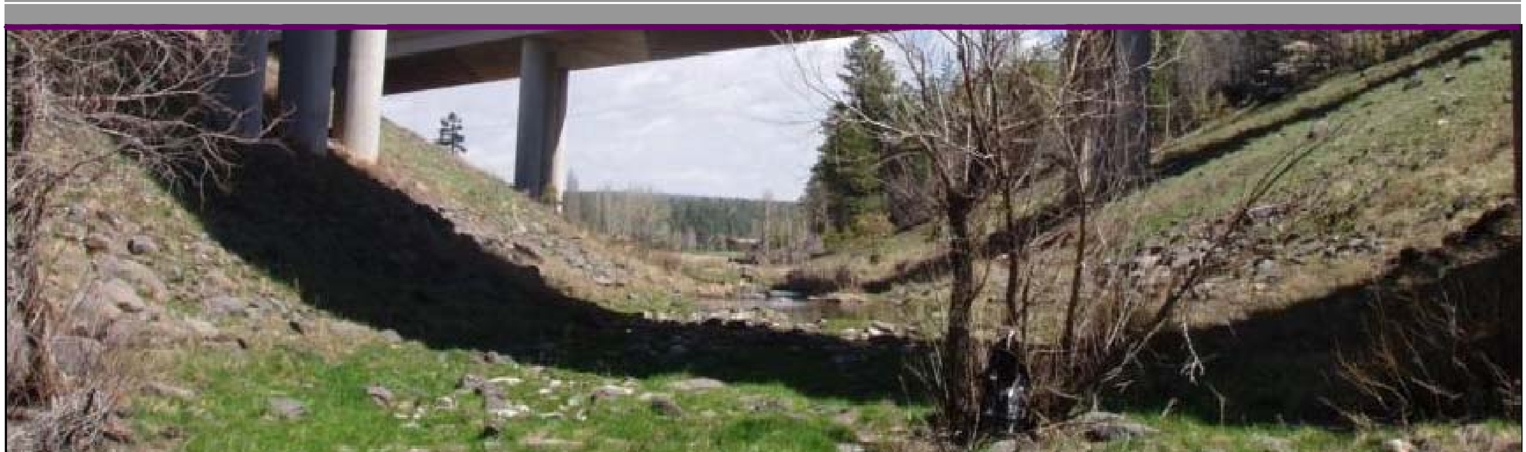
Elk Movements Associated with a High-traffic Highway: Interstate 17

Final Report 647
March 2013



ADOT
Arizona Department of Transportation
Research Center

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Prepared by:
Jeffrey W. Gagnon, Norris L. Dodd, Scott Sprague, Rob Nelson, Chad Loberger,
Susan Boe, and Raymond E. Schweinsburg
Arizona Game and Fish Department
Research Branch
5000 West Carefree Highway
Phoenix, Arizona 85068

Prepared for:
Arizona Department of Transportation
206 South 17th Avenue
Phoenix, Arizona 85007
in cooperation with
U.S. Department of Transportation
Federal Highway Administration

This report was funded in part through grants from the Federal Highway Administration, U.S. Department of Transportation. The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data, and for the use or adaptation of previously published material, presented herein. The contents do not necessarily reflect the official views or policies of the Arizona Department of Transportation or the Federal Highway Administration, U.S. Department of Transportation. This report does not constitute a standard, specification, or regulation. Trade or manufacturers' names that may appear herein are cited only because they are considered essential to the objectives of the report. The U.S. government and the State of Arizona do not endorse products or manufacturers.

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1. Report No. FHWA-AZ-13-647	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle **ELK MOVEMENTS ASSOCIATED WITH A HIGH-TRAFFIC HIGHWAY: INTERSTATE 17**		5. Report Date March 2013 6. Performing Organization Code
7. Authors Jeffrey W. Gagnon, Norris L. Dodd, Scott Sprague, Rob Nelson, Chad Loberger, Susan Boe, and Raymond E. Schweinsburg		8. Performing Organization Report No.
9. Performing Organization Name and Address Arizona Game and Fish Department Research Branch 5000 W. Carefree Highway Phoenix, AZ 85068		10. Work Unit No. 11. Contract or Grant No. SPR-PL-1(173) 647
12. Sponsoring Agency Name and Address Arizona Department of Transportation 206 S. 17th Avenue Phoenix, AZ 85007		13.Type of Report & Period Covered FINAL REPORT February'08 – December '11 14. Sponsoring Agency Code
15. Supplementary Notes Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration		

16. Abstract

The authors evaluated wildlife-highway relationships from 2007 to 2010 along a 46-mi stretch of Interstate 17 (I-17) in north-central Arizona (MP 294−340). This highway had an average annual daily traffic (AADT) volume of 16,100 vehicles/day during the study. The specific objectives of this research project were to:

- Assess elk movements, highway crossing patterns, and distribution, and determine permeability.
- Investigate spatial and temporal relationships of elk crossings and distribution to traffic volume.
- Investigate spatial and temporal wildlife-vehicle collision (WVC) patterns and traffic relationships.
- Investigate elk crossings and WVC in relation to riparian-meadow habitats.
- Develop recommendations to reduce WVC and promote highway permeability.

The research team instrumented 71 elk (*Cervus elaphus*) with GPS receiver collars along I-17. Elk crossed the highway 912 times and had a mean passage rate of 0.09 crossings/approach. Compared to other Arizona highways with lower AADT, I-17 was a significant barrier to elk passage. Passage rates were significantly higher along stretches with wide medians and near the Munds Canyon Bridge. In total, 395 WVC were analyzed, and an average of 79.0 elk-vehicle collisions occurred each year. Traffic volume influenced elk distribution, permeability, and WVC patterns. Proximity to riparian-meadow habitats also influenced elk crossing, approach, and WVC locations. The team recommended 17 wildlife passage structures and ungulate-proof fencing along the length of I-17 to reduce WVC and promote permeability, largely validating the recommendations in the draft environmental assessment (DEA).

17. Key Words		18. Distribution Statement		23. Registrant's Seal
Cervus elaphus, elk, GPS telemetry, fencing, highway impact, deer, permeability, traffic volume, wildlife passage structures, wildlife-vehicle collisions		No restriction. Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161		
9. Security Classification Unclassified	20. Security Classification Unclassified	21. No. of Pages 119	22. Price	

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ACRONYMS AND ABBREVIATIONS

AADT ....average annual daily traffic
ADOT ....Arizona Department of Transportation
AGFD.............Arizona Game and Fish Department
ANOVA ....analysis of variance
ATR................automatic traffic recorder
BACI ....before-after-control-impact (experimental design)
DCR ....design concept report
DPS ....Department of Public Service
DVC ....deer-vehicle collision(s)
DEA ....draft environmental assessment
EVC................elk-vehicle collision(s)
ft ....foot/feet
GIS ....geographic information system
GMU ....game management unit
GPS ....global positioning system
hr ....hour(s)
IDCR ....initial design concept report
IGA ....intergovernmental agreement
in ....inch(es)
I-17.................Interstate 17
I-40.................Interstate 40
MCP ....minimum convex polygon (home range)
mi ....mile(s)
MP.................milepost(s)
mph ....miles per hour
NB..................northbound (lanes)
NF ....National Forest
SB ....southbound (lanes)
SDI ....Shannon diversity index
SE...................standard error
SR 64..............State Route 64
SR 260............State Route 260
TI....................traffic interchange(s)
US 89 .............U.S. Route 89
US 93 .............U.S. Route 93
USFS ..............U.S. Forest Service
VHF................very high frequency
WVC ....wildlife-vehicle collisions

LIST OF SPECIES

Animals

Bald eagle	*Haliaeetus leucocephalus*
Bighorn sheep	*Ovis canadensis*
Black bear	*Ursus americanus*
Coyote	*Canis latrans*
Elk	*Cervus elaphus*
Gray fox	*Urocyon cineroargenteus*
Javelina	*Tayassu tajacu*
Mountain lion	*Puma concolor*
Mule deer	*Odocoileus hemionus*
Pronghorn	*Antilocapra americana*
Raccoon	*Procyon lotor*
White-tailed deer	*Odocoileus virginianus*
Wolf	*Canis lupus*

Plants

Apache plume	*Fallugia paradoxa*
Blue grama	*Bouteloua gracilis*
Cliffrose	*Cowania mexicana*
Gambel oak	*Quercus gambelii*
One-seed juniper	*Juniperus monosperma*
Ponderosa pine	*Pinus ponderosa*
Pinyon	*Pinus edulis*
Rabbitbrush	*Ericameria nauseosa*
Utah juniper	*Juniperus osteosperma*
Winterfat	*Ceratoides lanata*

ACKNOWLEDGEMENTS

This project was funded by the Arizona Department of Transportation's (ADOT) Research Center and the Federal Aid Wildlife in Restoration Act, Project W-78-R supporting Arizona Game and Fish Department (AGFD) research. The research team commends ADOT for its proactive commitment to promoting wildlife connectivity and highway safety. The Federal Highway Administration (FHWA) also was instrumental in the funding and support of the project.

Many individuals at ADOT provided endless support and guidance. The Roadway Predesign Section is to be commended for their 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. The team also thanks Todd Williams, Justin White, Bruce Eilerts, Tom Eckler, and Siobhan Nordhaugen of the Office of Environmental Services for their commitment to the project and efforts to address wildlife permeability. ADOT Little Antelope Maintenance personnel contributed tremendous support and commitment to the project, including the thorough documentation of wildlife-vehicle collisions.

The AGFD Flagstaff Region personnel, including Ron Sieg, Lee Luedeker, Larry Phoenix, and Tom McCall, played a crucial role in supporting the project. The region office assisted with project logistics, landowner coordination, and elk trapping, and provided elk survey information.

Highway patrolmen with the Arizona Department of Public Safety's (DPS) Flagstaff District made an outstanding effort to record all wildlife-vehicle collisions along Interstate 17 (I-17). They collected and recorded additional information beyond that required on accident reports that was important to the research project.

The Coconino National Forest (NF) provided invaluable logistical support. In particular, Henry Provencio offered valuable project guidance and coordination.

Lastly, the project technical advisory committee members made many suggestions toward improving its effectiveness and applicability. Their tremendous support, oversight, and commitment throughout the duration of the project were appreciated.

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EXECUTIVE SUMMARY

The research team assessed wildlife-highway relationships from 2007 to 2010 along a 46-mile stretch of Interstate 17 (I-17), the primary highway artery between Phoenix and northern Arizona and I-40. For most of its length, I-17 is a four-lane divided highway with an approximately 85-ft median between northbound and southbound lanes; however, along a 4.5-mi stretch the median exceeds 500 ft in width and along 2.5 mi its lanes are separated by 2,500 ft or more. The average annual traffic volume (AADT) for I-17 during the study was 16,100 vehicles/day, making it a high-volume highway compared to other Arizona highways where similar research has been done: State Route (SR) 260 (8,700 vehicles/day; Dodd et al. 2007*a*) and SR 64 (4,275 vehicles/day; Dodd et al. 2010). The predominant I-17 posted speed is 75 mph.

The incidence of wildlife-vehicle collisions (WVC) for much of the study area is a significant problem that is being addressed with a wide range of concurrent activities. ADOT is evaluating the long-range reconstruction of I-17 to address increased traffic volume and highway safety issues. In 2006, ADOT began environmental surveys and development of a design concept report (DCR) for project H6960 01L: I-17, Jct. SR 179 to I-40, of which the initial DCR (IDCR; Stanley Consultants 2011) included a preliminary WVC assessment. Along a 6-mi stretch constituting one of the worst WVC "hotspots," a wildlife fencing enhancement project (H7740 01C - Wildlife-Vehicle Collision Reduction, Munds Park to Woods Canyon, mileposts (MP) 316.8–322.72, JPA 10-168-I) was begun in summer 2011, which is intended to reduce collisions and promote wildlife passage across the highway. With its high traffic volume, I-17 has the potential to be a significant barrier to wildlife passage. Theoretical models predict that at 10,000 AADT and above highways are impermeable barriers to wildlife passage (Iuell et al. 2003, Seiler 2003). I-17 presents an opportunity to empirically assess the wildlife barrier effect under such extreme traffic volume circumstances and compare the effect to lower volume highways. The objectives of this research project were to:

- Assess elk movements, highway crossing patterns, and distribution; and determine permeability across the highway corridor.
- Investigate spatial and temporal relationships of elk highway crossing and distribution patterns to traffic volume.
- Investigate spatial and temporal WVC patterns and traffic volume relationships.
- Investigate elk crossing patterns and WVC in relation to meadow and riparian habitats, and validate and refine the habitat model assessing the influence of riparian-meadow habitats developed for SR 260 (Manzo 2006).
- Develop strategies to reduce WVC and promote wildlife permeability across I-17.
- Address elk movements, permeability, and WVC patterns in association with the 6-mi wildlife fencing retrofit enhancement project (MP 316.– 322.7) to establish before-construction WVC baselines for subsequent after-construction evaluation.

ELK MOVEMENTS AND HIGHWAY PERMEABILITY

The research team determined the number of highway crossings and calculated crossing and passage rates for elk using global positioning system (GPS) telemetry. Passage rates, which served as the team's relative measure of highway permeability, were derived from the proportion of times elk crossed the highway versus approached to within 0.15 mi of I-17. The team assessed mean daily elk crossing and passage rates spatially at various temporal scales and compared them among three different highway median width classes. Anticipating relatively few elk highway crossings due to the barrier effect, the team used the number of approaches by elk to within 0.15 mi of I-17 to determine the distribution of animals adjacent to the highway to assess potential locations of passage structures. The researchers tracked 71 elk fitted with GPS collars that accrued 297,283 fixes.

Collared elk crossed I-17 912 times. The spatial crossing distribution was not random and exhibited two large peak crossing zones. The highest peak crossing zone corresponded with the location of Munds Canyon Bridge, an underpass structure, while the other crossing peak zone corresponded with a 1-mi stretch of highway between MP 310 and MP 311 where lanes were separated by over 0.5 mi; combined, these two sections constituted only 4.3 percent of the entire length of highway yet accounted for 45.1 percent of all crossings. The mean crossing rate for elk using highway segments with extremely wide medians (460 ft or wider) was four times higher than for elk found along segments with standard median width (85 ft). The majority of crossings occurred between midnight (00:00) and 06:00, and crossing frequency was inversely associated with mean traffic volume. The highest number of crossings occurred during the summer.

The I-17 elk passage rate averaged 0.09 crossings/approach, considerably lower than those previously documented for SR 260 (0.50 crossings/approach) and SR 64 (0.44 crossings/approach). Elk passage rates were highest from 02:00 to 06:00; the team found an inverse association between elk passage rate and mean traffic volume by time of day, as well as by month. The mean passage rate for elk approaching and crossing at the 0.5-mi stretch around the Munds Canyon Bridge was over three times higher than the adjacent highway segments. The mean combined passage rate for elk along highway segments with wide medians was three times higher than segments with standard median width.

This study confirmed that I-17 constitutes a significant barrier to the passage of elk across the highway, validating models that suggest that highways with AADT above 10,000 constitute impermeable barriers. This was especially apparent when compared to passage rates for SR 260 and SR 64 with lower AADT. Highway stretches with wide medians apparently were perceived by elk as separate two-lane highways with lower traffic volume, resulting in significantly higher crossing and passage rates. This has implications for locating passage structures to maximize effectiveness. Elk permeability along the stretch around the Munds Canyon Bridge illustrates the potential for underpasses to promote permeability with below-grade passage.

TRAFFIC AND ELK DISTRIBUTION RELATIONSHIPS

The research team measured traffic volume using a permanent automatic traffic recorder programmed to record hourly traffic volumes at MP 319.4. Traffic and GPS data were combined to correlate the traffic volume each animal experienced in the hour prior to movement. The researchers examined how the proportion of elk GPS fixes at different distances from the highway varied with traffic volume by calculating the proportion of GPS fixes in each 330-ft distance band (out to a maximum of 1,980 ft) with separate analyses for the three median width classes. Frequency distributions of mean probabilities showed a shift in distribution away from I-17 with increasing traffic volume. Even at relatively low traffic volume of up to 300 vehicles/hr, the mean probability of elk occurring within 330 ft of I-17 was a static 0.12. The probability of elk occurring within 990 ft of the highway was similar when traffic volume was below100 vehicles/hr (0.49) and 300–400 vehicles/hr (0.50), but decreased when traffic volume was above 600 vehicles/hr (0.37). In comparing elk distributions across traffic volume classes for I-17, SR 64, and SR 260, the most dramatic difference occurred for low traffic (<100 vehicles/hr) in the 330-ft zone adjacent to roadway where the probability of elk occurrence declined as AADT increased; the probability of elk occurring adjacent to I-17 was half that of SR 64 and a third lower than for SR 260. Unlike SR 260 and SR 64, even at low traffic volume elk did not exhibit a shift in distribution back to within the 330-ft zone immediately adjacent to I-17, suggesting a permanent shift caused by the overall high traffic volume. When considering elk distribution relative to traffic volume on I-17 sections with wide medians, the probability of elk occurring within 330 ft of the highway at low traffic volume (<100 vehicles/hr) was 25 percent higher than the probability associated with standard medians. High I-17 traffic levels serve as a “moving fence” that physically renders highways impermeable to wildlife, increases the likelihood of an elk-vehicle encounter, and results in a “noise effect zone” adjacent to the highway. Comprehensive measures to reduce noise impact with quiet zones along the highway corresponding to passage structures could facilitate approaches by elk and other animals and help overcome the near-permanent traffic impact zone.

WILDLIFE-VEHICLE COLLISION RELATIONSHIPS

Elk-vehicle collisions (EVC) are a significant issue along I-17. The research team documented 395 WVC involving 10 species during the study. An average of 79.0 EVC a year involving elk were recorded, or 80.0 percent of all WVC, while deer accounted for 14.2 percent. The spatial distribution of EVC differed from a random distribution with several peak zones corresponding to the highway segment with the extremely wide median and meadow complexes. The frequency of EVC by hour differed from expected, with the highest incidence of collisions occurring at 02:00 and 03:00. The research team found a strong inverse association between EVC and traffic volume, and between the frequency of EVC by time and elk highway crossings. For both elk and deer, the researchers found that observed collisions with vehicles differed from expected depending upon the month; aggregated by season, spring had the highest incidence of EVC followed closely by summer, and fall had the highest incidence of deer-vehicle collisions (DVC) with a sharp spike in DVC in October. The team found a stair-stepped traffic volume threshold in I-17 EVC, one at an AADT-equivalent of approximately 10,000 vehicles/day, and another approximately 20,000 vehicles/day beyond which few EVC occurred. Given the strong barrier effect the team confirmed along I-17, the incidence of EVC likely reflects the lethality associated with high traffic volume; though a small proportion of elk cross I-17, those that do are likely to be hit by a vehicle. And when considered by relative crossing frequency, there was a highly disproportionate frequency of GPS-collared elk killed in EVC, as relatively frequent crossers accounted for only 8.4 percent of the collared elk, but accounted for 60.0 percent of those killed in EVC. Using recent established cost figures, the team estimated the annual WVC cost at $1,466,561 for elk and $117,432 for deer, totaling $1,583,933/year; these costs could largely be eliminated under an effective passage structure and fencing strategy.

RELATIONSHIPS TO RIPARIAN-MEADOW HABITAT

The research team incorporated results from a model derived from SR 260 to predict the occurrence of elk crossing, approaches and collisions, using a geographic information system (GIS) to measure the distance from I-17 at each 0.1-mi segment to the nearest riparian-meadow. Once the model was created the research team used contingency table analyses to determine the proportion of crossings, approaches and collisions predicted by the model and showed that proximity to riparian-meadow habitat had a significant influence on the locations of elk highway crossings, elk approaches, and EVC. The odds of an elk crossing occurring at a 0.1-mi segment located within 0.6 mi of riparian-meadow habitat was three times that of occurring at a segment farther from riparian-meadow habitat. The greater odds of elk approaches occurring in proximity to riparian-meadow habitats were especially dramatic compared to approaches at segments away from meadows, nearly 37 times higher. Elk-vehicle collisions were 70 percent more likely to occur at 0.1-mi segments located in proximity to riparian-meadow habitat. Conversely, deer-vehicle collisions were 40 percent less likely to occur at segments in proximity to open riparian-meadow habitat, suggesting that cover adjacent to I-17 was a stronger influence. Elk movement to and use of riparian-meadow habitats adjacent to I-17 for foraging and watering is particularly important during the late spring-summer season when these habitats provide forage of highest nutritional quality.

IDENTIFICATION OF PASSAGE STRUCTURE SITES

The research team used elk highway crossings, elk highway approaches weighted by the number of animals approaching within each segment, WVC, human disturbance, and topography to rate 75 0.6-mi long segments for suitability as potential passage structure locations. The team's ratings ranged from 2 to 41 points of a possible 54 points, with a mean of 16 points. Most of the segments scoring above 25 points located north of the Red Hill Scenic Overlook (MP 312−340) corresponded to riparian-meadow complexes, and passage structures were recommended at each of these priority sites. The researcher's ratings and recommendations concurred with the 16 structures recommended in the I-17 draft environmental assessment (DEA; ADOT 2011). Average spacing between these structures is 2.0 mi. The research team recommended one additional priority passage structure in the vicinity of Rattlesnake Canyon (MP 307) as necessary to provide a logical southern terminus for ungulate-proof fencing. Several studies point to the integral role that ungulate-proof fencing plays in achieving highway reconstruction objectives for minimizing WVC and promoting highway safety, as well as promoting wildlife permeability . The team strongly recommends that ungulate-proof fencing be erected along the entire length of I-17 from MP 306.3 (Stoneman Lake traffic interchange [TI]) to MP 340.0 (I-40).

CONCLUSION

This research project, when combined with other similar studies along Arizona highways, provides an opportunity to investigate highway barrier effects on wildlife permeability against gradients of traffic volume, highway size, and prevalence of riparian-meadow habitat. GPS telemetry is an invaluable tool that has facilitated increased understanding of wildlife-highway relationships in promoting safer and ecologically sensitive transportation systems. This study has established before-construction baselines, allowing for a sound before-after-control-impact (BACI) experimental design once planned short-term (wildlife fencing retrofit enhancement project) and long-term (mainline highway) reconstruction projects occur.

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1.0 INTRODUCTION

1.1 BACKGROUND

Highways constitute one of the most significant forces altering natural ecosystems in North America (Noss and Cooperrider 1994, Trombulak and Frissell 2000, Farrell et al. 2002, Forman et al. 2003). Direct mortality from WVC has been recognized as a serious and growing threat to wildlife populations as well as contributing to human injuries, deaths, and property loss (Schwabe and Schuhmann 2002, Bissonette and Cramer 2008). Over 38,000 human deaths attributable to WVC occurred in the United States between 2001 and 2005, and the economic impact exceeds $8 billion/year (Huijser et al. 2007).

Numerous assessments of WVC have been conducted, most focusing on deer (Bashore et al. 1985, Romin and Bissonette 1996*a*, Hubbard et al. 2000), though recent assessments have addressed elk-vehicle collision (EVC) patterns (Gunson and Clevenger 2003; Biggs et al. 2004; Dodd et al. 2009*a*, 2010; Gagnon et al. 2010). WVC generally do not occur randomly, either spatially or temporally (Bashore et al. 1985, Clevenger et al. 2001, Gunson and Clevenger 2003, Biggs et al. 2004, Dodd et al. 2007*a*). Many spatial factors contribute to the distribution of WVC (Farrell et al. 2002), including topography, wildlife concentrations and density (Hubbard et al. 2000), and highway proximity to preferred and seasonal habitats (Farrell et al. 2002, Romin and Bissonette 1996*b*, Gordon and Anderson 2003, Manzo 2006). Consistent tracking of WVC constitutes a valuable tool to assess the impact of highways (Romin and Bissonette 1996*a*) and the efficacy of passage structures and other measures (e.g., fencing) in reducing WVC (Ward 1982, Clevenger et al. 2001, Dodd et al. 2007*a*). Insights gained from such assessments have been instrumental in developing comprehensive strategies to reduce WVC (Farrell et al. 2002, Clevenger et al. 2002, Bissonette and Cramer 2008).

Indirect barrier and fragmentation effects associated with highways pose an even greater impact on wildlife than WVC, and these pervasive impacts have contributed to diminished habitat connectivity and highway permeability, or ability to cross highways, for many species (Noss and Cooperrider 1994, Forman and Alexander 1998, Forman 2000, Forman et al. 2003, Bissonette and Adair 2008). Highways constitute barriers to wildlife movement that fragment populations and habitats, and limit juvenile dispersal (Beier 1995), genetic interchange (Epps et al. 2005, Riley et al. 2006, Sprague 2010), and population viability. The degree of barrier effect caused by roadways varies by wildlife species, highway type and standard, and traffic volume (Jaeger et al. 2005). Only recently have studies yielded quantitative data relative to assessing highway impact to permeability, employing BACI (Underwood 1994, Hardy et al. 2003, Roedenbeck et al. 2007) experimental designs that elucidate highway reconstruction permeability impact and the influence of passage structures and other measures in promoting permeability (Dodd et al. 2007*b*, Olsson 2007). Such assessments of permeability and long-term benefit to genetic interchange are needed to justify the high cost of passage structures (Corlatti et al. 2009). Arizona researchers have stressed the value of using GPS telemetry for a quantifiable and consistent metric of permeability and calculated highway passage rates for several wildlife species on Arizona highways. This serves to derive comparable estimates of permeability and traffic impact (Dodd et al. 2007*a*,*b*; 2009*a*,*b*; 2010; Gagnon et al. 2007*a*, 2010). Collectively, studies using consistent, comparable methodologies and metrics have added substantially to the understanding of highway impact and traffic relationships to wildlife permeability. The studies have addressed multiple species and highways with 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, 2006).

The integration of structures designed to reduce WVC and promote wildlife passage across highways in transportation projects has increased in the past decade (Bissonette and Cramer 2008). Passage structures have shown benefit in promoting highway permeability for a variety of species (Farrell et al. 2002; Clevenger and Waltho 2003, Dodd et al. 2007*a*), and in conjunction with fencing, have dramatically reduced the incidence of WVC (Clevenger et al. 2001, Dodd et al. 2006, Olsson et al. 2008, Gagnon et al. 2010). Whereas early passage structures were typically approached as single-species mitigation measures to address WVC (Reed et al. 1975), the focus today is on preserving ecosystem connectivity and permeability benefiting multiple species (Clevenger and Waltho 2000). Recent studies have yielded quantitative data under BACI experimental designs pointing to the benefit of wildlife passage structures in promoting permeability (Dodd et al. 2009*a*). Such assessments, along with assessments of genetic interchange, help justify the high cost of passage structures (Corlatti et al. 2009).

Dodd et al. (2007*a*) found that the elk passage rate along one SR 260 segment with seven passage structures averaged 0.79 crossings/approach during reconstruction when traffic was limited to two lanes. After reconstruction but before ungulate-proof fencing was erected, the passage rate declined to 0.52 crossings/approach; once fenced, the passage rate rebounded to 0.82 crossings/approach, as well as achieving an 85 percent reduction in EVC (Dodd et al. 2007*c*). In assessing traffic influences on elk permeability, Gagnon et al. (2007*a*) found that increasing traffic volume decreased the probability of at-grade crossings and temporarily shifted elk away from the highway. Conversely, Gagnon et al. (2007*b*) found that traffic levels did not influence elk passage rates during below-grade underpass crossings. This finding likely accounts for the benefit of structures and fencing in promoting permeability, where fences funnel elk to underpasses where traffic has minimal impact compared to crossing at-grade. Dodd and Gagnon (2011) calculated white-tailed deer passage rates, which averaged only 0.03 crossings/approach on control sections. However, compared to controls, the five-fold higher deer permeability after reconstruction with passage structures points to the efficacy of passage structures even to relatively low-mobility species. Like elk, deer passage rates were less affected by traffic on sections where passage structures facilitated below-grade passage (Dodd and Gagnon 2011).

Along with structural characteristics, proper location and placement of wildlife crossing structures are vital considerations to maximizing wildlife use (Reed et al. 1975; Foster and Humphrey 1995; Clevenger and Waltho 2000, 2003; Dodd, Gagnon, Manzo, et al. 2007; Gagnon et al. 2011; Clevenger and Huijser 2011). Spacing between passage structures also is an important consideration, and Bissonette and Adair (2008) recommended passage structure spacing for several species tied to isometric scaling of home ranges. Their spacing recommendations, when used with other criterion, were intended to help maintain landscape connectivity. Dodd et al. (2009*a*) found that elk (n = 100) permeability averaged 0.67 crossings/approach on SR 260 control sections compared to 0.41 crossings/approach after reconstruction on three sections; however, after-reconstruction permeability varied widely among sections (0.09–0.81 crossings/approach) and was inversely associated (r = -0.847) with passage structure spacing. The availability of wildlife movements and highway crossing information, along with WVC data, are valuable in developing comprehensive strategies and locating passage structures such that their success is maximized in promoting permeability and highway safety.

1.2 RESEARCH JUSTIFICATION

The incidence of WVC along a 33-mi stretch of I-17 south of Flagstaff is a significant problem, and one that could potentially worsen as Arizona's population continues to grow and traffic on I-17 increases. A wide range of concurrent activities are ongoing along I-17 in the area where WVC involving elk are a significant and growing concern, extending from the Stoneman Lake TI at MP 306 to the I-40 TI in Flagstaff (MP 340); this stretch accounts for 97 percent of all I-17 EVC. The activities detailed below both provide an opportunity as well as a need for research to provide information for data-driven decision making, as well as adding substantially to the understanding of complex road ecology relationships.

Design Concept Report

ADOT is currently evaluating the long-range reconstruction of I-17 from MP 299 to MP 340 to address increased traffic volume and highway safety issues. In 2006, ADOT began environmental surveys and development of an IDCR (H6960 01L: I-17, Jct. SR 179 to I-40; Stanley Consultants 2011) to address planned reconstruction from the SR 179 TI to the I-40 junction in Flagstaff. As part of the IDCR, ADOT commissioned a proactive analysis of WVC data from 2001 to 2006. The agency found that WVC accounted for the highest percentage of all accidents on northbound (NB) I-17 (21.2 percent), and the second highest percentage of accidents on southbound (SB) I-17 (20.4 percent, second only to overturned vehicles at 22.6 percent), with several 1-mi segments exceeding 30 percent; the national average for wildlife-related accidents is 4.6 percent (Huijser et al. 2008; Figure 1). Over half the northbound I-17 WVC occurred between MP 310 and MP 325, and 62 percent of the southbound collisions occurred along this same 15-mi stretch. This information has been crucial to the ongoing design concept study and development of a final DCR for the eventual reconstruction of I-17. The DCR team has used the WVC assessment, additional WVC data, and other input to identify and evaluate 22 potential wildlife passage structures for inclusion in future I-17 reconstruction; all are addressed in the I-17 DEA (ADOT 2011). These structures include constructing new underpasses and overpasses, converting TI to dual-use structures, and retrofitting large bridges. However, additional site-specific information on elk movements and WVC patterns is crucial to making informed, data-driven recommendations for wildlife passage structures and other mitigations in the final DCR process.

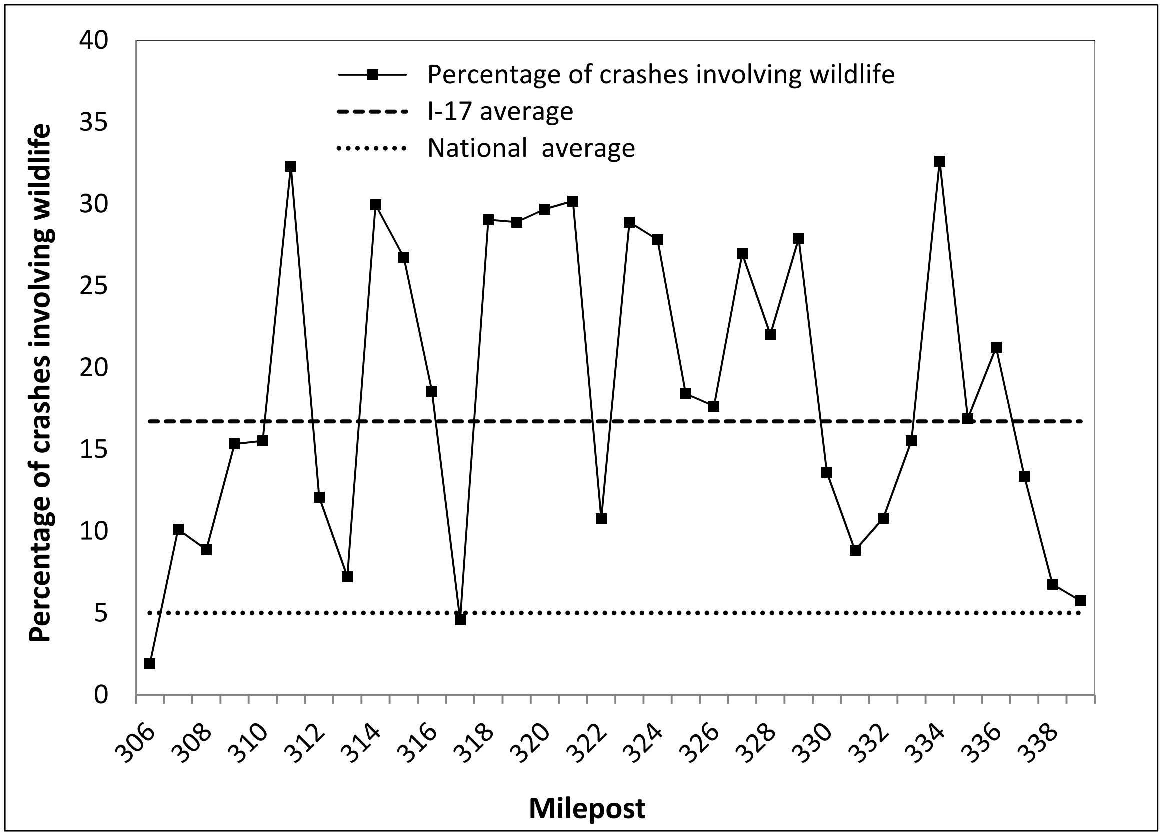

Figure 1. Percentage of Single-vehicle Accidents along I-17 Involving Wildlife from 1994 to 2008 and the National and I-17 (MP 306–339) Averages.

(Note: I-17 data are unpublished by ADOT, national data from Huijser et al. 2008.)

Wildlife Fencing Retrofit Project

Since 2003, personnel from ADOT and the Arizona Game and Fish Department (AGFD) have been assessing the feasibility of using existing bridges and large box culverts along I-17 to convey wildlife under the highway, thus reducing the potential for WVC. It was recognized that the eventual I-17 reconstruction as being planned in the DCR process likely would not occur for several years. Thus, retrofitting provided an option for short-term resolution to the EVC problem (Figure 2). In 2006, ADOT provided AGFD funding via an interagency agreement (JPA 2007-0710) for an elk movements pilot study employing GPS telemetry in the Munds Park area. This project was intended to support development of an enhancement grant proposal for retrofit fencing, including providing information on where to place fencing and assessing before-fencing elk movements and permeability. Elk were the primary focus of this pilot study, as they accounted for most (>75 percent) WVC along I-17 between MP 316.8 and MP 322.7. While accounting for only 12 percent of the stretch of I-17 addressed by the IDRC (Stanley Consultants 2011), the 6-mi retrofit enhancement project area constitutes a “hotspot” that accounts for a disproportionate 28 percent of all WVC.

Figure 2. Bull Elk Killed by a Vehicle near Munds Park along I-17 (left) and a Truck Involved in an EVC along I-17 that Caused Human Injuries (right).

In July 2007, AGFD and ADOT jointly submitted a Round 15 Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users highway enhancement grant application for the I-17 retrofit project. This project was approved for funding (TRACS No. 017 CN 317 H7740 01C) and the project assessment was completed (AZTEC Engineering 2010). Project implementation began during summer 2011. It entails retrofitting 6 mi of right-of way fence, extending it upward to 7.5−8 ft with barbed wire. This fencing will link and funnel elk to two existing large structures suitable for wildlife passage (Woods Canyon and Munds Canyon bridges) and create two dual-use structures (Fox Ranch Road overpass and Schnebly Hill Road underpass) with the goal of reducing the incidence of EVC and promoting elk permeability across the highway.

Traffic Relationships

Increasing traffic volume can magnify the impact of roads and highways on elk and other ungulates, including altered habitat use (Rowland et al. 2000, Wisdom et al. 2005), restricted movements and fragmented populations (Epps et al. 2005), and increased mortality through collisions with vehicles (Groot-Bruinderink and Hazebroek 1996, Gunson and Clevenger 2003). The magnitude of these highway impacts increase with increasing traffic volume and highway standard, though traffic volume exerts the greatest impact according to modeling done by Jaeger et al. (2005). Most previous studies have examined elk movements and distributions along roads focused on relatively low-use Forest Service roads, and very few studies have examined the effects of roads and highways with high-traffic levels on elk movement and distribution.

The AGFD conducted a comprehensive eight-year wildlife-highway interaction study and calculated elk passage rates in a BACI context to assess the impact of highway reconstruction and passage structures on permeability (Dodd et al. 2007*a*, 2009*a*), as well as the effect of traffic volume (Gagnon et al. 2007*a*). SR 260 is a moderately high traffic volume highway, with an average annual daily traffic (AADT) volume of 8,700 vehicles/day. In assessing traffic influences on elk permeability, Gagnon et al. (2007*a*) found that increasing traffic volume decreased the probability of at-grade crossings and temporarily shifted elk distribution away from the highway. Dodd et al. (2009*a*) found that SR 260 elk permeability (*n* = 100) averaged 0.67 crossings/approach on two-lane control sections. Gagnon et al. (2007*a*) reported that elk crossing probability was strongly influenced by proximity to riparian and meadow habitats, and concluded that these attractive habitats provided a motivation for animals to tolerate higher traffic volumes while crossing during the spring when forage growth was most vigorous and in highest demand (Dodd et al. 2007*a*).

Along SR 64 between Williams and the Grand Canyon, a two-lane highway with an AADT of 4,275 vehicles/day, Dodd et al. (2010) found that elk permeability was less than that for SR 260, averaging 0.44 crossings/approach (*n* = 23) though SR 64 had a lower AADT. However, this lower elk permeability may reflect the absence of the attractive riparian or wet meadow habitats adjacent to SR 64 and thus a lower motivation for elk to cross SR 64 compared to SR 260 (Manzo 2006, Gagnon et al. 2007*a*.)

Compared to SR 260 and SR 64, I-17 is a very high-volume highway with an AADT exceeding 16,000 vehicles/day (Figure 3). Theoretical models (Mueller and Berthoud 1997, Seiler 2003, Iuell et al. 2003) suggest that highways with 4,000–10,000 AADT present strong barriers to wildlife passage that repel animals away from the highway (Figure 4), as elk did temporarily along SR 260 (Gagnon et al. 2007*a*). But at 10,000 AADT and above, Seiler (2003) and Iuell et al. (2003) hypothesized that highways would become impermeable barriers to many wildlife species, though they never tested this (Figure 4). Thus, I-17 presents an opportunity to empirically assess elk permeability under such extreme traffic volume circumstances and compare to lower volume highways (Figure 4). Further, I-17 includes sections where the highway median exceeds 0.5 mi in width, presenting an opportunity to compare elk movements and passage rates to sections with narrow medians, validating modeling done by Jaeger et al. (2005, 2006). The research team hypothesized that the stretches of I-17 with wide medians would have a lower impact on elk highway permeability than the highway with narrow medians since each set of lanes (NB and SB) would have lower associated traffic volume and road size.

Iuell et al. (2003) and Seiler (2003) also hypothesized that WVC would drop off dramatically on highways with AADT >10,000 vehicles/day due to the barrier effect precluding crossings and thus exposure to potential collisions with vehicles; at 15,000 AADT, it was theorized that only 10 percent of the animals attempting to cross highways are killed while the remaining 90 percent are repelled, with very few successful crossings (<1 percent; Figure 4). Paradoxically along I-17, in spite of very high traffic volumes, WVC nonetheless constitute a significant problem that compromises highway safety and impacts wildlife populations. Waller and Servheen (2005) developed a probabilistic model of road mortality and theorized that highway lethality was related to both traffic volume and time spent on the roadway by crossing animals. Dodd et al. (2007*a*) reported that 88 percent of EVC involving GPS-collared animals along SR 260 involved those characterized as relatively "frequent crossers" (>0.4 crossings/day) though they constituted only 22 percent of all collared elk (n = 63). Thus, a relatively small proportion of elk exhibited tolerance for higher traffic volume and accounted for a large proportion of the vehicle-related mortality. Elk that show a higher tolerance to traffic volume may be biologically important in maintaining genetic diversity among populations separated by barriers such as I-17 (Mills and Allendorf 1996).

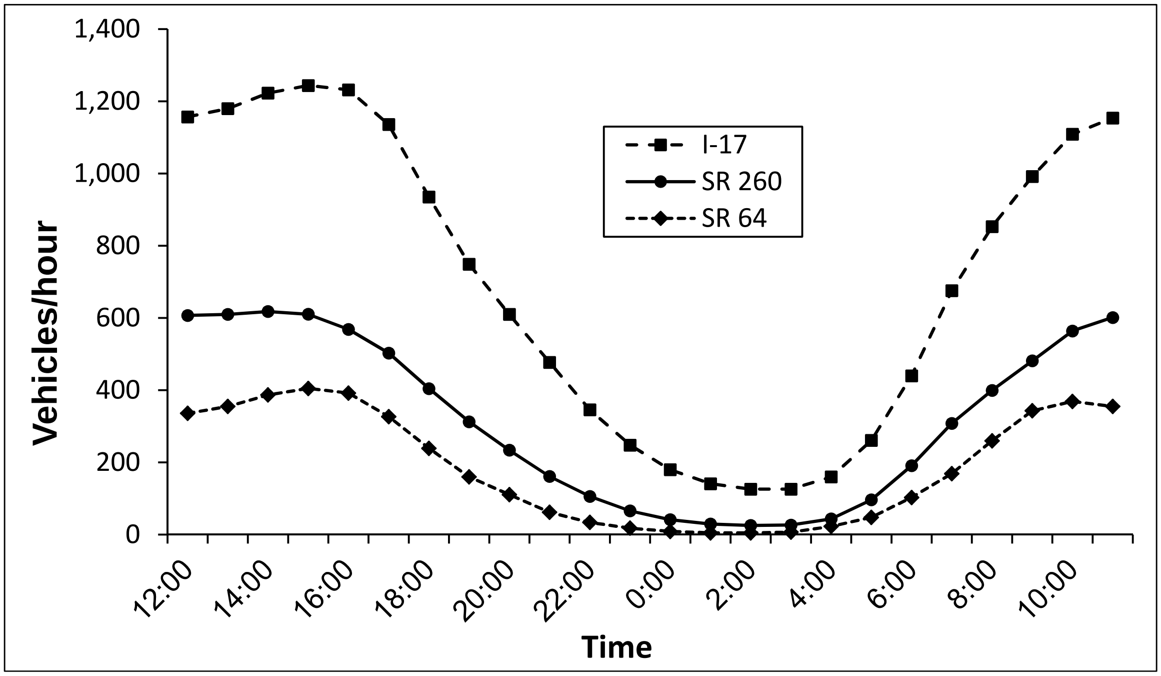

Figure 3. Comparative Hourly Traffic Volumes for I-17, SR 64, and SR 260 Where Elk GPS Telemetry Research Has Been Conducted.

(Note: SR 64 data from Dodd et al. 2010; SR 260 data from Dodd et al 2009a.)

Habitat Relationships

Like SR 260, several large meadows and riparian habitats are situated adjacent to I-17, and peaks in historic I-17 WVC generally coincide with the location of these meadows. Manzo's (2006) modeling indicated that the distribution of elk GPS crossings along SR 260 was associated with proximity to meadows and permanent water sources. Dodd et al. (2007*c*) also found a strong association between SR 260 EVC (r = 0.751, P = 0.003, n = 28) and highway crossings (r = 0.772, P < 0.001, n = 28) and proximity to meadow and riparian habitats at the 0.6-mi scale. Research along I-17 presents an opportunity to validate Manzo's (2006) SR 260 model and investigate the relationships among traffic volume, WVC spatial patterns, elk highway crossings, and proximity to meadow and riparian habitats similar to Dodd et al. (2006, 2007*a*). Understanding these relationships is critical to developing sound strategies to reduce WVC and promote permeability for consideration in the DCR process.

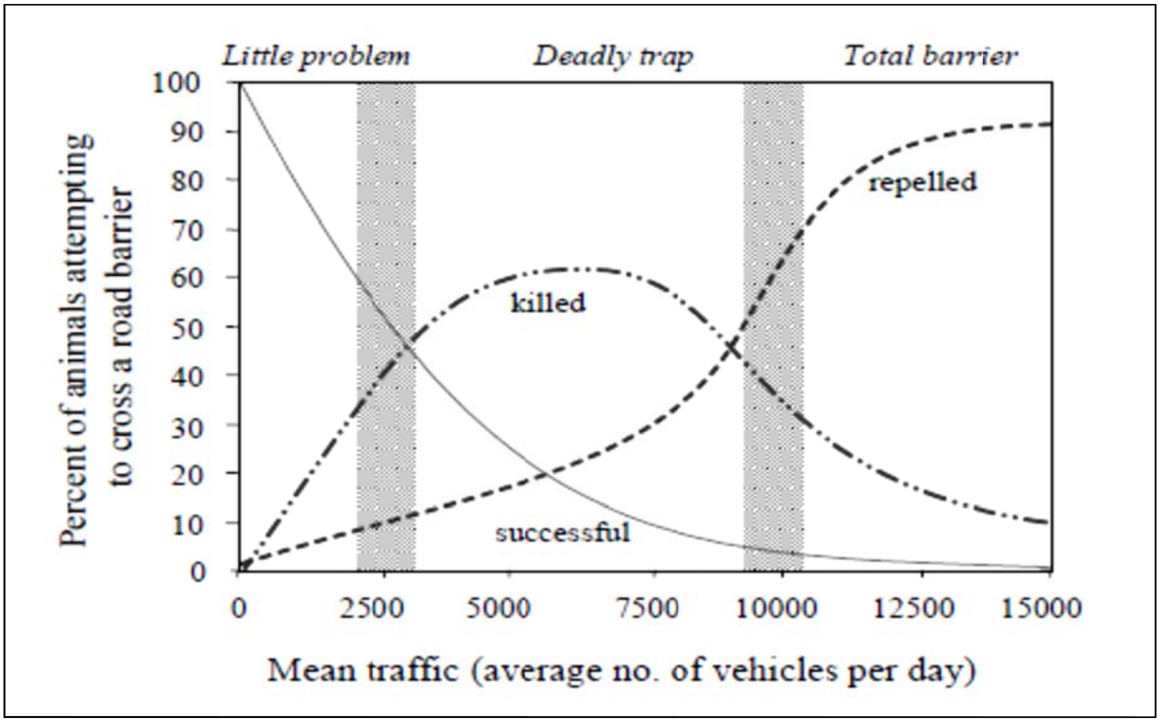

Figure 4. Conceptual Model of the Percentage of Animals that Cross or Are Repelled from Highways or Are Killed along Highways at Increasing Traffic Volume.
(Source: Seiler 2003)

Expanded Elk GPS Telemetry Project

Elk telemetry research along I-17 was continued and expanded beyond the initial pilot telemetry study. In February 2008, ADOT executed an interagency agreement (JPA 08-007T) with AGFD to fund a comprehensive I-17 elk telemetry movements project from MP 306 to MP 340 (Stoneman Lake TI to I-40). This study was intended to provide additional insights into elk movements and permeability associated with a high-volume highway for integration into the retrofit enhancement project and the I-17 DEA (ADOT 2011) and final DCR. This elk movements information will serve as an essential before-construction baseline for the retrofit enhancement project on the short term and the ultimate reconstruction of the I-17 mainline under the DCR on the long term. Further, this baseline will facilitate the sound evaluation of these projects under a BACI experimental design.

1.3 RESEARCH OBJECTIVES

This I-17 research project will add considerably to the understanding of elk movements along high-traffic highways, a relatively unknown topic. The goal of this research project was to apply insights gained from the long-term SR 260 (Dodd et al. 2007*a*, 2009*a*) and SR 64 (Dodd et al. 2010) research projects to address and compare WVC patterns and elk permeability to those associated with I-17. The research team's specific objectives of research, incorporating both the elk movements pilot study and the subsequent expanded elk movements project, include:

- Assess elk movements, highway crossing patterns, and distribution; and determine permeability across the highway corridor.
- Investigate the spatial and temporal relationships of elk highway crossing and distribution patterns to traffic volume.
- Investigate spatial and temporal WVC patterns and traffic volume relationships.
- Investigate elk crossing patterns and WVC in relation to meadow and riparian habitats, and validate and refine the habitat model assessing the influence of riparian-meadow habitats developed for SR 260 (Manzo 2006).
- Develop strategies and recommendations to reduce WVC and maintain or promote wildlife permeability across I-17.
- Address elk movements, permeability, and WVC patterns in association with the 6-mi wildlife fencing retrofit enhancement project (MP 316.8–322.7) to establish before-construction WVC baselines for subsequent after-construction evaluation.

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2.0 STUDY AREA

This study was conducted along a 46-mi stretch of I-17, extending from MP 294 south of the Stoneman Lake TI northward to the I-40 TI at MP 340 in Flagstaff (lat 34°76′–35°17′N, long 111°65′–111°66′W; Figure 5). I-17 is the primary highway between Phoenix and northern Arizona. It connects with and supports the transport of motorists and goods along I-40 to the east and west. It is traveled by millions of tourists each year visiting northern Arizona national parks and recreation areas, as well as the Navajo and Hopi reservations. Much of I-17 through the study area exists as it was constructed originally in the mid-1970s, a two-lane road (SR 79) then converted to a four-lane highway, though spot improvements have been made over the past 20 years.

For most of its length through the study area, I-17 is a four-lane divided highway with an approximately 85-ft median between NB and SB lanes. However, at two places the median exceeds 500 ft in width, though the opposite lanes are generally visible from each other; between MP 307.0 and MP 309.5 (2.5 mi) and MP 312.5 and MP 314 (1.5 mi). Most notable, however, is the 2.5-mi section of highway between MP 309.5 to 311.5 where the highway lanes are separated by more than 2,500 ft (Figure 5). This extremely wide separation is potentially significant since the highway becomes functionally two separate two-lane highways with half the traffic volume, thus acting as lower-volume, smaller highways (Jaeger et al. 2005). This wider lane separation could affect the degree of barrier effect and how wildlife approach and cross I-17.

2.1 NATURAL SETTING

The I-17 study area lies at the southernmost extent of the Colorado Plateau physiographic province (Spence et al. 1995). The highway corridor varies in elevation from 5,325 ft at the southern end to 7,000 ft near Flagstaff. At the southern end, the topography is a mix of broken terrain with canyons and ridges dominated by Rattlesnake and Cedar Tank canyons, which converge near the Red Hill Scenic Overlook at MP 312.0 at 6,500 ft in elevation. From there to Flagstaff, the topography is relatively gentle (Figure 6), punctuated by several narrow canyons across which only two sets of bridges are sufficient to accommodate elk passage; Munds and Woods Canyon bridges (Figure 7). The study stretch of I-17 was identified as Linkage 23, Oak Creek Canyon-Munds Park in the *Arizona's Wildlife Linkages Assessment* (Arizona Wildlife Linkages Workgroup 2006), where the primary threats were associated with the upgrade of I-17 and private land development. Land ownership adjacent to the I-17 corridor is predominantly (>90 percent) U.S. Forest Service (USFS) lands, with limited private land holdings (Figure 5).

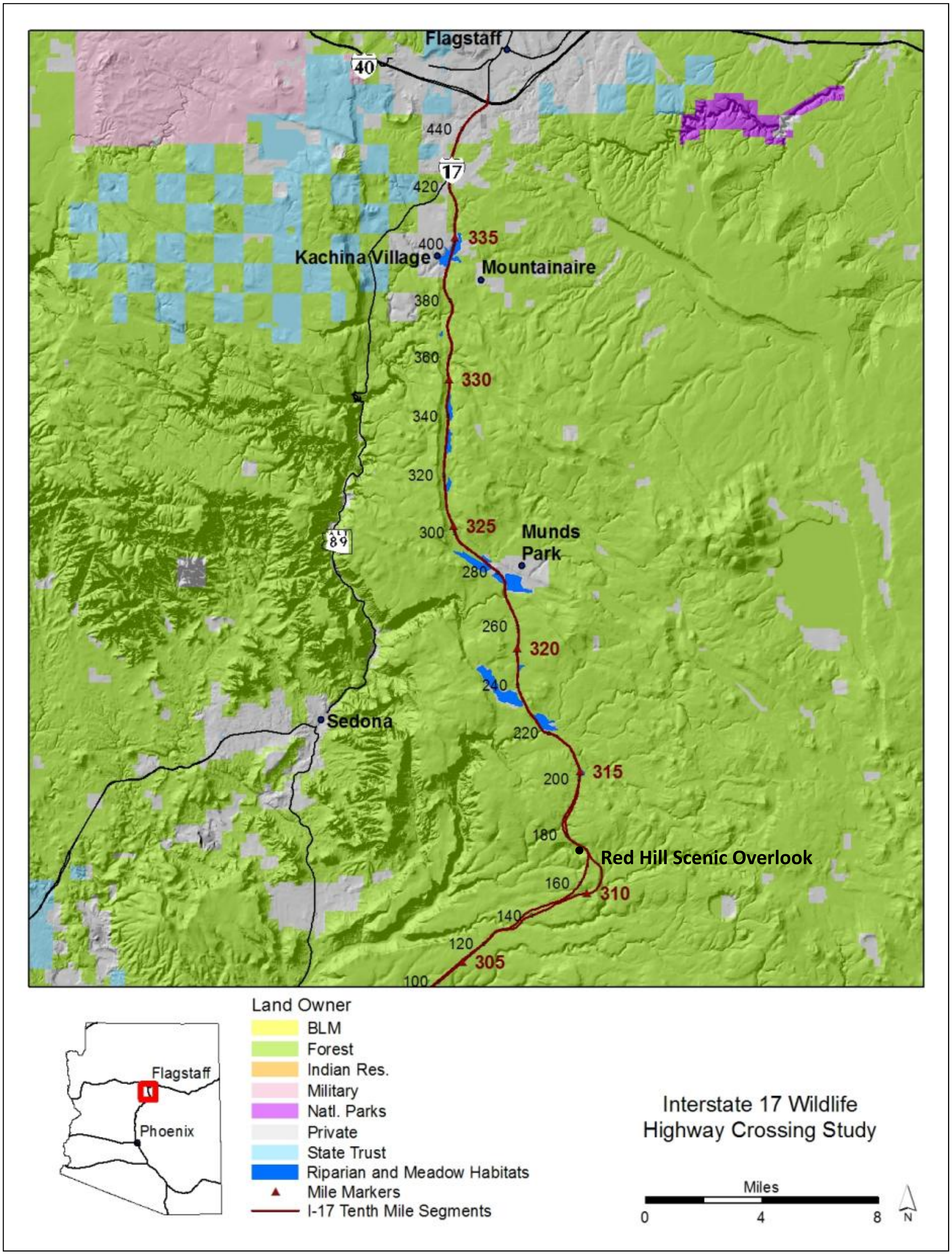

Figure 5. Map of the I-17 Study Area Showing Landownership, Mileposts (red numbers), 0.1-mi Segments (black numbers), Riparian-meadow Habitats, and the Wide Median in the Vicinity of MP 310.

Figure 6. Photograph (looking southeast) of I-17 Corridor near Woods Canyon Showing Dominant Ponderosa Pine Vegetation and Interspersed Riparian-meadow Habitat.

Figure 7. Photograph of Munds Canyon Bridge Looking East toward Munds Park.

Climate

Generally, the climate is characterized as being semi-arid, dominated by hot summers and cool winters, with a strong bimodal precipitation pattern. At the northern end of the study area near Flagstaff (Flagstaff Airport weather station), the average maximum temperature is 61.2^{o} F, with July being the warmest month (mean = 81.9^{o} F). Winter daily low temperatures average 30.7^{o} F, with January being the coolest month (mean = 16.0^{o} F). Annual precipitation averages 21.3 in, with average winter snowfall accumulation of 99.1 in. Nearly 40 percent of the annual precipitation occurs in winter (December–March) and summer (July–September). At the southern end and lower elevations (USFS Sedona and Beaver Creek ranger stations), the average maximum (75^{o} F) and minimum (42^{o} F) temperatures are higher, with lower average annual precipitation (13.5 in) and snowfall (4 in).

Vegetation

Vegetation in the study area exhibits characteristics of the Petran Montane Coniferous Forest and Great Basin Conifer Woodland biotic communities (Brown 1994, Spence et al. 1995). Ponderosa pine dominates Montane Coniferous Forests along the northern two-thirds of the corridor (Figure 6), with Gambel oak is also found in the area. In some places rabbitbrush and cliffrose are found in small openings in the forest canopy. Numerous wet meadow-riparian habitats (Figure 6) are found adjacent to or near the highway corridor beyond the Red Hill Scenic Overlook (Figure 5), which likely have an influence on elk distribution and movements similar to along SR 260 (Manzo 2006, Dodd et al. 2007*a*). These vegetation types provide summer range for elk and other wildlife. Sparse to dense pinyon, one-seed juniper, and Utah juniper dominate the overstory of the Great Basin Conifer Woodlands at the southern third of the corridor, south of the Red Hill Scenic Overlook. Cliffrose, Apache plume, and other shrubs occur in the understory, along with blue grama and other grasses in openings. This vegetation corresponds to intermediate and winter range of elk and other wildlife species, depending on the amount of snowfall.

Elk Population

The focus of this study was elk, as this species accounts for more than 75 percent of all WVC along I-17. The highway bisects Game Management Unit (GMU) 6A along the majority of the study area, except for the last 5 mi north of Mountainaire, which is in GMU 11M, an urban management unit surrounding Flagstaff. The elk population moves freely between these two GMU along either side of I-17. North of the Red Hill Scenic Overlook at MP 312.0, the highway crosses through predominantly elk summer range, with elk found in moderate densities (Figure 8). South of the overlook, I-17 bisects intermediate and winter range, with elk densities dependent on the amount of winter snow.

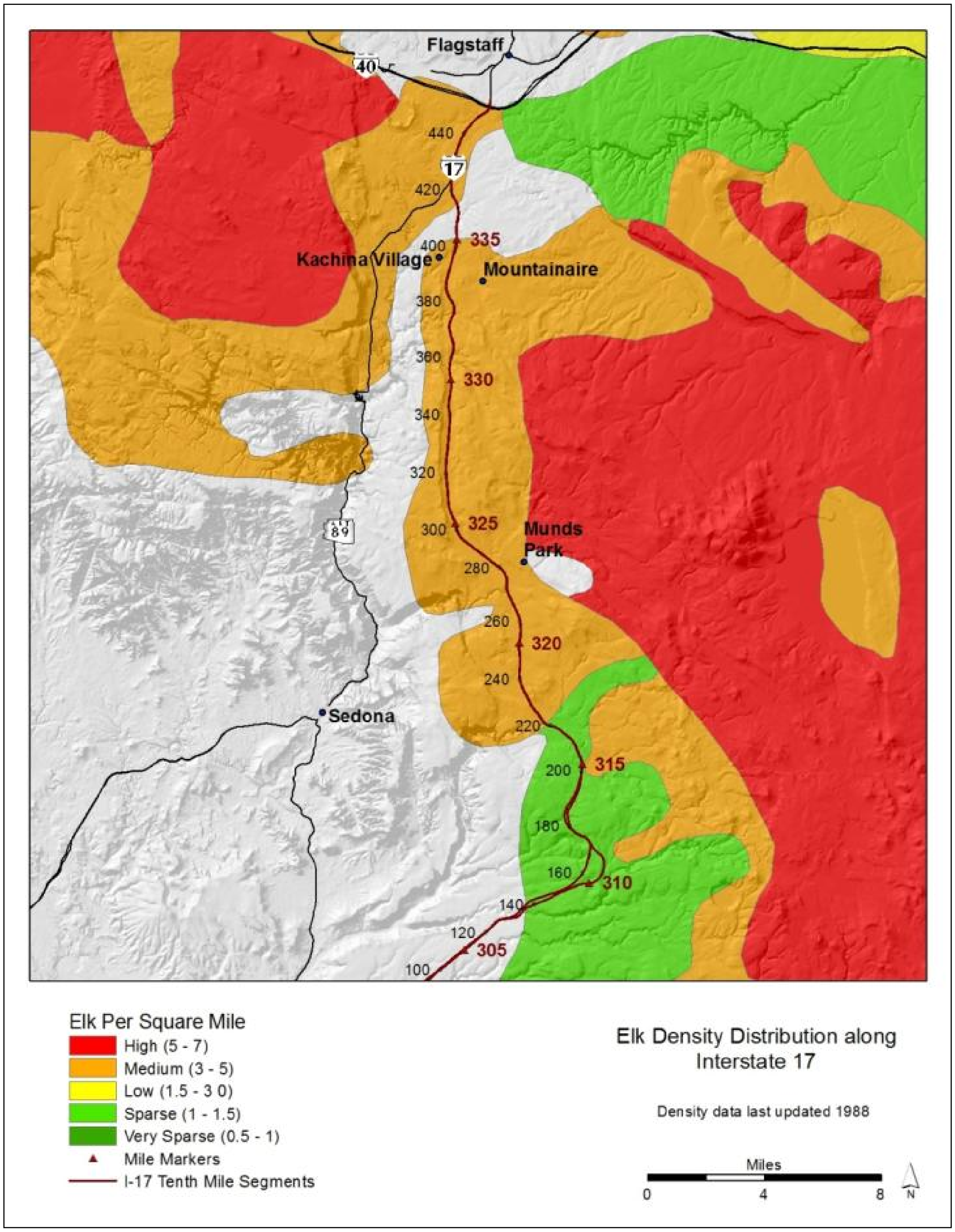

Figure 8. Summer Range Elk Density Distribution Adjacent to the I-17 Highway Corridor.

(Notes: 1: Gray area=Very Space; 2: Elk density data from AGFD)

AGFD ran a computer simulation model integrating elk survey information to estimate the GMU 6A elk population (unpublished AGFD report, Phoenix). According to the modeling, the elk population has declined nearly 50 percent from approximately 10,000 elk in 2000 to 5,400 in 2007; since 2007, the elk herd has continued to be reduced and was estimated at 3,300 elk in 2010 (Table 1). Aggressive hunt structures throughout the 1990s and into the 2000s have reduced the elk herd, resulting in a declining population trend, though AGFD also cites elk mortality along I-17 as a factor in the reduced populations. The male to female ratio in the population has been static over the past four years and has averaged 32 bulls : 100 cows (Table 1.)

Table 1. Elk Population Estimates and Surveyed Sex Ratios for GMU 6A from 2007 to 2010.

Year	Adult Elk Population Estimate	Change from Previous Year	Ratio of Surveyed Elk # Bulls : 100 Cows
2007	5,451	-14%	29
2008	4,644	-15%	34
2009	3,930	-15%	31
2010	3,322	-15%	34

2.2 TRAFFIC VOLUME

The I-17 AADT volume in 2008 was 17,112 vehicles/day and 14,917 vehicles/day in 2009, as measured by a permanent automatic traffic recorder (ATR) at MP 319.4 south of Flagstaff; the two-year average AADT was 16,015 vehicles/day. Between Kachina Village and Flagstaff, the AADT exceeds 25,000 vehicles/day (ADOT Transportation Data Management System). Traffic volumes were highest during daytime hours, with peak (14:00–16:00) hourly traffic approaching an equivalent AADT of 30,000 vehicles/hr (Figure 9). Throughout the day, commercial trucks constituted an average of 26 percent of all traffic, but between 01:00 and 03:00, accounted for half the vehicles travelling I-17, (Figure 9) reflective of the highway's important role in the transport of goods. Traffic volume was highest from Friday to Sunday, averaging 19,242 vehicles/day compared to the rest of the week that averaged 14,614 vehicles/day (Figure 10). The higher weekend traffic likely reflected the recreation and tourist nature of motorists traveling I-17 to visit national parks and recreation areas; the proportion of commercial vehicles on these days was less than 20 percent. Also reflective of tourist and recreational traffic were differences in monthly traffic volumes. Peak traffic volumes occurred during summer (May–July) and exceeded 18,000 vehicles/day, compared to the fall through spring period (November–April) that averaged 12,500 vehicles/day (Figure 11).

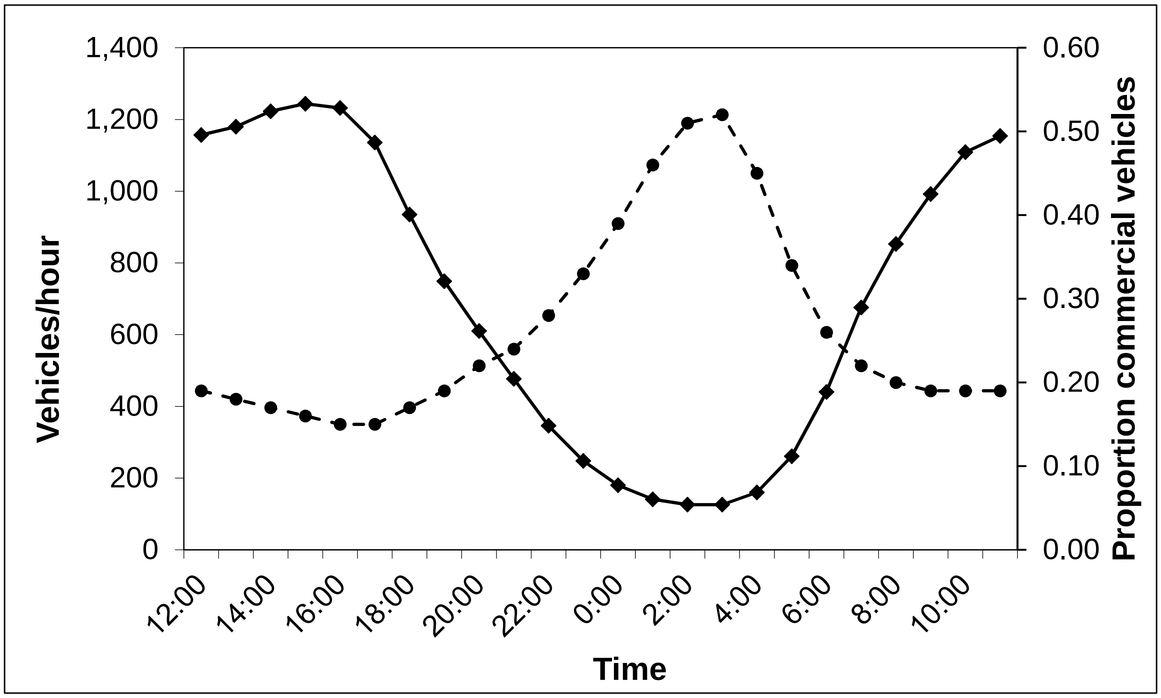

Figure 9. Average I-17 Hourly Traffic Volume (solid line) and Proportion of Traffic Comprised of Commercial Vehicles, 2007 to 2010.

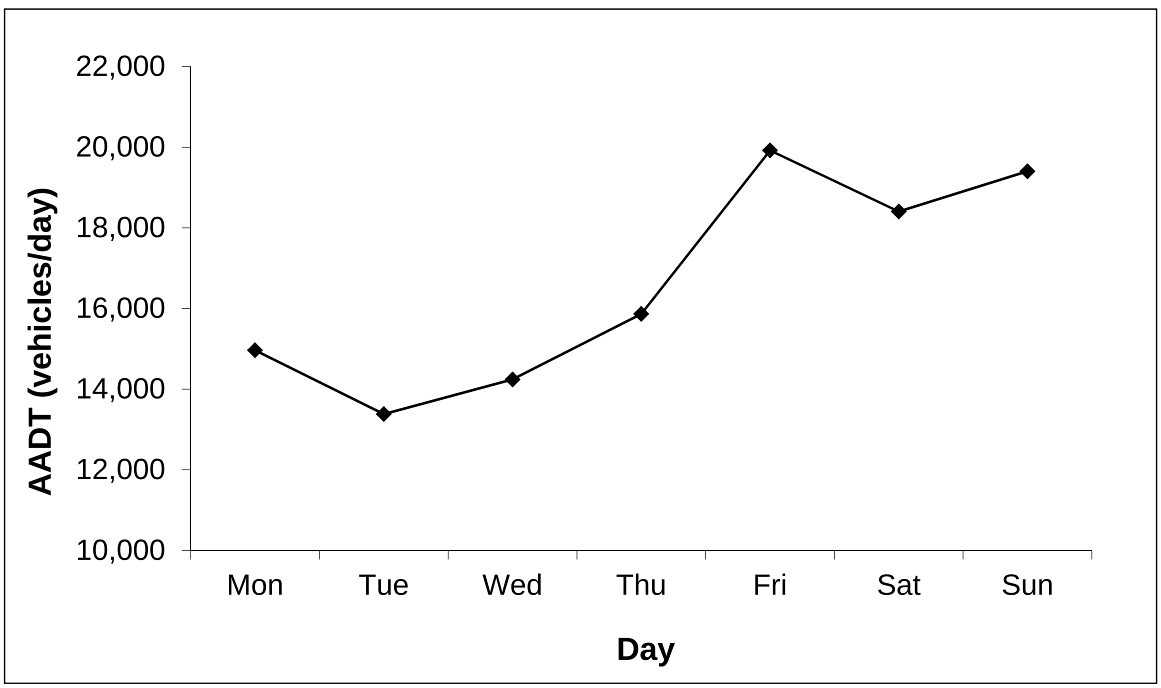

Figure 10. Average I-17 Traffic Volumes by Day, 2007 to 2010.

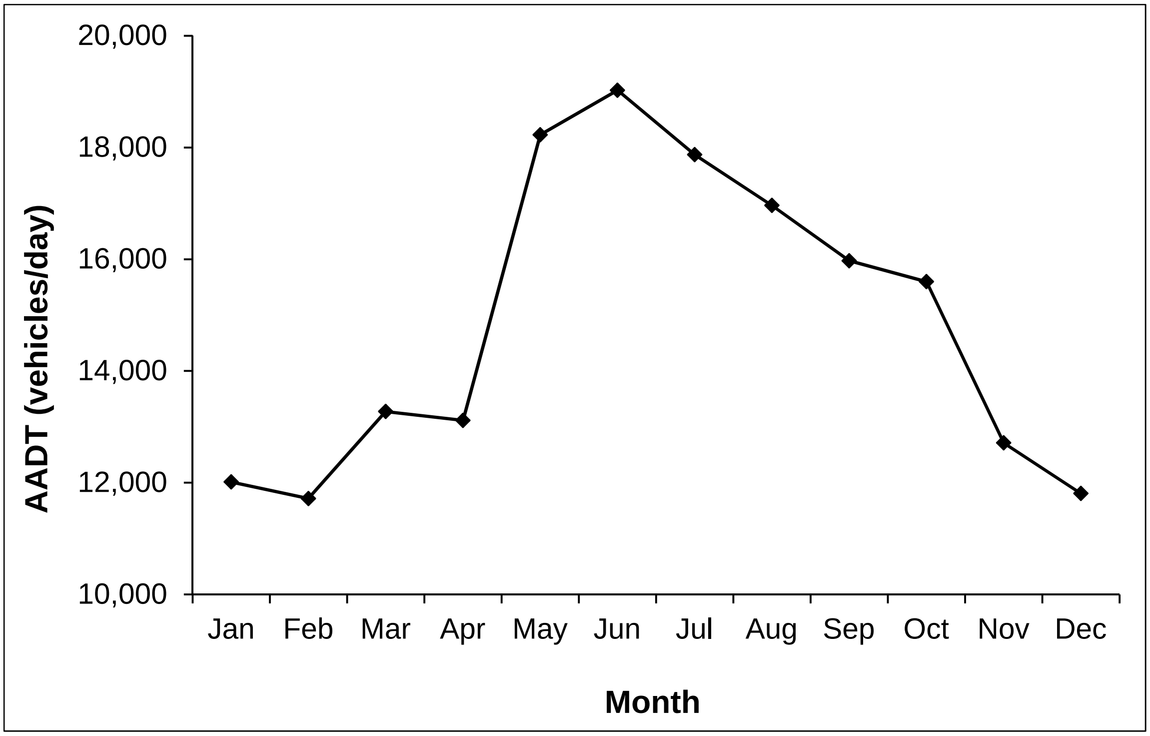

Figure 11. Average I-17 Traffic Volumes by Month, 2007 to 2010.

3.0 METHODS

3.1 WILDLIFE CAPTURE, GPA TELEMETRY, AND DATA ANALYSIS

Elk Capture

The research team captured elk at 33 trap sites adjacent to I-17 stretching approximately 27 mi from near Kachina Village (MP 334) south to the vicinity of the Stoneman Lake TI (MP 307). The team trapped elk in net-covered Clover traps (Clover 1954) baited with salt and alfalfa hay; all traps were located within 0.5 mi of the highway corridor and typically near permanent water sources (Figure 12). Once the elk were captured, the team physically restrained, blindfolded, ear tagged, and fitted them with GPS receiver collars (Figure 12). The team instrumented elk with a combination of Telonics, Inc. Model TG3 and Model TG4 store-on-board and Model SST-TG3 Spread Spectrum GPS collars programmed to receive a GPS relocation fix every 2 hr; the latter model allowed for periodic aerial uploading of stored GPS data. All collars had VHF beacons, mortality sensors, and programmed release mechanisms to allow recovery. Battery life for the GPS units was approximately two years.

GPS Analysis of Animal Movements

Once the researchers recovered the GPS collars and downloaded data, they employed ArcGIS Version 8.3 Geographic Information System (GIS) software (ESRI, Redlands, California) to analyze GPS data similar to analyses previously done for elk by Dodd et al. (2007*b*, 2009*a,* 2010). The team calculated individual minimum convex polygon (MCP) home ranges by connecting the outermost GPS fixes to encompass all fixes (White and Garrott 1990) and assessed differences in means using analysis of variance (ANOVA) with ±1 standard error (SE).

Figure 12. Elk Captured in a Clover Trap and Being Physically Restrained with Ropes (left) and Fitted with a GPS Telemetry Collar before Being Released from the Trap (right).

Calculation and Analysis of Crossing and Passage Rates

The team divided the study area into 450 sequentially numbered 0.1-mi segments corresponding to the units used by ADOT for tracking WVC and highway maintenance, and identical to the approach used by Dodd et al. (2007*a*, 2009*a*, 2010; Figure 13). The researchers calculated the number and proportion of GPS fixes within 0.15, 0.30, and 0.60 mi of I-17 for each elk.

To determine highway crossings, the team drew lines connecting all consecutive GPS fixes and inferred highway crossings where lines between fixes crossed each set of highway lanes, NB or SB, through a given segment (Dodd 2007*a*; Figure 13). 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 (00:00 – 23:59). They calculated crossing rates for individual elk by dividing the number of crossings by the days a collar was worn.

The team calculated passage rates for collared elk, which served as its relative measure of highway permeability and directly comparable to other wildlife-highway projects throughout Arizona (Dodd et al. 2007*b*, 2009*b*, 2010). 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 I-17, determined by successive GPS fixes (Figure 13). 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 by Dodd et al. (2007*b*, 2009*a*, 2010). Animals that directly crossed I-17 from a point beyond 0.15 mi were counted as an approach and a crossing. The research team calculated passage rates as the proportion of highway crossings (across both NB and SB lanes) to approaches for those elk that had at least five approaches to I-17. The researchers 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. 2007*a*).

The research team compared mean elk crossing and passage rates among three different I-17 highway median width classes, with the widths measured at each 0.1-mi segment by geographic information system (GIS) analysis and assigned to these classes:

- Standard median (<230 ft wide).
- Wide median (231−460 ft wide).
- Extremely wide median (>460 ft wide).

Researchers derived values for individual elk approaching and crossing I-17 and pooled them by median width class. Researchers used ANOVA to test the null hypothesis that no differences in mean elk crossing and passage rates existed as a function of highway width class. Where the team obtained significant ANOVA results among classes then conducted post hoc pairwise comparisons using a Tukey test for unequal sample sizes (Statsoft Inc.

1999). The researchers applied arc sine transformations to the raw passage rate data to allow comparison of proportions and ensure normality in the datasets (Neter et al. 1996).

The team compared crossing (crossings/day) and passage rates at various temporal scales, including time, day of week, month, and season. It used 2-hr intervals for comparing crossing and passages rates corresponding to the GPS relocation interval. They used the same seasons as those used in other Arizona highway assessments (Dodd et al. 2007*a*, Dodd and Gagnon 2011): winter (December−February), spring (March−May), summer (June−August), and fall (September−November). The researchers used chi-square tests to compare observed versus expected frequencies of elk crossings by time, day, and month. Linear regression was employed to assess the association between crossing and passage rates versus mean corresponding traffic volume by time, day, and month. The team compared mean crossing and passage rates aggregated by season by ANOVA and post hoc pairwise comparisons using a Tukey test.

Calculation of Approaches

Based on the conceptual model that suggests that highways with traffic volume >10,000 vehicles/day are total barriers to passage of many wildlife species (Seiler 2003; Figure 3), the researchers anticipated relatively few collared elk would cross I-17, especially compared to SR 260 where 100 elk crossed 11,052 times (Dodd et al. 2009*a)*. As such, the team used the number of approaches by elk to within 0.15 mi of I-17 to determine the distribution of animals adjacent to the highway for the purposes of assessing the need for and potential location(s) of passage structures, as well as assessing habitat relationships. A similar approach was used for pronghorn on US Route 89 (Dodd et al. 2009*b*) and SR 64 (Dodd et al. 2010). As with the crossings data, 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.

Calculation of Weighted Approaches

To account for the number of individual elk that approached each I-17 highway segment, as well as evenness in approach frequency among animals, the research team calculated Shannon diversity indices (SDI; 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 -($p_i \ln p_i$) for each animal that had approached in the segment, where each p_i is defined as the number of individual collared elk approaches within each segment divided by the total number of respective approaches in the segment. The team used SDI to calculate weighted approach frequency estimates for each segment, multiplying uncorrected approach frequency × SDI. Weighted highway approaches better reflect the number of approaching elk and equity in distribution among collared elk (Dodd et al. 2007*a*, 2009*b*).

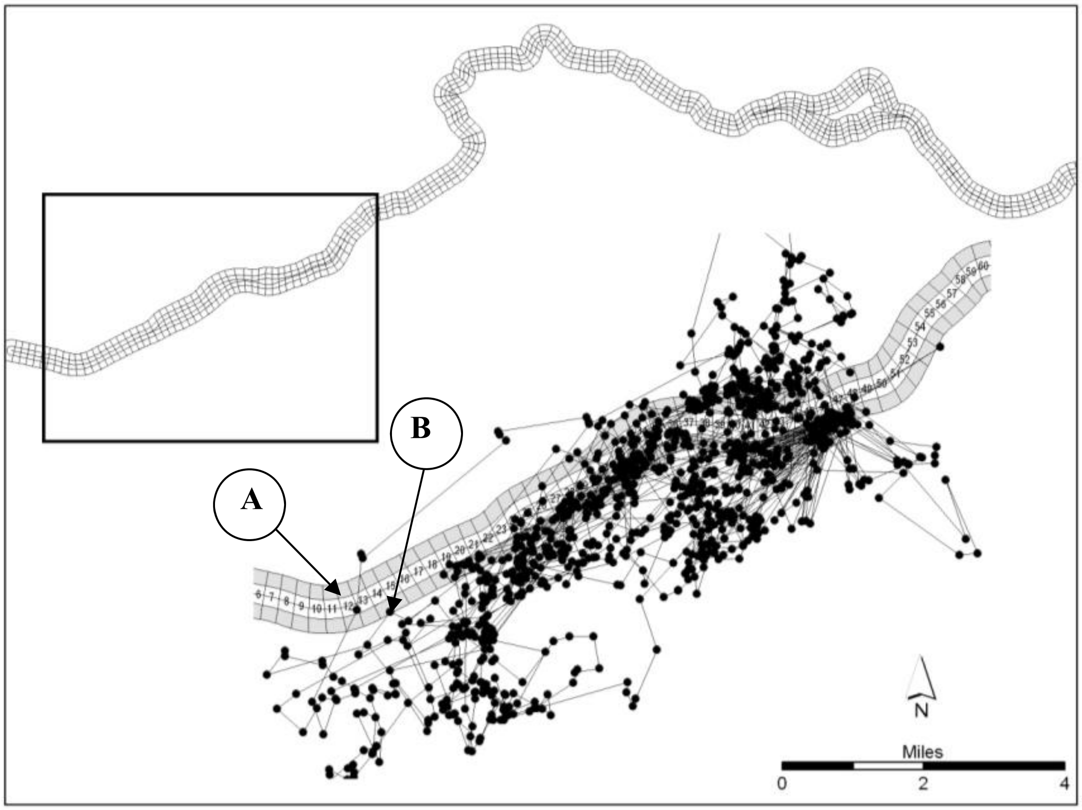

Figure 13. GPS Locations and Lines between Successive Fixes to Determine Highway Approaches and Crossings in 0.10-mi Segments.
(Note: The expanded section shows GPS locations and lines between successive fixes to determine approaches to the highway (shaded band) and crossings. Example A denotes an approach and crossing; B denotes an approach without a crossing.)

3.2 TRAFFIC AND ELK DISTRIBUTION RELATIONSHIPS

The research team measured traffic volume using a permanent ATR programmed to record hourly traffic volumes. ADOT's Multimodal Planning Division Data Team provided data collected from an ATR installed near the midpoint of the study area (MP 319.4).

The team examined how the proportion of elk GPS fixes 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 1,980 ft. As done for elk elsewhere in Arizona (Gagnon et al. 2007*a*, Dodd and Gagnon 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. This allowed them to correlate the traffic volume each animal experienced in the hour prior to movement to a particular point within 1,980 ft of the road, 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 researchers calculated a mean proportion of fixes for all animals within each 330 ft-distance band from I-17 at varying traffic volumes: <100, 101−200, 201−300, 301-400, 401−500, 501−600, and >600 vehicles/hr (Gagnon et al. 2007*a*). The team compared elk distribution and highway impact along I-17, and compared the distributions to those for elk on SR 260 (Gagnon 2007*a*) and SR 64 (Dodd et al. 2010) exhibiting different traffic volume levels and patterns. For comparison, means were combined by adding them across multiple distance bands or traffic volumes.

The research team hypothesized that traffic volume could have a differential impact on elk distribution along stretches of I-17 with wide and extremely wide medians, as the traffic volume here might be perceived as being lower when adjacent to the individual separated NB and SB lanes along these sections (e.g., half the combined traffic volume of highway stretches with standard medians). As such, the researchers conducted a separate analysis for I-17 stretches with wide and extremely wide medians.

3.3 WILDLIFE-VEHICLE COLLISION RELATIONSHIPS

The study documented the incidence of WVC along I-17 by two methods. First, the research team relied on the submission of forms by agency personnel, primarily DPS highway patrolmen and ADOT maintenance personnel, to determine the incidence of WVC during the study. These personnel made a concerted effort to record the species and sex of animals involved in WVC where such could be determined. These records were augmented by regular searches of the highway corridor for evidence of WVC 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 WVC, the species and sex of the animal(s) involved where known, and the reporting agency. WVC records were compiled and summarized by year. The team compared the ratio of male to female (e.g., bull : 100 cows) elk involved in EVC to the surveyed elk population ratio (Table 1) using a chi-square test to compare observed (EVC) and expected (population) ratios for 2007 to 2010. Researchers used the database compiled by the ADOT Traffic Records Branch (HES Crash Data) from DPS accident reports to determine the proportion of single-vehicle accidents that involved wildlife along I-17; Huijser et al. (2007) reported that nearly all WVC are single-vehicle crashes.

The research team compiled the frequency of WVC for elk and deer by 0.1-mi segments. They tested the hypothesis that the observed EVC distribution among 0.10-mi segments did not differ from a discrete randomly generated approach distribution using a Kolmogorov-Smirnov test. The team compared the temporal incidence of WVC involving deer and elk among years, seasons, month, day, and time with chi-square tests to compare observed versus expected WVC frequencies using the same seasons as those used to compare crossing and passage rates. The research team used linear regression to assess the associations between temporal WVC frequency and traffic volume. For the assessment of EVC versus time, the team excluded EVC and traffic data between 10:00

and 17:00 from the regression analysis as few accidents involving elk occurred here or on other Arizona highways during these hours, even at considerably lower traffic volumes than I-17 (Dodd et al. 2007*a*, Dodd et al. 2010). Inclusion of these data could bias the regression analysis by overestimating the impact of high traffic volume when elk are not active.

Researchers explored the relationship of varying traffic volume on the frequency of EVC, and validated Seiler's (2003) theoretical model (Figure 3) by assessing the existence of thresholds in the mean frequency of EVC/hr for traffic volume classes corresponding to AADT-equivalent volume (mean hourly volume × 24 hr): <5,000 vehicles/day, six volume classes increasing by 2,500 vehicle/day increments between 5,000 and 20,000 vehicles/day, and >20,000 vehicles/day. For this analysis, the team also excluded EVC and traffic that occurred between 10:00 and 17:00 to avoid potential bias associated with low incidence of EVC documented on I-17 and on other highways at these times at high traffic volumes.

Lastly, the research team assessed the number of elk fitted with GPS collars that were involved in EVC as a function of their relative highway crossing frequency, as done for SR 260 by Dodd et al. (2007*a*). The team compared the actual versus expected frequency of elk collared and killed in EVC within these mean highway crossing frequency classes, and compared the expected versus actual frequencies by chi-square analysis:

- Infrequent crossers (<0.01 highway crossings/day).
- Intermediate frequency crossers (0.02–0.10 highway crossings/day).
- Frequent crossers (>0.10 highway crossings/day).

Huijser et al. (2007) conducted an extensive review of costs associated with WVC including 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 EVC to be $18,561 and each deer-vehicle collision (DVC) to be $8,388. The research team used these figures and the WVC incidence data from 2007 to 2010 to calculate the estimated mean annual cost associated with I-17 WVC.

3.4 RELATIONSHIPS TO RIPARIAN-MEADOW HABITAT

The researchers used GIS to measure the distance from I-17 at each 0.1-mi segment to the nearest riparian-meadow habitat using a vegetation cover layer. This analysis was conducted for the length of I-17 located within ponderosa pine forest between Segments 175 to 455 (MP 312.0−340.0), along which all riparian-meadow habitats occurred adjacent to the highway. The team used this information to assess the proximity of the nearest riparian-meadow habitat to I-17 associated with each 0.1-mi segment (n = 279) and by the mean distance from the highway associated with the six 0.1-mi segments aggregated into 0.6-mi segments (n = 45). These measures of the proximity of riparian-meadow habitat were used as the independent variables in linear regression against three dependent variables of the frequency of: elk highway crossings, weighted elk approaches, and EVC. The team compared the strength of the correlations between the proximity of riparian-meadow habitat and the three dependent variables using correlation coefficients (r).

Manzo's (2006) SR 260 model, specific to riparian-meadow habitats within ponderosa pine forest, found that 85 percent of all elk crossings were located within 0.6 mi (1.0 km) of permanent waters/riparian-meadow habitat. The research team used this model to predict the locations where elk crossings, weighted approaches, EVC, and DVC would be expected to occur along the stretch of I-17 between Segments 175 and 455 (MP 312.3−340.3). The team also conducted chi-square contingency table analysis (Agresti 1996) of the number of 0.1-mi segments with and without elk crossings, weighted approaches, and EVC and DVC (individually and combined) as a function of whether or not segments were within 0.6 mi of the nearest riparian-meadow habitat. The team calculated the differences between observed and expected numbers of 0.1-mi segments with and without crossings, approaches, EVC and DVC, and calculated odds ratios reflecting the likelihood that crossings, approaches, EVC, and DVC would occur at 0.1-mi segments in proximity (<0.6 mi) to riparian-meadow habitat.

3.5 IDENTIFICATION OF PASSAGE STRUCTURE SITES

Sawyer and Rudd (2005) identified several important considerations for locating the most suitable sites for placing passage structures, primarily for pronghorn, though these criteria are applicable for other species. In the assessment of potential passage structure sites and validation of the findings in the DEA (ADOT 2011), the researchers considered the criteria identified by Sawyer and Rudd (2005), but recognized that the 0.1-mi segment scale was too small and cumbersome to discern and analyze differences among segments. Dodd et al. (2006, 2007*a*) reported that the optimum scale to address management recommendations for accommodating wildlife passage needs using GPS telemetry or WVC data was the 0.6-mi (approximately 1 km) 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 450 0.1-mi segments from MP 294.0 to MP 340.0 into 75 0.6-mi segments for analysis.

The research team used several criteria identified by Sawyer and Rudd (2005) with some modifications to rate each of the 75 0.6-mi segments using the elk GPS telemetry findings, WVC incidence, and other pertinent factors such as presence of terrain suitable for passage structures, as done previously for SR 64 (Dodd et al. 2010) and US 89 (Dodd et al. (2009*b*). Sawyer and Rudd (2005) and previous SR 64 and US 89 assessments also included land ownership, which is critical to future passage structure construction. However, as over 90 percent of the highway corridor was under USFS ownership, land ownership was not used for our I-17 analysis.

The team's criteria included:

Elk highway crossings – This rating was based on the frequency of I-17 crossings made by GPS-collared elk within each aggregated 0.6-mi segment and reflected the influence of median width and existing structures. Ratings were:

0	No crossings.
1	0−10 elk crossings.
3	11−30 elk crossings.
5	31−60 elk crossings.
7	61−100 elk crossings.
9	>100 elk crossings.

Weighted elk approaches – This criterion was considered the most important and indicative of where animals approached and would potentially cross I-17 via passage structures, based on SDI weighted approaches. Ratings were:

0	No weighted approaches.
1	1−100 weighted approaches.
3	101−250 weighted approaches.
6	251−500 weighted approaches.
9	501−1,000 weighted approaches.
12	1,001−2,500 weighted approaches.
15	>2,500 weighted approaches.

Elk-vehicle collisions – This criterion also was heavily weighted due to the EVC impact on highway safety, and was based upon the number of non-duplicate EVC recorded by 0.6-mi segment during the project. The ratings were:

0	No EVC.
1	1−3 EVC.
3	4−7 EVC.
6	8−11 EVC.
9	12−15 EVC.
12	16−20 EVC.
15	>20 EVC.

Deer-vehicle collisions – The number of non-duplicate DVC recorded by 0.6-mi segment during the project. The ratings were:

0	No DVC.
1	1 DVC.
2	2 DVC.
3	3 DVC.

4	4 DVC.
5	>4 DVC.

Human activity – Ideally, no human activity should occur near a passage structure; however, road access, businesses, developments, overlooks, and other activities do occur adjacent to I-17. Ratings were:

0	Significant human activity (business, housing, etc.).
1	Moderate human activity (access road, scenic overlook).
3	Limited human activity.
5	No human activity.

Topography – The ability to situate overpasses oriented along existing ridgelines that elk, deer, or wildlife can traverse, or locate underpasses in association with drainages, is desirable. Ratings were:

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 considered other factors in its identification of potential passage structure sites. These factors included whether the 0.6-mi segments coincided with the preliminary sites recommended in the DEA (ADOT 2011), the types of structures suited for each site, and how the priority segments from this study relate to the minimum recommended passage structure spacing determined by Bissonette and Adair (2008).

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4.0 RESULTS

4.1 WILDLIFE CAPTURE, GPS TELEMETRY, AND DATA ANALYSIS

Elk Capture and Movements

Between March 2006 and October 2010, the research team captured, tracked, and recovered data from 71 elk (54 females, 17 males) instrumented with GPS receiver collars; 55 were fitted with store-on-board collars and16 with Spread-Spectrum up-loadable units. GPS collars were affixed to elk for an average of 473.6 days (±32.2 SE), during which time the collars accrued 297,283 GPS fixes (65.7 percent highest-accuracy 3-D fixes) for a mean of 4,128.9 fixes/elk (±252.3; Figure 14). Sixty-five elk yielded sufficient approaches to calculate passage rates. Of the GPS fixes, 77,314 (26.0 percent) were recorded within 0.6 mi of I-17, and 20,900 (7.0 percent) of the fixes were made within 0.15 mi of the highway. Elk travelled an average of 728.4 ft (±26.5) between GPS fixes, with no difference in distance traveled by female (724.8 ft) and male (730.0 ft) elk. Elk MCP home ranges averaged 107.3 mi^2 (±15.1); mean male home ranges (154.1 mi^2 ±39.6) were marginally larger than female home ranges (93.1 mi^2 ±15.4; $P = 0.088$).

Highway Crossings

Collared elk crossed I-17 NB and SB lanes a combined total of 912 times, or a mean of 12.7 crossings/elk (±3.4), with a range of 2−173 highway crossings/elk. Of these crossings, 29.9 percent ($n = 273$; 3.9/elk ±1.1) spanned the entire highway corridor. Nearly half, or 33 (46 percent), of the elk never crossed I-17. The I-17 crossing rate was substantially lower than those determined for SR 260 and SR 64 (Table 2). Elk crossed I-17 0.03 (±0.01) times/day, also well below the crossing rates for SR 260 and SR 64 (Table 2); crossing rates did not differ by sex, as females averaged 0.03 crossings/day and males 0.02.

Overall, there were 30.2 percent more crossings of the NB (543 crossings) than SB ($n = 369$) lanes. However, the greatest difference in lane crossing frequency occurred on the 1.5-mi stretch with the extremely wide median south of the Red Hill Scenic Overlook, with 56.7 percent more crossings of the NB ($n = 210$) versus SB (91) lanes where elk often crossed one set of lanes and not the other (Figure 15). Along the remainder of I-17, the NB lanes ($n = 333$) crossing frequency was only 16.5 percent higher than the SB lanes ($n = 278$), indicating that the vast majority of crossings were made across both sets of lanes.

Spatial Patterns. I-17 elk crossings were distributed between Segments 58 and 404 (MP 299.7−335.3), or a length of 34.6 mi, with an average of 2.6 crossings/segment (Figures 14 and 16). The crossing distribution among the segments was not random and exhibited two large aggregated peak crossing zones (Figure 16). The observed distribution differed from a random crossing distribution (Kolmogorov-Smirnov $d = 0.309$, $P < 0.001$). The number of different collared elk crossings per segment averaged 0.9, and the range was 0−9 crossing elk/segment.

The highest peak crossing zone corresponded to Munds Canyon (MP 322.0), where 11 elk crossed 145 times (16.1 percent of total) within the 0.1-mi segment associated with the Munds Canyon Bridge (Segment 273) and two 0.1-mi segments on either side (Figure 16). This 0.5-mi stretch accounted for just 1.4 percent of the total highway length where crossings occurred but accounted for 16.1 percent of all crossings, and averaged 29.0 crossings/segment. The research team suspects that many of the crossings here occurred below grade under the Munds Canyon Bridge compared to at-grade crossings made elsewhere along I-17.

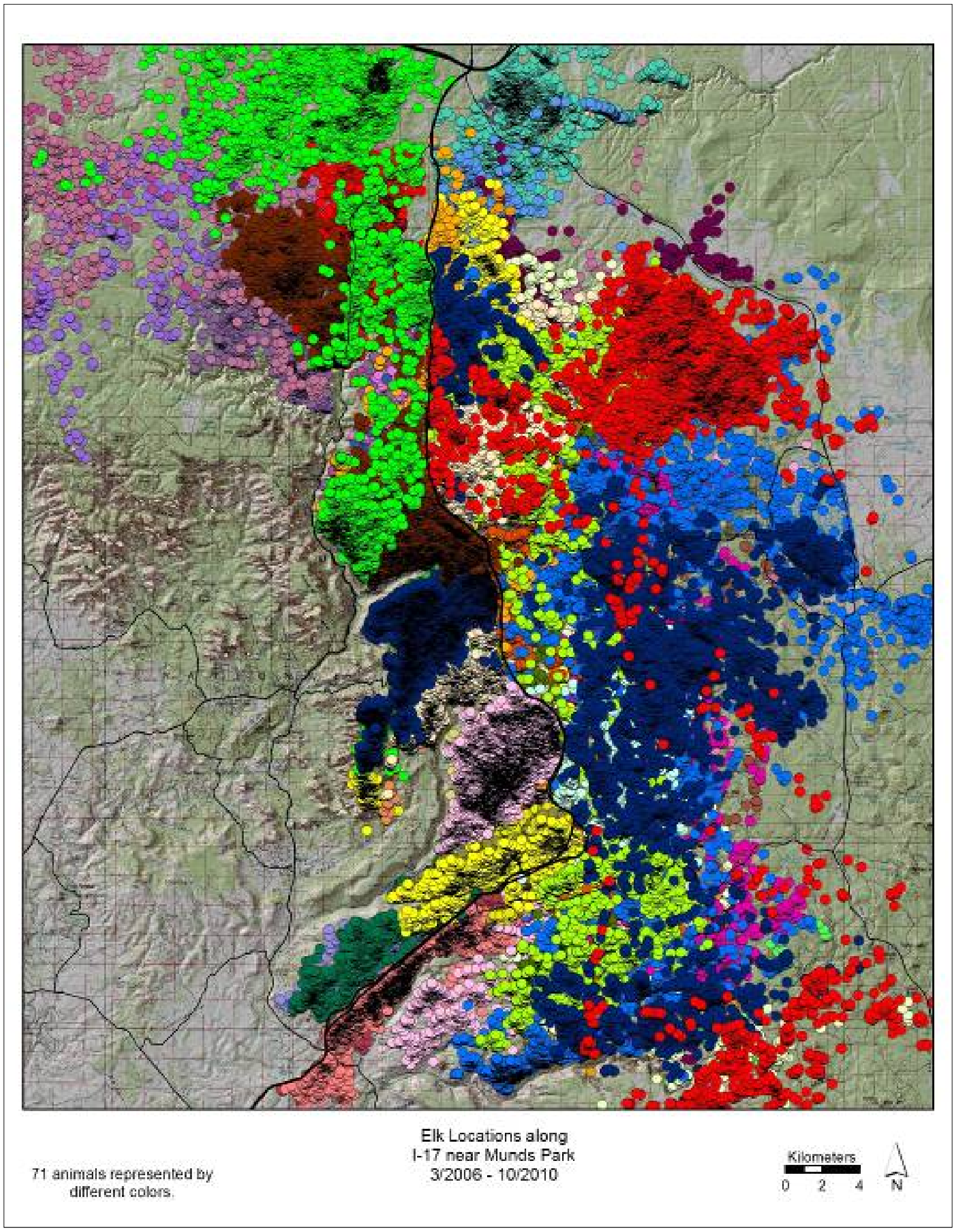


Figure 14. Distribution of GPS Relocations by 71 Elk Collared along I-17.

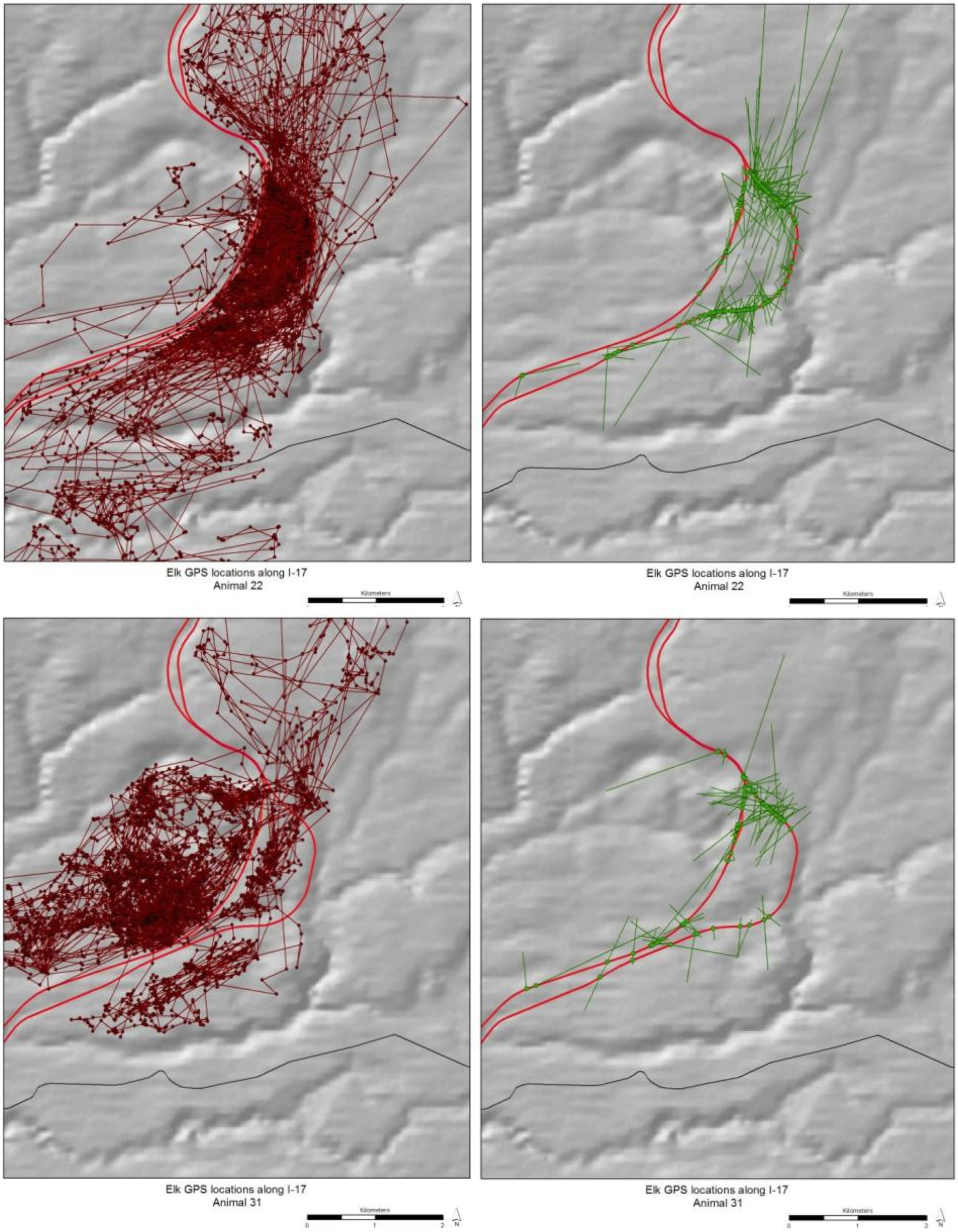


Figure 15. Example of Elk GPS Relocations (left) and Crossing Locations (green dots; right) along the NB and SB Lanes with Extremely Wide Medians.

(Note: Elk No. 22 [top] had 173 crossings, 147 across the NB lanes. No. 31 [bottom] had 88 crossings, 48 across the NB lanes. Elk No. 22 spent considerable time in the median compared to No. 31.)

Table 2. Comparative Mean Values for GPS-collared Animals along I-17, SR 260, and SR 64.

Parameter	Mean Value per GPS-Collared Animal by Highway (±SE)		
	I-17[a] (n = 71)	SR 260[a,b] (n = 100)	SR 64[a,c] (n = 15)
No. Highway Crossings	12.7 (3.4)	110.5 (16.6)	40.1 (11.2)
Highway Crossings/day	0.03 (0.01)	0.26 (0.06)	0.12 (0.03)
GPS Fixes ≤0.6 mi of Highway/Year	1,073.8 (135.5)	2,100.9 (273.1)	632.2 (164.4)
GPS Fixes ≤0.15 mi of Highway/Year	290.3 (48.4)	342.5 (95.9)	346.6 (97.7)
Highway Approaches/Day	0.22 (0.02)	0.47 (0.07)	0.21 (0.04)
Passage Rate (crossings/approach)	0.09 (0.02)	0.50 (0.03)	0.44 (0.07)
MCP Home Ranges (mi^2)	107.3 (15.1)	28.2 (4.3)[b]	284.8 (56.3)

[a]AADT (vehicles/day): I-17 = 16,015, SR 260 = 8,700, SR 64 = 4,275
[b]From Dodd et al. (2007*a*)
[c]From Dodd et al. (2010)

The other crossing peak corresponded to the stretch of highway where the lanes were separated by over 0.5 mi, between MP 310.0 and 312.0 (Figures 5 and 16). Along the 1-mi stretch with the greatest separation (Segments 160−169), 261 elk crossings occurred, or 29.0 percent of the total along just 2.9 percent of the length of I-17 with crossings. Elk crossings along this stretch of I-17 by nine collared elk averaged 26.1 crossings/segment.

These two sections constitute only 4.3 percent of the entire length of highway with elk crossings, yet accounted for 45.1 percent of all recorded crossings. Excluding these two sections, the crossing rate averaged only 1.5 crossings/segment. Though the crossing concentrations in these two areas provide meaningful insight of the benefit of an existing bridge adjacent to attractive foraging habitat and widely separated northbound and southbound lanes, they nonetheless are skewed and overwhelm the crossing patterns for elk elsewhere along the highway. As such, the research team also relied upon elk approaches to assess passage structure needs and habitat relationships.

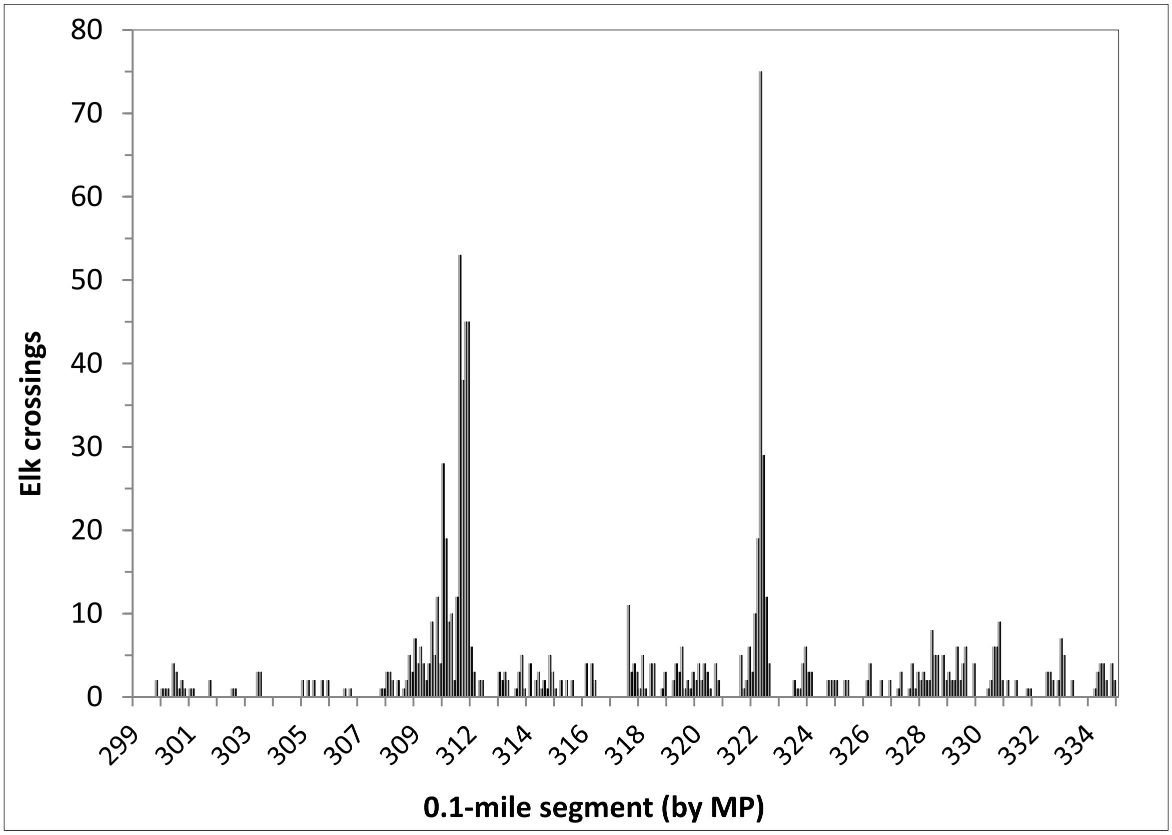


Figure 16. Elk Highway Crossing Frequency by 0.1-mi Segment along I-17 Determined from Telemetry, 2006 to 2010.

(Note: The two peaks correspond to the extremely wide median location and area near the Munds Canyon Bridge.)

Crossing Rate by Median Width Class. When the team assessed elk crossing rates by highway median width class, it found differences among the mean passage rate classes (Table 3; ANOVA; $F_{2,100} = 3.2$; $P = 0.043$). The mean crossing rate for elk using highway segments with the extremely wide medians was four times higher (14.5 crossings/elk) than the crossing rate for elk using the highway with standard median width (3.7 crossings/elk; $P = 0.049$; Table 3).

Temporal Patterns and Traffic Relationships. The observed elk crossing frequency by 2-hr intervals differed from expected ($\chi^2 = 678.7$, df = 11, $P < 0.001$), with the vast majority of crossings occurring between 0:00 and 06:00 (Figure 17). No crossings were recorded between 08:00 and 16:00. Elk crossings by time were strongly and inversely associated with mean traffic volume for the corresponding time ($r = -0.855$, $n = 12$, $P < 0.001$).

Elk crossing frequency by day was highest on Mondays and Tuesdays (Figure 17). By day, the observed frequency of elk crossings marginally did not differ from expected ($P = 0.089$). Likewise, the inverse association between crossings by day and corresponding mean traffic volume was marginally not significant ($r = -0.720$, $n = 7$, $P < 0.065$).

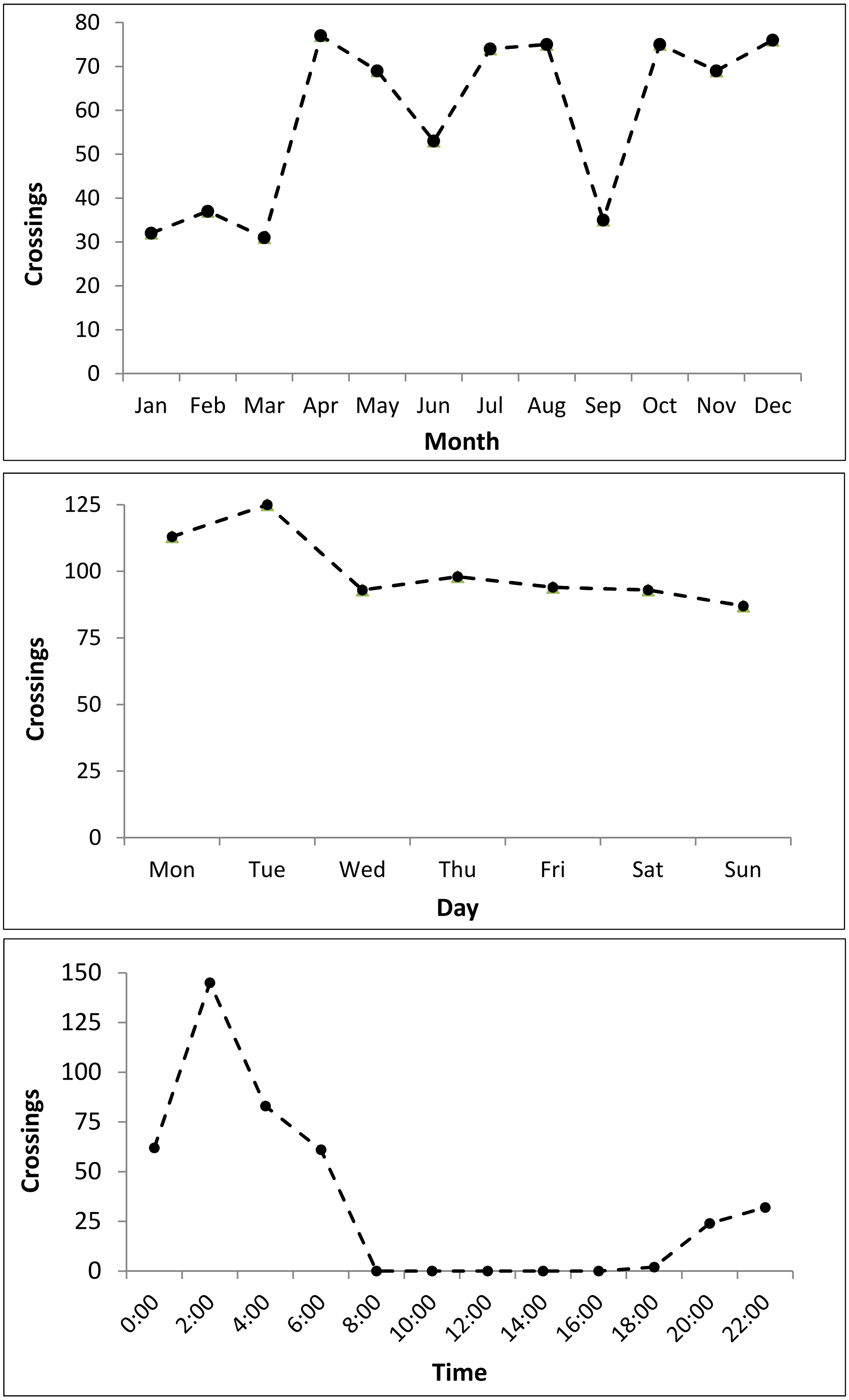


Figure 17. I-17 Elk Crossing Frequency by Time (bottom), Day (middle), and Month (top).

Table 3. Mean Elk Highway Passage Rate (crossings/approach) Comparison.
(Letters [A and B] denote differences among means by width class.)

Median Width Class	0.1-mi Segments (%)	No. Elk	Mean Crossings/ elk (±SE)[a]	Mean Passage Rate (±SE)[c]
Standard (<230 ft)	224 (64.0%)	65	3.7 (0.8) A[b]	0.06 (0.01) A[d]
Wide (231 – 460 ft)	48 (13.7%)	18	3.2 (0.6) A, B	0.15 (0.04) A, B
Extremely Wide (>460 ft)	78 (22.3%)	21	14.5 (6.4) B[b]	0.21 (0.05) B[d]

[a] Crossing rates differed among highway median width classes (ANOVA; $F_{2,100} = 3.2$; $P = 0.043$)
[b] Crossing rate for elk using extreme medians greater than standard medians ($P = 0.049$)
[c] Passage rates differed among highway median width classes (ANOVA; $F_{2,100} = 6.51$; $P = 0.002$)
[d] Passage rate for elk using extreme medians greater than standard medians ($P = 0.011$)

Elk crossings by month were lowest from January to March and consistent the remainder of the year except for dips in June and September (Figure 17). The observed frequency of monthly crossings did not differ from expected ($P = 0.365$), and the team found no association with traffic volume. Though the mean crossings/month by season in winter (48.3 crossings/month) was lower than the other three seasons that ranged from 59.0 to 67.3 crossings/month, the difference was not significant (ANOVA $P = 0.757$; Table 4).

Highway Passage Rates

The elk passage rate across I-17 averaged just 0.09 crossings/approach (±0.02) and was considerably lower than those documented for SR 260 and SR 64 (Table 2). For the elk that crossed I-17 ($n = 38$), the mean individual elk passage rates ranged from 0.01 to 0.61. The passage rate for males (0.11 crossings/approach ±0.03) differed little from that of females (0.09 crossings/approach ±0.02).

Passage Rate by Median Width Class. When considering the highway median width class, the research team found differences among the mean passage rates (Table 3; ANOVA; $F_{2,99} = 6.9$; $P = 0.002$). The mean passage rate for elk using highway segments with extremely wide medians was three times higher (0.21 crossings/approach) than the passage rate for elk using the highway with standard median width (0.06 crossings/ approach; $P = 0.011$). The mean combined passage rate for highway with wide and extremely wide medians (0.18 crossings/approach) was three times higher than highway with standard median width ($t_{100} = 3.8$, $P < 0.001$).

Table 4. Seasonal Mean Elk Crossings and Passage Rates along I-17.
(Letters [A and B] denote differences among seasonal means.)

Season	Months	Mean Crossings/ Month (±SE)	Mean Passage Rate[a] (±SE)
Winter	Dec-Feb	48.3 (±13.9) A	0.15 (±0.03) A[b]
Spring	Mar-May	59.0 (±14.2) A	0.07 (±0.01) B
Summer	Jun-Aug	67.3 (±7.2) A	0.06 (±0.01) B
Fall	Sep-Nov	59.7 (±12.4) A	0.05 (±0.02) B
All	Jan-Dec	58.5 (±5.6)	0.09 (±0.01)

[a]Passage rates differed among seasons (ANOVA $F_{3,8} = 4.5$, $P = 0.039$)
[b]Passage rate for elk in winter was higher than all other seasons ($P = 0.043$)

The mean passage rate for the 24 elk approaching and crossing at the five 0.1-mi segments encompassing the Munds Canyon Bridge was 0.24 crossings/approach (±0.09), over three times higher than the adjacent highway with standard-width medians.

Temporal Patterns and Traffic Relationships. Like elk crossings by time, the I-17 elk passage rate was highest from 02:00 to 06:00, peaking at 0.26 crossings/approach at 06:00 and then dropping off to zero between 08:00 and 18:00, when traffic volume was highest (Figure 18). There was a significant inverse association between elk passage rate and mean traffic volume by time of day ($r = -0.677$, $n = 12$, $P < 0.015$). The elk passage rate by day was highest on Wednesdays and lowest on Saturdays, but the association between traffic volume and passage rate was not significant ($P = 0.179$; Figure 18).

The elk passage rate was highest in February (0.22 crossings/approach) when traffic volume was at its lowest, and <0.10 crossings/approach from March to November (Figure 18). By month, the elk passage rate was inversely associated with traffic volume ($r = -0.646$, $n = 12$, $P < 0.023$). While elk crossings were lowest during winter, the mean passage rate per month during this season (0.15 crossings/approach) was higher than all other seasons (average = 0.05; ANOVA $F_{3,8} = 4.5$, $P = 0.043$; Table 4).

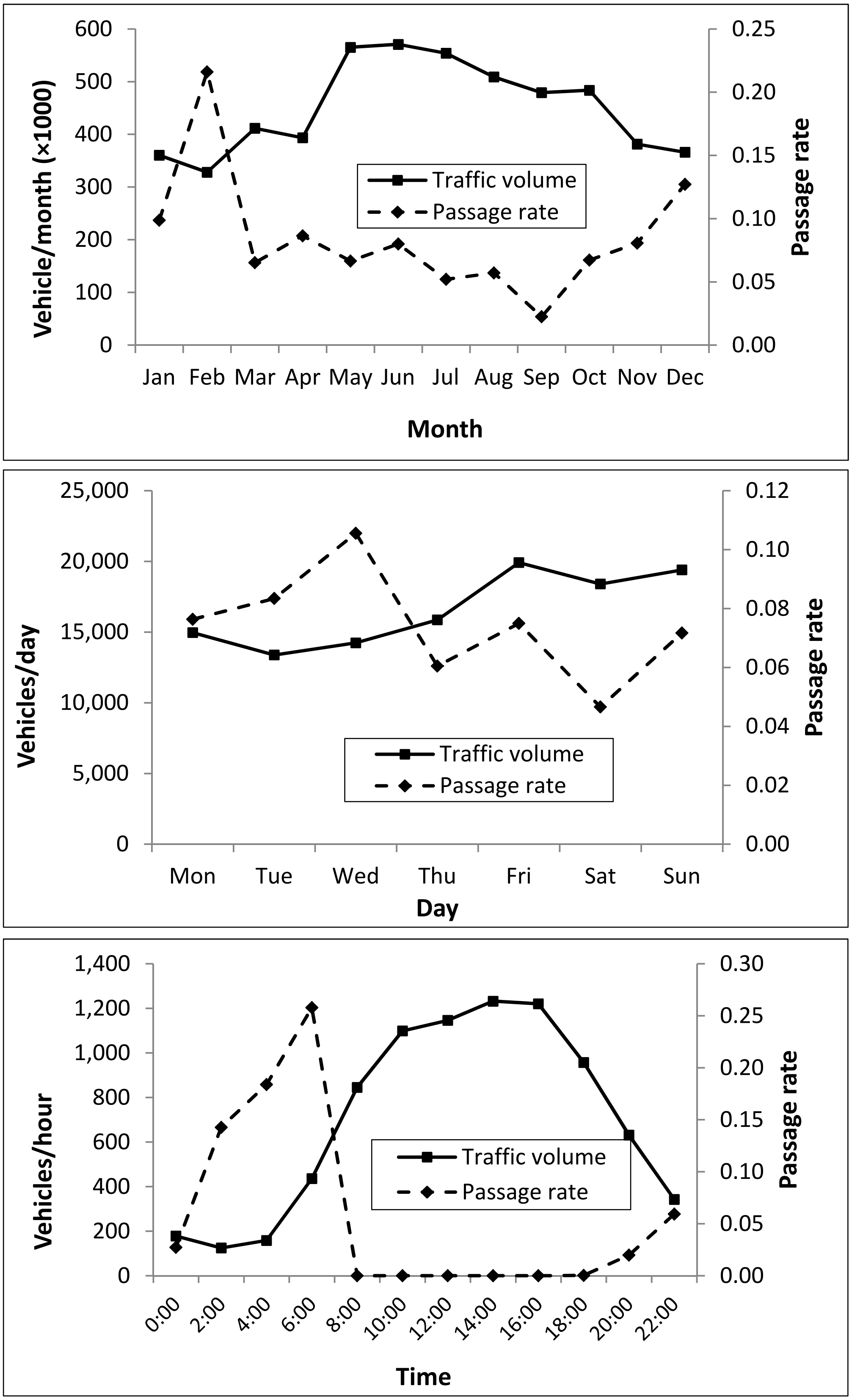


Figure 18. I-17 Elk Passage Rates and Traffic Volume by Time (bottom), Day (middle), and Month (top).

Highway Approaches

In spite of the low highway crossing rate when compared to SR 260 and SR 64, GPS-collared elk were located within 0.15 mi of I-17 a total of 20,830 times, for a mean of 293.4 approaches/elk (±48.3) and a range of 4 to 1,471 approaches/elk. The approaches were accrued by all but one collared elk between Segments 34 and 445, or 41.1 mi (Figure 19). The spatial elk approach pattern adjacent to I-17 differed from a random distribution pattern (Kolmogorov-Smirnov $d = 0.177$, $P < 0.001$), exhibiting several peaks along the highway (Figure 19). These peaks corresponded to the section of highway with the wide median south of the Red Hill Scenic Overlook and several meadow complexes north of the overlook. A mean of 50.6 approaches were recorded for each 0.1-mi segment (±3.7), with a range of 1–491; only 44 segments (10.7 percent) had no elk approaches. An average of 6.6 different elk (±0.3) approached within each of the 0.1-mi segments, with a range of 1–23 approaching elk/segment.

The research team's application of SDI to calculate weighted approaches for each 0.1-mi segment yielded 36,475 weighted approaches, with a mean of 83.7/segment (±7.0). Weighted approaches reduce bias of individual elk movements by accounting for the number of different elk approaching within each segment. The weighted approach distribution also differed from a random distribution (Kolmogorov-Smirnov $d = 0.277$, $P < 0.001$), as most of the same approach peaks were accentuated with weighting, especially those associated with the meadow complexes north of the Red Hill Scenic Overlook (Figure 19). To illustrate the influence that a large component of collared elk approaching I-17 played, especially north of the overlook, the 38 segments (9 percent of total) at which 15 or more collared elk approached had weighted approach frequencies that increased an average of 130 percent; this small proportion of the segments accounted for 50 percent of the entire increase over uncorrected approaches after the research team applied SDI corrections.

4.2 TRAFFIC AND ELK DISTRIBUTION RELATIONSHIPS

The research team's elk distribution analysis was based on 16,384 GPS fixes recorded within 1,980 ft of the highway. Frequency distributions of mean probabilities showed a shift in distribution away from I-17 with increasing traffic volume (Table 5, Figure 20). Even at relatively low traffic volume up to 300 vehicles/hr, the mean probability of elk occurring within 330 ft of I-17 was a static 0.12 (Table 5, Figure 20). The combined (additive) probability of elk occurring within 990 ft of the highway was similar when traffic volume was <100 vehicles/hr (0.49) and 300–400 vehicles/hr (0.50), but decreased when traffic was >600 vehicles/hr (0.37; Figure 21). Conversely, the combined probability of elk occurring beyond 990 ft increased nearly one-third from 0.49 when traffic volume was <100 vehicles/hr to 0.63 at >600 vehicles/hr (Table 5, Figure 21).

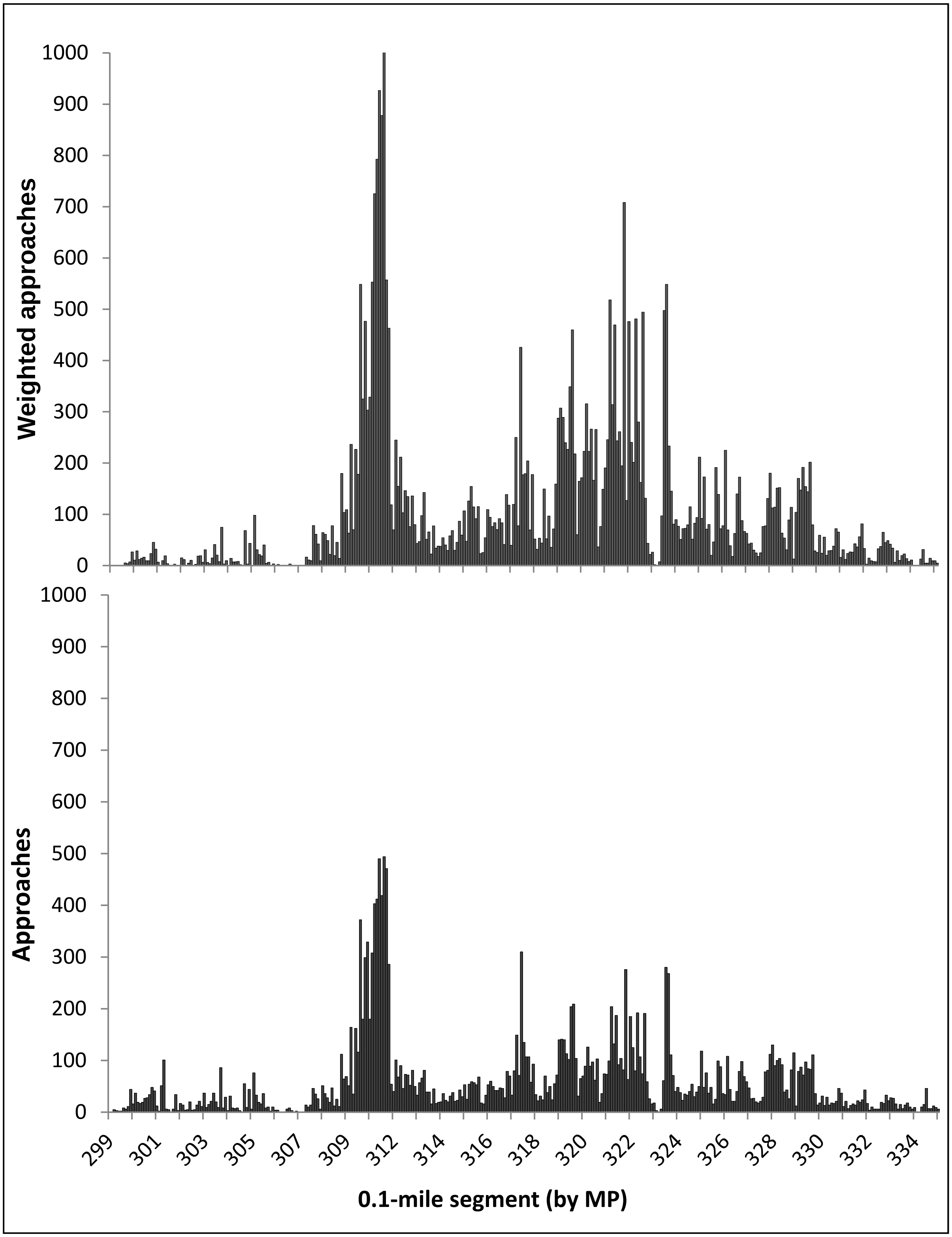


Figure 19. Approaches Made by GPS-collared Elk to within 0.15 Mi of I-17 (bottom) and SDI-weighted Approach Frequency (top).

(Note: The Red Hill Scenic Overlook is at MP 312.0 and the extremely wide median is at MP 309.5 to 311.5.)

Table 5. Mean Probabilities of Collared Elk Occurring within Various Distance Bands from I-17, SR 260, and SR 64 at Varying Traffic Volumes.

Distance from Roadway by Highway	Probability of Occurring in Distance Band by Traffic Volume (vehicles/hr)						
	<100	100−200	200−300	300−400	400−500	500−600	>600
0−330 ft							
I-17 (All)[a]	0.12	0.12	0.12	0.10	0.08	0.06	0.05
I-17 (Wide)[a]	0.15	0.17	0.18	0.15	0.11	0.10	0.09
SR 64[b]	0.24	0.12	0.08	0.08	0.06	0.08	0.10
SR 260[c]	0.18	0.16	0.11	0.10	0.07	0.04	0.06
330−660 ft							
I-17 (All)	0.15	0.19	0.19	0.19	0.17	0.16	0.15
I-17 (Wide)	0.21	0.25	0.24	0.22	0.21	0.17	0.20
SR 64[a]	0.20	0.18	0.16	0.10	0.11	0.06	0.16
SR 260[b]	0.22	0.21	0.17	0.17	0.16	0.14	0.15
660−990 ft							
I-17 (All)	0.20	0.19	0.19	0.21	0.19	0.20	0.18
I-17 (Wide)	0.18	0.19	0.17	0.18	0.19	0.19	0.20
SR 64[a]	0.14	0.14	0.17	0.20	0.16	0.13	0.11
SR 260[b]	0.16	0.18	0.20	0.19	0.19	0.20	0.20
990−1,320 ft							
I-17 (All)	0.21	0.18	0.18	0.18	0.19	0.20	0.19
I-17 (Wide)	0.16	0.14	0.16	0.16	0.17	0.20	0.20
SR 64[a]	0.13	0.15	0.16	0.16	0.18	0.22	0.24
SR 260[b]	0.15	0.16	0.19	0.18	0.20	0.18	0.19
1,320−1,650 ft							
I-17 (All)	0.18	0.17	0.17	0.18	0.19	0.20	0.22
I-17 (Wide)	0.16	0.14	0.13	0.16	0.17	0.18	0.18
SR 64[a]	0.13	0.18	0.18	0.28	0.20	0.20	0.25
SR 260[b]	0.15	0.15	0.17	0.18	0.19	0.21	0.20
1,650−1,980 ft							
I-17 (All)	0.12	0.15	0.15	0.14	0.18	0.19	0.22
I-17 (Wide)	0.16	0.12	0.12	0.13	0.15	0.16	0.14
SR 64[a]	0.15	0.22	0.26	0.20	0.29	0.32	0.15
SR 260[b]	0.14	0.14	0.16	0.18	0.18	0.23	0.21

[a] I-17 (All) refers to all study segments; I-17 (Wide) refers to segments with wide medians
[b] Dodd et al. 2010
[c] Gagnon et al. 2007*b*

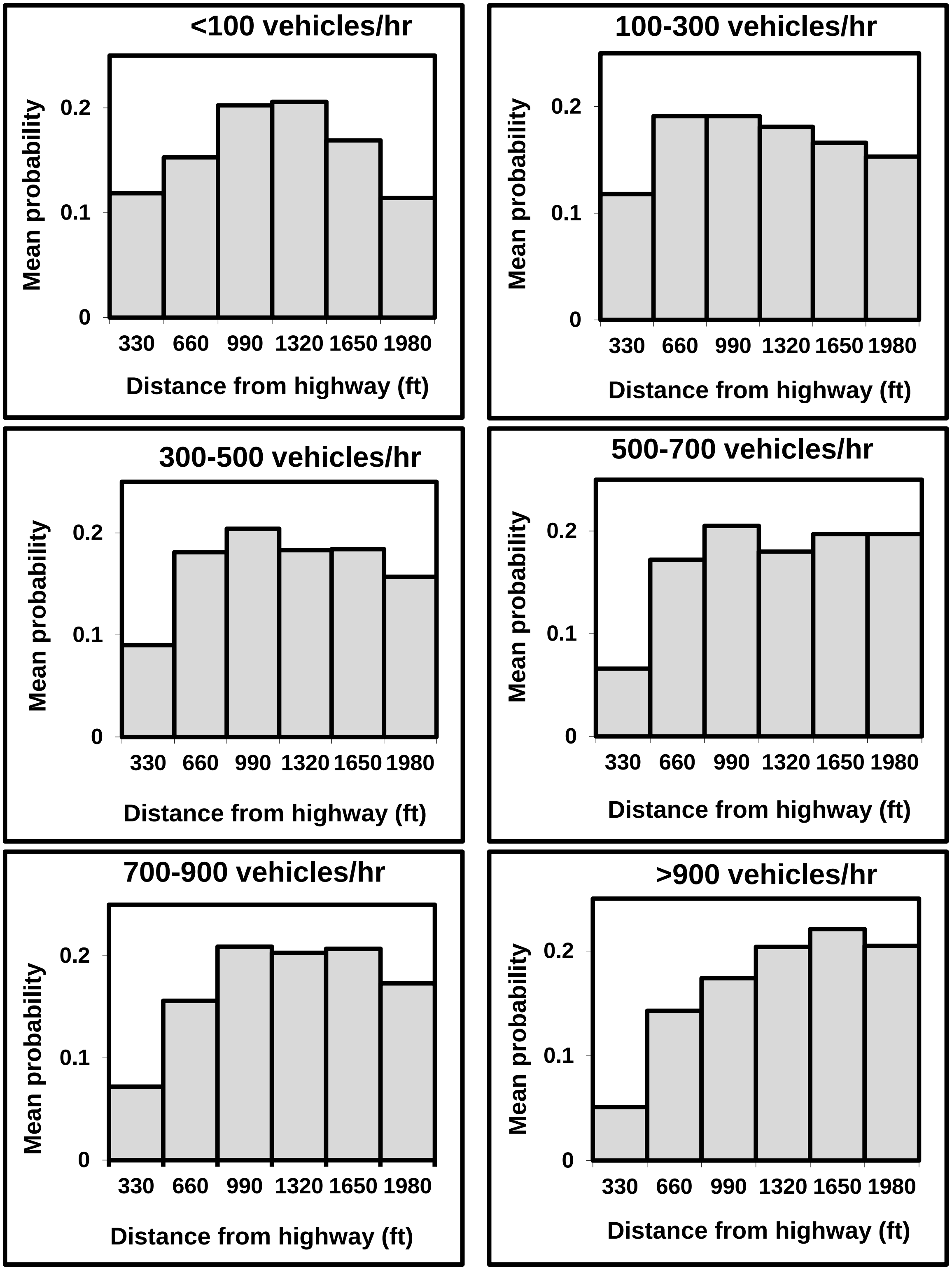


Figure 20. Mean Probability that Collared Elk Occurred within 330-ft Distance Bands Away from All Stretches of I-17 at Varying Traffic Volumes.

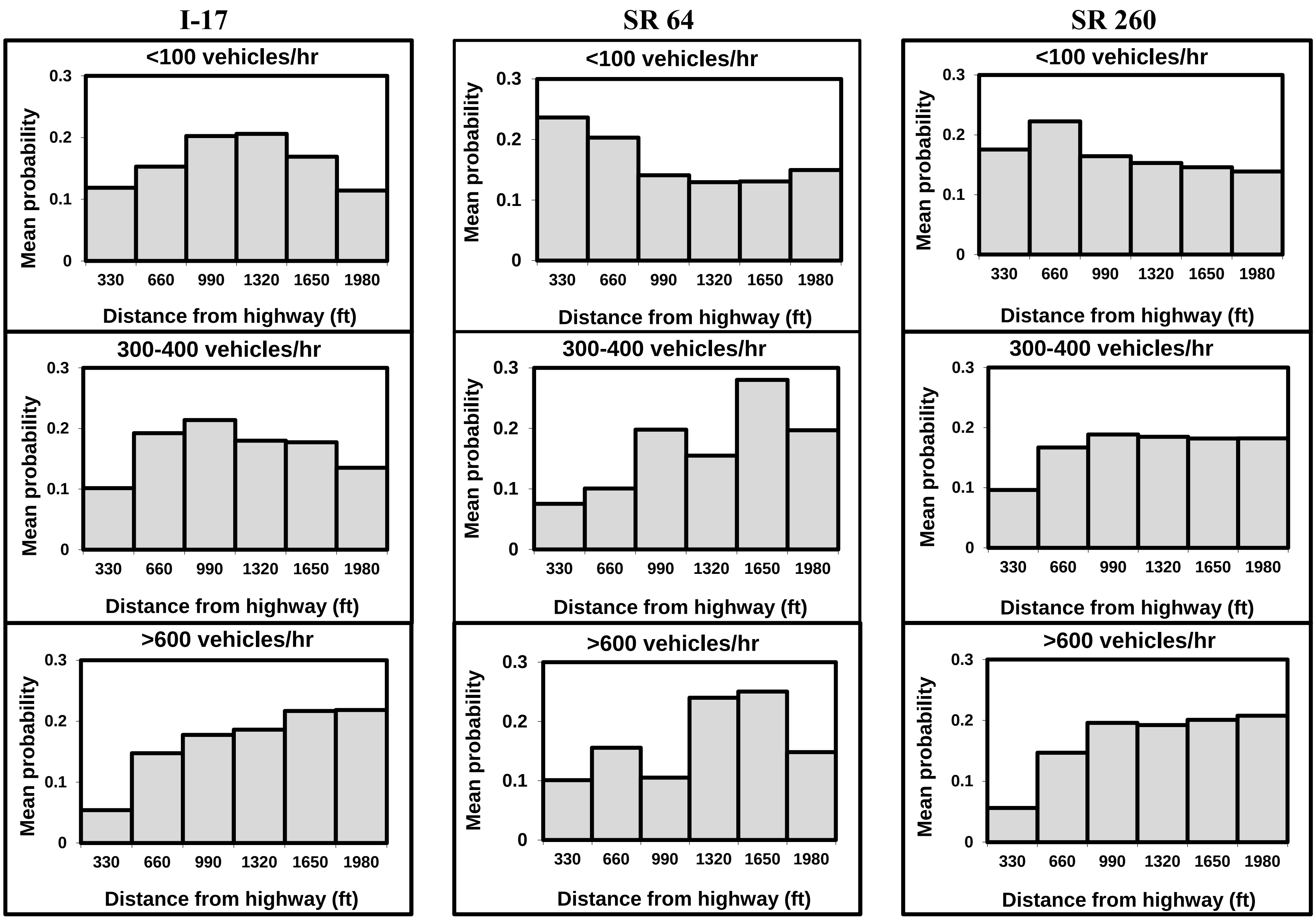


Figure 21. Comparison of Mean Probability that Collared Elk Occurred within 330-ft Distance Bands Away from I-17 (left), SR 64 (center), and SR 260 (right) at Varying Traffic Volumes.

In comparing elk distributions across traffic volume for I-17, SR 64, and SR 260 (Table 5, Figure 21), the most dramatic difference among highways occurred for low traffic volume (<100 vehicles/hr) in the 330-ft zone adjacent to the roadway. Here, the probability of elk occurrence declined as a function of increasing AADT (Figure 22), with the probability of elk occurring adjacent to I-17 (0.12) being half that of SR 64 (0.24). Unlike SR 64, and to a lesser degree SR 260, elk did not exhibit a shift in distribution back to the band within 330 ft of I-17 when traffic was at its lowest level.

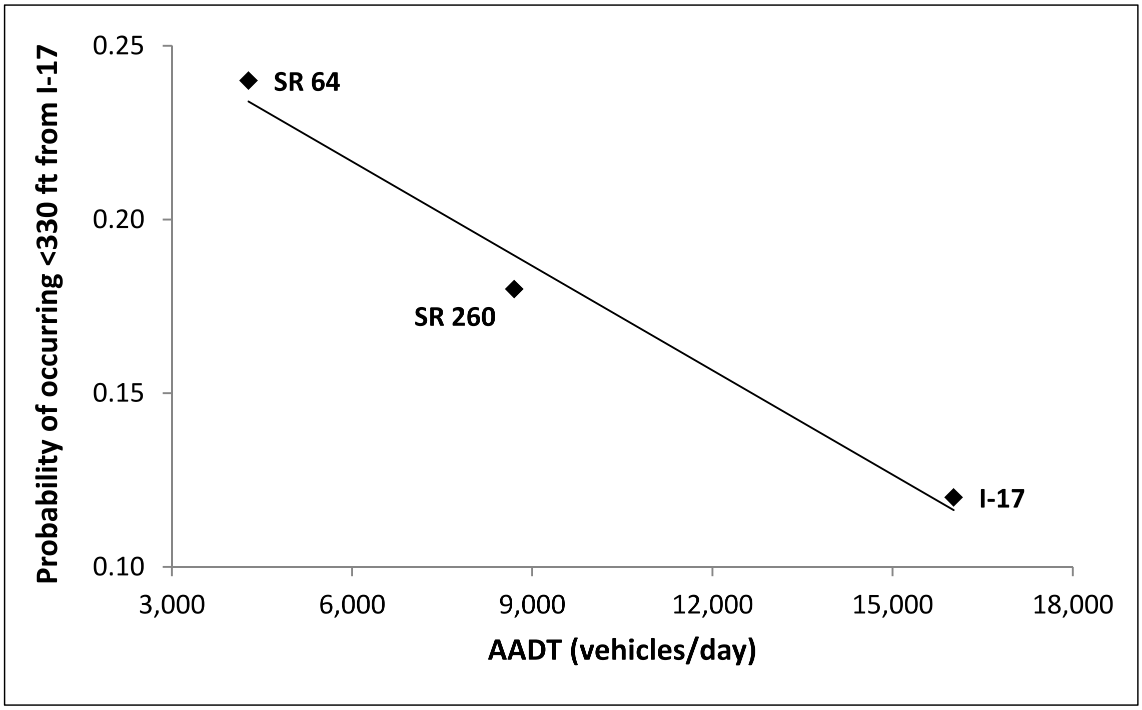


Figure 22. Mean Probability of Elk Occurring within 330 Ft of I-17, SR 64, and SR 260 at Their Respective AADT When Traffic Volume Was <100 Vehicles/hr.

When considering elk distribution relative to traffic volume on I-17 sections with wide medians (Table 5), the probability of elk occurring within 330 ft of the highway at low traffic volume (<100 vehicles/hr) was 25 percent higher (0.15) than the probability associated with standard medians (0.12). The probabilities for elk occurring within 990 ft of I-17 across all traffic volumes were consistently higher, an average of 17.5 percent, on highway sections with wide medians when compared to standard medians (Table 5).

4.3 WILDLIFE-VEHICLE COLLISION RELATIONSHIPS

Agency personnel and project researchers recorded 395 WVC from 2007 to 2010, accounting for 10 species (Tables 6 and 7). Elk accounted for 80.0 percent of the WVC, while deer accounted for 14.2 percent, with seven black bears involved in WVC (1.8 percent). Of the 56 DVC (Table 7), species was identified in just 22 instances. The preponderance (n = 18; 81.8 percent) were identified as mule deer and four (18.2 percent) as white-tailed deer; regardless, the team assessed all deer records collectively as “deer.” Of the 316 EVC, 23 (7.3 percent) resulted in two or more animals being killed, with three of these accidents involving three elk (Table 6). Sex was identified in nearly half (47.5

percent) the EVC records, with females accounting for 59.3 percent and males 40.7 percent. Compared to the average surveyed bull : cow ratio for the elk population adjacent to I-17 (32.0 bulls : 100 cows; Table 1), males were disproportionately overrepresented in EVC with an mean ratio of 74.5 bulls : 100 cows ($\chi^2 = 262.7$, df = 3, $P < 0.001$). Only 15 DVC were identified as to sex, with eight females and seven males; deer data was too limited to support further analysis.

Table 6. EVC along I-17 from 2007 to 2010 and the Proportion of Single-vehicle Accidents in Which Wildlife Were Involved.

Year	EVC (MP 305–338)			Proportion of Single-vehicle Accidents
	No. of Collisions	No. of Elk Killed	Collisions/Mi	
2007	88	92	2.7	0.18
2008	86	86	2.6	0.16
2009	85	101	2.6	0.16
2010	57	63	1.7	-
All	316	343	9.6	0.17
Mean (±SE)	79.0 (±7.3)	85.5 (±8.1)	2.4 (±0.2)	0.17 (±0.01)

Table 7. Frequency of WVC Involving Species Other Than Elk from 2007 to 2010 and Annual Means.

Species	No. of WVC (MP 305–338)					
	2007	2008	2009	2010	All	Mean (±SE)
Deer[a]	18	14	17	7	56	14.0 (±2.5)
Black Bear	2	1	0	4	7	1.8 (±0.9)
Coyote	2	2	1	0	5	1.2 (±0.5)
Gray Fox	3	1	0	0	4	1.0 (±0.7)
Raccoon	2	0	0	1	3	0.8 (±0.5)
Javelina	0	1	1	0	2	0.5 (±0.3)
Mountain Lion	1	0	0	0	1	0.2 (±0.2)
Bald Eagle	0	0	1	0	1	0.2 (±0.2)

[a] Mule deer, white-tailed deer, and unidentified deer species combined.

Spatial Relationships

The frequency of EVC by 0.1-mi segment between Segments 150 and 450 (Figure 23) ranged from 0 to 7, with an average of 1.1 EVC/segment (±0.1); EVC occurred within 157 of the 300 segments (52.3 percent). The observed spatial distribution of EVC differed from a random distribution (Kolmogorov-Smirnov $d = -0.477$, $P < 0.001$), with several peak EVC zones apparent along the length of I-17 corresponding to the highway with the wide median south of the Red Hill Scenic Overlook and meadow complexes to the north (Figure 23). The frequency of WVC involving deer averaged just 0.2 collisions/segment (±0.1), and ranged from one to three collisions along the same stretch of I-17 as EVC occurred (Figure 24). In the case of DVC however, collisions with vehicles occurred within only 41 of the 0.1-mi segments, or 13.5 percent. No peaks or "hotspots" in DVC were apparent along the length of I-17 with the exception of the cluster of 11 (22.4 percent) DVC in the 1.5-mi stretch from Segment 253 to 276 (MP 322.4−320.1), on either side of the Schnebly Hill TI (Figure 24).

Temporal, Traffic, and Highway Crossing Relationships

The frequency of EVC by hour along I-17 differed from expected ($\chi^2 = 148.7$, df = 15, $P < 0.001$), with the highest incidence of collisions occurring at 02:00 and 03:00 (Figure 25). Between 08:00 and 17:00, relatively few EVC were recorded, supporting the exclusion of this time from the chi-square and regression analyses. The research team found a strong inverse association between EVC and traffic volume ($r = -0.926$, $n = 16$, $P < 0.001$; Figure 25). The researchers also determined that there was a strong association between the frequency of EVC by time (2-hr intervals) and elk highway crossings ($r = 0.770$, $n = 12$, $P < 0.003$). Thus, both I-17 elk crossings and EVC were significantly associated with traffic volume by time and with each other.

The frequency of DVC by time differed from expected ($\chi^2 = 41.1$, df = 23, $P < 0.011$), with the highest collision incidence at 08:00 and 17:00 (31 percent of total). However, the research team did not find a significant association with traffic volume ($P = 0.470$).

By day, the frequency of EVC differed from expected ($\chi^2 = 15.2$, df = 6, $P < 0.019$), with the highest incidence of collisions occurring on Tuesdays when traffic volume was the lowest (Figure 25). The research team found a significant inverse association between EVC and traffic volume ($r = -0.833$, $n = 7$, $P < 0.020$; Figure 24). And as for time, the team found a significant association between EVC and highway crossings by hour ($r = 857$, $n = 7$, $P < 0.014$)

For deer, the observed frequency of collisions with vehicles did not differ from expected by day ($P = 0.439$), and the researchers found no association between DVC and traffic volume ($P = 0.378$).

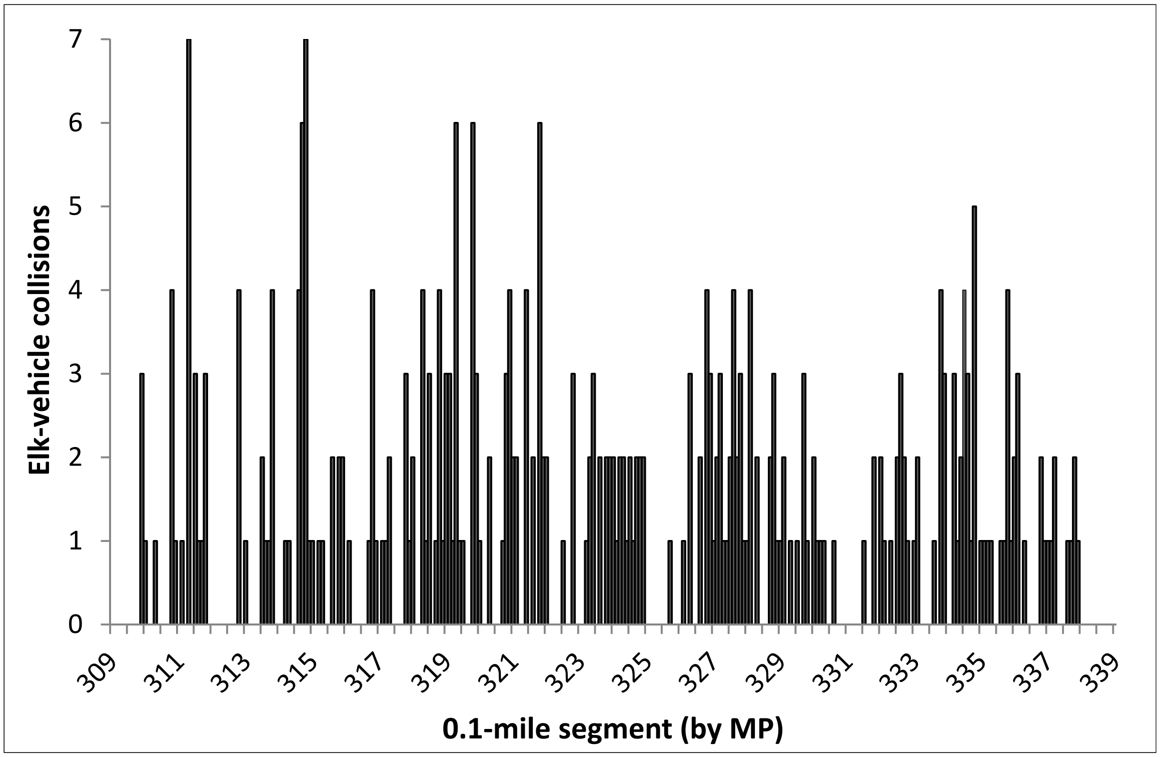


Figure 23. Frequency of EVC along I-17 between 2007 and 2010.

(Note: The Red Hill Scenic Overlook is at MP 312.0 and the extremely wide median is at MP 309.5 to MP 311.5)

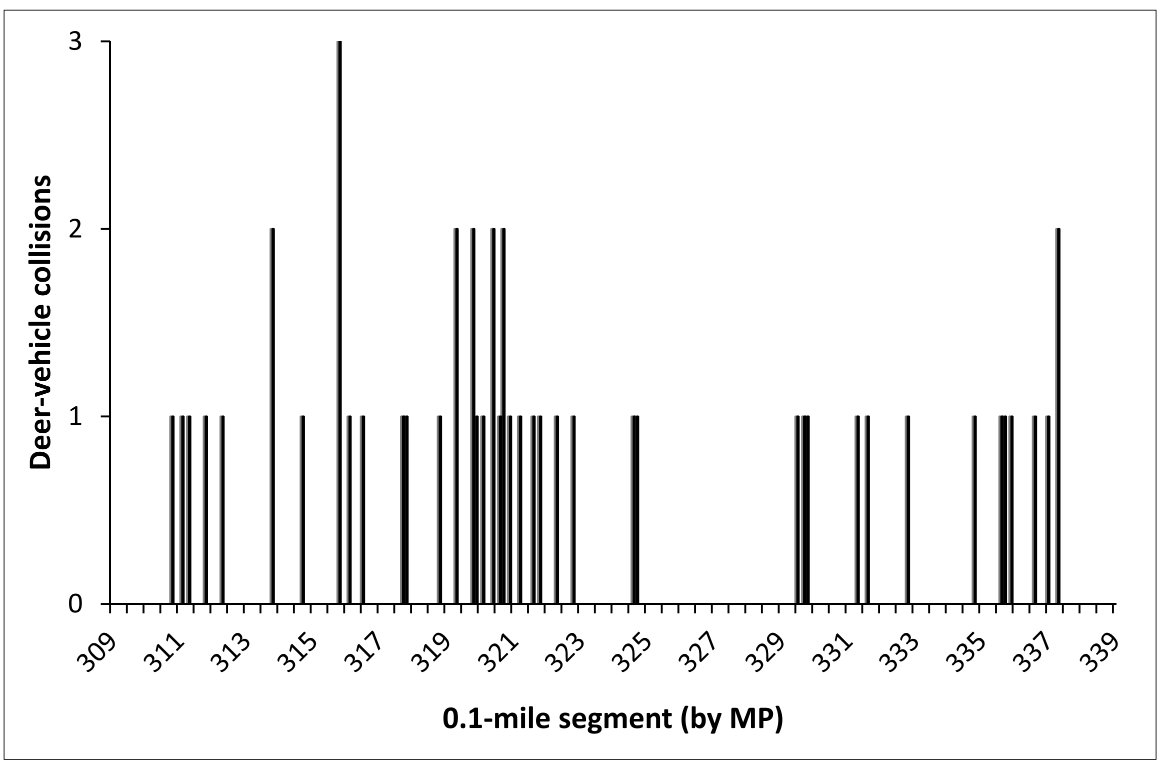
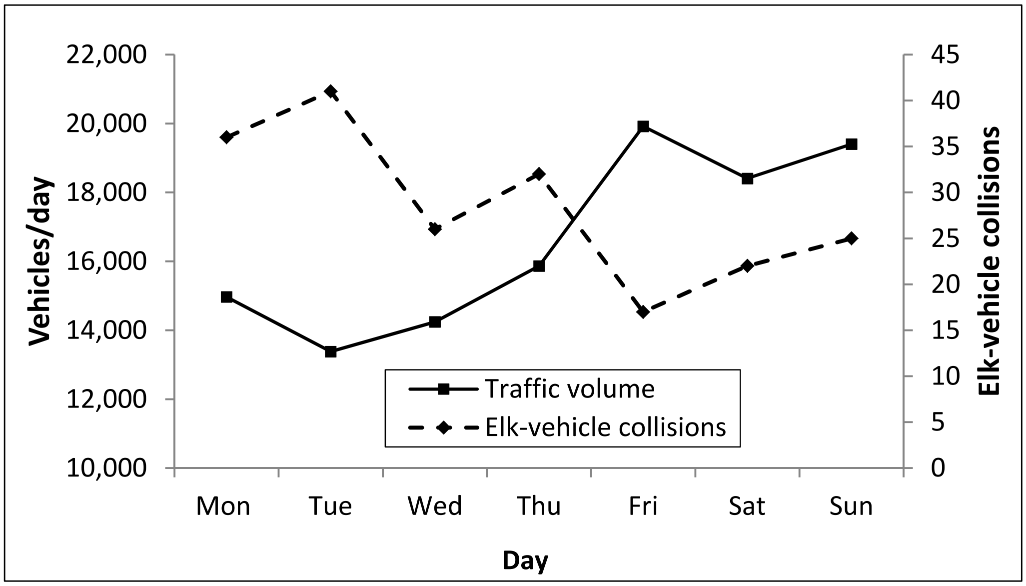


Figure 24. Frequency of DVC along I-17 between 2007 and 2010.



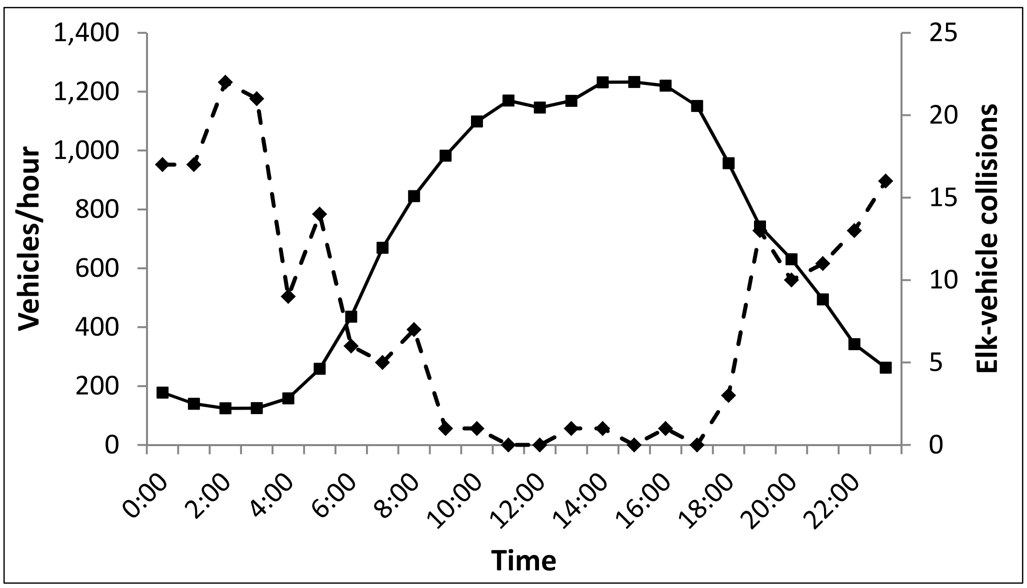


Figure 25. I-17 EVC and Traffic Volume by Time (bottom) and Day (top).

For both elk (χ^2 = 42.4, df = 11, P < 0.001) and deer (χ^2 = 23.3, df = 11, P = 0.016), the research team found that observed collisions with vehicles differed from expected by month (Figure 26). However, the team determined that collisions were not significantly associated with mean monthly traffic volume for either elk or deer (P = 0.095 and P = 0.284, respectively), nor were EVC and GPS-determined elk crossings by month. When monthly EVC and DVC were aggregated by season, the spring season had the highest incidence of EVC followed closely by summer, and fall had the highest incidence of DVC (Table 8). The observed frequency of collisions differed from expected for both elk (χ^2 = 20.2, df = 3, P < 0.001) and deer (χ^2 = 9.0, df = 3, P < 0.030). And while the highest monthly proportion of all EVC indeed occurred during spring and summer months, the proportion of monthly DVC (22 percent) spiked dramatically in October (Figure 26).

Table 8. Frequency of EVC and DVC with Vehicles along I-17 by Season.

		Frequency of WVC (%)	
Season	Months	Elk	Deer
Winter	Dec–Feb	54 (17.1%)	6 (11.1%)
Spring	Mar–May	106 (33.6%)	12 (22.2%)
Summer	Jun–Aug	92 (29.2%)	16 (29.6%)
Fall	Sep–Nov	69 (21.9%)	21 (38.5%)
All	Jan–Dec	321 (100%)	55 (100%)

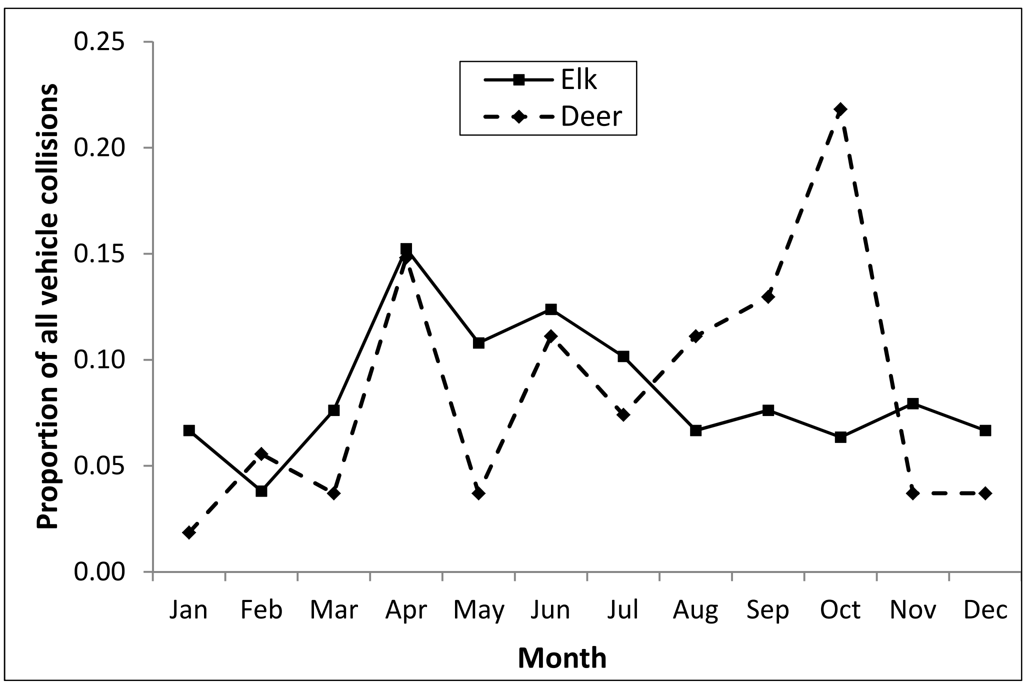


Figure 26. Monthly Proportion of All EVC and DVC along I-17.

Of the 71 GPS-collared elk, five (7.0 percent) were confirmed as being killed in I-17 EVC. When considered by elk highway crossing frequency class, there was a highly disproportionate frequency of elk killed in EVC (Table 9; $\chi^2 = 39.0$, df = 2, $P < 0.001$). Though frequent crossers accounted for only 8.4 percent of the collared elk, they accounted for 60.0 percent of the EVC involving collared elk. Two of the infrequent (or non-) crossers killed in EVC apparently attempted to cross I-17 only once when they were killed.

Table 9. Number of I-17 Elk Fitted with GPS Collars Versus Those Killed in EVC by Highway Crossing Frequency Class and the Percentage of the Totals.

Highway Crossing Frequency	No. of Collared Elk (%)	No. of Elk Killed in EVC[a] (%)
<0.02 crossings/day	43 (60.6%)	2 (40.0%)
0.02-0.10 crossings/day	22 (31.0%)	0 (0.0%)
>0.10 crossings/day	6 (8.4%)	3 (60.0%)
All	71 (100.0%)	5 (100.0%)

[a]Observed versus expected elk killed in EVC $\chi^2 = 39.0$, df = 2, $P < 0.001$.

Traffic Volume Thresholds in Elk-Vehicle Collisions

The research team assessed mean frequency of EVC/hr for eight traffic volume classes; 184 EVC with known times of occurrence, excluding EVC and traffic data between 10:00 and 17:00 when few EVC occurred, were considered (Table 10). For the 7 hr/day where traffic volume was equivalent to an AADT of <10,000 (e.g., 416 vehicles/hr × 24 hr), EVC averaged 15.1/hr (Table 10). For all traffic volume classes up to an AADT equivalent 10,000 vehicles/day, the actual mean EVC/hr was higher than expected; above this level, actual EVC/hr were less than the expected (Table 10). At the 10,000–12,500 AADT equivalent class, EVC dropped 46 percent to 8.5/hr and remained relatively static through 20,000 AADT (Table 10, Figure 26); there was a mean of 8.2 EVC/hr for the 6 hr/day experiencing 10,000 to 20,000 AADT. At an AADT-equivalent traffic volume >20,000, EVC dropped 76 percent to a mean of 2.0 EVC/hr for the 2 hr each day experiencing this extreme traffic volume (Table 10, Figure 26). From the mean EVC/hr level for AADT < 5,000 vehicles/hr to the mean for AADT >20,000 vehicles/hr, mean EVC declined by 88.4 percent.

Table 10. Mean I-17 EVC/hr by Traffic Volume Class and the Hr/day They Occurred, and the Expected EVC/hr for the Corresponding Traffic Volume Class.

Traffic Volume (AADT) Class (midpoint)	Mean EVC/Hr	No. Hr/Day	Expected EVC/Hr
<5,000	17.3	5	11.5
5,000–7,500 (6,250)	15.0	2	11.5
7,500–10,000 (8,750)	13.0	1	11.5
Subtotal <10,000	15.1	8	11.5
10,000–12,500 (11,250)	8.5	2	11.5
12,500–15,000 (13,750)	9.0	1	11.5
15,000–17,500 (16,250)	8.5	2	11.5
17,500–20,000 (18,750)	7.0	1	11.5
Subtotal 10,000–20,000	8.2	6	11.5
>20,0000	2.0	2	

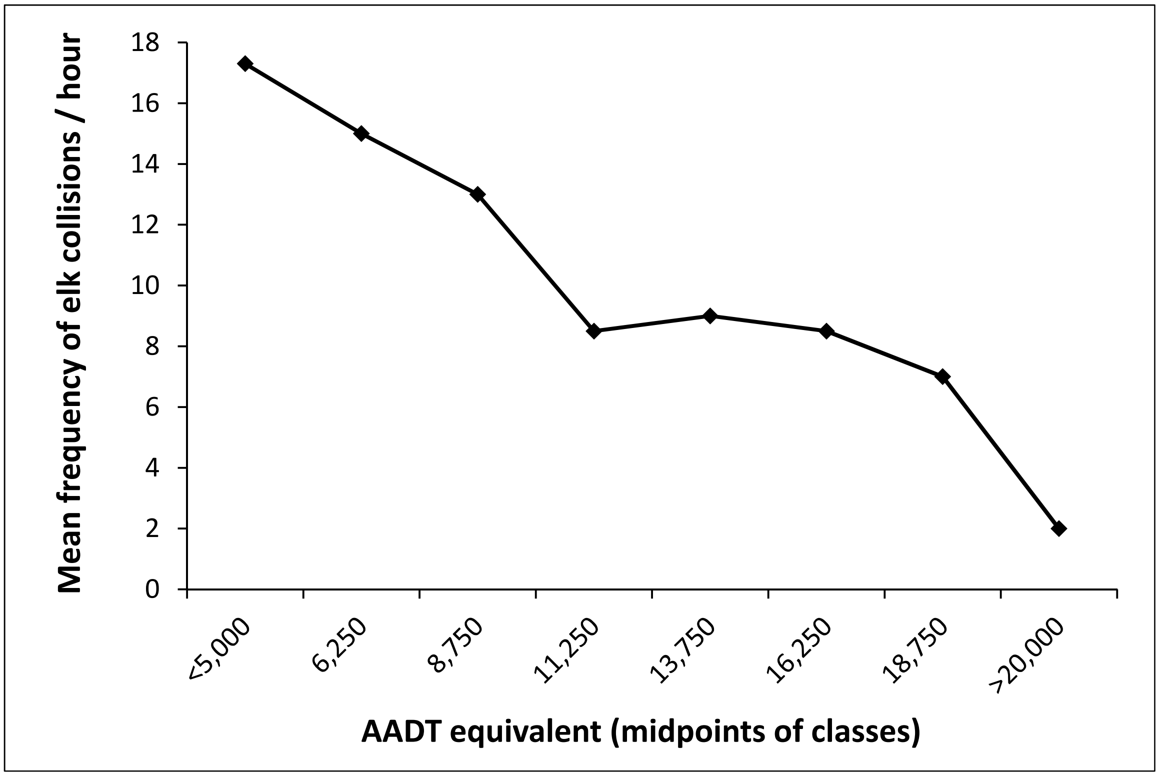


Figure 27. Mean I-17 EVC/hr for AADT-equivalent Traffic Volume Class Midpoints Corresponding to Classes in Table 10.

Cost Associated with WVC

Using the cost figures assembled by Huijser et al. (2007) and the I-17 WVC data for the mean annual incidence of vehicle collisions with elk (79.0/year; Table 6) and deer (14.0/year; Table 7), the team estimated that annual WVC cost $1,466,561 for elk and $117,432 for deer; estimated costs total $1,583,933/year.

4.4 RELATIONSHIPS TO RIPARIAN-MEADOW HABITAT

For the length of I-17 between 0.1-mi Segments 176 to 455 (n = 279), the distance to the closest riparian-meadow habitat averaged 5,034.9 ft (±338.8) by individual segments and 5,024.2 ft (±831.2) by aggregated 0.6-mi segments (n = 45). The research team excluded the five 0.1-mi segments corresponding to the Munds Canyon Bridge from its riparian-meadow analyses due to bias associated with the high proportion of elk crossings presumably using the underpass. When considered by 0.1-mi segments, the negative correlation between mean distance to riparian-meadow habitat and elk highway crossings, weighted approaches, and EVC were relatively weak, with correlation coefficients (r) all ≤ -0.335. However, due largely to the sample size, the correlations were highly significant ($P < 0.001$; Table 11). At the 0.6-mi segment scale, the correlations between the mean distance to riparian-meadow habitat and crossings, approaches, and EVC were somewhat stronger, though still relatively weak with all $r \leq -0.445$; all three correlations were nonetheless significant (Table 11).

Table 11. Correlation Coefficients for Regression Analyses Between I-17 Elk Crossings, Weighted Elk Approaches, EVC, and Proximity to Riparian-meadow Habitat

Highway Segment Scale	Independent Variable	Correlation Coefficients (r) by Dependent Variable		
		Highway Crossings	Highway Approaches	EVC
0.1 mi (n = 275)	Mean distance to riparian-meadow habitat	r = -0.286 (P < 0.001)	r = -0.264 (P < 0.001)	r = -0.335 (P < 0.001)
0.6 mi (n = 45)	Mean distance to riparian-meadow habitat	r = -0.445 (P = 0.002)	r = -0.341 (P = 0.020)	r = -0.368 (P = 0.013)

GIS analysis based on Manzo's (2006) model found that 136 (49.6 percent) 0.1-mi segments were located within 0.6 mi (1 km) of riparian-meadow habitat adjacent to I-17, and 138 (50.4 percent) segments were further than 0.6 mi of the habitat. Thus, the null model predicted that 50 percent of the I-17 elk crossings, weighted approaches, and collisions with vehicles should have occurred at segments within 0.6 mi of riparian-meadow habitat. However, the riparian-meadow proximity model actually predicted 61.4 percent of EVC and 64.2 percent of both elk crossings and weighted approaches (Table 12); the model predicted only 35.5 percent of DVC locations.

Contingency table analyses showed that proximity to riparian-meadow habitat had a significant influence on the locations of elk highway crossing, weighted approach, and EVC (Table 13). The odds of an elk crossing occurring at a 0.1-mi segment located within 0.6 mi of riparian-meadow habitat was three times that of occurring at a segment farther from riparian-meadow habitat (Table 13). The greater odds of weighted elk approaches occurring in proximity to riparian-meadow habitats were especially dramatic compared to approaches at segments away from meadows, nearly 37 times higher (Table13). EVC were 70 percent times more likely to occur at 0.1-mi segments located in proximity to riparian-meadow habitat. Conversely, DVC were 40 percent less likely to occur at segments in proximity to open riparian-meadow habitat. This suggests that cover adjacent to I-17 likely influenced DVC to a greater degree than riparian-meadow habitat. When both EVC and DVC were considered together, the influence of riparian-meadow habitat proximity to I-17 was negated, with no increase in the odds of a WVC occurring at segments either closer to or farther than 0.6 mi from riparian-meadow habitat (Table 13).

Table 12. Number and Percentage of Elk Highway Crossings, Weighted Approaches, EVC, and DVC Predicted to Occur at 0.1-mi Segments Located within 0.6 Mi of Riparian-meadow Habitats between Segments 175 and 450.

Parameter	No. Predicted by Riparian-Meadow Model	Total	Percent of Total
Elk Crossings	233	363	64.2%
Weighted Elk Approaches	15,315	23,852	64.2%
EVC	178	290	61.4%
DVC	16	45	35.5%

Table 13. Contingency Table Analysis and Statistics of 0.1-mi Segments Regarding Elk Approaches and Crossings with Respect to Distance from Riparian-meadow Habitats.

	Segments[a] with and without Crossings, Weighted Approaches, and Collisions by Proximity to Riparian-meadow Habitat				Contingency Table Statistics	
	With		Without		χ^2 Statistic	Odds Ratio
Parameter	<0.6 mi	>0.6 mi	<0.6 mi	>0.6 mi	(*P*)	(95% CI)
Elk Crossings	79	44	57	94	$\chi^2 = 19.0$ ($P < 0.001$)	*PE* = 3.0 : 1 (1.8−4.8)
Elk Approaches	129	92	7	46	$\chi^2 = 112.3$ ($P < 0.001$)	*PE* = 36.9 : 1 (15.9−85.3)
EVC	80	64	56	74	$\chi^2 = 4.3$ ($P = 0.039$)	*PE* = 1.7 : 1 (1.0−2.7)
DVC	14	23	122	115	$\chi^2 = 2.4$ ($P = 0.120$)	*PE* = 0.6 : 1 (0.3−1.2)
All WVC	78	80	58	58	$\chi^2 = 1.4$ ($P = 0.920$)	*PE* = 1.0 : 1 (0.6−1.6)

[a] 274 segments

4.5 IDENTIFICATION OF PASSAGE STRUCTURE SITES

The research team's ratings of the 75 0.6-mi segments between MP 294.0 to 339.9 for their suitability and priority for potential passage structure locations ranged from 2 to 41 points of a possible 54 points, with a mean of 16 points (Figures 27 and 28, Appendix A). Twenty-four of the 0.6-mi segments scored at least 20 points, and all but one section of these segments (along the extremely wide median section) either had a passage structure proposed in the DEA (ADOT 2011) or one was proposed on an adjacent 0.6-mi segment (Figure 28).

The highest rated 0.6-mi segment (Segment 28, MP 310.9−311.4) was located south of a proposed overpass where I-17 has the extremely wide median, just south of the Red Hill Scenic Overlook (Figures 28 and 29). This stretch had the highest number of elk crossings and weighted approaches made by 28 different collared elk (39.4 percent of all collared elk), as well the fifth highest incidence of WVC (n = 15).

Most of the segments scoring above 25 points north of the Red Hill Scenic Overlook corresponded to riparian-meadow habitat complexes adjacent to I-17 (Figure 30), including Rocky Park, Skeleton Park, Munds Park, Willard Springs meadow, Newman Park, and the meadow associated with Pumphouse Wash by Kachina Village. Passage structures were recommended at each of these priority sites in the DEA (ADOT 2011; Figure 30).

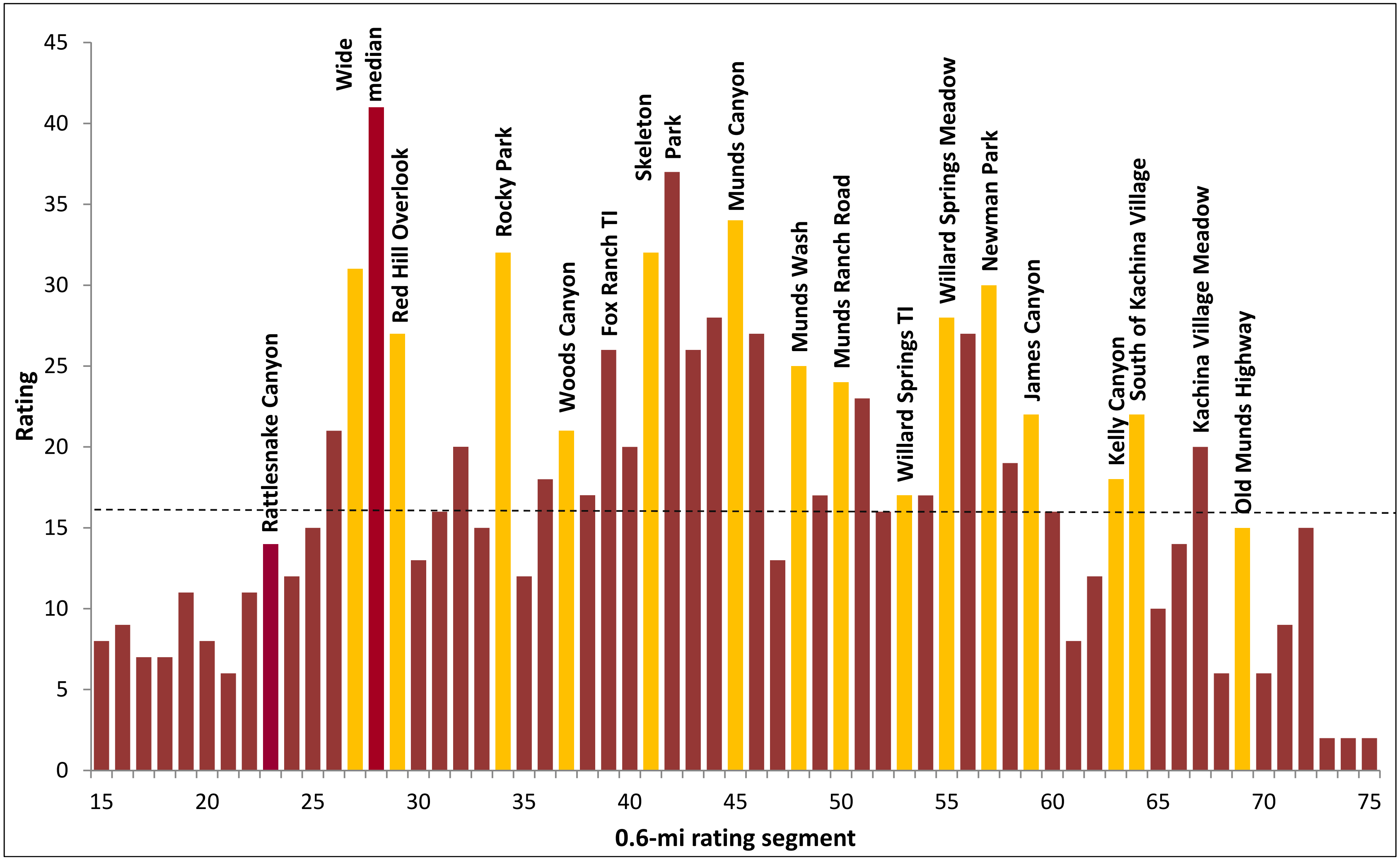


Figure 28. Rating Scores for Aggregated 0.6-mi Segments along I-17 Based on Six Rating Criterion.

(Notes: Mean score [15] indicated by the dashed line. Orange bars correspond to segments in which passage structures were recommended in the DEA [ADOT 2011; mileposts corresponding to 0.6-mi segments and specific ratings are found in Appendix A.])

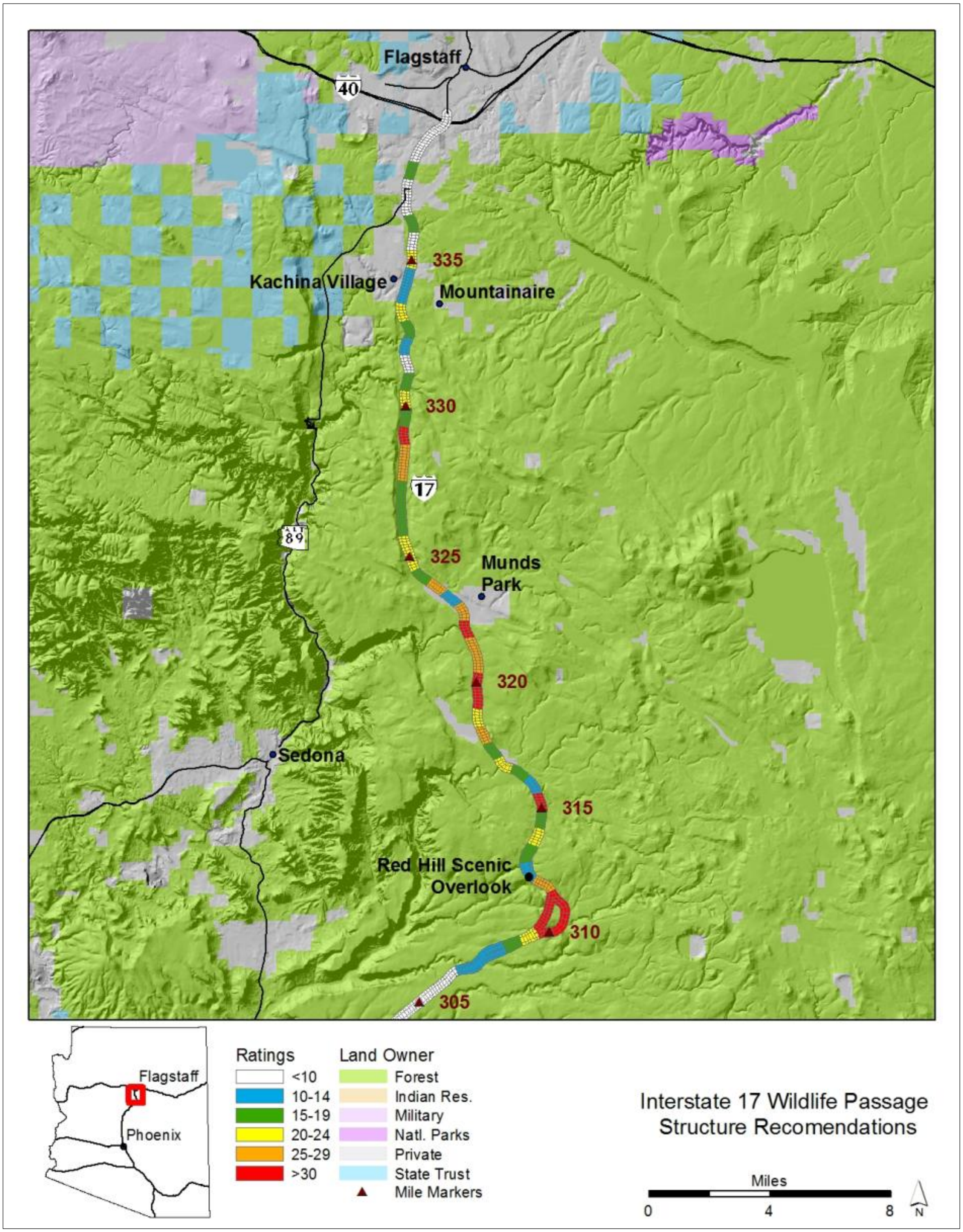


Figure 29. Rating Score Categories for Aggregated 0.6-mi Segments along I-17 between MP 305 and MP 339.

(See Appendix A for segment-specific ratings.)

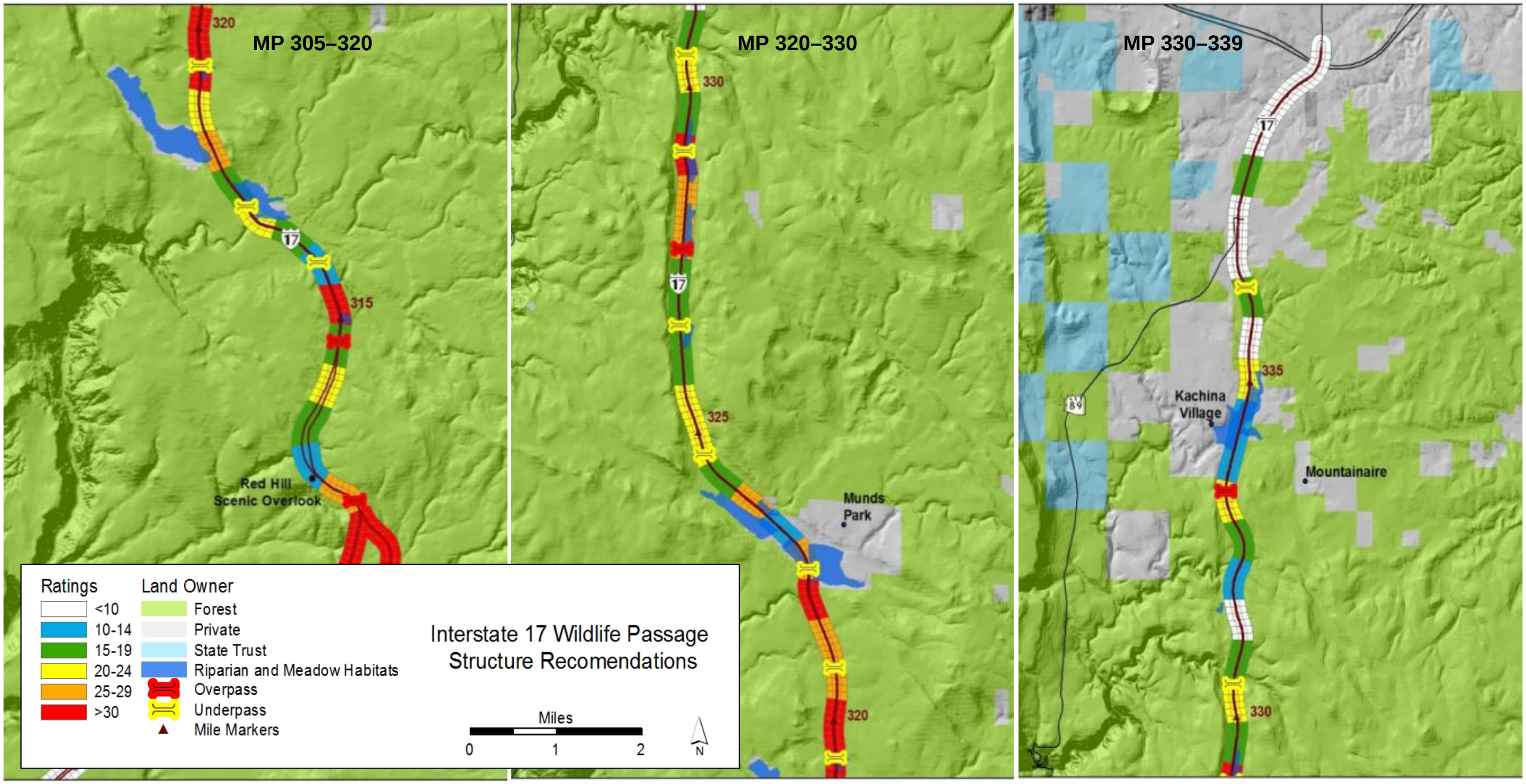


Figure 30. Rating Score Categories for Aggregated 0.6-mi Segments along I-17 and DEA Proposed Passage Structures.

5.0 DISCUSSION

This research project, when combined with other similar studies along Arizona highways, provided an opportunity to investigate highway barrier effects on wildlife permeability against gradients of traffic volume, highway size, and prevalence of riparian-meadow habitat. After 10 years of near-continuous elk GPS telemetry spanning three highways from which over 837,000 GPS fixes have been accrued, the collective results provide a clearer understanding of the complex relationships between wildlife and highways and validate heretofore largely theoretical models to describe such relationships. Though costly, GPS telemetry is an invaluable tool that has facilitated this increased understanding of wildlife-highway relationships that ultimately will promote safer and ecologically sensitive transportation systems in Arizona and elsewhere. This study has established before-construction baselines against which future after-reconstruction assessments of elk permeability and EVC relationships under sound BACI experimental design may be conducted once short-term (a 6-mi wildlife fencing retrofit enhancement project) and long-term mainline highway reconstruction projects occur.

5.1 ELK-HIGHWAY PERMEABILITY RELATIONSHIPS

This study supports the view that within the study area, I-17 constitutes a significant barrier to the passage of elk across the highway corridor, empirically validating models that theorize that highways with AADT above 10,000 constitute impermeable barriers to many wildlife species (Figure 4; Seiler 2003). This barrier effect was especially apparent when I-17 elk permeability was compared to that measured on other Arizona highways with lower AADT; I-17 elk permeability was just 16 percent of that recorded along SR 260 (Dodd et al. 2009*a*) and 18 percent along SR 64 (Dodd et al. 2010). The low I-17 elk passage rate (0.09 crossings/approach) was comparable to the rates measured for species typically considered more sensitive to highway barrier effects, including white-tailed deer along SR 260 control sections (0.03 crossings/approach; Dodd and Gagnon 2011), pronghorn along US 89 and SR 64 (<0.006 crossings/approach; Dodd et al. 2009*b*, 2010), and wolves along the high traffic-volume Trans-Canada Highway (0.06 crossings/approach; Paquet and Callaghan 1996). However, the I-17 barrier effect was mitigated considerably in the following three circumstances, further underscoring the role played by traffic volume and highway size on elk permeability (Jaeger et al. 2005, 2006), the potential for passage structures to promote permeability, and the relative adaptability of elk:

1) Stretches of I-17 with wide medians exhibited elk permeability 200−250 percent higher (0.18−0.21 crossings/approach) than standard-width median stretches (0.06), empirically validating models of the influence of traffic volume and highway size as theorized by Jaeger et al. (2005). Apparently, I-17 stretches with extremely wide medians were perceived by elk as independent two-lane highways with lower traffic volume, and thus resulted in significantly higher crossing and passage rates. This information has implications for locating passage structures to maximize effectiveness.

2) Temporally, average elk permeability (0.26 crossings/approach) between 02:00 and 06:00 when traffic averaged an AADT-equivalent volume of 5,750 vehicles/day was 1,900 percent higher than the rest of the day (0.01 crossings/approach) when the AADT equivalent traffic averaged 20,402 vehicles/day.
3) Elk permeability along the 0.5-mi stretch around the Munds Canyon Bridge (0.24 crossings/approach) was 333 percent higher than the adjacent highway stretch with standard-width median, illustrating the potential for underpasses to promote permeability with below-grade passage.

Modeling by Jaeger et al. (2005) of the impact of traffic volume and highway size on highway barrier effects found that traffic volume exerts the greater influence of the two factors, but along with increasing highway size the degree of barrier effect was amplified (e.g., a large highway with high AADT had a greater impact to permeability than a small highway with the same AADT). Based on the modeling and the wide gradient of both AADT (near doubling between each of the three highways along the gradient) and highway sizes among SR 64 (low AADT-small highway), SR 260 (intermediate-intermediate), and I-17 (high-large), the research team expected to find a gradient of elk permeability ranging from low to high (Table 14). While measured I-17 elk permeability matched the expected low level, and SR 260 permeability was intermediate along a gradient (Dodd et al. 2009*a*), SR 64 failed to match the expectation for permeability. With the lowest AADT and low late-nighttime traffic coupled with its small size, the team expected SR 64 elk permeability to be higher than the measured 0.44 crossings/approach (Dodd et al. 2010), and certainly higher than the SR 260 passage rate given its higher AADT and size.

Dodd et al. (2010) believed that the lower SR 64 elk passage rate was partly attributable to the relative absence of attractive riparian-meadow foraging areas that largely accounted for SR 260 elk movement and EVC patterns (Manzo 2006, Dodd et al. 2007*a*), and likewise had a strong influence on I-17 elk movements and EVC. Proximity to these habitats along SR 260 resulted in seasonally higher elk tolerance to increasing traffic in pursuit of high-quality forage (Gagnon 2007*a*). Such attraction by elk to these habitats along I-17 likely resulted in higher passage rates (and EVC incidence) than otherwise may have occurred in their absence (as with SR 64).

As is the case along SR 260, elk movement to and use of riparian-meadow habitats adjacent to I-17 for foraging and watering is particularly important during the late spring–summer season when the highest crossing rates occurred. These habitats provide forage of highest nutritional quality, are available earlier in the growing season than adjacent forest habitats (Nelson and Leege 1982), and best meet the high protein demands of cows during latter stages of gestation and the mineral demands of bull antler growth (Nelson and Leege 1982). Riparian areas and drainages also are preferred travel lanes and corridors for elk (Skovlin 1982, Servheen et al. 2003). For these reasons, the I-17 segments adjacent to several meadow complexes have contributed to long-term wildlife-vehicle conflicts, yet provide an opportunity for pursuit of measures to enhance permeability.

Table 13. Gradients Associated with Highway Characteristics for I-17, SR 64, and SR 260.

Highway	Highway Characteristic Gradients			Expected Elk Permeability (Actual Crossings/Approach)
	Traffic Volume (AADT)	Size (No. of Lanes[a])	Proportion of Meadow Habitat[b]	
SR 64	Low (4,225)	Small (2 lanes)	Low (<0.05)	High (0.44)
SR 260	Intermediate (8,700)	Intermediate (3 lanes)	Intermediate (0.44)	Intermediate (0.50)
I-17	High (16,100)	Large (4 lanes)	High (0.50)	Low (0.08)

[a] Average number of lanes along study area length
[b] Proportion of 0.1-mi segments located within 0.6 mi of riparian-meadow habitat

Jaeger et al. (2006:159) modeled the effects of road "bundling" and suggested that "it is better to bundle the roads close together than to distribute them evenly across the landscape." The higher incidence of I-17 EVC in the wide median area indicates this may be the case for traffic-related mortality. However, from a highway permeability standpoint, splitting the traffic into separate roadways appears to provide greater opportunity for elk to traverse the landscape.

5.1 TRAFFIC VOLUME THRESHOLDS IN ELK PERMEABILITY

Compared to SR 260 and SR 64, the low I-17 mean elk highway permeability appears to confirm Seiler's (2003; Figure 4) and others' theoretical models predicting that highways with AADT above 10,000 constitute impermeable barriers to some wildlife species. However, the near doubling in AADT between SR 260 (8,700 vehicles/day) and I-17 (16,100 vehicles/day) makes it difficult to conclusively assess exactly where a permeability threshold occurs along this AADT gradient.

In assessing where a threshold in mean hourly elk permeability occurs relative to corresponding traffic volume, the research team aggregated the data from all three highways (Figure 31). Hourly elk passage rates (excluding 08:00−17:00) declined 81 percent from an average passage rate of 0.86 crossings/approach (n = 17) below an AADT-equivalent 5,000 vehicles/day to an average of 0.16 crossings/approach (n = 3) between 5,000 and 10,000 vehicles/day. This suggests that a threshold in hourly passage rate may actually occur below an AADT-equivalent traffic volume of 10,000 vehicles/day (Figure 31). And as expected, above an AADT-equivalent 10,000 vehicles/day, average permeability was very low (0.06 crossings/approach; n = 4). It is important to note that AADT-equivalent hourly traffic volumes differ from actual AADT where volumes are averaged across all hours of the day. The aggregated elk passage rate

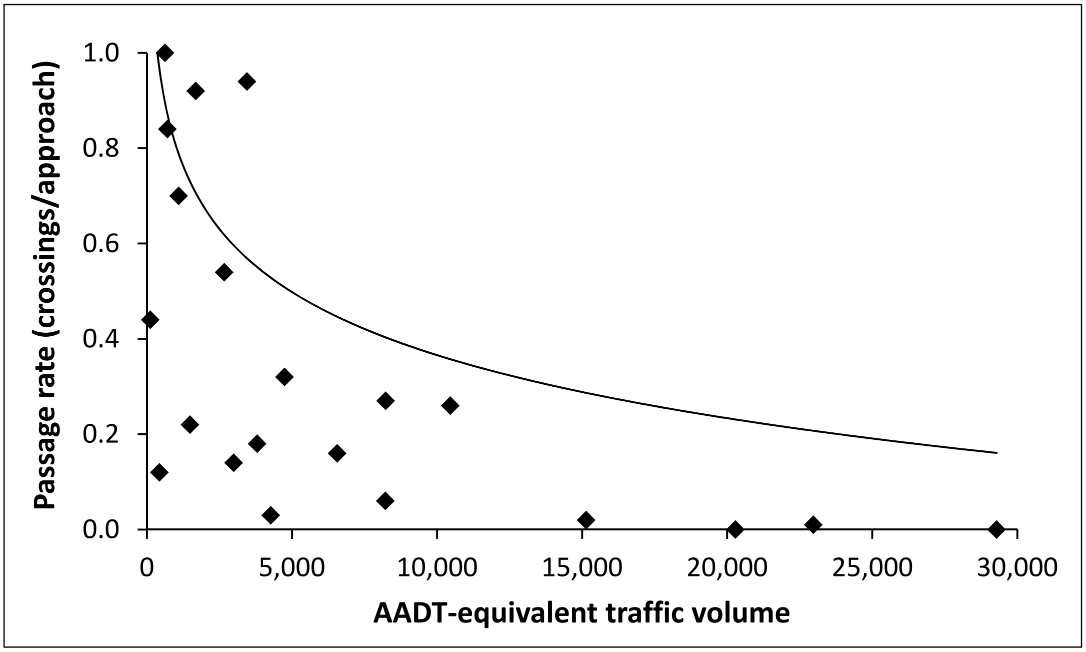


Figure 31. Bi-hourly Elk Passage Rates and Corresponding AADT-equivalent Traffic Volumes Aggregated for I-17, SR 260, and SR 64.
(Note: SR 260 data from Dodd et al. 2009 and for SR 64 from Dodd et al. 2010.)

and traffic volume relationship (Figure 31) closely approximates the theoretical one hypothesized for successful crossings by Seiler (2003: Figure 4).

Of the three highways studied, I-17 was the only one where extensive passage rate data was obtained above an hourly mean of an AADT-equivalent 10,000 vehicles/day during elk activity periods. The hourly AADT-equivalent traffic volume on I-17 spanned a nine-fold range from 3,000 to over 27,000 vehicles/day during the peak activity period. At 06:00, the AADT-equivalent traffic volume averaged 10,400 vehicles/day and corresponded to the highest hourly passage rate (0.26 crossings/approach) recorded during the day. By 07:00, however, traffic volume increased to an average AADT-equivalent of 16,000 vehicles/day and a concomitant decline in the elk passage rate to zero until the evening hours. Though certainly providing further credence to a theoretical threshold, the peak passage rate did correspond to the period near sunrise when elk typically leave riparian-meadow feeding areas for daytime bedding areas, as reported by Dodd et al. (2007*a*, *d*). The passage rate at sunrise may reflect the "necessity" of elk to leave feeding areas and return to bedding/cover areas across the highway.

5.2 TRAFFIC RELATIONSHIPS

Aside from the aforementioned impact of traffic volume on elk highway permeability, traffic also exerted a significant and pervasive impact on temporal patterns of I-17 elk crossings, passage rate, and EVC patterns. Here, more so than SR 260 and SR 64, vehicular traffic serves as a "moving fence" that physically renders highways impermeable to wildlife (Bellis and Graves 1978) and increases the likelihood of an elk-vehicle encounter (Waller and Servheen 2005). Along I-17, early evening and morning traffic volumes that exceeded 800 vehicles/hr equated to a vehicle passing by every 5 seconds on average. Further, high traffic volume results in a "noise effect zone" adjacent to highways that varies with volume and affects wildlife passage and habitat use (Reijnen et al. 1995). This zone can extend 0.25 mi with volumes equivalent to 8,000−15,000 vehicles/day, 0.40 mi at 15,000−30,000 vehicles/day, and over 0.75 mi at AADT-equivalent volumes of 30,000 or more vehicles/day (Forman and Deblinger 2000). Such traffic and noise impacts resulted in elk distributions shifting away from roads with increasing traffic volume (Witmer and deCelesta 1985, Wisdom et al. 2005, Gagnon et al. 2007*a*) and permanent avoidance of habitats and reduced "habitat effectiveness" (Lyon and Christensen 1992) adjacent to highways with persistent road-mediated disturbance (Rowland et al. 2000). Such permanent shifts in elk distribution were not noted along SR 260 (Gagnon et al. 2007*a*) or SR 64 (Dodd et al. 2010), but were evident in the distribution along I-17. Unlike SR 260 and SR 64, at even low traffic volume (<100 vehicles/hr) elk did not exhibit a shift in distribution back to within the 330-ft zone adjacent to I-17, suggesting a permanent shift caused by high traffic volume. Here, the probability of elk occurring immediately adjacent to I-17 was half that of SR 64 and a third lower than SR 260 (Figure 22).

The research team found strong inverse associations between mean hourly traffic volume and elk crossing frequency, passage rate, and EVC frequency. A dramatic peak in all three occurred during the late night to early morning (02:00-07:00) lull in traffic volume, which created a break or window in the moving traffic fence, and increased elk crossings occurred. It is not surprising that increased elk crossings were not only associated (inversely) to hourly traffic volume, but also were strongly associated with EVC by both time and day; this also was noted along SR 260 (Dodd et al. 2007*c*). Traffic volume has frequently been reported as a factor contributing to WVC for a wide range of wildlife (Inbar and Mayer 1999, Joyce and Mahoney 2001, Forman et al. 2003), and typically WVC incidence increases with increasing traffic volume. However, like was found for the high-volume TransCanada Highway (Gunson and Clevenger 2003), the research team observed a significant negative association between EVC and traffic volume along I-17, adding credence to Seilier's (2003) theoretical model of the impact of high traffic volume on WVC (Figure 4).

Wildlife passage structures, especially underpasses, have the potential to help mitigate the impact of high traffic volume and associated noise along I-17, as demonstrated by Gagnon et al. (2007*b*) along SR 260 where traffic had minimal impact on below-grade elk underpass crossings. As evidenced by the significantly higher elk crossing and passage rates associated with the Munds Canyon Bridge, even in the absence of wildlife funnel fencing, the prospect for passage structures to promote I-17 permeability is encouraging. However, with the extreme I-17 traffic volumes, comprehensive measures to reduce noise impact with "quiet zones" along the highway corresponding to passage structures could facilitate approaches by elk, deer, and other animals and help overcome the near-permanent impact zone within 330 ft of the highway. Such a set of measures include appropriate highway design, noise barriers, and pavement treatments (Kaseloo and Tyson 2004). Soil berms or sound walls adjacent to passage structures may be warranted to help reduce traffic impact. Such barriers could reduce traffic noise by as much as half, depending on their height (FHWA 2001). Shielding vegetation planted atop berms could further reduce traffic-associated noise, as would rubberized asphalt application on the pavement near passage structures.

5.3 WILDLIFE-VEHICLE COLLISION RELATIONSHIPS

EVC are a significant issue along I-17, especially with its high traffic volume and posted speed limit (75 mph); an average of 79.0 EVC/year were recorded during the four-year study. Among all other assessments of EVC, the mean I-17 EVC rate (2.4/mi/year) exceeded those reported for SR 64 (1.9/mi/yr; Dodd et al. 2010) and highways in Alberta (Gunson and Clevenger 2003) and British Columbia (Sielecki 2004). The rate was comparable to that reported by Biggs et al. (2.6/mi/year; 2004) in New Mexico and across all SR 260 highway reconstruction treatments (2.5/mi/year; Dodd et al. 2009*a*). The annual incidence of I-17 EVC was very consistent during the first three years of the study, ranging from 85 to 88 EVC/year, but dropped by a third in 2010. The team is uncertain if this decline in EVC was tied to the reduction in the GMU 6A elk population from 2007 to 2010 (Table 1), as the annual incidence of SR 260 EVC was related to elk population levels (Dodd et al. 2007*a*). However, with the decline in the elk population occurring over four years, a more gradual decline in EVC over the same period would have been expected. ADOT experienced maintenance personnel turnover during the latter part of the study, potentially creating WVC reporting inconsistency and thus providing another partial explanation for the drop. Regardless, continued monitoring of EVC will help address the nature and future persistence of this decline.

The research team found that male elk were significantly (>two-fold) overrepresented in EVC compared to their proportion in the GMU 6A surveyed elk population. Some of this could be explained by a bias in ADOT and DPS reports identifying male elk more frequently than females. Gunson and Clevenger (2003) also reported greater numbers of female EVC in Alberta, though the sex ratio of EVC was actually skewed toward bulls. Along SR 260, Dodd et al. (2007*a*) found that when the sex ratios of elk involved in EVC (which strongly favored females) was tempered with the seasonal sex ratio of elk highway crossings, which favored males, EVC involving both sexes occurred in proportion to their ratio in the surveyed population.

Traffic Volume Thresholds in EVC

The research team found a stair-stepped traffic volume threshold in I-17 EVC, one between an AADT-equivalent 8,750−11,250 vehicles/day, or in the neighborhood of 10,000 vehicles/day, and another between 18,750−20,000 vehicles/day beyond which few EVC occurred (Figure 27). Also, the actual EVC/hr exceeded expected until 10,000 vehicles/day, at which point the expected EVC/hr exceeded the actual. Consistent with this, Seiler's (2003) model predicted a large drop in WVC when highway AADT exceed 10,000 vehicles/day; at a 15,000 AADT, he theorized that only 10 percent of animals attempting to cross highways are killed (Figure 4). Based on the ratio of total I-17 GPS-collared elk (n = 71) involved in EVC (n = 5) being proportional to the ratio of the total elk population adjacent to I-17 that was killed in EVC each year (85.5/year; Table 6), the researchers calculated the average annual total elk population at 1,214 elk. All of the GPS-collared elk approached I-17 during the study, and by extrapolation, one would expect the entire population to attempt to cross the highway each year. Thus, the actual number of elk killed in EVC/year represents 7.1 percent of all elk attempting to cross I-17, validating Seiler's (2003; Figure 4) model predicting that high traffic volume limits both permeability and the relative proportion of elk killed in EVC.

Given the strong barrier effect found along I-17, which Seiler (2003) and Iuell et al. (2003) predicted would result in a low proportion of elk being killed in traffic accidents, the high incidence of EVC appears to present a paradox. The probabilistic road mortality model developed by Waller and Servheen (2005) theorized that highway lethality was related to traffic volume and time spent on the roadway by crossing animals. I-17 with its high traffic volume would be expected to have a high degree of lethality, especially as elk attempt to negotiate the divided roadway. For the TransCanada Highway with an AADT of 25,000 vehicles/day, fast-moving animals like elk face a 58 percent chance of being killed even if it takes only three seconds to cross; the lethality increases to 68 percent if elk take just four seconds to clear all lanes (Waller and Servheen 2005). Thus, though a relatively small proportion of elk cross I-17, those that do are subject to a high likelihood of being hit by a vehicle, largely answering the paradox. And like SR 260, where 88 percent of EVC involving GPS-collared animals involved frequent crossers that constituted only 22 percent of all collared elk (Dodd et al. 2007*a*), the research team found a similar phenomenon along I-17. Though the I-17 frequent crossers constituted only 8.4 percent of all collared elk, they accounted for 60.0 percent of those involved in EVC. Thus, within a small portion of the elk population that crosses I-17, an even smaller proportion exhibited tolerance for higher traffic volume and accounted for a large proportion of the vehicle-related mortality. Such traffic-tolerant elk may be biologically important in maintaining genetic diversity among populations separated by barriers such as I-17 (Mills and Allendorf 1996).

Seiler's (2003) theoretical model predicted a peak in WVC between an AADT of 5,000 and 7,500 vehicles, with WVC dropping off at both higher *and* lower AADT. At lower traffic volumes, the reduced incidence of WVC is hypothesized to reflect the relative lower highway lethality. Results for I-17, with few data points for WVC incidence at AADT-equivalent traffic volumes below 5,000 vehicles/day, did not reflect a drop in hourly EVC at the lowest volumes. However, when the team aggregated data for I-17 with SR 260 and SR 64 (excluding 08:00−17:00) where lower traffic volume levels occurred regularly, the data and trend line did reflect a drop-off in hourly EVC incidence at AADT-equivalent traffic volume below 5,000 vehicles/day (Figure 32), similar to Seiler's (2003) model (Figure 4).

Temporal WVC Patterns

Haikonen and Summala (2001) reported that a large peak in WVC, e.g., 46 percent of moose and 37 percent of whitetail deer collisions, occurred within 3 hr after sunset and appeared tied to circadian rhythms associated with light. Along SR 260, Dodd et al. (2007*a*) found an even more dramatic peak in WVC after sunset; 67 percent of EVC and

64 percent of deer collisions occurred within a 3-hr departure of sunset. Gunson and Clevenger (2003) and Biggs et al. (2004) noted similar evening peaks in EVC, though the latter also noted a secondary peak in the morning tied to increased commuter traffic volume. Along I-17, the influence of high traffic volumes around sunset and sunrise likely resulted in a lower proportion of EVC at these times. Just 10 percent occurred around sunrise and 18 percent around sunset; 53 percent of EVC occurred between 23:00 and 04:00 when traffic was lowest. By contrast, peak I-17 DVC did coincide with sunrise and sunset and were not significantly associated with traffic volume; however, the sample sizes were limited when compared to EVC.

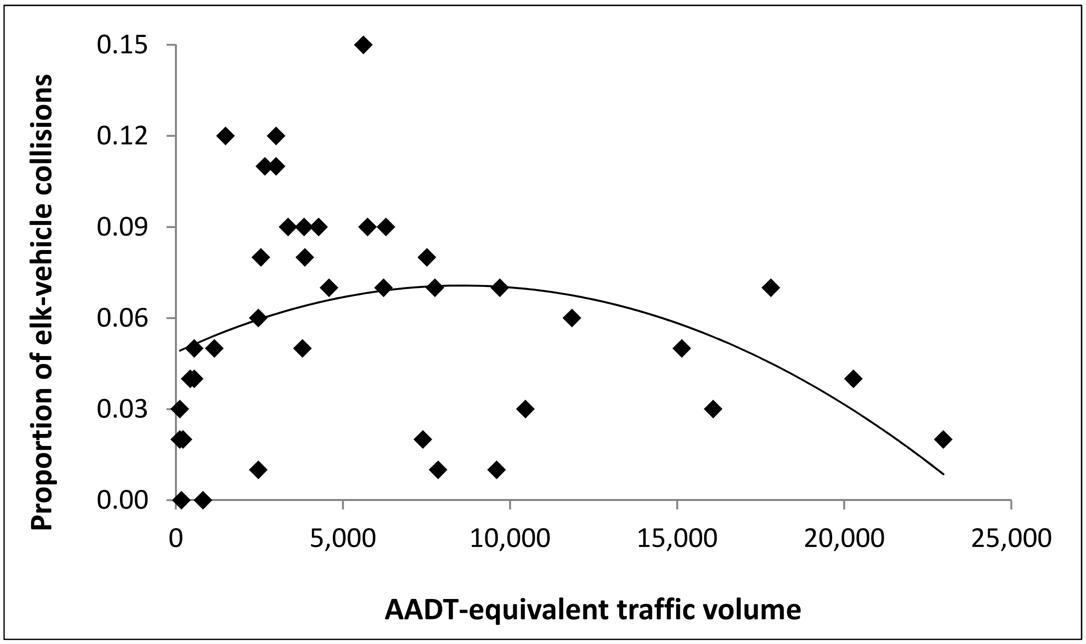


Figure 32. Proportion of All Hourly EVC That Occurred along I-17, SR 260, and SR 64 by AADT-equivalent Traffic Volumes with a Trend Line.

Gunson and Clevenger (2003) reported more EVC on weekend days (Friday–Sunday) versus weekdays, attributable to high recreational and tourist traffic. Along I-17, however, the lowest incidence of EVC occurred on weekend days, when the average traffic volume on these days was 32 percent higher than weekdays. EVC along SR 260 also reflected a behavioral response to avoiding high traffic volume on Friday and Saturday, followed by elevated EVC on Sunday and Monday despite lower traffic volume.

The spring season accounted for over a third of EVC, which coincided with the increased crossings by elk to utilize riparian-meadow habitats for foraging and watering. This differed from most other studies, including those along SR 64 and SR 260 where late summer–fall accounted for the largest proportion of EVC. Along SR 260, Dodd et al. (2007*a*) reported that EVC were tied to the breeding season and an influx of migrating elk. Gunson and Clevenger (2003) also reported an increase in EVC in fall attributable to increased elk numbers from calf recruitment, and Biggs et al. (2004) reported increased collisions in fall.

The highest frequency of I-17 DVC occurred during fall, and a large spike in DVC occurred in October. Late summer to fall DVC along SR 64 accounted for half of all collisions, and as was found by Puglisi et al. (1974), Romin and Bissonette (1996*a*), and Hubbard et al. (2000), this increase in DVC was attributed to sport hunting and the onset of breeding.

5.4 PASSAGE STRUCTURE RECOMMENDATIONS

The integration of wildlife passage structures during highway projects has shown benefit and increasing application in promoting passage for a variety of species (Farrell et al. 2002; Clevenger and Waltho 2003, Bissonette and Cramer 2008). In Arizona, elk-highway permeability across SR 260 increased 58 percent after underpasses were constructed and ungulate-proof fencing was erected (Dodd et al. 2007*c*), and white-tailed deer permeability was 433 percent higher on reconstructed sections with underpasses compared to controls (Dodd and Gagnon 2011). Critical to the success of underpasses was the fact that traffic levels did not influence passage rates during below-grade underpass crossings for elk (Gagnon et al. 2007*b*) or white-tailed deer (Dodd and Gagnon 2011). The 333 percent higher mean elk passage rate recorded at the Munds Canyon Bridge, compared to adjacent I-17 stretches with standard medians, reflects this reduced traffic impact associated with below-grade crossings. And the higher permeability associated with the Munds Canyon Bridge occurred without the benefit of ungulate-proof funnel fencing, which was shown to be necessary to achieve effective use of SR 260 underpasses by elk and deer (Dodd et al. 2007*c*). With fencing, it is anticipated that even greater improvement in permeability will occur. Along with benefit to permeability, passage structures integrated with fencing have reduced the incidence of WVC by over 85 percent (Clevenger et al. 2001, Dodd et al. 2006, Gagnon et al. 2010).

Structural characteristics and the proper location and placement of wildlife crossing structures are vital considerations to maximizing wildlife use (Clevenger and Huijser 2011), as is the spacing between passage structures. Bissonette and Adair (2008) recommended spacing of 2.2 mi to maintain elk permeability. Along SR 260, elk permeability was inversely associated ($r = -0.847$) with passage structure spacing (Dodd et al. 2009*a*, Gagnon et al. 2010). The data suggest that spacing closer than the 2.2 mi may be warranted for elk, as well as lower-mobility species including deer. Nonetheless, the research team recognizes the need to balance efforts to promote permeability against construction costs, and used the 2.2-mi spacing recommendation by Bissonette and Adair (2008) as a guideline to evaluate proposed I-17 passage structure spacing.

Although recommendations are provided at 0.6-mi scale to allow ADOT engineers latitude to determine the best technical location for passage structures along the segment, elk GPS movement data at the 0.1-mi segment can help guide specific locations and recommendations, where appropriate.

Passage Structures within Summer Range (MP 312–340)

Within the ponderosa pine summer elk range of the study area, the DEA (ADOT 2011) recommended 14 passage structures including 12 underpasses and five overpasses (Table 14, Figure 30). The ratings for the 0.6-mi segments including these structures scored an average of 22.6 points (Figure 30; Table 14). The research team concurs fully with the structures recommended in the DEA (ADOT 2011), which have been validated by its ratings and the elk movement and WVC assessments. The team also concurs with the DEA (ADOT 2011) recommendations to not build structures evaluated at several sites, including Munds Wash (MP 323.4), Kelly Canyon TI (MP 331.1), and Pumphouse Wash (MP 334.3). The recommended 14 passage structures will provide an average spacing of 2.0 mi between structures, meeting Bissonnette and Adair's (2008) 2.2-mi spacing recommendation for elk.

Four of the DEA recommended passage structures, at the Rocky Park, Schnebly Hill, Willard Springs, and Newman Park TI, are new "dual-use" underpasses (Table 14). Here, new widened bridges would accommodate road traffic under the highway along with a separate unpaved travel lane for wildlife. The research team is confident such structures will be effective for wildlife passage, even with limited nighttime vehicular traffic passing through the underpasses. However, the team harbors some reservations associated with the historic and potential continued nighttime congregation of commercial trucks parked alongside I-17 on- and off-ramps, often with motors idling all night. Without an effective means to limit such truck congregations near dual-use TI, their effectiveness for wildlife could be significantly compromised and alternative sites away from commercial truck parking would be preferred.

Passage Structures within Intermediate/Winter Range (MP 306–312)

The DEA (ADOT 2011) recommendations for the southern 6-mi elk intermediate/winter range portion of I-17, beginning just south of the Stoneman Lake TI to just north of the Red Hill Scenic Overlook, reflect the preliminary results of this study. It evaluated structures at three sites along this stretch and recommended implementation of structures at two (Table 14): an overpass near the Red Hill Scenic Overlook at MP 311.7 and a paired structure along the 0.6-mi segment just south of Segment 28. The research team concurs that an overpass at the Red Hill Scenic Overlook is a high priority due to the area's transition location between summer and winter range, as well as its topography.

As the team's highest-rated 0.6-mi segment, Segment 28 (MP 310.9−311.4), corresponded to the I-17 stretch with an extremely wide median (Figures 28 and 33) that was used by most of the GPS-collared elk. This stretch was particularly important due to its location within intermediate range between high summer and lower-elevation winter range for both elk and deer, with a natural topographic and landscape funneling of animals through this area (Figure 15). The research team found significantly higher crossing and passage rates along the extremely wide median stretch of I-17, where the highway functionally acts as two separate two-lane highways with approximately half the traffic volume of the combined adjacent roadway in other areas. Thus, an excellent opportunity is offered to locate a passage structure(s) near here to capitalize on this reduced traffic impact and thus enhance the prospect for acceptance and use by wildlife. Suitable sites to accommodate paired structures within the adjacent Segment 27 were identified and recommended by the research team and incorporated into the DEA (ADOT 2011) — an overpass proposed at MP 310.3 SB and a pre-cast arch underpass at MP 309.8 NB. The team believes these structures are a very high priority. During its field review (in March 2011), the team documented extensive recent elk use at this site that was consistent with its rating and landscape setting as an important elk migration corridor.

The only unresolved disagreement between the research team and DEA (ADOT 2011) passage structure recommendations is for the area near Rattlesnake Canyon (Segment 23, MP 307.1–307.4; Figure 33). Though this 0.6-mi segment did not rate high (14 points; Figures 28 and 33), the team nonetheless believes that providing for wildlife passage here constitutes a very high priority. A passage structure(s) here is important to facilitate the logical southern ungulate-proof fencing terminus at the Stoneman Lake TI and will provide adequate spacing of passage structures along the fenced highway stretch within elk intermediate/winter range of 2.0 mi, meeting Bissonette and Adair's (2008) guideline. Without a passage structure(s) here, there would be an excessive 4-mi stretch of fenced corridor north of the Stoneman Lake TI with no means for wildlife to cross I-17. Without any other structures along this stretch of highway, large numbers of elk and deer could potentially be funneled to the Stoneman Lake TI where they could cross the highway at grade, causing potential fencing "end run" and highway safety concerns. The DEA (ADOT 2011) identified either a single overpass near Rattlesnake Canyon at MP 307.0 or paired pre-cast arch underpasses at MP 307.1 SB and MP 307.4 NB. The cost-effective arches could be installed at existing fill slopes where small structures already exist along the historic domestic sheep driveway. Regardless, either structure type/location near Rattlesnake Canyon would be suitable to satisfy the team's priority need for wildlife passage here.

Role of Fencing

Several studies and a growing body of evidence point to the integral role that 6.5−8 ft ungulate-proof fencing plays in achieving highway reconstruction objectives for minimizing WVC and promoting highway safety, as well as promoting wildlife permeability (Dodd et al. 2007*c*, 2009*a*). This important role of fencing in conjunction with passage structures has been stressed by Romin and Bissonette (1996*a*), Forman et al. (2003), and others, and the empirical basis for fencing's role in reducing WVC has continued to grow, with reductions in WVC of anywhere from 80 percent (Clevenger et al. 2001) to over 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 WVC (Feldhamer et al. 1986, Woods 1990, Clevenger et al. 2001), an important consideration in determining where to terminate fencing.

Table 14. Recommended Wildlife Passage Structure Locations along I-17 (MP 306−340).

Passage Structure MP	0.6-Mi Segment	Segment Rating Score	DEA Recommendation		Current Study Recommendation		Passage Structure Location and Comments
			Underpass	Overpass	Underpass	Overpass	
307.4 NB 307.1 SB	23	14	NO NO		YES YES		Rattlesnake Canyon – new paired underpasses
309.8 NB 310.3 SB	27	31	YES	 YES	YES	 YES	Extremely wide median – new paired structures; near highest-rated Segment 28
311.7	29	27		YES		YES	Red hill Scenic Overlook – new overpass
314.4	33	15		YES		YES	Rocky Park Meadow – new overpass
315.6	35	12	YES		YES		Rocky Park Rd TI – new dual-use bridge
317.0	37	21	YES		YES		Woods Canyon – new bridges
319.2	41	32	YES		YES		Skeleton Park – new bridges
320.5	43	26	YES		YES		Schnebly Hill Rd TI – new dual-use bridges
322.0	45	34	YES		YES		Munds Canyon Bridge – modified bridges
324.4	50	24	YES		YES		Munds Ranch Rd – new bridges
326.3	53	17	YES		YES		Willard Springs TI – widen existing bridges
327.4	55	28		YES		YES	Willard Springs Meadow
328.8	57	30	YES		YES		Newman Park TI – new bridges
330.3	60	22	YES		YES		James Canyon – new underpass
332.2	63	18	YES		YES		Kelly Canyon – new bridges
333.1	64	22		YES		YES	South of Kachina Village; very high priority
336.1	69	15	YES		YES		Old Munds Highway – new bridges
Totals	**Mean = 22.8**		**12**	**5**	**14**	**5**	

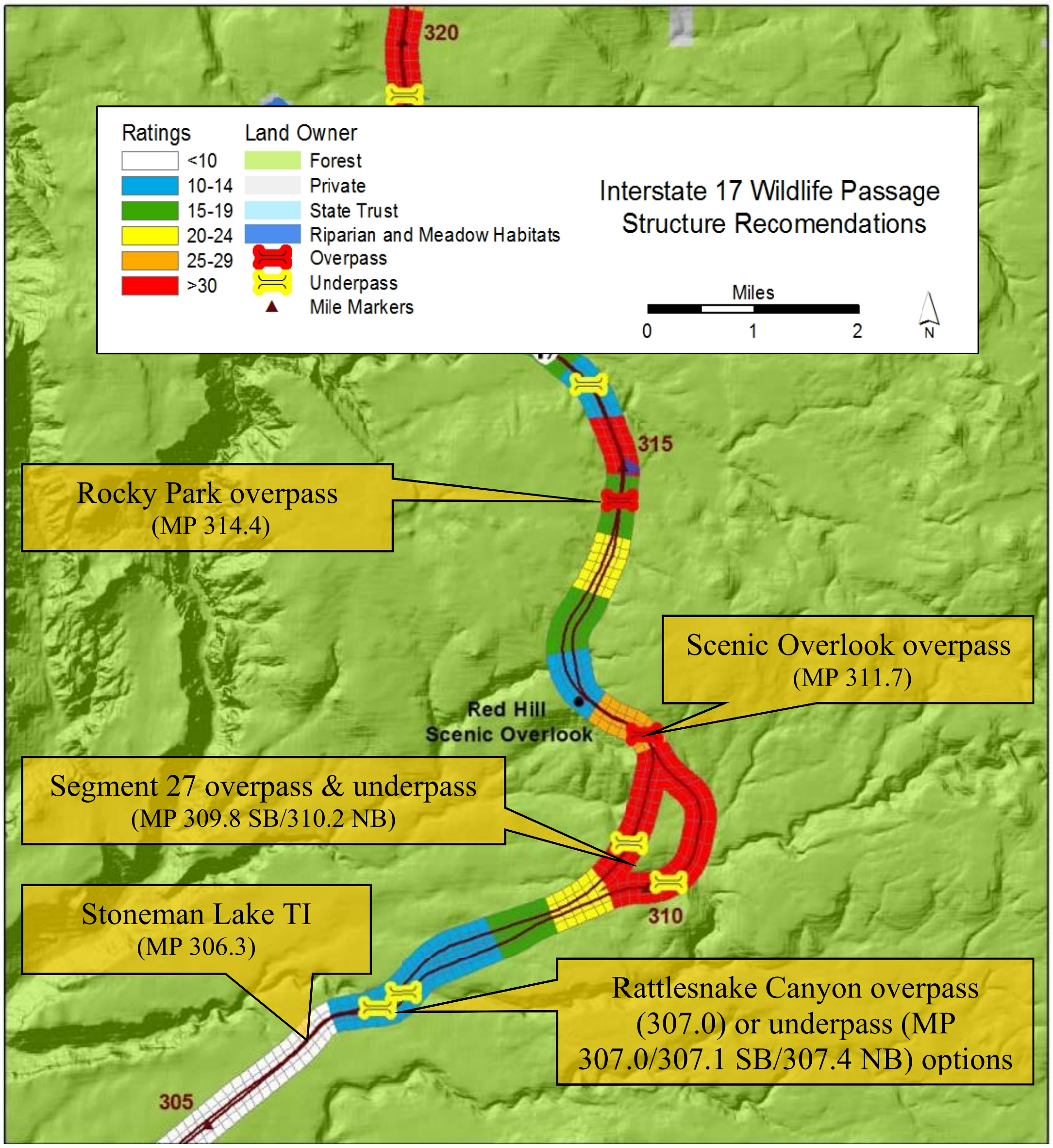


Figure 33. Potential I-17 Passage Structures Evaluated South of the Red Hill Scenic Overlook between MP 306 and MP 312.

Fencing is costly and requires substantial maintenance (Forman et al. 2003), often making it difficult for transportation officials to justify fencing long stretches. However, failure to erect adequate fencing in association with passage structures, even when adequately spaced, was found to substantially decrease their effectiveness in reducing WVC and promoting permeability (Dodd et al. 2007*c*, 2009*a*). For these reasons, the research team strongly recommends that ungulate-proof fencing be erected along the entire length of I-17 from the northern abutments of the Stoneman Lake TI underpass (MP 306.3) to the I-40 TI (MP 340.0), possibly tying into the existing chain-link fence south of Flagstaff in the vicinity of Fort Tuthill (approximately MP 337.5).

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6.0 CONCLUSIONS AND RECOMMENDATIONS

This project facilitated a data-driven approach to quantifying I-17 elk permeability, as well as determining the best locations for potential passage structures to reduce WVC and enhance permeability. In combination with studies previously completed on other Arizona highways (employing consistent and comparable methodologies), this project has contributed significantly the understanding of wildlife-highway interactions in relation to gradients of traffic volume, highway size, and prevalence of riparian-meadow habitats. Key conclusions and recommendations from this research project follow below, with the symbol ☞ used to highlight recommendations.

6.1 DESIGN CONCEPT REPORT PROCESS ROLE

- The ongoing I-17 DCR and DEA (ADOT 2011) process and assessments represent a proactive commitment on ADOT's part to analyzing WVC data and developing comprehensive strategies for reducing WVC and promoting wildlife passage across I-17.
- This approach is especially useful in helping prioritize and streamline highway reconstruction planning to effectively address wildlife-related issues, as has been done for other highways.

  ☞Where appropriate, assessments similar to the IDCR (Stanley Consultants 2011) should be accomplished on other highways to address WVC and wildlife permeability issues. Such assessments should be prioritized using the *Arizona's Wildlife Linkages Assessment* (Arizona Wildlife Linkages Workgroup 2006) and WVC databases.
- The ratings applied to the 0.6-mi segments to identify potential wildlife passage structures sites using GPS telemetry, WCV, and other criteria concurred with the DEA (ADOT 2011) for 16 of 17 recommended passage structure locations; the team's recommendations also concurred with recommendations that eliminated passage structure locations for consideration. This high level of concurrence reflects the utility of WVC data in developing strategies for WVC and permeability mitigation, application of preliminary GPS-telemetry insights, and especially the benefit of cooperation and collaboration in the DCR process.

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

  ☞When possible, GPS telemetry should be used to document wildlife movements to locate passage structures and fencing in the best possible locations to ensure effectiveness.

6.2 ELK HIGHWAY PERMEABILITY

- The I-17 elk GPS assessment and comparison to other Arizona highways was facilitated by use of passage rate as a comparable metric for permeability (Dodd et al. 2007*b*).
- The GPS telemetry analysis for 71 elk found that I-17 constitutes a significant barrier to elk passage, with only 912 highway crossings and an average passage rate of just 0.09 crossings/approach. This degree of elk-highway permeability was substantially lower than that for SR 260 (0.50 crossings/approach) and SR 64 (0.44 crossings/approach), both with lower traffic volumes.
- The I-17 elk-highway permeability assessment served to validate and provide empirical evidence for heretofore theoretical models of the impact of high traffic volume on wildlife permeability. Compared to and aggregated with SR 260 and SR 64 data, the low I-17 mean elk-highway permeability validates Seiler's (2003) and others' models predicting that highways with AADT above 10,000 constitute impermeable barriers to wildlife.
- Elk highway passage rates differed among I-17 median width classes, with stretches of highway with wide medians having significantly higher highway crossing rates and 200–250 percent higher passage rates than standard-width median stretches. It appears that those stretches with wide medians were perceived by elk as separate two-lane highways with lower traffic volume. This also served to validate modeling by Jaeger et al. (2005) of the impact of traffic volume and highway size on highway barrier effects.
- Elk permeability along the 0.5-mi stretch around the Munds Canyon Bridge was 333 percent higher than adjacent highway stretches even without ungulate-proof fencing. This finding points to the potential for underpasses to promote permeability with below-grade passage where traffic volume has minimal impact (Gagnon et al. 2007*b*).

  ☞ The 16 wildlife passage structures recommended in the DEA (ADOT 2011) and validated by the team's research, as well as the team's recommendation for an additional structure near Rattlesnake Canyon (MP 307), should dramatically improve elk and other wildlife highway permeability along I-17. Reduced WVC incidence may also lead to improved highway safety.

6.3 IMPACT OF TRAFFIC AND NOISE

- I-17 AADT averaged 16,100 vehicles/day but fluctuated considerably on an hourly, daily, and seasonal basis. Traffic volumes were highest during daytime hours, often exceeding an AADT-equivalent 25,000 vehicles/day. The research team found strong inverse associations between mean hourly traffic volume and elk crossing frequency, passage rate, and EVC frequency. A dramatic peak in all three occurred during the late night to early morning lull in traffic volume.
- In assessing where a threshold in mean hourly elk passage rates occurred relative to a full range of corresponding traffic volume for I-17, SR 260, and SR 64 combined, passage rates declined from an average of 0.86 crossings/approach

below an AADT-equivalent 5,000 vehicles/day to an average of 0.16 crossings/approach at 5,000 to 10,000 vehicles/day. This suggests existence of a permeability threshold below an AADT-equivalent traffic volume of 10,000 vehicles/day postulated by others (Iuell et al. 2003, Seiler 2003). Above this traffic level, average permeability was very low (0.06 crossings/approach).

☞ As evidenced for the Munds Canyon Bridge, wildlife passage structures (underpasses) can mitigate the significant impact of high traffic volume on permeability, as animals crossing below grade are relatively unaffected by traffic volume compared to at-grade highway crossings (Gagnon et al. 2007*a*,*b*; Dodd and Gagnon 2011).

- High I-17 vehicular traffic creates a "moving fence" that physically renders highways impermeable to wildlife, increases the likelihood of an elk-vehicle encounter, and results in elk distributions shifting away from roads with increasing traffic volume and permanent avoidance of habitats adjacent to highways. Unlike elk along SR 260 and SR 64, at even low traffic volume (<100 vehicles/hr) I-17 elk did not exhibit a shift in distribution back to within the 330-ft zone adjacent to the highway, suggesting a permanent shift caused by high traffic volume. High traffic volume also results in a noise effect zone adjacent to highways that varies with volume and affects wildlife passage and habitat use that can extend outward 0.40 mi at 15,000−30,000 vehicles/day.

☞ A comprehensive set of measures to reduce traffic-associated noise impact should be employed to create "quiet zones" along the highway corresponding to passage structures to facilitate highway approaches and crossings. These measures can include integrating noise barriers such as berms, vegetation, and sound walls, and applying pavement treatments like rubberized asphalt. Without a comprehensive effort to reduce noise impact, the ultimate success of passage structures could be compromised.

6.4 PASSAGE STRUCTURE DESIGN AND PLACEMENT

- Structural design characteristics and placement of passage structures are important in maximizing their efficacy in promoting wildlife passage (Clevenger and Huijser 2011). SR 260 research found underpass structural characteristics to be the most important factor in determining the probability of achieving successful crossings by both elk and deer (Dodd et al. 2009*a*, Gagnon et al. 2011).
- Structure openness for underpasses is important to achieving high probability of successful crossings by wildlife (Gagnon et al. 2011). The SR 260 data suggest that underpass length, the distance that animals must travel through an underpass, is an especially important factor in maximizing their effectiveness.

☞ Where possible, the length through underpasses should be minimized, consistent with terrain and other factors including budget constraints. Atria, or openings between underpass bridge spans, contribute to openness, especially for underpasses having longer lengths.

☞ The team recommends that the bridges be placed in line so that animal visibility through the structures is maximized. Offset bridges should be avoided; where offset bridges are necessary, the use of fill material that limits animal visibility should be minimized.

☞ For the four dual-use wildlife underpasses recommended in the DEA (ADOT 2011), continued nighttime congregation of commercial trucks parked alongside I-17 on- and off-ramps has the potential to compromise the efficacy of these structures for wildlife passage. Effective strategies to address such truck congregations near dual-use TI ranging from signage and enforcement to erection of parking barriers is critical.

- Across North America, relatively few wildlife overpasses have been constructed compared to underpasses, although three overpasses were recently implemented along US 93 near Hoover Dam to promote desert bighorn sheep passage. For overpasses, important considerations include gently sloped approaches or integrating overpasses into existing terrain features such as ridges (Clevenger and Huijser 2011). Another potentially important consideration is overpass width, for which there are few published guidelines (Clevenger and Huijser 2011). Overpass widths for US 93 overpasses range from 50 to 100 ft.

  ☞ The research team recommends that overpasses be at least 75 ft wide to maximize openness for crossing elk, deer, and other species.

Passage Structure Locations and Spacing

- The research team's ratings of 0.6-mi segments concur with the 16 passage structures recommended in the DEA (ADOT 2011), including underpasses and overpasses (Table 14). On average, these structures will be spaced 2.0 mi apart, consistent with guidelines for elk, though greater than the recommendation for mule deer (Bissonette and Adair 2008).
- The team identified the priority need for an additional passage structure in the vicinity of Rattlesnake Canyon (MP 307.0). A passage structure here is important to provide a logical southern fencing terminus at the Stoneman Lake TI. It will provide adequate spacing of passage structures along the fenced highway stretch within elk intermediate/winter range of 2.0 mi.

  ☞ The DEA (ADOT 2011) identified as a potential solution, either a single overpass near Rattlesnake Canyon at MP 307.0 or paired pre-cast arch underpasses at MP 307.1 SB and 307.4 NB. This study recommends that either one of the two cost-effective alternatives be implemented at this location.

Role of Fencing

- Ungulate-proof fencing has been shown to be crucial to achieving underpass effectiveness, playing an instrumental role in promoting permeability and highway safety from reduced WVC. Without fencing, elk and deer continued to cross SR 260 at grade adjacent to underpasses (Dodd et al. 2007*c*). With fencing, elk and deer passage rates and probabilities of successful crossing through underpasses increased dramatically while at-grade crossings decreased.

- Along SR 260, ADOT initially employed a "limited-fencing" approach that failed to adequately resolve WVC issues (Dodd et al. 2009*a*). Ultimately, the entire 17-mi reconstructed stretch of SR 260 will be fenced, with WVC reduced 97 percent on already fully-fenced segments (Gagnon et al. 2010).

  ☞ The research team recommends fencing the entire highway corridor with 8-ft ungulate-proof fencing extending from the northern abutments of the Stoneman Lake TI (MP 306.3) to the I-40 junction (MP 340.0), or 34 mi. Fencing the entire corridor will dramatically enhance highway safety and wildlife highway permeability.

- Fencing of the extremely wide corridor stretch of I-17 between MP 307.0–309.5 is potentially problematic, as fencing just the outer bounds of the right-of-way and linking passage structures across the median with fencing could result in a large area (> 2 mi^2) being excluded from wildlife use, which currently is substantial (see Figure 15). This issue must be addressed with the USFS in the future.
- Though beneficial in reducing WVC, maximizing passage structure use and promoting permeability, fencing requires constant maintenance and attention to ensure its integrity.

  ☞ Future ungulate-proof fencing along I-17 integrated with passage structures should have regular maintenance to ensure its long-term integrity and continued benefit in promoting a safe highway. Adequate funding is needed for ADOT to effectively maintain fencing and passage structures, as these measures are increasingly applied on Arizona's highways.

6.5 HIGHWAY SAFETY/WILDLIFE-VEHICLE COLLISIONS

- The incidence of WVC along I-17 is a significant highway safety issue, as addressed in the IDCR (Stanley Consultants 2011). The research team documented an average of 98.8 WVC/year during the study (MP 305.0–338.0), of which 80 percent involved elk.
- During the study, an average of 17 percent of all single-vehicle accidents within the area involved wildlife, compared to the national average of just 5 percent.
- Using nationally accepted cost estimates associated with elk and mule deer collisions (Huijser et al. 2007), the research team estimates the annual cost associated with I-17 WVC to be $1,466,561 for elk and $117,432 for deer, totaling $1,583,933/year. Thus, over 20 years the total cost associated with WVC could exceed $31 million (in current dollars).

  ☞ It is anticipated that WVC will be reduced greatly once passage structures and wildlife fencing are implemented on I-17, possibly achieving a similar 97 percent reduction obtained on other highways (Gagnon et al. 2010) and realizing a substantial economic benefit of over $30 million. The benefit to be realized with such WVC and their associated significant costs should be a factor in helping justify the implementation of mitigation measures.

6.6 MONITORING

- Several concurrent efforts are planned and ongoing for I-17 to address WVC and permeability issues. Long-term, the DCR provides a framewordk for a comprehensive approach to addressing these issues with wildlife passage structure construction, wildlife fencing, and other measures. Short-term, ADOT is implementing the 6-mi wildlife fencing retrofit enhancement project begun in summer 2011. The research team's findings provide a solid before-construction baseline against which the benefits of these short- and long-term projects can be evaluated with scientifically rigorous BACI experimental designs (Hardy et al. 2003, Roedenbeck et al. 2007).
- Monitoring of wildlife passage structures and associated fencing is vital to evaluating their effectiveness, especially along a highway like I-17 with high traffic volume.

  ☞The research team recommends that ADOT fund scientifically sound after-reconstruction evaluations for both short- and long-term projects to further the knowledge and understanding of road ecology.

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APPENDIX A: RATINGS OF SUITABILITY FOR WILDLIFE PASSAGE STRUCTURE SITES BASED ON SIX CRITERIA BY 0.6-MI SEGMENT BETWEEN I-17 MP 294.0 AND 339.8

0.6-Mi Segment	MP	Elk Highway Crossings	Score	Weighted Elk Approaches	Score	Elk-Vehicle Collisions	Score	Deer-Vehicle Collisions	Score	Human Impact Score	Terrain Score	TOTAL SCORE
1	294.0–294.6	0	0	0	0	0	0	0	0	5	1	**6**
2	294.7–295.2	0	0	0	0	0	0	0	0	5	1	**6**
3	295.3–295.8	0	0	0	0	0	0	0	0	5	1	**6**
4	295.9–296.4	0	0	0	0	0	0	0	0	5	1	**6**
5	296.5–297.0	0	0	0	0	0	0	0	0	5	1	**6**
6	297.1–297.6	0	0	0	0	0	0	0	0	5	1	**6**
7	297.7–298.2	0	0	2	1	0	0	0	0	5	1	**7**
8	298.3–298.7	0	0	9	1	0	0	0	0	5	1	**7**
9	298.8–299.3	0	0	0	0	0	0	0	0	5	1	**6**
10	299.4–299.9	3	1	31	1	0	0	0	0	5	1	**8**
11	300.0–300.5	10	1	65	1	0	0	0	0	5	1	**8**
12	300.6–301.1	5	1	48	1	0	0	0	0	5	1	**8**
13	301.2–301.7	2	1	5	1	0	0	0	0	5	1	**8**
14	301.8–302.3	0	0	19	1	0	0	0	0	5	1	**7**
15	302.4–302.9	2	1	58	1	0	0	0	0	5	1	**8**
16	303.0–303.6	6	1	62	1	1	1	0	0	5	1	**9**
17	303.7–304.2	0	0	69	1	0	0	0	0	5	1	**7**
18	304.3–304.7	0	0	60	1	0	0	0	0	5	1	**7**

0.6-Mi Segment	MP	Elk Highway Crossings	Score	Weighted Elk Approaches	Score	Elk-Vehicle Collisions	Score	Deer-Vehicle Collisions	Score	Human Impact Score	Terrain Score	TOTAL SCORE
19	304.8–305.3	6	1	172	3	1	1	0	0	5	1	**11**
20	305.3–306.0	4	1	31	1	0	0	0	0	5	1	**8**
21	306.1–306.6	1	1	5	1	0	0	0	0	1	3	**6**
22	306.7–307.2	1	1	0	0	0	0	0	0	5	5	**11**
23	307.3–307.8	1	1	218	3	0	0	0	0	5	5	**14**
24	307.9–308.4	13	3	174	3	0	0	0	0	5	1	**12**
25	308.5–309.0	18	3	478	6	0	0	0	0	5	1	**15**
26	309.1–309.6	29	3	1193	12	0	0	0	0	5	1	**21**
27	309.7–310.4	77	7	2770	15	5	3	0	0	5	1	**31**
28	310.5–311.4	160	9	3088	15	15	9	2	2	5	1	**41**
29	311.5–312.2	58	5	976	9	7	3	2	2	3	5	**27**
30	312.3–312.8	3	1	746	9	0	0	1	1	1	1	**13**
31	312.9–313.4	8	1	361	6	2	1	0	0	5	3	**16**
32	313.5–314.0	13	3	138	3	8	6	2	2	5	1	**20**
33	314.1–314.6	14	3	246	3	1	1	0	0	5	3	**15**
34	314.7–315.2	8	1	786	9	25	15	1	1	5	1	**32**
35	315.3–315.8	2	1	355	6	3	1	0	0	1	3	**12**
36	315.9–316.4	10	1	443	6	2	1	4	4	5	1	**18**

0.6-Mi Segment	MP	Elk Highway Crossings	Score	Weighted Elk Approaches	Score	Elk-Vehicle Collisions	Score	Deer-Vehicle Collisions	Score	Human Impact Score	Terrain Score	TOTAL SCORE
37	316.5–317.0	0	0	961	9	6	3	1	1	3	5	**21**
38	317.1–317.6	18	3	648	9	1	1	0	0	3	1	**17**
39	317.7–318.2	14	3	641	9	13	9	1	1	1	3	**26**
40	318.3–318.8	8	1	881	9	10	6	0	0	3	1	**20**
41	318.9–319.4	16	3	2033	12	10	6	1	1	5	5	**32**
42	319.5–320.0	14	3	714	9	23	15	4	4	5	1	**37**
43	320.1–320.6	14	3	866	9	8	6	4	4	1	3	**26**
44	320.7–321.2	0	0	2433	12	8	6	4	4	5	1	**28**
45	321.3–321.8	17	3	2594	15	11	6	2	2	3	5	**34**
46	321.9–322.4	149	9	1650	12	6	3	1	1	1	1	**27**
47	322.5–323.0	0	0	125	3	9	6	2	2	1	1	**13**
48	323.1–323.6	8	1	1235	12	14	9	0	0	0	3	**25**
49	323.7–324.2	12	3	409	6	9	6	0	0	1	1	**17**
50	324.3–324.8	8	1	777	9	12	9	1	1	1	3	**24**
51	324.9–325.4	4	1	446	6	13	9	1	1	5	1	**23**
52	325.5–326.0	6	1	916	9	0	0	0	0	5	1	**16**
53	326.1–326.6	2	1	656	9	4	3	0	0	1	3	**17**
54	326.7–327.2	6	1	118	3	14	9	0	0	3	1	**17**

0.6-Mi Segment	MP	Elk Highway Crossings	Score	Weighted Elk Approaches	Score	Elk-Vehicle Collisions	Score	Deer-Vehicle Collisions	Score	Human Impact Score	Terrain Score	TOTAL SCORE
55	327.3–327.8	11	3	514	9	10	6	0	0	5	5	**28**
56	327.9–328.4	25	3	681	9	14	9	0	0	5	1	**27**
57	328.5–329.0	14	3	717	9	16	12	0	0	3	3	**30**
58	329.1–329.6	18	3	844	9	0	0	1	1	5	1	**19**
59	329.7–330.2	5	1	185	3	8	6	2	2	5	5	**22**
60	330.3–330.8	25	3	112	3	4	3	1	1	5	1	**16**
61	330.9–331.4	4	1	142	3	0	0	0	0	1	3	**8**
62	331.5–332.0	2	1	167	3	1	1	1	1	5	1	**12**
63	332.1–332.6	8	1	102	3	4	3	1	1	5	5	**18**
64	332.7–333.2	16	3	161	3	9	6	0	0	5	5	**22**
65	333.3–333.8	0	0	59	1	4	3	0	0	5	1	**10**
66	333.9–334.4	14	3	23	1	9	6	0	0	1	3	**14**
67	334.5–335.0	6	1	21	1	22	15	1	1	1	1	**20**
68	335.1–335.6	2	1	0	0	3	1	0	0	3	1	**6**
69	335.7–336.2	0	0	0	0	9	6	3	3	3	3	**15**
70	336.3–336.8	0	0	0	0	2	1	1	1	3	1	**6**
71	336.7–337.4	0	0	0	0	8	6	1	1	1	1	**9**
72	337.5–338.0	0	0	0	0	14	9	2	2	3	1	**15**

0.6-Mi Segment	MP	Elk Highway Crossings	Score	Weighted Elk Approaches	Score	Elk-Vehicle Collisions	Score	Deer-Vehicle Collisions	Score	Human Impact Score	Terrain Score	TOTAL SCORE
73	338.1–338.6	0	0	0	0	0	0	0	0	1	1	**2**
74	338.7–339.2	0	0	0	0	0	0	0	0	1	1	**2**
75	339.3–339.8	0	0	0	0	0	0	0	0	1	1	**2**

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APPENDIX B: BEFORE-CONSTRUCTION BASELINE DATA SUMMARY FOR EVALUATION OF MUNDS CANYON WILDLIFE FENCING ENHANCEMENT PROJECT

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BEFORE-CONSTRUCTION BASELINE DATA SUMMARY FOR EVALUATION OF MUNDS CANYON WILDLIFE FENCING ENHANCEMENT PROJECT

In July 2007, AGFD and ADOT jointly submitted a Round 15 Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users highway enhancement grant application for the I-17 wildlife fencing retrofit project. This project was approved for funding (TRACS No. 017 CN 317 H7740 01C), the Project Assessment describing the project elements and design was completed in 2010 (AZTEC Engineering 2010), and project implementation began during summer 2011. The project entails retrofitting 6 mi of right-of way fence, extending it upward to 7.5−8 ft with barbed wire. This fencing will link and funnel elk to two existing large structures suitable for wildlife passage (Woods Canyon and Munds Canyon bridges) and create two dual-use structures (Fox Ranch Road overpass and Schnebly Hill Road underpass) accommodating wildlife and vehicular passage, all with the goal of reducing the incidence of EVC and promoting elk permeability across the highway. A similar enhancement retrofitting project along SR 260 has proven effective in reducing EVC by over 96 percent (Gagnon et al. 2009).

AGFD's Research Branch has been funded by ADOT's RC to conduct an after-reconstruction evaluation of the efficacy of this project in reducing WVC and promoting elk permeability, using a BACI experimental design. The current research project has provided the before-construction baseline in which to evaluate the effectiveness of the project. The enhancement project encompasses I-17 stretching from south of the Woods Canyon Bridge north to the Munds Park TI, MP 316.80 to MP 322.72. This before-construction evaluation summary also includes a mile-long stretch on either side to address the future for potential "end runs" in WVC and highway crossings that might occur after fencing, similar to the evaluation done along SR 260 (Gagnon et al. 2010). This evaluation will yield information to compare to the findings from the before-reconstruction assessment (Table B-1) using a BACI experimental design (Underwood 1994, Hardy et al. 2003) for the following parameters:

Elk-Highway Permeability

The before-construction assessment found that the elk passage rate on the 6-mi enhancement project stretch (0.07 crossings/approach) was quite low, but more than twice that of the end run stretches (Table B-1), largely due to the higher passage rate (0.24 crossings/approach) associated with elk passage under the Munds Canyon Bridge.

Elk Highway Crossings

Mean elk crossings of I-17 on the enhancement project section were over four times that of the adjacent end run stretches (Table B-1, Figure B-1) were considerably higher than the adjacent end run stretches. However, of the 250 crossings along the stretch, nearly half (123) occurred at the Munds Canyon Bridge and the 0.1-mi segments on either side (Figure B-2), or just 5 percent of the stretch.

Elk Approaches and Weighted Approaches

Mean GPS-collared elk approaches to within 0.15 mi of I-17 along the enhancement project stretch were higher than those on the adjacent end run stretches (Table B-1). Owing partly to the higher number of elk using the enhancement project stretch, as well as the paucity of approaches in the vicinity of the community of Munds Park (Figure B-2), weighted elk crossings were also higher here than the end run stretches (Table B-1).

Elk-Vehicle Collisions

A total of 86 EVC were recorded along the enhancement project stretch during the study, and averaged 0.36 EVC/0.1-mi segment/year, nearly twice that of the adjacent end run stretches (Table B-1, Figure B-3).

Deer-Vehicle Collisions

The mean incidence of DVC/year was comparable between the enhancement project stretch and the end runs (Table B-1), though 83 percent of the DVC on the end runs occurred on the south end run stretch (Figure B-4).

Table B-1. Before-Construction Baseline Data Summary for the Munds Canyon Wildlife Fencing Enhancement Project and Potential End Run Stretches along I-17.

Evaluation Parameter	Enhancement Project (MP 316.8 to 322.7)	South End Run (MP 315.8 to 316.7)	North End Run (MP 322.8 to 323.7)	Combined End Runs
Elk Highway Permeability				
Mean Passage Rate (crossings/approach ±SE)	0.07 (±0.02)	0.03 (±0.02)	0.04 (±0.02)	0.03 (±0.01)
No. Collared Elk	33	9	13	22
Elk Highway Crossings				
No. Crossings	250	10	18	28
Mean/0.1-mi Segment (±SE)	4.2 (±1.3)	1.0 (±1.1)	1.8 (±0.7)	1.4 (±0.9)
No. Collared Elk	16	2	6	8
Mean/Elk (±SE)	13.9 (±3.2)	5.0 (±3.0)	3.0 (±1.0)	3.5 (±2.1)
Elk Approaches				
No. Approaches	5,944	517	858	1,375
Mean/0.1-mi Segment (±SE)	99.1 (±16.4)	51.7 (±17.8)	85.8 (±33.3)	68.7 (±0.9)
No. Collared Elk	39	16	18	30
Mean/Elk (±SE)	58.8 (±31.2)	32.3 (±13.4)	45.7 (±20.4)	45.8 (±12.7)
Weighted Elk Approaches				
No. Weighted Approaches	12,766.4	906.3	1,638.1	2,544.4
Mean/0.1-mi Segment (±SE)	212.8 (±18.9)	90.6 (±8.5)	163.8 (±64.3)	127.2 (±32.7)
Elk-Vehicle Collisions				
No. EVC 2007-2010	86	7	9	16
Mean/0.1-mi Segment/Year (±SE)	0.36 (±0.05)	0.18 (±0.08)	0.23 (±0.10)	0.20 (±0.09)
Deer-Vehicle Collisions				
No. DVC 2007-2010	19	5	1	6
Mean/0.1-mi Segment/Year (±SE)	0.08 (±0.02)	0.13 (±0.08)	0.03 (±0.03)	0.08 (±0.06)

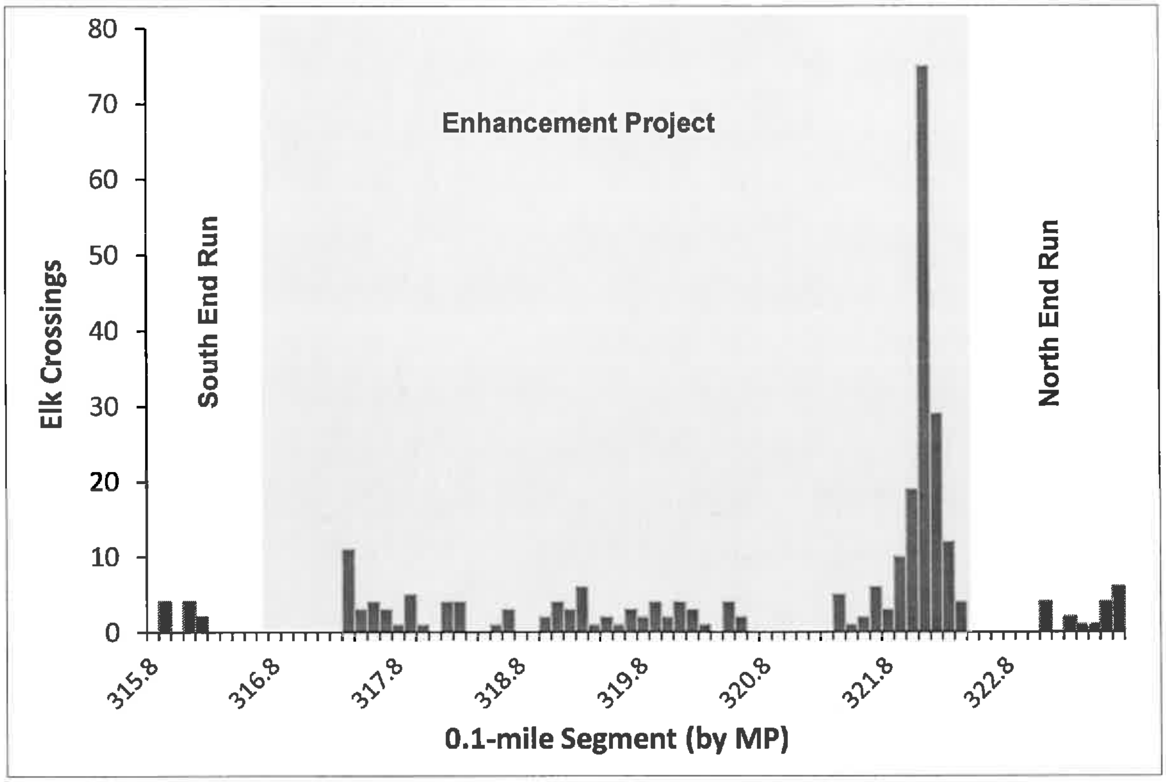

Figure B-1. Elk Crossings of I-17 by 0.1-mi Segment.

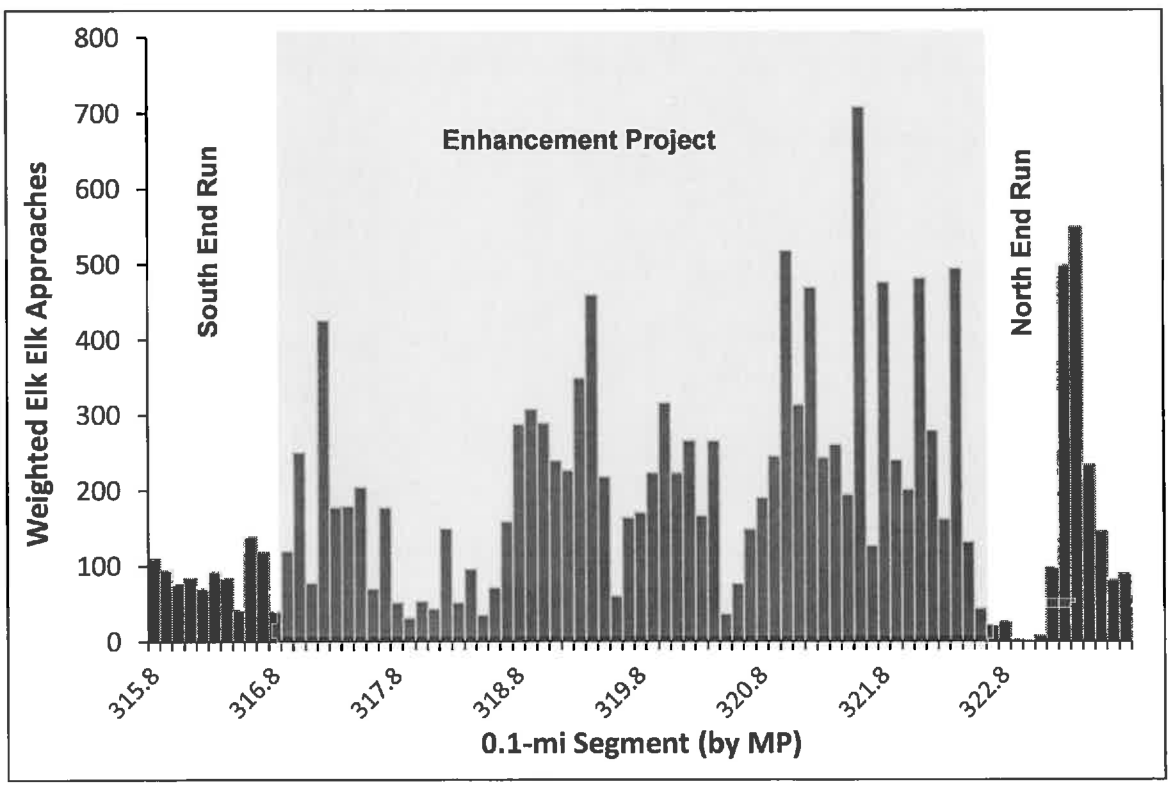

Figure B-2. Weighted Elk Approaches by 0.1-mi Segment.

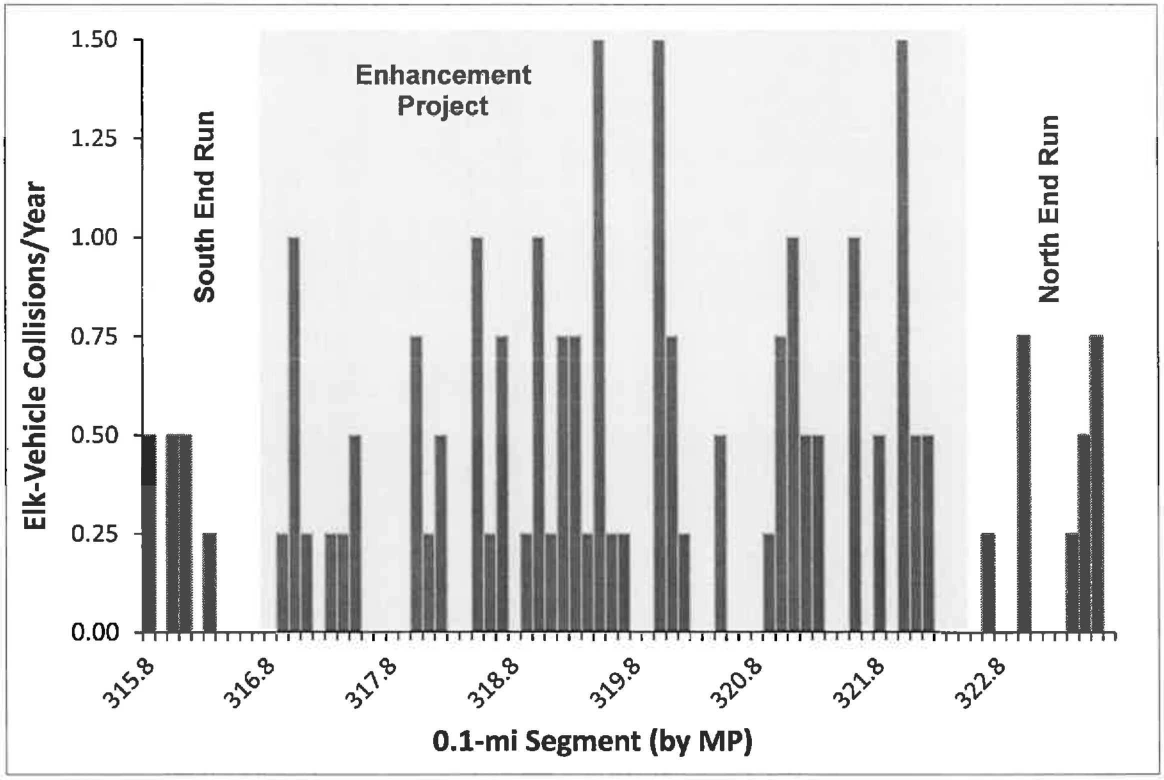

Figure B-3. EVC/Year by 0.1-mi Segment, 2007-2010.

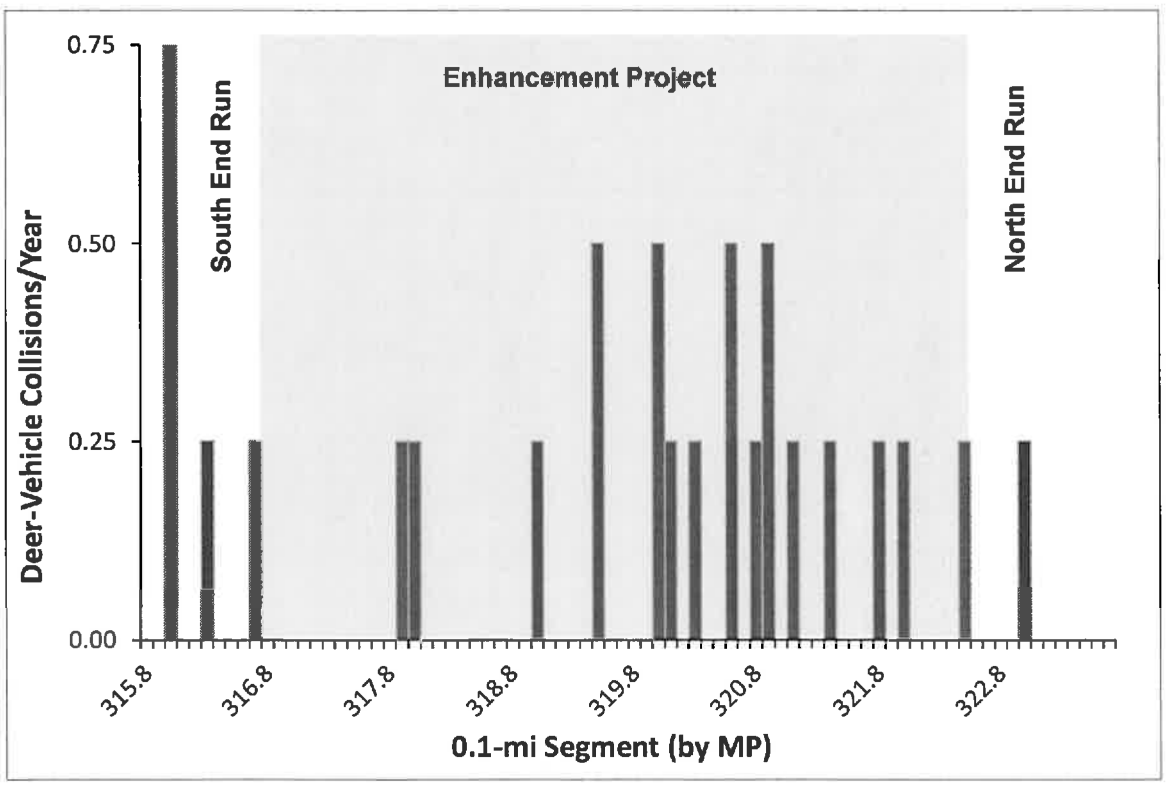

Figure B-4. DVC/Year by 0.1-mi Segment, 2007-2010.