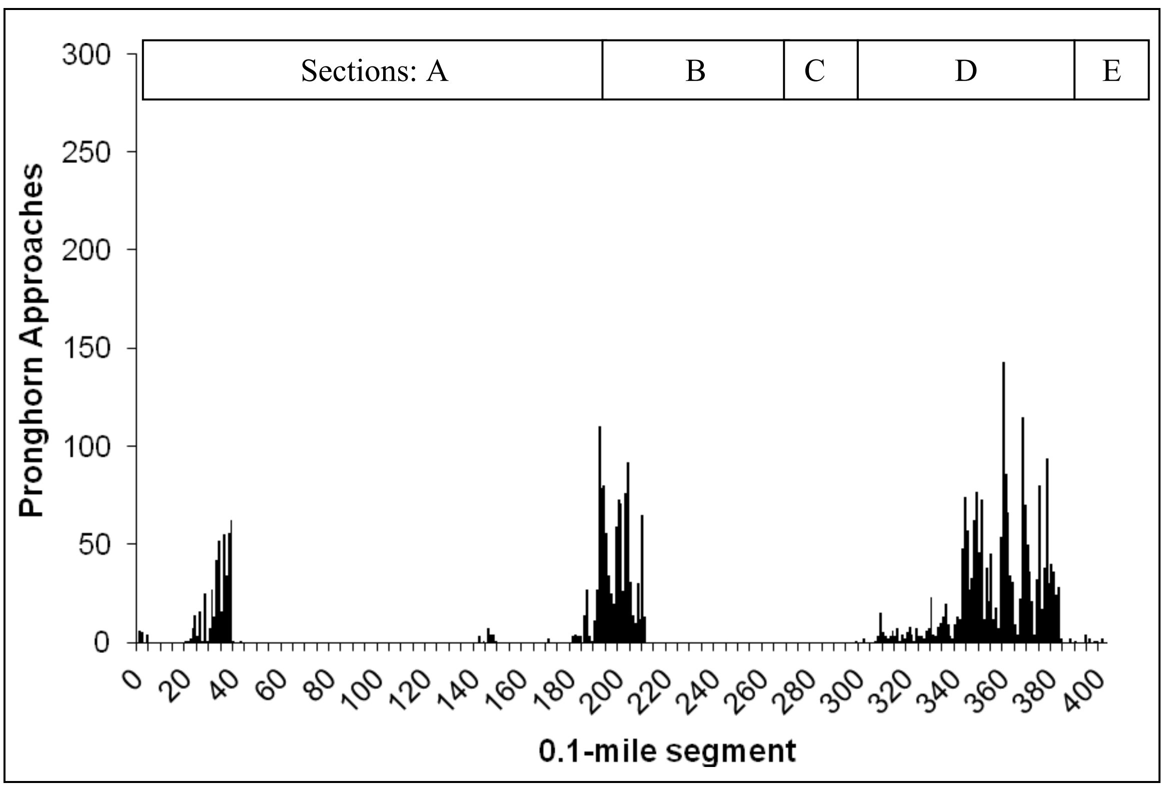




Figure 14. Highway Approaches (Top) and Weighted Approaches (Bottom) Made to within 0.3 mi of SR 64 by GPS-Collared Pronghorn and Sections A through E of the 2006 *Final Wildlife Accident Reduction Study*.

## 5.2 TRAFFIC RELATIONSHIPS

### 5.2.1 Elk-Traffic Relationships

The research team's elk distribution analysis was based on 12,483 GPS fixes recorded within 3300 ft of the highway. Frequency distributions of mean probabilities showed a shift in distribution away from SR 64 with increasing traffic volume (Table 4; Figure 15). The shift away from the highway occurred even at relatively low traffic volume (Figure 15), with a 64 percent decrease in probability of elk occurring within 660 ft from traffic volume less than 100 vehicles per hr (0.28 probability) to 200 to 300 vehicles per hr (0.10). The mean probability of elk occurring within 660 ft of SR 64 remained constant at 0.08 from 200 to 600 vehicles per hr. The mean probability of elk occurring farther away from the highway (1650 and 1980 ft distance bands) increased 65 percent from traffic less than 100 vehicles per hr (0.17) to 500 to 600 vehicles per hr (0.28).

Elk passage rates by 2 hr time blocks ranged from 0.01 (18:00–20:00) to 0.72 crossings per approach (04:00–06:00), with the passage rate between midnight and 04:00 when traffic was nearly absent along the highway (Figure 5) averaging 0.63 crossings per approach (±0.05; $n = 45$). This nighttime rate was more than three times higher than the mean passage rate during the rest of the day, averaging 0.19 crossings per approach (±0.04; $n = 72$; Figure 16). There was a significant negative association between the elk passage rate by 2 hour blocks and increasing traffic volume ($r = -0.660$, $P = 0.022$). The passage rate by day averaged 0.48 crossings per approach (±0.16) and was relatively constant for most days (0.42–0.49) except for Tuesday (0.64).

### 5.2.2. Mule Deer–Traffic Relationships

The research team's mule deer distribution analysis was based on 12,047 GPS fixes recorded within 3300 ft of the highway. Mule deer frequency distributions of combined mean probabilities showed shifts in distribution away from the highway with increasing traffic volume, though not as dramatic as for elk (Table 4; Figure 17). At low traffic volumes less than 200 vehicles per hr, probabilities for deer occurring within 660 ft of the highway averaged 0.21 but dropped when traffic was more than 200 vehicles per hr and remained static out to 1980 ft, averaging 0.11.

Mean deer probabilities of occurring within the 1650–1980 ft distance band largely remained unchanged across traffic volume classes (mean = 0.21) up to 500 vehicles per hr but dropped to a mean probability of 0.14 at more than 500 vehicles per hr. The most dramatic shift in deer distribution occurred in the intermediate distance bands, 990–1320 ft from SR 64, with the probability of deer occurring here doubling from 0.12 at less than 100 vehicles per hr to 0.24 at just 100 to 200 vehicles per hr; the probability of deer occurring at this distance remained static up to 500 vehicles per hr and averaged 0.21.

Deer passage rates by 2 hour time blocks ranged from 0.03 (19:00–21:00) to 0.78 crossings per approach (03:00–05:00 a.m.), with the passage rate between midnight and 04:00 a.m. when traffic was absent, averaging 0.58 crossings per approach (±0.03). This nighttime rate was more than two times the mean passage rate during the rest of the day, averaging 0.28 crossings per approach (±0.02; Figure 16). Unlike elk, the deer passage rate remained relatively high (0.61 crossings per approach [±0.02]) well into the morning hours up until the 09:00–11:00 time block (Figure 16).

Due to the passage rates remaining high into the morning hours, the negative association between the deer passage rate by 2 hr blocks and increasing traffic volume was not significant ($r = -0.07$, $P = 0.831$). The passage rate by day of the week averaged 0.47 crossings per approach (±0.10), which was relatively constant for most days, and ranged from 0.42 on weekend days to 0.50 the remainder of the week.

Table 4. Mean Probabilities that GPS-Collared Elk, Mule Deer, and Pronghorn Occurred within Distance Bands from SR 64 at Varying Traffic Volumes. Documented from 2007 through 2009.

| Distance from highway (ft) by species | Probability of occurring in distance band by traffic volume (vehicles per hour) | | | | | |
|---|---|---|---|---|---|---|
| | <100 | 100–200 | 200–300 | 300–400 | 400–500 | 500–600 |
| 0–990 | | | | | | |
| Elk | 0.36 | 0.21 | 0.18 | 0.18 | 0.15 | 0.15 |
| Mule deer | 0.38 | 0.32 | 0.23 | 0.17 | 0.18 | 0.19 |
| Pronghorn | 0.23 | 0.18 | 0.16 | 0.15 | 0.12 | 0.11 |
| All | 0.34 | 0.22 | 0.19 | 0.17 | 0.14 | 0.14 |
| 990–1980 | | | | | | |
| Elk | 0.26 | 0.26 | 0.28 | 0.31 | 0.31 | 0.40 |
| Mule deer | 0.27 | 0.34 | 0.33 | 0.31 | 0.31 | 0.21 |
| Pronghorn | 0.30 | 0.33 | 0.32 | 0.34 | 0.31 | 0.35 |
| All | 0.28 | 0.30 | 0.30 | 0.32 | 0.31 | 0.33 |
| 1980–2970 | | | | | | |
| Elk | 0.28 | 0.38 | 0.27 | 0.38 | 0.43 | 0.33 |
| Mule deer | 0.29 | 0.26 | 0.34 | 0.39 | 0.37 | 0.43 |
| Pronghorn | 0.37 | 0.38 | 0.43 | 0.38 | 0.47 | 0.45 |
| All | 0.30 | 0.36 | 0.40 | 0.38 | 0.43 | 0.40 |

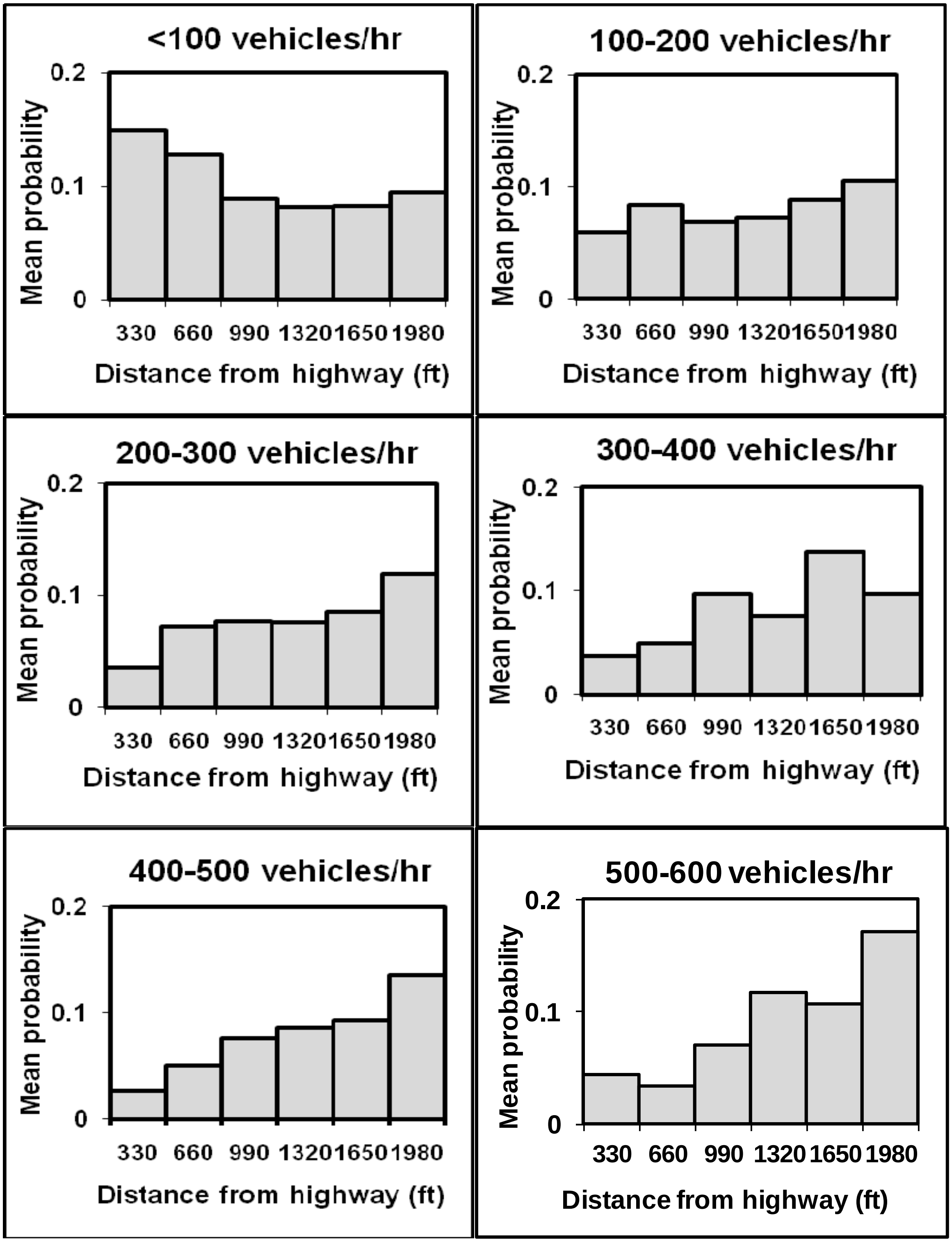



Figure 15. Mean Probability That GPS-Collared Elk Occurred within 330 ft Distance Bands along SR 64 at Varying Traffic Volumes.

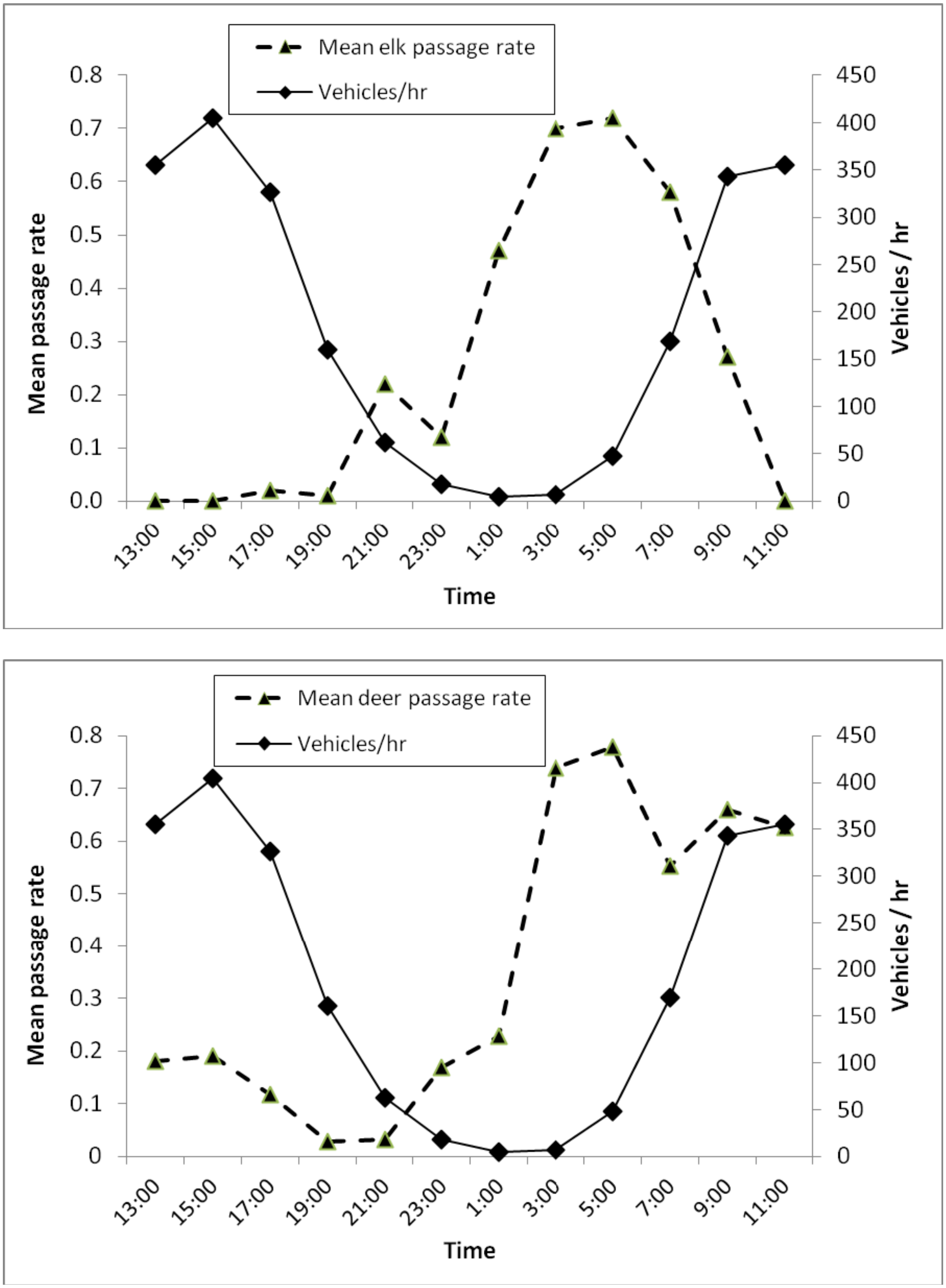



Figure 16. Mean SR 64 Passage Rates by Two-Hour Time Blocks (Reflected by the Midpoint of the Blocks) and Corresponding Mean Traffic Volumes during Each Time Block for Elk (Bottom) and Mule Deer (Top).

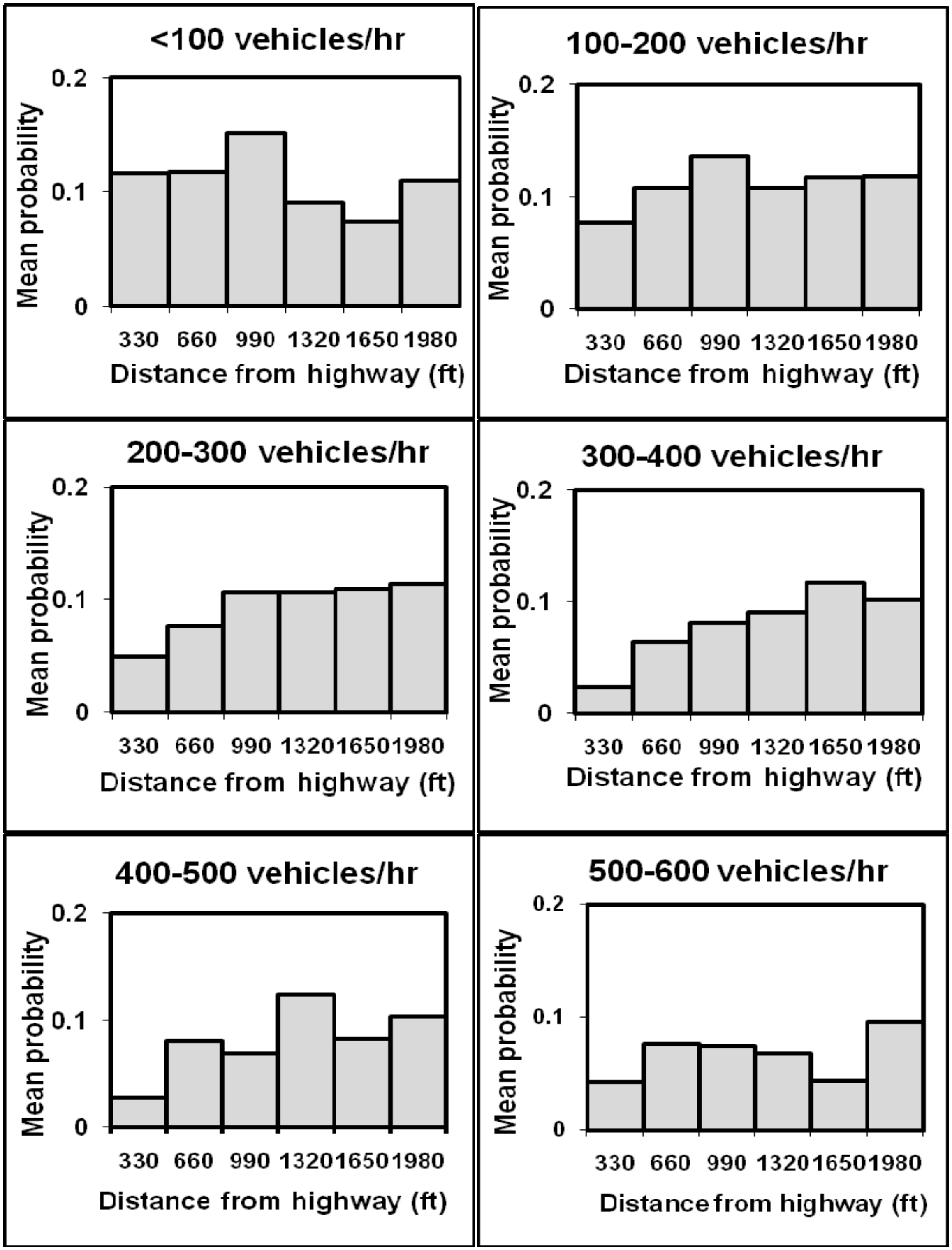



Figure 17. Mean Probability That GPS-Collared Mule Deer Occurred within 330 ft Distance Bands along SR 64 at Varying Traffic Volumes.

### 5.2.3. Pronghorn-Traffic Relationships

The team's distribution analysis was based on 9729 pronghorn GPS fixes recorded within 3300 ft of SR 64. Regardless of traffic volume, even at the lowest levels, pronghorn distribution within 660 ft of the highway was low, with all combined probabilities less than 0.07 (Figure 18). In the 990–1320 ft distance bands, the mean combined probability of occurrence dropped from 0.28 at less than 100 vehicles per hr but stayed relatively constant thereafter (0.20–0.21) up to 400 vehicles per hr, with a slight drop to 0.13 at 400–500 vehicles per hr. In the 1980 ft distance band, the mean probability of pronghorn occurring here increased from 0.07 at less than 100 vehicles per hr to 0.13 at just 100–200 vehicles per hr, and up to 0.16 at 500–600 vehicles per hr (Figure 18).

The proportion of pronghorn GPS approaches made to within 0.15 mi of SR 64 ($n$ = 951) varied throughout the day. Nearly half the approaches (48 percent) occurred between 16:30 and 19:00, when traffic was at its highest level during the day. During the morning hours (05:30–10:00 hr), 18 percent of the approaches occurred, as did an equal proportion of approaches made during midday hours (10:00–16:30).

## 5.3. WILDLIFE-VEHICLE COLLISION RELATIONSHIPS

From 2007 through 2009, DPS highway patrol officers and research team members recorded 157 WVCs involving elk and mule deer along the SR 64 study area (Table 5). Elk accounted for 63 percent ($n$ = 99) of these WVCs, followed by mule deer, which accounted for 35 percent ($n$ = 58). In addition, three coyotes, three rabbits and one mountain lion, black bear, and badger each were involved in WVCs during the study period. No collisions involving pronghorn were recorded. In total, 77 WVCs were recorded in 2007 (46 elk, 28 deer, 4 other), 51 in 2008 (33 elk, 16 deer, 2 other), and 40 in 2009 (20 elk, 14 deer, 3 other). DPS highway patrol accident reports indicated that 27 human injuries occurred in WVCs during the study.

Table 5. WVCs Involving Elk and Mule Deer on SR 64 Sections from 2007 through 2009, including the Total Number and Mean Collisions (per Mile).

| SR 64 section | Elk collisions | | Deer collisions | | All collisions | |
|---|---|---|---|---|---|---|
| | Total | Mean (per mile) | Total | Mean (per mile) | Total | Mean (per mile) |
| A | 26 | 1.3 | 30 | 1.6 | 56 | 2.9 |
| B | 4 | 0.5 | 0 | – | 4 | 0.5 |
| C | 0 | – | 0 | – | 0 | – |
| D | 13 | 1.4 | 3 | 0.3 | 16 | 1.8 |
| E | 56 | 4.7 | 25 | 2.1 | 81 | 6.8 |
| All | 99 | 1.9 | 58 | 1.2 | 157 | 3.1 |

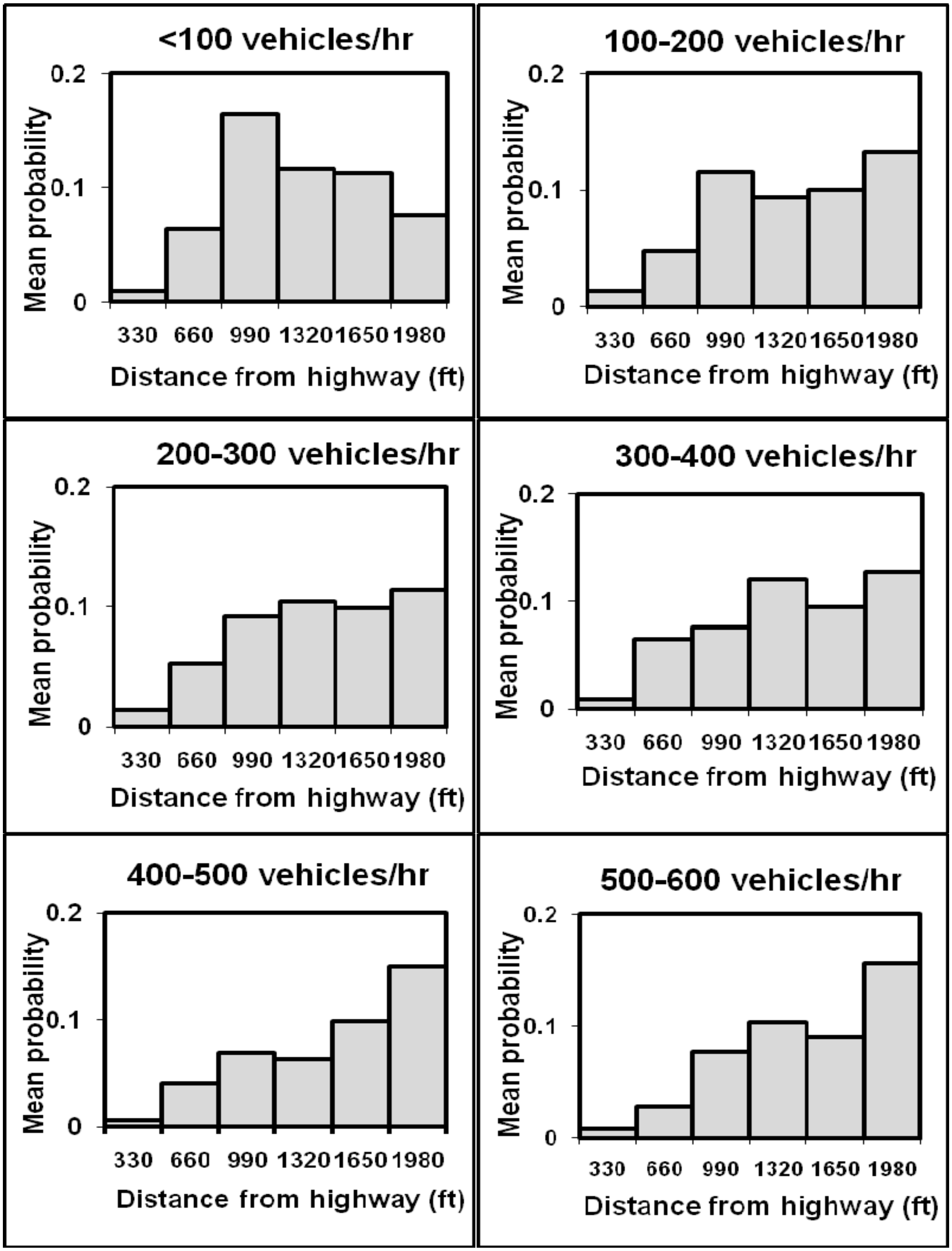



Figure 18. Mean Probability That GPS-Collared Pronghorn Occurred within 330 ft Distance Bands along SR 64 at Varying Traffic Volumes.

Section E (MP 223.4 to MP 235.4) had the highest incidence of elk and deer collisions, as well as collisions per mile and more than twice the collisions per mile than Section A (MP 185.5 to MP 204.7; Figure 19); these sections account for the highest density elk and deer range along SR 64 (Figure 3). The spatial association between elk-vehicle collisions and crossings at the 1.0 mi scale was significant ($r = 0.811$, $n = 27$, $P < 0.001$), as was the association for deer ($r = 0.705$, $n = 10$, $P = 0.022$).

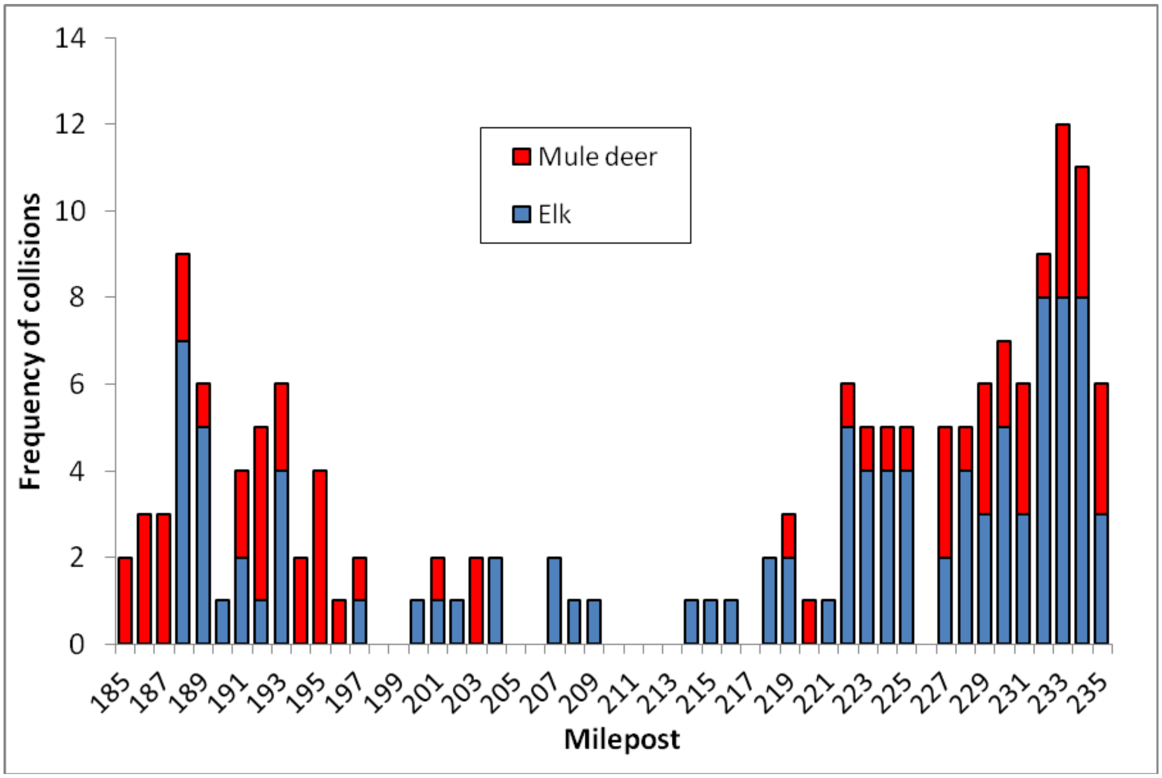



Figure 19. Frequency of Elk and Mule Deer Collisions with Vehicles by SR 64 Milepost from 2007 through 2009.

From 1998 through 2008, 41.7 percent of all single-vehicle accidents recorded along SR 64 involved wildlife, compared with the national average of just 4.6 percent (Huijser et al. 2007; Figure 20). The proportion of accidents involving wildlife (recorded by MP) was as high as 87 percent (MP 233), with wildlife-related accidents accounting for more than 75 percent of all single-vehicle accidents along five mileposts (all from MP 229 to MP 234; Figure 20).

For accidents where time was reported by DPS, the incidence of elk and deer collisions varied considerably among time periods (Table 6; Figure 21). The highest proportion of elk collisions (50 percent) occurred from 5:00 p.m. to 10:00 p.m., followed by 39 percent from 11:00 p.m. to 04:00 a.m. Only 11 percent of elk accidents occurred from 05:00 to 10:00 a.m., and none were recorded from 11:00 a.m. to 4:00 p.m. The observed frequency of elk-vehicle collisions by time period differed from expected values ($\chi^2 = 62.5$, df = 3, $P < 0.001$).

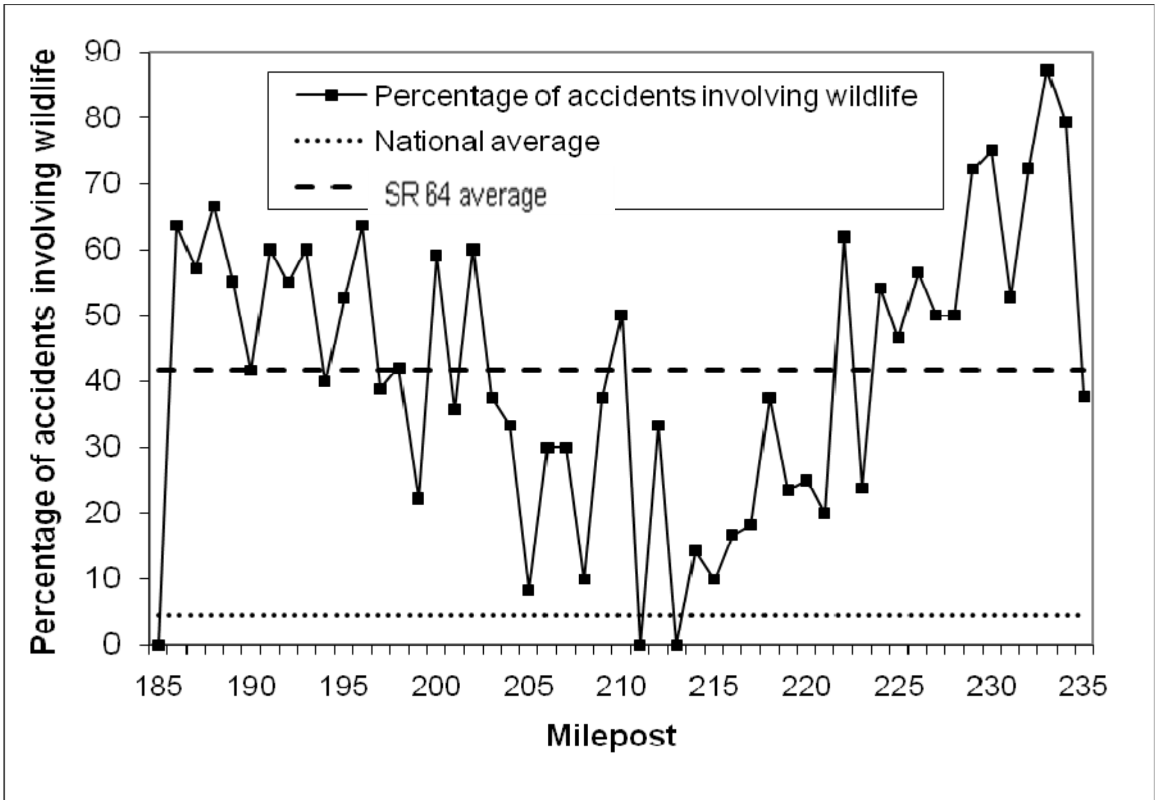



Figure 20. Proportion of SR 64 Single-Vehicle Accidents by Milepost from 1998 through 2008 that Involved Wildlife.

The negative association between the occurrence of elk-vehicle collisions and traffic volume by hour was significant ($r$ = -0.723, $P$ = 0.001) in spite of the disproportionately low incidence of collisions that occurred in the morning when traffic volume was low (Figure 21).

The timing of deer-vehicle collisions was more variable than those for elk (Table 6; Figure 21), though the observed frequency differed significantly from the expected by time period ($\chi^2$ = 26.8, df = 3, $P$ < 0.001). Though 49 percent of accidents involving deer occurred during the evening, only 8 percent occurred at night when traffic volume was lowest. Conversely, during the times of the day when traffic volume was at its highest, late morning and midday, a combined 43 percent of deer-vehicle collisions occurred (Figure 20), partly accounting for the poor association between deer collisions and traffic volume ($r$ = 0.016, $P$ = 0.941).

The incidence of elk collisions by day of the week did not vary significantly ($P$ = 0.800), though there were fewer collisions on Thursday than other days (Figure 22). For deer, however, the incidence of collisions on Monday was more than double that of the other six days, and the observed frequency of collisions by day was marginally different from what was expected ($\chi^2 = 11.5$, df = 6, $P = 0.075$). Neither association between both elk and deer collisions versus mean daily traffic volume was significant ($P = 0.879$ and $P = 0.562$, respectively).

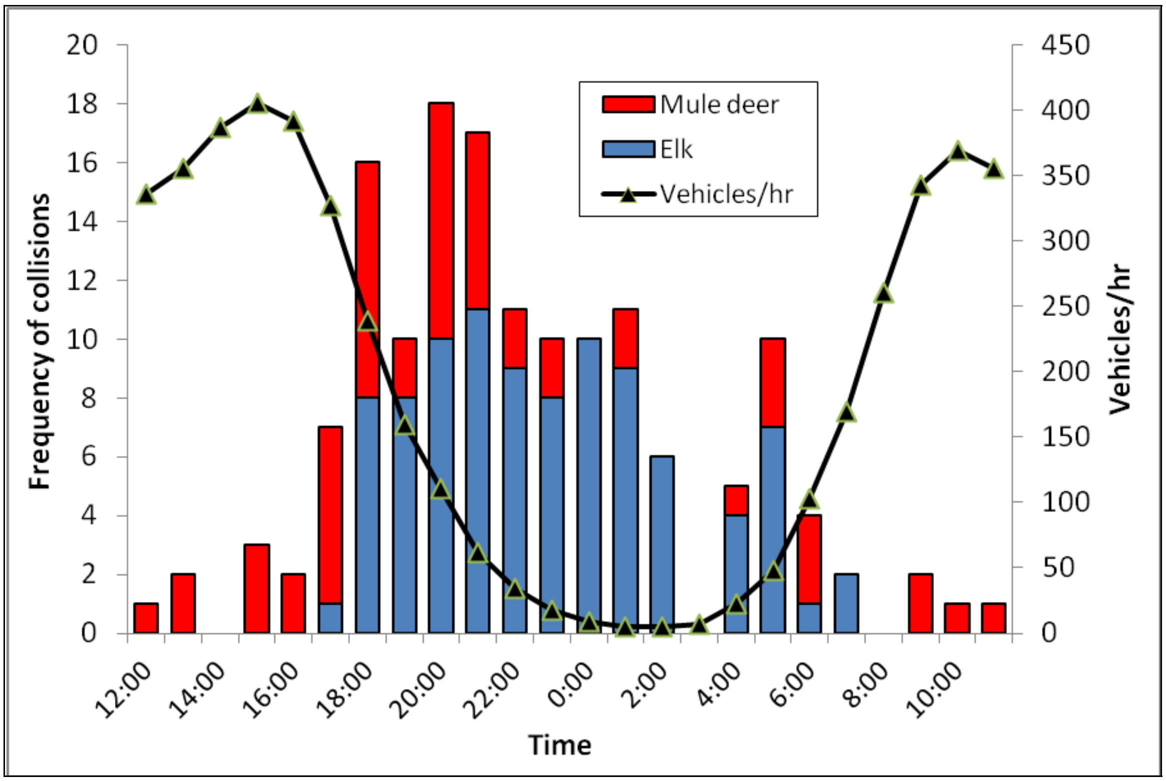



Figure 21. SR 64 Elk and Mule Deer Collisions with Vehicles by Time of Day and Associated Traffic Volume.

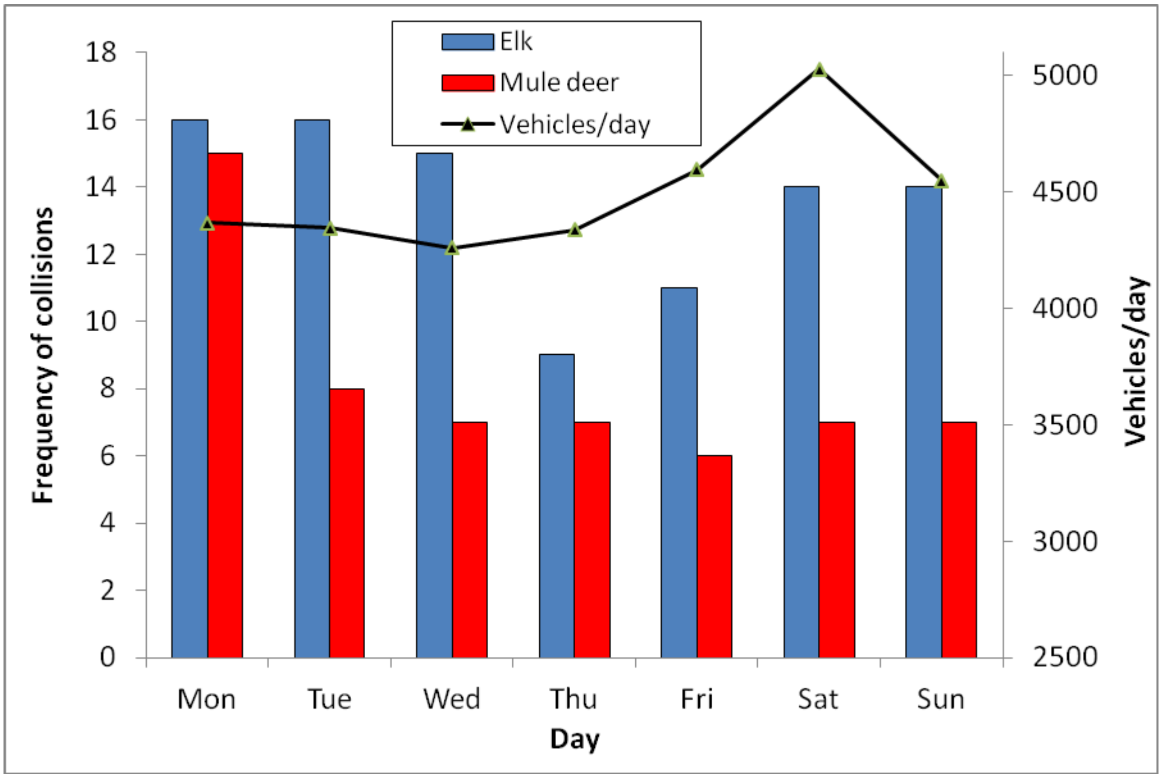



Figure 22. SR 64 Elk and Mule Deer Collisions with Vehicles by Day and Associated Traffic Volume.

There was a significant difference in the observed versus expected frequency of elk-vehicle collisions by season (Table 7; $\chi^2 = 17.4$, df = 2, $P < 0.001$). The driest season, early spring–summer (April–July), accounted for 43 percent of all elk-vehicle collisions along SR 64, while late summer–fall (August–November) accounted for another 38 percent (Table 7; Figure 23).

The association between elk collisions and mean monthly traffic volume was significant ($r = 0.789$, $P = 0.002$). For mule deer, the incidence of collisions was relatively constant through much of the year, except the late summer–fall season when nearly half of all collisions occurred (Table 7; Figure 23). The association between deer-vehicle collisions and traffic volume was not significant ($P = 0.210$). The association between elk crossings and collisions by month was significant ($r = 0.583$, $P = 0.047$), as was the association for deer ($r = 0.686$, $P = 0.014$).

Table 6. Frequency of Elk and Deer Collisions with Vehicles along SR 64 by Time Period.

| Time period | Hours | Frequency of WVCs (%) | |
|---|---|---|---|
| | | Elk | Mule deer |
| Evening | 17:00–22:00 | 47<br>(50.0%) | 32<br>(49.2%) |
| Nighttime | 23:00–04:00 | 37<br>(39.4%) | 5<br>(7.7%) |
| Morning | 05:00–10:00 | 10<br>(10.6) | 19<br>(29.2%) |
| Midday | 10:00–16:00 | 0<br>(–) | 9<br>(13.8%) |

Table 7. Frequency of Elk and Deer Collisions with Vehicles along SR 64 by Season.

| Season | Months | Frequency of wildlife vehicle collisions (%) | |
|---|---|---|---|
| | | Elk | Mule deer |
| Winter–early spring | Dec–Mar | 18<br>(18.2%) | 12<br>(20.3%) |
| Late spring–summer | Apr–Jul | 43<br>(43.4%) | 18<br>(30.5%) |
| Late summer–fall | Aug–Nov | 38<br>(38.4%) | 29<br>(49.1%) |

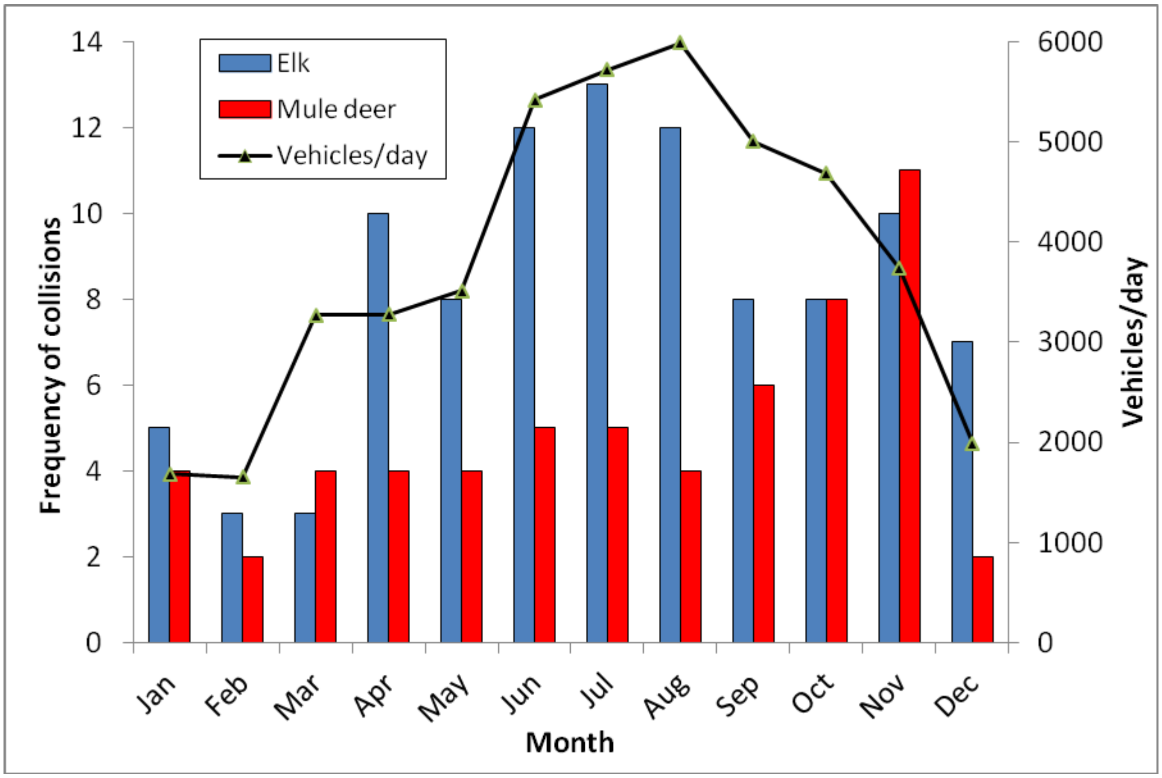



Figure 23. SR 64 Elk and Mule Deer Collisions with Vehicles by Month and the Mean Traffic Volume.

## 5.4 WILDLIFE USE OF CATARACT CANYON BRIDGE

Camera monitoring of Cataract Canyon Bridge was conducted from July 2008 through December 2009. A total of 126 wildlife images, including 13 elk and 37 mule deer, were recorded by the four cameras in the bridge cells (Table 8).

Of the limited number of elk that approached the bridge during the study, 92 percent successfully crossed through the bridge cells, while the remaining 8 percent turned back. For mule deer, for which a greater number of successful crossings were recorded ($n$ = 37) than elk, 89 percent of crossings were successful (Table 8). For smaller mammal species, including gray fox, raccoon, skunk, and various squirrel species, only 6 percent of these animals went all the way through the structure, while 94 percent turned back.

The relatively low mobility of some of these species (e.g., squirrels) may have limited their potential for crossing through the bridge. The vast majority of deer underpass use occurred from August through October, with 89 percent of the entries into the bridge in these three months. Elk use occurred only in October and December, with no entries the rest of the year. Of all deer and elk bridge crossings, 64 percent occurred in the 3 hr period from 10:00 p.m. to 01:00 a.m.

Table 8. Number of Animals by Species that Entered and Successfully Crossed through Cataract Canyon Bridge on SR 64, and Success Rates.

| Species | Animals entering bridge | | Animals crossing through bridge | | Success rate |
|---|---|---|---|---|---|
| | No. | Proportion | No. | Proportion | |
| Elk | 13 | 0.10 | 12 | 0.19 | 0.92 |
| Mule deer | 37 | 0.29 | 33 | 0.53 | 0.89 |
| Gray fox | 5 | 0.04 | 2 | 0.48 | 0.40 |
| Raccoon | 10 | 0.08 | 2 | 0.03 | 0.20 |
| Skunk | 7 | 0.06 | 1 | 0.02 | 0.14 |
| Squirrel | 54 | 0.43 | 0 | – | – |

In addition to wildlife use of Cataract Canyon Bridge, substantial presence by people was documented. In total, 191 humans were recorded, averaging 15.9 people per month; 29 all-terrain vehicles were recorded at the bridge. Human use of the bridge was largely restricted to daytime hours from 10:00 a.m. to 5:00 p.m., when 75 percent of the use occurred.

## 5.5 IDENTIFICATION OF PASSAGE STRUCTURE SITES

The research team used elk and mule deer highway crossings, WVCs, pronghorn approaches, and the proportions of animals crossing or approaching within each segment, among other criteria, to rate 95 0.6 mi segments for suitability as potential passage structure locations. Additional criteria included land ownership and topography that would support passage structure construction. Ratings of the 94 0.6 mi segments from MP 185.5 to MP 235.4 for their suitability for potential passage structures ranged from 1 to 33 points (mean = 10 points) of a possible 40 points (Figure 24). The highest-rated (33 points) 0.6 mi segment (Segment 82, MP 234.5 to MP 235.0) was on the Kaibab NF just south of the south entrance to Grand Canyon Airport, which corresponded to the stretch of highway with the highest proportion of elk crossings (14.3 percent; 121 crossings) and mule deer crossings (42.3 percent; 227 crossings), as well the highest incidence of WVCs ($n$ = 10).

The land ownership and terrain at this segment further make this site suited for a passage structure. ADOT (2006) identified this site as warranting an overpass, though it was not included in the preferred alternative. The next two highest-rated 0.6 mi segments scored 24 points each; one (Segment 81) was just south of the highest-rated segment, further pointing to the importance of this area. The other was just south of the Kaibab NF–GCNP boundary (Segment 85, Figure 24); the rating for this segment was largely tied to high elk and deer crossings, though no WVCs occurred here, reflecting the 35 miles per hour (mph) posted speed.

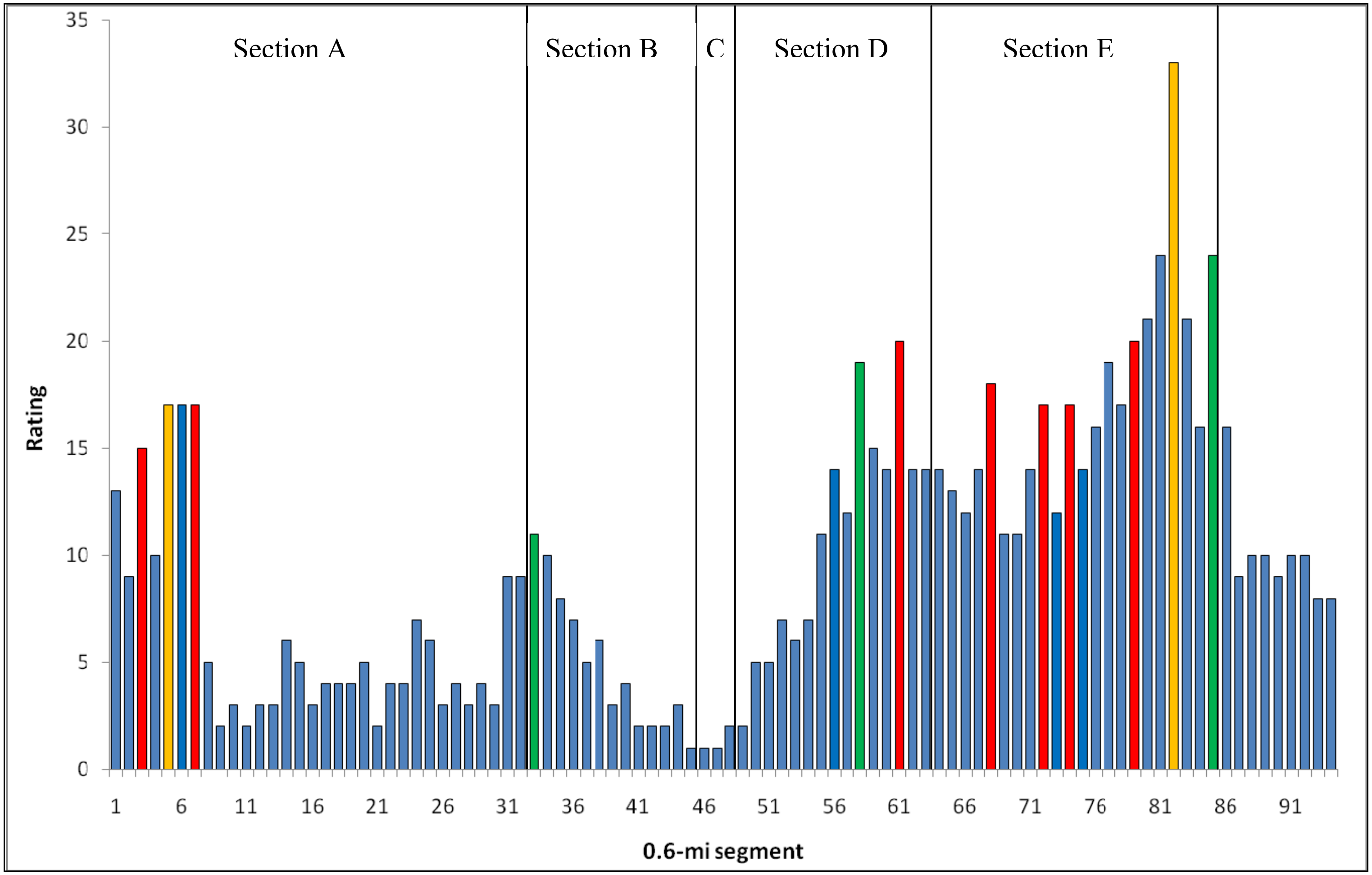



Figure 24. Ratings for 95 SR 64 0.6 mi Segments Using Wildlife Movement, WVC Data, and Other Criteria to Determine the Location of Potential Wildlife Passage Structures. Red Bars Denote Segments Where Underpasses Were Recommended in the 2006 *Final Wildlife Accident Reduction Study* and Orange Where Overpasses Were Recommended (Table 9). The Green Bars Represent Segments Where Additional Structures Are Recommended as a Result of This Study.

Of the 0.6 mi segments corresponding to the stretch of highway where weighted pronghorn approach peaks occurred (Figure 14), the highest-rated segment (MP 221.9 to MP 222.3) scored 20 points and corresponded to the location where ADOT (2006) recommended either an underpass at MP 222.2 or an overpass at MP 222.0. Because only one structure is needed here, the research team recommends an overpass to accommodate pronghorn, elk, and deer passage.

The research team's rating with the eight criteria was used to identify 11 priority wildlife passage structure locations (Table 9; Figure 24). Of these, six were at sites conducive to underpasses and five were at sites where the terrain was conducive to overpasses or the target species was pronghorn, or both (Table 9). Of the nine wildlife crossing structure locations identified by ADOT (2006) with underpass at MP 222.2 and overpass at 222.3 combined, including retrofitting of Cataract Canyon Bridge, the research team's rating of potential passage structure sites corroborated that passage structures were warranted at eight of those locations (Table 9; Figure 24).

In addition to the passage structure sites recommended in all alternatives in that study (ADOT 2006), which were based largely on WVC records and sites where the topography could support a structure, the team identified an additional three potential passage structure locations, including an underpass at the Kaibab National Forest, at the Grand Canyon National Park boundary. The other two structures are overpasses recommended for pronghorn passage in an area where the team recorded no WVC and none was reported in ADOT (2006).

For the rated 94 0.6 mi segments, the average rating was 10.0 points, while the average rating of the 11 segments where passage structures are recommended was 20.7 points (Figure 24). By highway section, the average rating for Section A segments was 4.0. The average rating for segments recommended for passage structures was 16.0. Structures were recommended at half of the highest-rated segments, with the other half the highest-rated segments being adjacent to the structures (Figure 24).

On Section B, the mean rating was 5.0 points, and an overpass was recommended at the highest-rated segment, with 11 points (Figure 24). Section D segments averaged 10.0 points and the rating for the two segments with recommended structures was nearly twice the mean, or 19.5 points (Figure 24). Section E segments rated the highest, averaging 17.0 points; the six segments with recommended passage structures here averaged 24.3 points (Figure 24). No structures have been recommended for Section C due to the prevalence of human development.

Table 9. Wildlife Passage Structure Locations along SR 64 by Milepost and Highway Section and Types Recommended in the Various 2006 *Final Wildlife Accident Reduction Study* Alternatives and Those Recommended as a Result of the Current Wildlife Movements Study.

| Passage structure MP | SR 64 section | *Wildlife Accident Reduction Study* recommendation | | Recommendation of current study | | Passage structure recommendation justification and focus |
|---|---|---|---|---|---|---|
| | | Underpass | Overpass | Underpass | Overpass | |
| 187.3 | A | Alt. A(W)-1 | | Yes | | Existing Cataract Canyon Bridge; elk and deer WVCs and connectivity |
| 188.0 | A | | Alt. A(W)-2 | | No | Need better spacing of passage structures |
| 189.2 | A | Alt. A(W)-1 | | | Yes | Elk and deer WVCs and pronghorn connectivity |
| 205.0–205.5 | B | | | | Yes | Pronghorn connectivity |
| 220.0–220.5 | D | | | | Yes | Pronghorn connectivity |
| 222.2 | D | Alt. D(W)-1 | | No | | Construct overpass nearby |
| 222.3 | D | | Alt. D(W)-2 | | Yes | Pronghorn connectivity |
| 226.6 | E | Alt. E(W)-1 | | Yes | | Elk and deer WVCs and connectivity |
| 228.8 | E | Alt. E(W)-1 | | Yes | | Elk and deer WVCs and connectivity |
| 229.7 | E | Alt. E(W)-1 | | Yes | | Elk and deer WVCs and connectivity |
| 233.0 | E | Alt. E(W)-1 | | Yes | | Elk and deer WVCs and connectivity |
| 234.4 | E | | Alt. E(W)-2 | | Yes | Elk and deer WVCs and connectivity |
| 236.8 | E | | | Yes | | Elk and deer WVCs and connectivity |
| Totals | All | 7 | 3 | 6 | 5 | |

### 5.5.1 Passage Structure Recommendations by Highway Section

***Highway Section A***. The research team recommends building two passage structures on Section A, including retrofitting Cataract Canyon Bridge as an underpass (MP 187.3), to address elk and mule deer WVCs and to promote permeability, and an overpass at MP 189.2 to address pronghorn permeability. Though an overpass was recommended in ADOT (2006) at MP 188.0, along with an underpass to the north and Cataract Canyon bridge to the south (Table 9; Figures 24 and 25), the team recommends that an overpass be constructed at MP 189.2 in addition to Cataract Canyon Bridge because an additional underpass will likely do little to promote pronghorn permeability and is spaced close to Cataract Canyon Bridge (within 0.7 miles). This provides a structure every 1.5 to 2.3 miles for the stretch from I-40 to the developed area approaching Red Lake. Both passage structure sites fall on land administered by the Kaibab NF.

***Highway Section B***. ADOT (2006) called for no passage structures on Section B, reflecting the lower incidence of elk and deer WVCs, widespread human development along portions of the section, and an absence of telemetry data for structures to promote pronghorn permeability. The team recommends a single overpass on the segment to address documented peak in pronghorn approaches (Figure 14) and to promote permeability. An overpass is proposed for the most suitable site within the 0.6 mi segment at MP 205.0 to MP 205.5 (Figure 25). Though it is recognized that constructing a single overpass on Section B provides limited options for pronghorn use, it nonetheless is warranted to maintain connectivity and genetic diversity on both sides of SR 64. This site falls on Arizona State Trust lands.

***Highway Section D***. On Section D, ADOT (2006) recommended either an overpass or underpass on adjacent 0.1 mi segments at MP 222.2 or MP 222.3. The research team recommends that an overpass be considered at MP 222.3 instead of an underpass because it will better promote pronghorn permeability along with that for elk and deer; this site falls within the highest peak approach zone for pronghorn (Figures 14 and 26). The team also recommends that another overpass be considered in the 0.6 mi segment at MP 220.0 through MP 220.59 corresponding to a zone of peak pronghorn approaches and spaced approximately 1.8 to 2.3 miles from the other overpass, depending on the actual location. Both overpass sites lie on Arizona State Trust lands.

***Highway Section E***. Along Section E, ADOT (2006) recommended integration of four underpasses and an overpass into future highway reconstruction. The research team's rating of 0.6 mi segments concurs with these recommendations, including an overpass that was not included in the preferred alternative in ADOT (2006). Also, the team recommends the addition of a fifth underpass near the GCNP boundary, at MP 236.8, corresponding to a high mule deer and elk use area with permanent water; the topography here is conducive to an underpass. Other underpasses located at MP 226.6, MP 228.8, MP 229.7, and MP 233.0 correspond to highly rated 0.6 mi segments (Figures 24 and 26) and topography (drainages) conducive to underpass integration into future highway reconstruction.

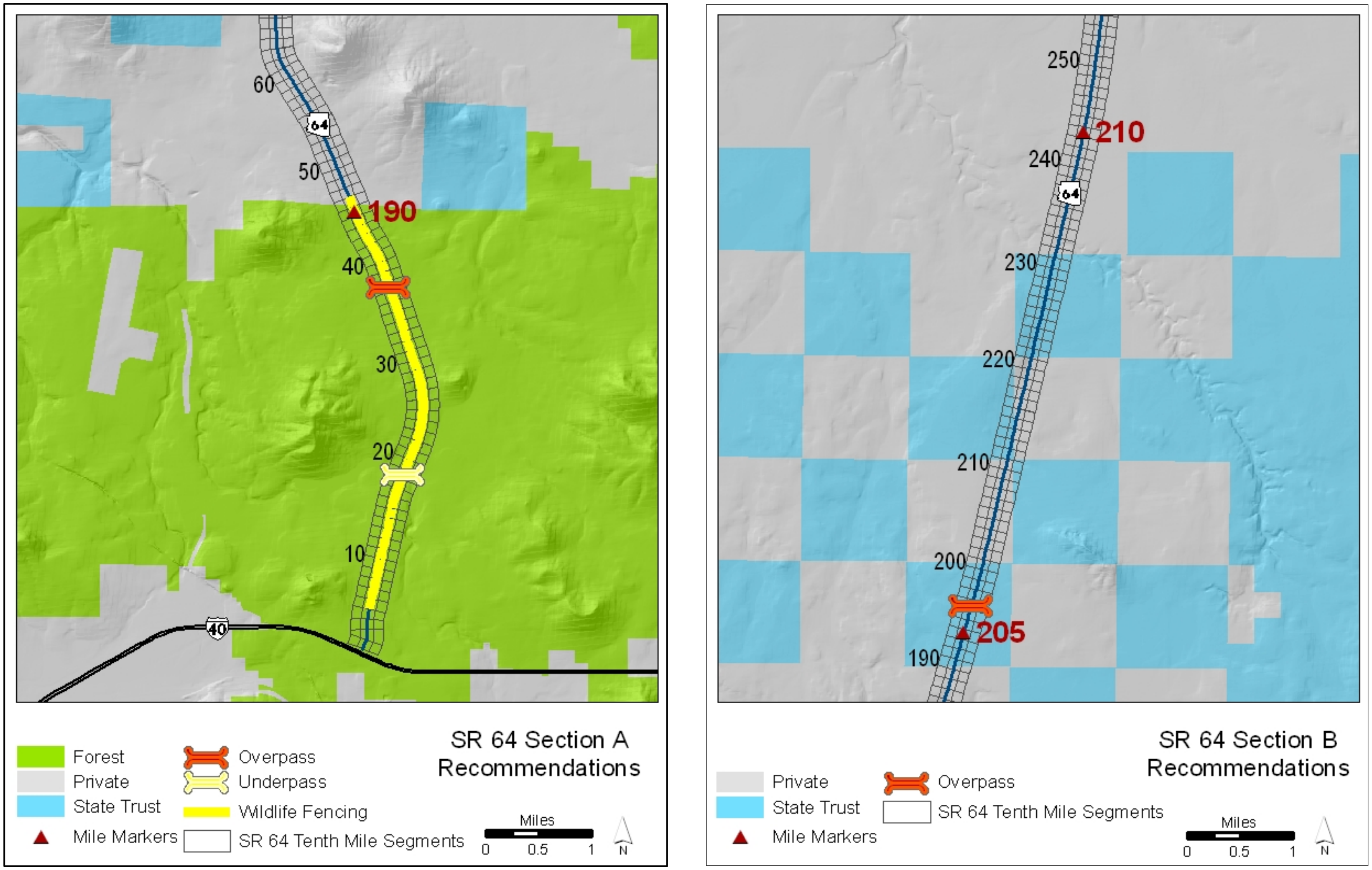



Figure 25. Recommendations for SR 64 Wildlife Passage Structures and Wildlife Fencing for Highway Section A (Left) and Section B (Right).


Figure 26. Recommendations for SR 64 Wildlife Passage Structures and Wildlife Fencing for Highway Sections D and E.

The overpass recommended at MP 234.4 corresponds to the highest-rated 0.6 mi segment along SR 64 (Figure 24). The high incidence of elk and mule deer crossings and WVCs here may reflect a funneling effect associated with Grand Canyon Airport's fenced perimeter.

Further, this location may be in conflict with long-range plans by ADOT's Facilities Management - Grand Canyon Airport, to build another access point and parking area south of the existing entrance, as reflected in ADOT (2006). As such, depending on terrain suitability, the overpass may be constructed as far south as possible; if the terrain is conducive to an underpass, then consider this as an option to an overpass. The spacing between these five structures ranges from 4.3 miles between the structure on Section D at MP 222.3 and the southernmost structure on Section E at MP 226.6 to 0.9 miles between structures at MP 222.8 and MP 229.7 (Figure 26). The average spacing between these structures on Section D and E is 2.3 miles. All six recommended passage structures on Section E lie on Kaibab NF land.

# 6.0 DISCUSSION

The research team's wildlife movement and WVC assessment were greatly aided by the proactive earlier effort documented in ADOT (2006) which was commissioned by ADOT. The results of this study confirmed and complemented that *study*, providing more refined data to support passage structure locations, especially for pronghorn for which no WVC data existed.

Dodd et al. ("Evaluation of Measures," 2007) advocated utilizing WVC data where it exists as a surrogate to costly GPS telemetry movement data to plan and identify locations for wildlife passage structures, as they found that the spatial incidence of WVCs was strongly associated with GPS-determined highway crossings. This project further confirms the utility of WVC data for locating wildlife passage structures, as eight of nine (89 percent) recommended passage structure locations using WVC data in ADOT (2006) were confirmed as being warranted by telemetry in this study; the ninth was not recommended only for spacing (and cost) considerations.

The team found that the associations between SR 64 crossings and vehicle collisions for both elk and mule deer were significant, explaining 66 percent and 49 percent of the variation between the two factors, respectively. This further underscores the utility of WVC data, with GPS telemetry playing a role in helping refine passage structure and fencing locations. And in the instance of pronghorn, for which the highway constitutes a passage barrier to the degree that pronghorn-vehicle collisions do not occur, GPS telemetry data was essential to developing informed, data-driven recommendations for passage structure placement, as done previously by Dodd et al. (2011) on US 89.

This study served to expand the collective understanding of road ecology and wildlife-highway relationships, benefiting from consistent, comparable methodologies and metrics to assess wildlife permeability and traffic volume relationships. The SR 64 study on elk, mule deer, and pronghorn conducted under a different set of experimental conditions (e.g., traffic volume patterns, habitat conditions) complements previous GPS telemetry research on elk and white-tailed deer (Dodd et al. "Effectiveness of Wildlife," *in review*, Gagnon et al. 2010) and pronghorn (Dodd et al. 2011).

## 6.1 WILDLIFE PERMEABILITY

The mean SR 64 elk passage of 0.44 crossing per approach was similar to that (0.50) obtained from extensive telemetry (100 GPS collared elk) along SR 260 (Dodd et al. "Effectiveness of Wildlife," *in review*). However, the mean SR 260 passage rate on two-lane control sections similar to SR 64, but with higher AADT (approximately 8700 versus 4300 vehicles per day), was 52 percent higher than the SR 64 average.

The SR 260 elk crossing rate of 0.26 crossings per day, which was consistent across all SR 260 construction classes and treatments, was more than twice the SR 64 mean of only 0.12 crossings per day. The lower elk passage and crossing rates for SR 64 are surprising considering the dearth of traffic during much of the nighttime, especially compared to SR 260. The lower crossing rate can partly be explained by the absence of attractive wet meadow/riparian foraging areas that largely account for SR 260 elk movement and WVC patterns (Manzo 2006, Dodd et al., "Evaluation of Measures," 2007). These areas resulted in seasonally higher elk tolerance to increasing traffic in pursuit of high-quality forage (Gagnon et al. "Traffic volume alters,"2007).

However, the presence of elk along SR 64 was heavily tied seasonally to the limited permanent water sources adjacent to the highway, accounting for a combined 80 percent of the crossings during late spring and summer when water demand was highest. Yet the lack of wet, attractive foraging habitats does not solely explain why the SR 64 passage rate was lower than SR 260 when traffic volume was so low during much of the peak elk activity period, though the passage rate was greater than 0.70 crossing per approach from 02:00 to 06:00. Even with lower crossing rates reflecting a lack of an "incentive" to cross SR 64 like SR 260 (Gagnon et al. "Traffic volume alters,"2007), the passage rate during low volume periods would have been expected to be higher.

The mean passage rate for mule deer along SR 64 was higher than that for elk, 0.54 crossings per approach, as was the mean crossing rate of 0.26 crossings per day. These rates were dramatically higher than those for white-tailed deer along SR 260, where the mean control section passage rate was just 0.03 crossing per approach and the crossing rate was 0.02 crossings per day. Mule deer were located near the highway to a relatively high degree, with over half of all GPS fixes occurring within 0.6 miles of SR 64.

Though the research team tried to collar deer along the entire length of Section E, only a small proportion (3 of 13 deer) was captured south of Grand Canyon Airport. This partly explains why 87 percent of the mule deer crossings occurred in the 2.5 miles between the airport and the GCNP boundary, encompassing the community of Tusayan. The three deer captured south of the airport did not cross north of the airport and accounted for only 36 crossings, 6 percent of the total.

Though the mean passage rate (0.63 crossings per approach) for these three deer was higher than the overall mean, their mean crossing rate (0.16 crossings per day) was 38 percent lower than the overall mean. Thus, deer near the airport and Tusayan appeared to cross at a higher rate, likely reflecting the lower posted speed limit (55 mph), habituation to humans, and presence of permanent water sources.

Similar to the findings of Dodd et al. (2011) for GPS-collared pronghorn along US 89, the pronghorn passage rate along SR 64 was also negligible, 0.004 crossings per approach, as was the crossing rate at 0.001 crossings per day. With only one of 15 animals crossing the highway three times, SR 64 constitutes a near barrier to pronghorn passage and accounts for the lack of pronghorn-vehicle collisions recorded in 12 years.

Prior VHF telemetry studies in northern Arizona have demonstrated paved highways with fenced ROW constitute near total barriers to pronghorn passage. Ockenfels et al. (1994) found that individual pronghorn never occurred on opposite sides of Interstate 17, and Ockenfels et al. (1997), van Riper and Ockenfels (1998), and Bright and van Riper (2000) never documented a pronghorn crossing of fenced ROW adjacent to US 89, I-40, or US 180. These studies point to the combined impact of fenced ROW and highways, though it is difficult to partition their contributory impact on pronghorn permeability.

Sheldon (2005) found that fences in Wyoming significantly influenced pronghorn movements and distribution, and that home ranges were located in areas exhibiting the lowest fence densities. The presence and type of ROW fences determined whether roads were included in seasonal ranges and where pronghorn crossed highways. Sheldon (2005) found that seasonal crossings consistently occurred along unfenced highway sections.

Based on the reduced permeability found for elk along SR 260 associated with highway reconstruction compared with research controls (Dodd et al. "Evaluation of Measures," 2007) and as predicted by Jaeger et al. (2005), the team assumed that elk (and deer) permeability likely will be reduced along SR 64 as the highway is upgraded from a narrow two-lane to a four-lane divided highway. However, as demonstrated for elk and white-tailed deer along SR 260, effective passage structures with adequate spacing can significantly mitigate the impact of the highway reconstruction as well as reduce WVCs (Dodd et al. "Effectiveness of Wildlife," *in review*).

## 6.2 WILDLIFE DISTRIBUTION AND TRAFFIC RELATIONSHIPS

The pattern of elk, mule deer, and, to a lesser degree, pronghorn distribution with fluctuating traffic along SR 64 is broadly consistent with road-impact models with reduced "habitat effectiveness," as reflected in diminished use of available habitat near roads (Lyon and Christensen 1992).

The availability of habitat within 990 ft of the highway, as measured by probability of presence by all three species, was clearly reduced at higher traffic volumes, with the mean proportion for the three species dropping nearly in half—from 0.34 at less than 100 vehicles per hr to 0.19 at 200 to 300 vehicles per hour (4800–7200 AADT equivalent). However, the fact that elk and deer returned to areas adjacent to the highway, including to within 330 ft, in proportions greater than 0.12 when traffic volumes were low indicates that the relative temporary reduction in habitat effectiveness depends on the duration of higher traffic volumes.

Other studies of lower volume roadways have similarly documented that elk and mule deer distribution shifted away from areas close to roads and that this response increased with higher traffic volume (Rost and Bailey 1979, Witmer and deCalesta 1985, Rowland et al. 2000, Wisdom et al. 2005, Wisdom 1998). Likewise, studies of low-volume roads demonstrated that elk and deer were often farther from roads during the day and came nearer roads during the night (Wisdom 1998, Ager et al. 2003), suggesting a short-term temporal response to lower nighttime traffic volumes.

These results also are consistent with theoretical models that suggest that highways averaging 4000 to 10,000 vehicles per day present strong barriers to wildlife and would repel animals away from the highway (Iuell et al. 2003, Mueller and Berthoud 1997). The highest levels of permeability (passage rates greater than 0.70 crossings per approach) occurred at night when traffic was lowest. Paradoxically, the tendency for elk to move close to the highway at lower traffic volumes appeared to contribute to increased incidence of elk-vehicle collisions when traffic volumes were lowest.

This study added to the understanding of the pronghorn-traffic relationships reported for US 89 by Dodd et al. (2011). Whereas most deer and elk crossings occur at night when traffic volume is lowest, pronghorn are diurnal and active when traffic volumes are typically at their highest, and SR 64 was no exception. Pronghorn uniformly avoided habitats adjacent to SR 64 (within 330 ft), thus reflecting a permanent loss in habitat effectiveness. Also, in the absence of attractive habitats adjacent to the highway, as reported for elk by Gagnon et al. ("Traffic volume alters,"2007), SR 64 pronghorn lacked an incentive or attractant to tolerate even the impact of relatively low traffic volumes.

Whereas Reeve (1984) reported that regular vehicular traffic produced minimal disturbance among pronghorn due to habituation, the research team believes that pronghorn along SR 64 are consistently negatively impacted by traffic volume at even low levels, though this seldom occurs in the daytime when pronghorn are most active.

During periods when peak daytime traffic volumes approach 10,000 vehicles/day, especially in the summer, highways become strong barriers to wildlife passage (Mueller and Berthoud 1997). Pronghorn appear more sensitive to traffic volume impact than elk and mule deer, and their avoidance of the area adjacent to the highway is problematic in terms of implementing effective passage structures to promote permeability. In Alberta, pronghorn close to roads across all traffic levels exhibited higher vigilance levels, further suggesting an overall perception of risk toward roads (Gavin and Komers 2006).

## 6.3 WILDLIFE-VEHICLE COLLISION RELATIONSHIPS

The incidence of WVCs along SR 64 is a significant and growing issue affecting highway safety. The incidence of ungulate (elk and mule deer) WVCs in this study (52.0 per year) was an increase from the 36.7 per year reported between 1991 and 2003 in ADOT (2006). However, the WVC rate along Section E remained nearly constant, at 2.2 collisions per mile per year from 1991 to 2003, compared with 2.3 collisions per mile per year from 2007 through 2009, but dropped from accounting for 70 percent of all SR 64 WVCs between 1991 and 2003, to a 52 percent contribution in this study.

Section A accounted for 28 percent of all WVCs in the study area from 1991 to 2003 but 36 percent during the study, pointing to the need for management actions to mitigate WVCs on this section as well as Section E. The rate of elk-vehicle collisions along Section E during the current study (1.6 per mi per year) was comparable to the mean for SR 260 sections before reconstruction (1.2 per mi per year; Dodd et al. "Effectiveness of Wildlife," *in review*), as well as rates reported in previous studies in North America, including Alberta (Gunson and Clevenger 2003), British Columbia (Sielecki 2004), and New Mexico (Biggs et al. 2004).

Traffic volume has frequently been reported as a factor contributing to WVCs for a wide range of wildlife (Inbar and Mayer 1999, Joyce and Mahoney 2001, Forman et al. 2003). However, the research team observed a significant negative association between elk-vehicle collisions and traffic volume. Gunson and Clevenger (2003) also found that mean elk-vehicle accidents declined as traffic volume increased ($r^2 = 0.82$), and Brody and Pelton (1989) reported a negative relationship between black bear crossings and traffic volume, as did Waller and Servheen (2005) for grizzly bears.

These results run counter to Waller et al. (2006), who developed probabilistic measures of road mortality and theorized that highway lethality was related to traffic volume and time spent on the roadway by crossing animals. On SR 64, elk passage rates and occurrence within 330 ft of the highway were highest when traffic volume was lowest. When traffic was low, elk were often observed adjacent to the roadway feeding on vegetation deemed more attractive due to increased moisture runoff from the pavement as well as deicing salt applied during the winter. This proximity of elk to the roadway likely contributed to making elk (and motorists) vulnerable to collisions. Also contributing to higher collision incidence with elk at night were poor visibility conditions and increased vehicular speeds.

The large proportion of elk-vehicle accidents that occurred during the evening hours (39 percent) is consistent with the 31 percent documented along SR 260 by Dodd et al. ("Evaluation of Measures," 2007). Gunson and Clevenger (2003) and Biggs et al. (2004) noted similar evening peaks in elk-vehicle collisions. Though SR 64 mule deer-vehicle collision incidence and traffic volume were not associated with a large portion of collisions during the day, nearly half of the collisions occurred at night as traffic volume diminished.

Haikonen and Summala (2001) reported that a large peak in WVCs—46 percent of moose collisions and 37 percent of white-tailed deer collisions—occurred within 3 hours after sunset, tied to circadian rhythms associated with light. Dodd et al. ("Evaluation of Measures," 2007) found that 55 percent of elk and 50 percent of white-tailed deer collisions along SR 260 occurred within 2 hr of sunrise and sunset (Dodd et al., "Evaluation of Measures," 2007), similar to the high evening WVC incidence along SR 64.

The highest proportion of elk-vehicle collisions and elk highway crossings occurred in late spring–summer, when water was most limited. Elk likely crossed SR 64 to seek water at the limited permanent water sources along Section E as well as to seek forage along the roadway. Late summer–fall accounted for a large proportion of SR 64 elk-vehicle collisions.

Dodd et al. ("Evaluation of Measures," 2007) recorded the largest proportion of elk-vehicle collisions along SR 260 tied to the breeding season and an influx of migrating elk. Gunson and Clevenger (2003) reported an increase in elk-vehicle collisions in fall attributable to increased elk numbers from calf recruitment, and Biggs et al. (2004) reported increased collisions in fall. Nearly half of SR 64 deer-vehicle collisions occurred in the late summer–fall. Romin and Bissonette (1996), Hubbard et al. (2000), and Puglisi et al. (1974) attributed increased deer collisions in fall to breeding and sport hunting.

Huijser et al. (2007) conducted an extensive review of costs associated with WVCs, including costs associated with vehicle property damage, human injuries and fatalities, removal and disposal of carcasses, and loss of recreational value associated with vehicle-killed animals. They reported the cost associated with each elk-vehicle collision to be $18,561 and each deer-vehicle collision to be $8388.

Using these figures and the WVC data from 2007 through 2009, the research team estimated the annual cost associated with SR 64 vehicle collisions with elk and mule deer to be $612,500 and $162,200 respectively, for a combined annual cost of $775,000. Over a 20 year period, assuming the WVC incidence remained unchanged or unmitigated, the cost from WVCs would total more than $15.5 million in current dollars.

## 6.4 CATARACT CANYON BRIDGE WILDLIFE USE

Dodd et al. ("Video surveillance to assess," 2007) used complex and costly four-camera video systems at several SR 260 underpasses to document wildlife use and behavioral response while approaching and crossing through the structures.

The single-frame Reconyx™ cameras with capability to record five frames per second that were used in this project constituted a cost-effective and reliable alternative to video camera systems, and the placement of cameras high on the bridge abutments successfully deterred theft and vandalism even though there was substantial human presence at the bridge. However, the team was not able to effectively measure wildlife passage rates as per Dodd et al. ("Video surveillance to assess," 2007) using these cameras, and high use of Cataract Canyon Bridge by people would likely have rendered a video camera system vulnerable to vandalism and theft.

Relative to the number of elk- and deer-vehicle collisions recorded near Cataract Canyon Bridge, coupled with the relatively high density of both species along this stretch of the study area (Figure 3), the documented wildlife use of the bridge for passage was nominal, especially compared with the number of deer and elk recorded on videotape at SR 260 underpasses (more than 15,000). However, without ungulate-proof fencing to limit at-grade crossings and funnel animals to the bridge, the research team's expectation for significant use was low.

At SR 260 wildlife underpasses before fencing was erected, the elk and deer passage rate was only 0.12 crossings per approach; most animals continued to cross the highway at grade. Once fencing was erected to funnel animals, the passage rate jumped to 0.64 crossings per approach, with no at-grade crossings by deer and elk (Dodd "Evaluation of Measures," 2007). ADOT was willing to accommodate the research objectives by erecting ungulate-proof fencing north and south of Cataract Canyon Bridge while doing a ROW fence replacement project. However, various logistical challenges, such as preventing wildlife end run effects at each end of the fence that could exacerbate the WVC situation, precluded the erection of ungulate-proof fencing near Cataract Canyon Bridge. As such, it is not surprising that so few elk and deer used the bridge for passage.

Despite the limited number of animals captured on cameras using Cataract Canyon Bridge, the research team believes the bridge has the potential to be a highly effective retrofitted wildlife passage structure (underpass). The high success rates for mule deer and elk that approached the bridge cells and crossed through (more than 0.89 crossings per entry for both) indicate that ungulates readily accept and use the structure with minimal behavioral resistance to passage; a similar response could be expected once fencing is erected to funnel more animals to and through the bridge.

Cataract Canyon Bridge exceeds the structural and placement guidelines for effective elk and mule deer passage structures recommended by Reed et al. (1975), Gordon and Anderson (2003), and Gagnon et al. (2011). The high level of human use of the bridge likely will not substantially impact or limit effective wildlife use of the structure, as noted in similar situations by Clevenger and Waltho (2000). Gagnon et al. (2011) found no conflict in wildlife and human use of a dual-use underpass along SR 260 linking two communities; nearly all wildlife use occurred in the evening and at night, while human use occurred exclusively during the day. However, it is important to note that avoiding dual-use structures for diurnal species such as pronghorn and bighorn sheep is essential to the success of the structures.

## 6.5 IDENTIFICATION OF PASSAGE STRUCTURE SITES

Integration of wildlife passage structures in transportation projects has shown considerable benefit in reducing the incidence of WVCs and promoting wildlife passage across highways (Foster and Humphrey 1995; Farrell et al. 2002; Clevenger and Waltho 2003; Gordon and Anderson 2003; Dodd et al., “Assessment of elk,” 2007; Gagnon et al. 2011). Critical to the effectiveness of passage structures in achieving desired use by wildlife is their structural design; placement relative to terrain, topography, and habitat; spacing between structures; and effective integration of fencing. Failure to address any one of the factors could diminish a structure’s effectiveness in achieving wildlife use.

### 6.5.1 Passage Structure Design Considerations

The efficacy of promoting wildlife connectivity and WVC reduction has been especially well documented for elk (Clevenger and Waltho 2003; Dodd et al., “Evaluation of Measures,” 2007; “Effectiveness of Wildlife,” *in review*) and mule deer (Reed et al. 1975, Gordon and Anderson 2003, Plumb et al. 2003). Gagnon et al. 2011 reported on the adaptive capability of elk in using wildlife underpasses with a range of design “limitations,” taking four years to achieve nearly equal use of underpasses. This learning and habituation by elk also was stressed by Clevenger and Waltho (2003). Mule deer appear to have similar learning capability (Reed et al. 1975, Clevenger and Waltho 2003, Gordon and Anderson 2003), though this has not been as rigorously addressed as for elk.

Passage structures have proved effective for elk, deer, and other species, but their application to promote pronghorn permeability has been limited (Sawyer and Rudd 2005). Though Plumb et al. (2003) documented 70 crossings by pronghorn at a concrete box culvert underpass in Wyoming (81 percent in a single crossing), pronghorn overall exhibited reluctance to use the structure, and the majority of crossing pronghorn accompanied mule deer through the underpass. Crossing pronghorn composed a small portion of the local pronghorn herd. In six years of monitoring Interstate 80 underpasses, through which thousands of mule deer passed, only a single pronghorn was recorded passing through the structures monitored by Ward et al. (1980).

Despite the limited use of structures to date, there is recognition of the need for special strategies to promote pronghorn permeability (Ockenfels et al. 1994, Hacker 2002, Yoakum 2004, Sawyer and Rudd 2005, Dodd et al. 20011). Sawyer and Rudd (2005:6) reported that “with the exception of Plumb et al. (2003) and several anecdotal observations, we could not find any published or documented information on pronghorn utilizing crossing structures.” Still, they believed that large open-span bridged underpasses might be more effective in promoting pronghorn passage than overpasses, though no studies have been done to support this contention.

To date, no passage structure intended for pronghorn passage has been implemented in North America. In urging long-term studies to evaluate passage structure effectiveness in promoting population and genetic viability to justify overpass application in highway projects given their high cost, the recommendation of Corlatti et al. (2009) is particularly relevant to pronghorn given the limited application of passage structures.

Structural design characteristics have a significant bearing on the eventual use and acceptance of passage structures by wildlife (Foster and Humphrey 1995; Clevenger and Waltho 2003; Gordon and Anderson 2003; Ng et al. 2004; Dodd et al., “Assessment of elk,” 2007; Gagnon et al. 2011). Most important is the requirement that any type of structure considered to promote passage be as open and wide as possible (Ruediger 2002, Sawyer and Rudd 2005), with special attention paid to avoiding obstructed line-of-sight views through or across structures (Foster and Humphrey 1995; Sawyer and Rudd 2005; Dodd et al., “Evaluation of Measures,” 2007; Gagnon et al., 2011). This is especially the case for pronghorn because this species’ adaptation to an open plains/grassland environment has resulted in a strong survival reliance on visual stimuli and avoidance of dense habitats and situations that restrict their view or mobility (Hart et al. 2008).

Though Yoakum (2004) questioned the ability to achieve pronghorn use of passage structures across high traffic volume roadways due to behavioral characteristics (e.g., highway avoidance), Sawyer and Rudd (2005) concluded that properly designed and located structures could be effective. Rather than overpasses, they favored wide (more than 60 ft between bridge supports) and high (more than 24 ft) open-span bridge/underpass structures, and in recognizing the lack of insights for pronghorn passage, believed underpasses to have the widest application and lower cost, also helping address drainage needs.

The research team stresses that topography and the maximization of visual continuity for pronghorn are also critical concerns that may make overpasses attractive, applicable, or both along certain SR 64 locales. Most wildlife underpasses implemented along SR 260 that have proved so successful in promoting elk and deer passage (Gagnon et al. 2011) would not function well for pronghorn passage. In addition, no similar wide-open topographic features in which to situate underpasses are within the high-use pronghorn areas along SR 64—a strong selling point made by Sawyer and Rudd (2005) for underpasses.

With the impact evident from high daytime traffic on SR 64, including visual and noise impacts to pronghorn (Mueller and Berthoud 1997), comprehensive measures to reduce traffic-associated impacts could create “quiet zones” along the highway corresponding to passage structures, especially for pronghorn overpasses. Such quiet zones could facilitate pronghorn approaching (and successfully crossing) the highway and play a potentially significant role in promoting passage.

A comprehensive set of measures to reduce traffic-associated impacts should include incorporation of highway design, noise barriers that do not restrict movements, and pavement treatments (Kaseloo and Tyson 2004). In conjunction with passage structure construction, highway approaches to the structure could be recessed below grade to reduce noise impact while supporting overpass construction. Soil berms or sound walls adjacent to passage structures may be warranted to help reduce traffic impact, as well as to visually shield pronghorn from traffic. Such barriers could reduce traffic noise by as much as half, depending on their height (Federal Highway Administration 2001).

Vegetation atop berms could further shield traffic-associated noise, as would rubberized asphalt application on the pavement near passage structures. Without a comprehensive effort to reduce noise impact, the success of passage structures could be compromised by continued pronghorn avoidance of approaching the highway at high traffic volumes (Mueller and Berthoud 1997, Yoakum 2004).

A variety of passage structure types may be considered for application along SR 64 (Figure 27), including single-span bridges used effectively along SR 260 as underpasses, cost-effective multi-plate arch underpasses, and CON/SPAN® pre-cast concrete arches that can span 60 ft with various heights up to 24 ft and widths up to and exceeding 100 ft; these overpass structures can be integrated into existing terrain, as recommended for US 89 (Dodd et al. 2011), or constructed as a stand-alone structure (Figure 27).


Figure 27. Various Wildlife Passage Structure Options for SR 64, Including CON/SPAN® Pre-Cast Concrete Arches for Overpasses, with a Rendering of a Pronghorn Overpass on US 89 Integrated into Cut Slopes (Top Left) and a Stand Alone Overpass on US 93 in Montana (Top Right), Single-Span Bridged Underpasses Similar to Those Used on SR 260 (Center), and Corrugated Multi-Plate Arch Underpasses Used along US 93 in Montana (Bottom).

### 6.5.2 Role of Passage Structure Spacing

The spacing of wildlife passage structures has a potentially significant impact on the ability to promote highway permeability (Olsson 2007, Bissonette and Adair 2008, Dodd et al. "Effectiveness of Wildlife," *in review*, Gagnon et al. 2010). Bissonette and Adair (2008) recommended spacing based on isometric scaling of home ranges: 2.0 miles between passage structures to accommodate pronghorn permeability, 1.1 miles for mule deer, and 2.2 miles for elk. However, Dodd et al. ("Effectiveness of Wildlife," *in review*) and Gagnon et al. (2010) reported that the spacing of 2.2 miles between passage structures for elk may be high because elk passage rates along reconstructed SR 260 highway sections dropped off dramatically above 1.6 miles spacing.

The research team recommends spacing passage structures 1.5 to 2.3 miles apart on Section A (elk, deer, and pronghorn), 1.8 to 2.3 miles apart on Section D (pronghorn), and 2.3 miles apart on Section E (elk and deer); however, the lower end of these ranges will provide more effective permeability.

The team's recommendations for elk and pronghorn are generally consistent with those made by Bissonette and Adair (2008). Dodd et al. (2011) recommended 3.2 miles spacing between passage structures for pronghorn on US 89, reflecting daily movements and linear distance traveled. The team's recommended spacing distance along SR 64 is double that recommended for mule deer by Bissonette and Adair (2008).

However, the considerably larger mean home ranges measured for all three species along SR 64, especially for mule deer (excluding the five animals that exhibited long-distance movements), was more than 15 times the size reported by Bissonette and Adair (2008). This suggests that the recommended spacing may be adequate; regardless, the topography on Sections A and D effectively preclude additional cost-effective passage structures to achieve closer spacing.

### 6.5.3 Role of Fencing

Several studies point to the integral role that 6.5 to 8 ft ungulate-proof fencing plays in achieving highway reconstruction objectives for minimizing WVCs and promoting highway safety, as well as promoting wildlife permeability (Dodd et al., "Evaluation of Measures," 2007; "Effectiveness of Wildlife," *in review*). This important role of fencing in conjunction with passage structures has been stressed by Romin and Bissonette (1996), Forman et al. (2003), and others, and the empirical basis for fencing's role in reducing WVCs has continued to grow, with reductions in WVCs of anywhere from 80 percent (Clevenger et al. 2001) to more than 90 percent (Ward 1982, Woods 1990, Gagnon et al. 2010).

Conversely, some mixed results have been reported (Falk et al. 1978), especially where animals cross at the ends of fencing, resulting in zones of increased incidence of WVCs (Woods 1990, Clevenger et al. 2001), an important consideration in determining where to terminate fencing. Fencing is costly and requires substantial maintenance (Forman et al. 2003), often making it difficult for transportation officials to justify fencing long stretches of highways. However, failure to erect adequate fencing in association with passage structures, even when adequately spaced, was found to substantially mitigate their effectiveness in reducing WVCs and promoting permeability (Dodd et al., “Evaluation of Measures,” 2007; “Effectiveness of Wildlife,” *in review*).

Fencing in conjunction with pronghorn passage structures presents a unique situation compared with elk and mule deer. Pronghorn evolved in open plains/grassland environments where speed and mobility was their defense against predators (Hart et al. 2008). Pronghorn have exhibited limited ability to adapt to fences like elk and deer. Whereas fencing has been instrumental in preventing at-grade highway crossings and funneling animals to passage structures to reduce WVCs and promote permeability such an approach may not be necessary for pronghorn that exhibit virtually no at-grade highway crossings or collisions with vehicles in Arizona (Clevenger et al. 2001, Dodd et al. “Video surveillance to assess,” 2007).

Sawyer and Rudd (2005:18) stressed the advantage of avoiding fences altogether in association with passage structures to promote pronghorn use. They stated that “ideally, a crossing structure would be located in an area with no fencing. If fencing is required, then the crossing structure should be located in an area where fence design is pronghorn-friendly and does not inhibit pronghorn movements to and from the structure.”

On land where livestock grazing occurs (e.g., Kaibab NF, Arizona State Trust lands), creative approaches such as pulling fences back 0.25 to 0.5 miles or resting pastures and removing fencing could minimize the impact of ROW fences, beyond the installation of “goat bars” (plastic pipe to the bottom strand of a fence; B. Cordasco, Babbitt Ranches, personal communication, 2008), or raising/removing the bottom strand of barbed-wire fences (Hart et al. 2008). ROW fencing in association with passage structures is not needed to preclude at-grade pronghorn crossings of SR 64. Fencing would play less of a physical funneling role than providing a visual cue as to a path of least resistance across the highway barrier, provided no fencing is used at the mouth of the passages.

The research team’s specific recommendations for the erection of 8 ft ungulate-proof (wildlife) fencing along SR 64 include:

- Erecting fencing along Section A from MP 186.0, near the I-40 junction (with appropriate flaring or other measures to prevent an end run onto the interstate), to MP 189.2 at the south abutment of the recommended overpass, or 3.2miles. This would serve to funnel elk and deer toward the two passage structures (including Cataract Canyon Bridge) and limit the potential for an end run at the I-40 junction. From the north abutments of the overpass at MP 189.2, extend fencing 0.9 miles north to MP 190.1 at the Kaibab NF boundary (Figure 25).
- Erecting 12.1 miles of fencing from the north abutment of the Section D overpass at MP 222.3 to the south abutments of the overpass at roughly MP 234.4 (Figure 26). From the northwest abutment, the fence would link into the existing 8 ft chain-link fence around Grand Canyon Airport just south of the ADOT housing compound. From the northeasternmost extent of chain-link fence around the airport, extend the wildlife fence to the ROW and north to Long Jim Road. From the northeast abutment,

the fence would continue along the highway ROW north to Forest Road 302. Where the fence terminates, sealing the fenced corridor to prevent breaching of the fenced corridor could be accomplished with an electrified guard installed into the pavement (Figure 28).

- Erecting fencing in the town of Tusayan is highly problematic due to visual impact and numerous lateral access points. With 35 mph posted speed and good visibility, lending to the low incidence of WVCs within the developed stretch of Tusayan wildlife fencing can be foregone within the developed portion of Tusayan, recognizing that deer and elk will frequent this area; special warning signage may be warranted here. Wildlife fencing should be erected on both sides of SR 64 beginning at the north end of the developed portion of Tusayan near MP 235.5. Fencing should continue to the underpass recommended at MP 236.8, as well as from the underpass, terminating 0.5 miles beyond this point at the GCNP, for a total of approximately 1.8 miles (Figure 26). At the beginning of the fenced section at the north end of Tusayan, another electrified barrier across the highway may be considered to secure the fenced corridor (Figure 28).

Figure 28. An Electrified Barrier Installed in the Pavement to Prevent Wildlife from Breaching the Fenced Corridor at the Fencing Terminus. This Mat was Installed on I-40 Off-Ramps in New Mexico.

# 7.0 CONCLUSIONS AND RECOMMENDATIONS

This project implemented a data-driven approach to quantify elk, mule deer, and pronghorn permeability across SR 64 and to determine the best locations for potential passage structures to reduce WVCs and enhance permeability. For pronghorn, this study was particularly important given the lack of WVC data for the species. Key conclusions and recommendations from this research project follow.

Recommendations are highlighted using the symbol ☞.

## 7.1 FINAL WILDLIFE ACCIDENT REDUCTION STUDY ROLE

- The study effort in ADOT (2006) represents a proactive commitment by ADOT to analyze WVC data and develop strategies to reduce WVCs and promote wildlife passage across Arizona's highways. This approach is especially useful in helping prioritize and streamline highway reconstruction planning processes, including the Design Concept Report process, to effectively address wildlife-related issues.

  ☞ Assessments similar to ADOT (2006) should be accomplished on other highways, where appropriate, to address WVCs and wildlife permeability issues. Such assessments should be prioritized using the *Arizona's Wildlife Linkages Assessment* (Arizona Wildlife Linkages Workgroup 2006) and WVC databases.

- This project further confirms the utility of WVC data for locating wildlife passage structures as confirmed by GPS telemetry. Eight of nine (89 percent) recommended passage structure locations using WVC data in ADOT (2006) were confirmed as being warranted by telemetry from this study; the ninth was not recommended only for space (and cost) considerations. Dodd et al. ("Evaluation of Measures," 2007) advocated using WVC data where it exists to plan and identify locations for wildlife passage structures, with the 0.6 mile scale showing the greatest management utility.
- The research team found that the spatial association between elk-vehicle collisions and crossings at the 1.0 mile scale was significant ($r = 0.811$, $P < 0.001$), as was the association for deer ($r = 0.705$, $P = 0.022$). This association points to the utility of WVC data in planning strategies to reduce WVCs and promote permeability.

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

- In the case of pronghorn, for which the highway constitutes such a barrier that pronghorn-vehicle collisions do not occur, GPS telemetry data was essential to developing informed, data-driven recommendations for passage structure placement.

☞ For species for which highways constitute strong barriers to passage, such as pronghorn, GPS telemetry studies are vital to developing strategies to promote permeability and connectivity.

## 7.2 WILDLIFE PERMEABILITY AND PASSAGE STRUCTURES

- GPS telemetry afforded a valuable technique to assess and compare wildlife permeability for three ungulate species along SR 64 and to compare the results to telemetry studies elsewhere (e.g., SR 260, US 89) for the same species under different highway conditions. Assessments and comparisons in this study were facilitated by the use of "passage rate" as a comparable metric for permeability (Dodd et al., "Assessment of elk," 2007).

☞ When possible, GPS telemetry should be used to document wildlife movements to facilitate positioning passage structures and fencing in the best available locations to ensure effectiveness, particularly for those species that do not readily cross highways and for which limited WVC data exists (e.g., pronghorn).

### 7.2.1 Elk and Mule Deer Permeability

- Elk crossed the highway 843 times, an average of 0.12 times per day, with the highest proportion of crossings during the driest season (April–July; 60 percent). Movements to limited water sources likely influenced movement and crossing patterns. The elk crossing distribution was not random and exhibited several peak crossing zones, especially at the north end of the study area. The highest proportion of crossings occurred in late April - July (60 percent), followed by August–November (27 percent), and December–March (13 percent).
- The elk passage rate averaged 0.44 crossings per approach. This was 52 percent lower than the rate on SR 260 sections with similar highway standards from previous telemetry research.
- Elk passage rates by 2 hour blocks ranged from 0.03 to 0.78 crossings per approach. The passage rate between midnight and 04:00 a.m., when traffic was nearly absent (less than 10 vehicles per hour), averaged 0.58 crossings per approach, more than two times the mean passage rate during the rest of the day (0.28 crossings per approach).
- Mule deer crossed the highway 550 times, more than twice as frequently as elk (0.26 times per day). Seasonal deer crossings were more consistent than elk, though 46 percent of crossings occurred during August through November. The mule deer crossing distribution did not occur in a random fashion; two peak crossing zones were identified at the north end of the study area. Ninety-two percent of the crossings occurred along a 3.2 mile stretch between the Grand Canyon Airport and GCNP.
- The overall average mule deer passage rate (0.54 crossings per approach) was higher than the rate for elk in this study. This passage rate was substantially higher that the

rate for white-tailed deer on SR 260. Unlike SR 64 elk, the deer passage rate remained relatively high (0.61 crossings per approach) well into the morning hours.

- It is anticipated that SR 64 elk and mule deer permeability levels will be impacted with future SR 64 reconstruction, possibly to even a higher degree than reported for SR 260 given the current lower passage rate across the two-lane highway (Dodd et al., "Evaluation of Measures," 2007), and consistent with predictions by Jaeger et al. (2005). As such, measures to promote permeability, including passage structures and fencing, will be critical once the highway is widened.

  ☞ The team recommends that six wildlife underpasses and one overpass be constructed along SR 64 to accommodate elk and deer passage; four other overpasses are recommended to accommodate pronghorn passage, and they too may receive use by elk and deer (Table 9; Figures 25 and 26).

  ☞ Though the wildlife use documented by cameras at Cataract Canyon Bridge was limited, the research team nonetheless believes the bridge has the potential to be a highly effective retrofitted wildlife passage structure due to the high passage rates for deer and elk that crossed through with minimal behavioral resistance. The bridge also exceeds all structural and placement guidelines for effective passage structures. The high level of human use at the bridge should not significantly limit effective wildlife use because animal use primarily occurs in the evening and at night, while human use occurred exclusively in the daytime.

### 7.2.2 Pronghorn Permeability

- SR 64 constitutes a near-total barrier to the passage of pronghorn, with only one of 15 tracked animals having crossed the highway.
- The pronghorn highway crossing rate averaged 0.001 crossings per day among the pronghorn that approached to within 0.15 miles of SR 64. The pronghorn passage rate was negligible, only 0.004 crossings per approach. These rates were nearly identical to those documented for pronghorn along US 89 (Dodd et al. 2011).
- The barrier effect associated with SR 64, coupled with the need to maintain the viability and size of the pronghorn population, points to the need for passage structures to promote permeability for this species.

  ☞ Two of the research team's eleven potential passage structure locations are for pronghorn passage, and another two are recommended at locations likely to be used by elk and mule deer as well. At all four locations, overpasses are preferred over underpasses to accommodate pronghorn passage because these structures provide a greater level of openness, which is important to achieve pronghorn use.

## 7.3 IMPACT OF TRAFFIC AND NOISE

- Traffic volumes along SR 64, averaging 4275 vehicles per day, fluctuated greatly on an hourly, daily, and seasonal basis. Traffic volumes were highest during daytime hours. However, compared with other study areas in Arizona, SR 64 is unique in that traffic is virtually nonexistent late at night, averaging less than 10 vehicles per hour for a 4 hour period, reflecting the predominant tourist destination nature of motorists traveling to and from the GCNP.

  Elk, mule deer, and pronghorn distribution with fluctuating traffic was consistent with models of road impact that resulted in reduced habitat availability within 990 ft of the highway. The probability of presence within 990 ft of SR 64 by all three species was clearly reduced at higher traffic volumes, with the mean proportion dropping nearly in half, from 0.34 at less than 100 vehicles per hour to 0.19 at traffic volumes of just 200 to 300 vehicles per hour. Though elk and deer returned to areas adjacent to the highway, including to within 330 ft, in proportions greater than 0.12 when traffic volumes were low, the impact to pronghorn resulted in a permanent loss in habitat effectiveness. Pronghorn uniformly avoided areas adjacent to the highway and were consistently negatively impacted by traffic at even low levels.

  The highest levels of permeability for elk and deer (passage rates greater than 0.70 crossings per approach) occurred at night when traffic was lowest. Pronghorn appeared more sensitive to traffic volume impact than elk and deer, and their avoidance of the area adjacent to the highway is problematic in terms of implementing effective passage structures to promote permeability.

- Pronghorn are primarily active during daytime hours when peak traffic volumes, often approaching 10,000 AADT, occur along SR 64 and highways become strong barriers to wildlife passage (Mueller and Berthoud 1997).

  ☞ A comprehensive set of measures to reduce traffic-associated noise impact should be employed to create “quiet zones” along the highway to facilitate pronghorn highway approaches and crossings via passage structures. These design measures could include; 1) recessing the roadway below grade, 2) integrating noise barriers such as berms, 3) vegetation, 4) sound walls, and 5) applying pavement treatments such as rubberized asphalt. Without a comprehensive effort to reduce noise and visual impact, the potential success of passage structures could be compromised.

## 7.4 PASSAGE STRUCTURE DESIGN AND PLACEMENT

- Structural design characteristics and placement of passage structures are important in maximizing their efficacy in promoting wildlife passage. SR 260 research found underpass structural characteristics to be the most important factor in determining the probability of achieving successful crossings by elk and deer (Gagnon et al. 2011).
- Structure openness is important to achieving a high probability of successful crossings by wildlife (Dodd et al. “Effectiveness of Wildlife,” *in review*). The SR 260

data suggest that underpass length, the distance that animals must travel through an underpass, is an especially important factor in maximizing effectiveness.

- ☞ Where possible, the length through underpasses should be minimized, consistent with terrain and other factors. Atria between underpass bridge spans contribute to openness, especially for longer underpasses.

- ☞ The research team recommends that ADOT investigate and consider other accepted and cost-effective passage structure designs (e.g., large metal multi-plate arched culverts). This can be done in an appropriate mix with large, open-span bridges to reduce cost while promoting permeability.

- ☞ The researchers recommend that the bridges be placed straight rather than skewed to maximize animal visibility through the structures. Offset bridges should be avoided; where offset bridges are necessary, the use of fill material that limits animal visibility should be minimized.

- To date, no structure designed specifically to accommodate pronghorn passage has been constructed in North America. As such, limited guidelines or insights exist as to what types of structures are best suited to promoting pronghorn permeability. The research team believes that overpasses and large elevated viaducts have the best potential for promoting permeability. Site-specific characteristics associated with passage structure locations will dictate what type of pronghorn passage structure (e.g., underpass, viaduct, overpass) might be appropriate from engineering and cost standpoints. However, structural design characteristics will have a significant bearing on the eventual use and acceptance of the passage structures.

  - ☞ The most important structural consideration for pronghorn is the requirement that the structure be as open and wide as possible, with attention paid to avoiding obstructed line-of-sight views through or across structures or any restrictions to mobility.

### 7.4.1 Role of Passage Structure Spacing

- The 11 structures recommended by the research team are spaced from 1.5 to 2.3 miles apart, with this spacing generally consistent with guidelines for elk and pronghorn (Bissonette and Adair 2008). The spacing for mule deer exceeds these guidelines, though deer along SR 64 exhibited home ranges considerably larger than those used to develop spacing guidelines by Bissonette and Adair (2008).

### 7.4.2 Role of Fencing

- In addition to playing an instrumental role in promoting permeability and highway safety from reduced WVCs, ungulate-proof fencing has been shown to be crucial to achieving underpass effectiveness. Without fencing, elk and deer continued to cross

SR 260 at a grade adjacent to underpasses (Dodd et al. "Evaluation of Measures," 2007). With fencing, elk and deer passage rates and probabilities of successful crossing through underpasses increased dramatically, while at-grade crossings decreased.

☞ The research team identified 14.2 miles of the highway corridor where fencing would be needed to meet WVC reduction and permeability objectives, differing little from the 2006 *Final Wildlife Accident Reduction Study* recommendations (Figures 25 and 26).

- Though beneficial in reducing WVCs, maximizing passage structure use by wildlife, and promoting permeability, fencing nonetheless requires constant maintenance and attention to maintain its integrity.

☞ Future ungulate-proof (wildlife) fencing along SR 64, integrated with passage structures, should be checked and maintained to ensure long-term integrity and continued benefit in promoting highway safety. Adequate funding is needed for ADOT to effectively maintain fencing and passage structures as these measures increasingly become par of Arizona's highways.

- Because pronghorn have exhibited limited ability to adapt to fences like other ungulate species, ROW fences contribute significantly to the highway barrier effect. Fencing, in conjunction with pronghorn passage structures (e.g., overpasses), may be more useful in providing a visual cue to a path of least resistance across the highway barrier, provided no fencing is used at the mouth of the passages.

☞ Where ROW and livestock pasture fencing are needed to preclude livestock access to SR 64, creative approaches should be used to minimize fencing's barrier effect to pronghorn. Near passage structures, fences can be pulled back from the highway 0.25 to 0.5 miles to separate fencing and highway barriers. A better approach would be the long-term resting of livestock pastures adjacent to passage structures with the temporary removal of fencing at the mouths of passage structures.

## 7.5 HIGHWAY SAFETY AND WILDLIFE-VEHICLE COLLISIONS

- The incidence of WVCs along SR 64 is a growing highway safety issue, with an increase in WVCs from that reported in ADOT (2006) of 36.7 such incidents per year to 52.0 per year in this study. The research team recorded 167 WVCs, with elk accounting for 59 percent and mule deer 35 percent of the WVCs. SR 64 sections on Kaibab NF lands at the north and south ends of the study area had the highest incidence of elk and deer collisions.
- From 1998 through 2008, 42 percent of all single-vehicle accidents along SR 64 involved wildlife, compared with the national average of just 5 percent. Along the 5 miles at the north end of the study area, wildlife-related accidents accounted for more than 75 percent of all single-vehicle accidents.

- No WVCs involving pronghorn were recorded during the study, which is thought to be due to the barrier effect of SR 64 on pronghorn passage.
- Based on recent average cost estimates for wildlife vehicle collisions (Huijser et al. 2007), along with available 2007-2009 collision figures, the research team estimated the annual cost of SR 64 WVCs to be $612,500 for elk and $162,200 for deer, a combined annual total of $775,000.

  ☞ It is anticipated that WVCs will be reduced greatly once passage structures and wildlife fencing are implemented on SR 64, possibly achieving a similar 95 percent reduction realized in other areas (Gagnon et al. 2010). The cost benefit to be realized with such potential reductions in WVCs can be an important factor to support implementing mitigation measures.

## 7.6 MONITORING

- Monitoring of wildlife passage structures and associated fencing is vital to providing insights and knowledge of their effectiveness in promoting wildlife permeability, particularly with the limited knowledge existing today for pronghorn.

  ☞ Once SR 64 passage structures are implemented, funding should be sought to conduct a thorough evaluation of their utilization by wildlife as well as the level of their contribution to promoting permeability. Monitoring should be conducted in a scientifically rigorous manner using a before-after-control experimental design (Hardy et al. 2003, Roedenbeck et al. 2007, Dodd et al. "Effectiveness of Wildlife," *in review*).

- The combined application of phased construction, adaptive management, and effective monitoring and evaluation of measures to reduce WVCs and promote permeability along SR 260 were instrumental to jointly achieving transportation and ecological objectives (Dodd et al. "Effectiveness of Wildlife," *in review*).

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

- Monitoring wildlife mitigation measures and WVCs yielded significant benefit in improving the efficacy of these measures.

  ☞ Consideration should be given to using an effective monitoring system incorporated and funded as part of construction projects, which would add to the body of knowledge on wildlife collision mitigation measures and contribute to the toolbox of potential measures for application on highways elsewhere.

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