Assessment of Pronghorn Movements and Strategies to Promote Highway Permeability: US Highway 89

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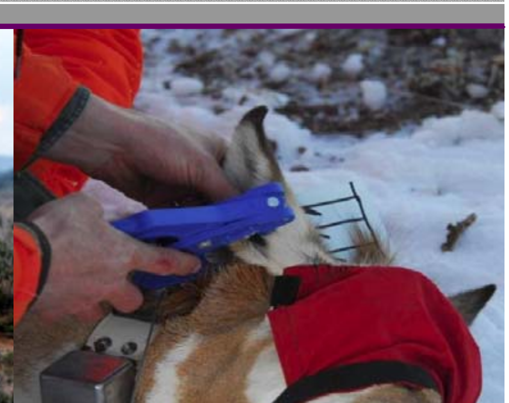

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16. Abstract

Pronghorn (*Antilocapra americana*) movements were investigated with Global Position System (GPS) telemetry from 2007 to 2008 along a 28-mile stretch of U.S. Highway 89 in northern Arizona to develop strategies to enhance permeability with future highway reconstruction. Research objectives were to:

- Assess pronghorn movement patterns and distribution and determine highway permeability.
- Investigate the relationships of pronghorn distribution patterns to vehicular traffic volume.
- Assess the influence of fencing on pronghorn highway crossing patterns and permeability.
- Investigate pronghorn-vehicle collision patterns.
- Develop recommendations to enhance pronghorn highway permeability.

The team tracked 37 pronghorn (20 females, 17 males) with GPS receiver collars. Of 118,181 GPS fixes, 1,125 occurred within 0.15 mile of US 89, and 3,794 occurred within 0.30 mile. Only one pronghorn crossed US 89 during the two years of tracking. The mean passage rate was a negligible 0.006 crossings/approach. No collisions with vehicles were recorded during the study. In total, 5,035 weighted pronghorn approaches, number of animals/segment, and five other criteria were used to rate 0.6-mile highway segments for suitability as passage structure locations. The team recommended 3.2-mile spacing between passage structures and three sites for passage structures integrated with fencing and noise reduction measures.

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SI (MODERN METRIC) CONVERSION FACTORS*

APPROXIMATE CONVERSIONS TO SI UNITS					APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH					**LENGTH**		
in	inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
ft	feet	0.305	meters	m	m	meters	3.28	feet	ft
yd	yards	0.914	meters	m	m	meters	1.09	yards	yd
mi	miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
		AREA					**AREA**		
in^2	square inches	645.2	square millimeters	mm^2	mm^2	Square millimeters	0.0016	square inches	in^2
ft^2	square feet	0.093	square meters	m^2	m^2	Square meters	10.764	square feet	ft^2
yd^2	square yards	0.836	square meters	m^2	m^2	Square meters	1.195	square yards	yd^2
ac	acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
mi^2	square miles	2.59	square kilometers	km^2	km^2	Square kilometers	0.386	square miles	mi^2
		VOLUME					**VOLUME**		
fl oz	fluid ounces	29.57	milliliters	mL	mL	milliliters	0.034	fluid ounces	fl oz
gal	gallons	3.785	liters	L	L	liters	0.264	gallons	gal
ft^3	cubic feet	0.028	cubic meters	m^3	m^3	Cubic meters	35.315	cubic feet	ft^3
yd^3	cubic yards	0.765	cubic meters	m^3	m^3	Cubic meters	1.308	cubic yards	yd^3
	NOTE: Volumes greater than 1000L shall be shown in m^3.								
		MASS					**MASS**		
oz	ounces	28.35	grams	g	g	grams	0.035	ounces	oz
lb	pounds	0.454	kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000lb)	0.907	megagrams (or "metric ton")	mg (or "t")	mg	megagrams (or "metric ton")	1.102	short tons (2000lb)	T
		TEMPERATURE (exact)					**TEMPERATURE (exact)**		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	°C	°C	Celsius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION					**ILLUMINATION**		
fc	foot candles	10.76	lux	lx	lx	lux	0.0929	foot-candles	fc
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2	cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE AND PRESSURE OR STRESS					**FORCE AND PRESSURE OR STRESS**		
lbf	poundforce	4.45	newtons	N	N	newtons	0.225	poundforce	lbf
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa	kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380

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ACRONYMS AND ABBREVIATIONS

2-D	two dimensional
3-D	three dimensional
AADT	average annual daily traffic
ADOT	Arizona Department of Transportation
AGFD	Arizona Game and Fish Department
ANOVA	analysis of variance
ATR	automatic traffic recorder
DPS	Department of Public Service
EA	environmental assessment
EPG	Environmental Planning Group
ft	foot/feet
FHWA	Federal Highway Administration
GIS	Geographic Information System
GMU	Game Management Unit
GPS	Global Positioning System
HR	home range
hr	hour
IGA	intergovernmental agreement
in	inch(es)
MCP	minimum convex polygon
min	minute(s)
mph	miles per hour
NF	National Forest
NPS	National Park Service
ROW	right(s)-of-way
SDI	Shannon diversity index
SE	standard error
SR	State Route
SR 260	State Route 260
US 89	U.S. Highway 89
US 180	U.S. Highway 180
USFS	U.S. Forest Service
VHF	very high frequency
WCTAC	Wildlife Connectivity Technical Advisory Committee

LIST OF SPECIES

Animals

Desert bighorn sheep	*Ovis canadensis*
Caribou	*Rangifer tarandus*
Elk	*Cervus elaphus*
Grizzly bear	*Ursus arctos*
Moose	*Alces alces*
Mule deer	*Odocoileus hemionus*
Pronghorn	*Antilocapra americana*
White-tailed deer	*Odocoileus virginianus couesi*
Wolf	*Canis lupus*

Plants

Alkali sacaton	*Sporobolus airoides*
Apache plume	*Fallugia paradoxa*
Black grama	*Bouteloua eriopoda*
Blackbrush	*Coleogyne ramosissima*
Blue grama	*Bouteloua gracilis*
Cliffrose	*Cowania mexicana*
Galleta	*Pleuraphis jamesii*
Greasewood	*Sarcobatus vermiculatus*
Indian ricegrass	*Achnatherum hymenoides*
Needle and thread grass	*Hesperostipa comata*
One-seed juniper	*Juniperus monosperma*
Ponderosa pine	*Pinus ponderosa*
Pinyon	*Pinus edulis*
Rabbit brush	*Ericameria nauseosa*
Sagebrush	*Artemesia* spp.
Saltbush	*Atriplex spp.*
Shadscale	*Atriplex confertifolia*
Winterfat	*Ceratoides lanata*

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Many individuals at ADOT provided endless support and guidance. Foremost was Environmental Planning Group's Justin White with his vision and commitment to addressing permeability needs of pronghorn in the environmental analysis for U.S. Highway 89 (US 89), and pursuing funding to make the project a reality. Estomih Kombe of ATRC provided project oversight and coordination. The research team thanks John Harper and Chuck Howe of the Flagstaff District for their tremendous support, as well as commitment to implementing project recommendations. Doug Eberline of the Transportation Planning Division provided traffic data support. The researchers appreciate the support of Todd Williams, Bruce Eilerts, and Siobhan Nordhaugen of Office of Environmental Services.

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Lastly, the Technical Advisory Committee for this project provided many suggestions toward improving its effectiveness and applicability, and the research team appreciates their guidance.

EXECUTIVE SUMMARY

Of all North American ungulate species, the barrier effect associated with highways appears to affect no species as much as it does pronghorn antelope. The fragmentation of pronghorn herds by highways has contributed to isolation of populations and disruption of seasonal migrations, contributing to reduced pronghorn populations. Several previous telemetry studies in northern Arizona, including adjacent to U.S. Highway 89 (US 89) have demonstrated paved highways with fenced rights-of-way (ROW) constitute near total barriers to pronghorn passage. While passage structures have proven effective for other wildlife species, their application to promote pronghorn highway permeability has been limited. The goal of this research project was to apply insights gained from pronghorn movements and crossings of US 89 to develop strategies to enhance permeability as part of future highway reconstruction. The specific objectives of this project along were to:

1) Assess pronghorn movement patterns and distribution and determine current permeability across the highway corridor.
2) Investigate the relationships of pronghorn highway crossing and distribution patterns to vehicular traffic volume.
3) Assess the influence of fencing on pronghorn highway crossing patterns and permeability.
4) Investigate pronghorn-vehicle collision patterns.
5) Develop recommendations to enhance pronghorn highway permeability.

The research team instrumented and tracked 37 pronghorn (20 females, 17 males) with Global Positioning System (GPS) receiver collars from January 2007 to December 2008 along 28 miles of US 89; 19 pronghorn were captured on the west side and 18 on the east side of the highway. Of the 118,181 GPS fixes accrued, 1,125 (1.0%) occurred within 0.15 mile of US 89, and 3,794 (3.2%) occurred within 0.30 mile of the highway, the distance used to determine highway approaches and potential locations for passage structures. During the GPS tracking, the pronghorn (n = 37) travelled an average of 3.2 miles each day. Most of the pronghorn (n = 31) were recorded within 0.30 mile of the highway along a mean linear distance of 6.5 miles adjacent to US 89.

A single GPS-collared pronghorn crossed US 89 during the nearly two years of tracking; none of the others did. The mean pronghorn crossing rate averaged 0.001 crossings/day among the 30 animals that approached US 89 to within 0.15 mile. The mean pronghorn passage rate was a negligible 0.006 crossings/approach. Due to the barrier effect and few crossings by pronghorn, no collisions with vehicles were recorded during the study, nor were any pronghorn-vehicle collision records found in ADOT's roadkill database dating back to 1990.

The frequency of approaches to within 0.30 mile of US 89 yielded considerably more information than crossings to assist in the determination of potential pronghorn passage structure locations. On the west side of US 89, 18 pronghorn approached the highway 2,875 times, for a mean of 159.7 approaches/animal. On the east side, 13 pronghorn approached the highway 952 times, with a mean of 73.9 approaches/pronghorn. The observed distribution of approaches from the east was not random. The research team calculated weighted pronghorn approaches that accounted for the number of approaches, number of different approaching animals, and the evenness of approaches over 0.1-mile segments. Combined weighted approaches by pronghorn from both sides of the highway totaled 5,035 approaches (16.2/segment). A significant peak accounting for nearly half (47%) the approaches occurred on the highway section at the north end of the Coconino National Forest (NF), which represents only 7% of the length of the area. Of the 31 pronghorn that approached the highway, 22 (71%) approached it in this 2-mile zone.

Pronghorn distribution remained constant among all distances and across all traffic volumes up to 500 vehicles/hr. Only at volumes above 500 vehicles/hr was a change in distribution observed. Pronghorn were consistently negatively impacted by traffic at even low levels. Daytime traffic volumes along US 89 typically exceed the 10,000 vehicles/day level, the point at which highways become strong barriers to wildlife passage and traffic repels animals away from the roadway. Pronghorn are primarily active during daytime hours when peak traffic volumes occur along US 89.

At and adjacent to the 0.1-mile segment where barbed-wire fencing was removed from the ROW fence within Wupatki National Monument approximately five years ago, there was no evidence of any attempt to cross the highway. As such, it does not appear pronghorn responded to the removal or modification of this short section of fencing.

The research team used pronghorn distribution and approaches in conjunction with five other criteria to rate 0.6-mile segments for suitability as passage structure locations. The research team recommended a spacing of 3.2 miles between passage structures. Based on the rating criteria, three sites between mileposts (MP) 440.0 and 458.0 were recommended as potential locations of passage structures. The most suitable location was the section between MP 440.6 and 441.1, at the north end of the Coconino NF. Another recommended site is on Wupatki National Monument (MP 444.2−444.6) three miles to the north of the aforementioned site. This site is attractive due to the ease of addressing ROW fencing issues (since no livestock grazing occurs here), the presence of high-quality pronghorn habitat, and the reconstructed highway's planned median width, which is considerably narrower than that of other recommended sites. A third recommended passage structure location is on Babbitt Ranch lands at MP 447.2−447.7 and spans both private and State Trust land. The high rating for this segment reflects Babbitt Ranches' proactive role in pronghorn management, including further modification of ROW fencing.

No passage structure designed specifically to accommodate pronghorn passage has been constructed in North America. As such, limited guidelines or insights exist as to what types of structure are best suited to promoting pronghorn permeability. The research team believes that overpasses and/or large elevated viaducts have the best potential for promoting permeability along US 89. Site specific characteristics associated with the different passage structure locations will dictate what type of potential structure might be appropriate from engineering and cost standpoints. The most important structural consideration is the requirement that passage structures be as open and wide as possible, with attention paid to avoiding obstructed line-of-sight views through or across structures.

The terrain near MP 441 is suited to the construction of an overpass, and since this stretch of US 89 has been previously reconstructed, a retrofit application is appropriate. The application of a pre-cast concrete arch overpass may hold potential. The research team recommends that implementation of such a structure at MP 440.9 be considered under an experimental enhancement grant. Insights would be gained on the efficacy of a passage structure where the prospect for success is highest. Further, the estimated cost for the structure not including fill material ($542,725 by one estimate) and relative ease of construction (just a few days) for an overpass makes an enhancement grant approval a possibility.

At the Wupatki National Monument site, the variation in terrain will support either an overpass near a ridgeline or an elevated viaduct. At the Babbitt Ranch site where terrain is predominantly flat, an elevated viaduct would function best in promoting permeability.

Ideally, passage structures should be located in areas with no ROW or livestock pasture fencing near the highway such that the fencing presents an impediment to free passage by pronghorn. Where it cannot be avoided, creative approaches should be used to minimize the barrier effect of fencing near passage structures. A comprehensive set of measures should be used to create “quiet zones” around passage structures to facilitate pronghorn highway approaches and crossings by reducing traffic-associated noise’s impact. Such measures include recessing the roadway below grade, integrating noise barriers, planting vegetation, erecting sound walls, and applying pavement treatments like rubberized asphalt.

This project reflects an incremental and proactive process of addressing permeability and habitat continuity for pronghorn along US 89. The project reflects ADOT’s commitment to obtaining data to make informed data-driven decisions in highway reconstruction planning on the need of and best locations for passage structures to promote pronghorn permeability.

1.0 INTRODUCTION

1.1 BACKGROUND

Direct and indirect highway impacts have been characterized as some of the most prevalent and widespread forces altering natural ecosystems in the U.S. (Noss and Cooperrider 1994, Trombulak and Frissell 2000, Farrell et al. 2002). Forman and Alexander (1998) and Forman (2000) estimated that highways have affected more than 20% of the U.S. land area through habitat loss and degradation. Mortality from vehicle collisions is a serious and growing problem for wildlife populations, and also contributes to human injuries, deaths, and tremendous property loss (Reed et al. 1982, Farrell et al. 2002, Schwabe and Schuhmann 2002, Bissonette and Cramer 2008). An even more pervasive impact of highways on wildlife is the indirect barrier and fragmentation effects resulting in diminished habitat connectivity and permeability (Noss and Cooperrider 1994, Forman and Alexander 1998, Forman 2000, Forman et al. 2003, Bissonette and Adair 2008). Highways act as barriers to free movement of wildlife between seasonal ranges or other vital habitats (Trombulak and Frissell 2000). Highways fragment and isolate habitats and populations, limit juvenile dispersal (Beier 1995), and reduce genetic interchange (Epps et al. 2005, Riley et al. 2006), all serving to disrupt viable wildlife population processes. Long-term fragmentation and isolation increases population susceptibility to random catastrophic events (Swihart and Slade 1984, Forman and Alexander 1998, Trombulak and Frissell 2000).

While many studies have alluded to highway barrier effects on wildlife (e.g., Forman et al. 2003), few have yielded quantitative data to measure permeability or quantify the barrier effect, particularly in an experimental (e.g., before and after construction) context with research controls (Hardy et al. 2003, Roedenbeck et al. 2007, Dodd et al. 2007*a*, Olsson 2007). Many studies have focused on the efficacy of passage structures in promoting passage (Clevenger and Waltho 2003, Ng et al. 2004). Dodd et al. (2007*a*) stressed the value of a quantifiable metric of permeability and calculated elk highway passage rates from GPS telemetry to conduct before-after-control reconstruction comparisons along State Route (SR) 260. They found that overall elk passage rates averaged 0.50 crossings/approach; among reconstruction classes, the mean elk passage rate for the before-reconstruction/control class (0.67) was 39% higher than the mean after-reconstruction passage rate (0.41). Dodd et al. (2009) also calculated white-tailed deer passage rates along SR 260, which averaged only 0.03 crossings/approach on control sections. Paquet and Callaghan (1996) reported that passage rates for wolves averaged 0.93 crossings/approach along a low-traffic highway but only 0.06 along the Trans-Canada Highway. Waller and Servheen (2005) compared grizzly bear highway crossing frequency determined by GPS telemetry to simulated random walk analyses to assess permeability; observed crossing frequency was 31% of the simulated frequency. Dyer et al. (2002) compared actual road crossings to simulated crossing rates. They found that caribou road crossings were 20% lower than suggested by the simulations. Olsson (2007) documented an 89% decrease in the mean moose-crossing rate between before- and after-reconstruction levels along a highway in Sweden.

1.1.1 Pronghorn and Highways

Highways' barrier effect appears to consistently affect pronghorn antelope more than any other North American ungulates. The fragmentation of pronghorn herds by highways, railways, canals, fences, human encroachment, and habitat degradation has contributed to isolation of populations and disruption of seasonal migrations, thereby contributing to a reduction of pronghorn populations (O'Gara and Yoakum 1992, Sawyer and Rudd 2005). Pronghorn are a nomadic species capable of long-distance movements in response to extreme seasonal weather conditions and variable forage and water availability (Yoakum and O'Gara 2000). Historically, pronghorn roamed freely in North America including northern Arizona (Yoakum and O'Gara 2000), but populations declined as much as 99% by the early 1900s (Yoakum 1968). In Arizona, populations declined from approximately 45,000 animals in the 1900s (Knipe 1944) to only 7,500 by 2002 (AGFD, unpublished data), and have since increased through aggressive management to 11,000 (AGFD 2007).

As early as 1950, Buechner (1950) recognized that fenced highways restricted pronghorn movement across Texas highways. In Wyoming, a state that harbors 60% of North America's pronghorn, Interstate-80 has long been considered a significant barrier to pronghorn movement (Sheldon 2005). Several VHF telemetry studies in northern Arizona have demonstrated that paved highways with fenced rights-of-way (ROW) constitute near total barriers to pronghorn passage. Ockenfels et al. (1994) tracked 47 animals adjacent to Interstate-17 and found that no individual pronghorn was observed on both sides of the highway. None had crossed the highway. Likewise, Ockenfels et al. (1997), van Riper and Ockenfels (1998), and Bright and van Riper (2000) never documented any pronghorn crossings of the fenced highways they monitored: US 89 at Wupatki National Monument, Interstate-40, U.S. Highway 180 (US 180), or a railroad at Petrified Forest National Park. Ockenfels et al. (1997) and van Riper and Ockenfels (1998) did however report that pronghorn crossed the low traffic-volume, paved but unfenced park road through Wupatki National Monument. Hart et al. (2008) confirmed that the railroad remained a total barrier to passage of eight collared pronghorn, even after the fence next to the railroad was modified to promote passage. These Arizona studies point to the combined impact of fenced ROW and highways with associated traffic, though it is difficult to partition their contributory impact to reduced pronghorn permeability. Sheldon (2005) found that fences in Wyoming significantly influenced pronghorn movements and distribution, and that home ranges were located in areas with the lowest fence densities. The presence and type of ROW fences determined whether roads were included in seasonal ranges and where pronghorn crossed highways. Sheldon (2005) also found that seasonal crossings consistently occurred along unfenced highway sections.

Limited information exists on the relationship of highway traffic volume to pronghorn movement and distribution patterns; such information could help assess the relative impact attributable to highways and fences. Theoretical models (Mueller and Berthoud 1997) suggest that highways averaging 4,000−10,000 vehicles/day present strong barriers to wildlife and would repel animals from the highway. Whereas most ungulate highway crossings (e.g., elk and deer) occur during nighttime hours when traffic volume is lowest, pronghorn are diurnal and active when traffic volumes are typically at their highest (Gagnon et al. 2007*a*). Gagnon et al. (2007*b*) found that increasing vehicular traffic volume decreased the probability of at-grade crossings by elk and that they moved away from the highway, consistent with Mueller and Berthoud (1997). For white-tailed deer, Dodd et al. (2009) found that at-grade passage rates were consistently low (≤0.1 crossings/approach) across all traffic volumes. Regular vehicular traffic on roads in Wyoming was reported to produce minimal disturbance among pronghorn due to habituation, though females with young remained sensitive to vehicular traffic (Reeve 1984). Gavin and Komers (2006) reported that pronghorn in Alberta exhibited higher proportions of vigilant behavior along high traffic roads during spring compared to lower traffic roads, suggesting that traffic volume influenced risk perception. Pronghorn close to roadways exhibited higher vigilance regardless of traffic levels, further suggesting they perceived roads to be a danger. Gavin and Komers (2006) also found that individuals in pronghorn herds with young were more risk averse than other social groupings; this is consistent with Reeve's findings (1984).

Integration of structures designed to promote wildlife passage across highways in transportation projects has increased in North America, particularly structures (e.g., underpasses or overpasses) designed specifically for large animal passage (Foster and Humphrey 1995; Clevenger and Waltho 2003; Gordon and Anderson 2003; Dodd et al. 2007*b*, 2009). Wildlife passage structures have shown benefit in promoting wildlife passage for a variety of wildlife species (Farrell et al. 2002; Clevenger and Waltho 2003; Dodd et al. 2007*b*, 2009). Dodd et al. (2007*c*, 2009) found that elk passage rates along one section of SR 260 increased 52% to 0.81 crossings/approach once reconstruction was completed and ungulate-proof fencing linking passage structures was installed. This pointed to the efficacy of passage structures and fencing in promoting permeability, as well as achieving an 85% reduction in elk-vehicle collisions (Dodd et al. 2006). Gagnon et al. (2007*c*) found that traffic levels did not influence elk passage rates during below-grade underpass crossings. This finding shows the benefit of underpasses and fencing in promoting permeability by funneling elk to underpasses where traffic has minimal effect compared to crossing at-grade in areas with high traffic volumes (Gagnon et al. 2007*b*). Dodd et al. (2009) reported five-fold higher white-tailed deer permeability (0.16 crossings/approach) along SR 260 after passage structures were added during reconstruction than the control's (0.03); like elk, deer passage rates were minimally affected by traffic on sections where passage structures facilitated below-grade passage.

While passage structures were shown to be effective in promoting below-grade crossings, Dodd et al. (2009) found considerable variation in mean passage rates on three reconstructed highway sections, ranging from 0.09 to 0.81 crossings/approach. This likely reflected the corresponding variation in passage structure spacing ranging from 1.5 to 0.6 miles between structures; there was a strong inverse association (r = -0.847) between passage rate and passage structure spacing. Bissonette and Adair (2008) conducted an assessment of recommended passage structure spacing for several species tied to isometric scaling of home ranges (HR). They used $HR^{0.5}$ as a daily movement metric and passage structure spacing distance, which when used with other criteria will help maintain landscape permeability. Bissonette and Adair (2008) recommended spacing of 2.0 miles between passage structures for pronghorn.

While passage structures have proven effective for other wildlife species, their application to promote pronghorn highway permeability has been limited. (Sawyer and Rudd 2005). Though Plumb et al. (2003) documented 70 crossings by pronghorn at a concrete box-culvert underpass in Wyoming (81% in a single crossing), pronghorn overall exhibited reluctance to use the structure and the majority of crossing pronghorn accompanied mule deer through the underpass; crossing pronghorn comprised a small proportion of the local pronghorn herd. In six years of monitoring underpasses along Interstate-80 through which thousands of mule deer passed, only a single pronghorn was recorded passing through the structures monitored by Ward et al. (1980). In spite of the limited use of structures to date, there is recognition of the need for strategies to promote pronghorn permeability (Ockenfels et al. 1994, Hacker 2002, Yoakum 2004, Sawyer and Rudd 2005). Yoakum (2004) believed that pronghorn behavioral characteristics might preclude effective use of both underpasses and overpasses on high-volume highways. Sawyer and Rudd (2005:6) reported that "with the exception of Plumb et al. (2003) and several anecdotal observations, we could not find any published or documented information on pronghorn utilizing crossing structures." Still, they believed that pronghorn would more readily use open-span bridges as underpasses than they would use overpasses, though no studies have been done to support this contention. To date, no passage structure intended for pronghorn passage has been implemented in North America. Corlatti et al. (2009) argued for long-term monitoring and genetic studies to evaluate passage structure effectiveness in promoting population growth and genetic viability. They believed monitoring was needed to justify the building of overpasses during highway projects as a means to maintain connectivity, in view of their high cost. Such an argument is particularly relevant to pronghorn since highways present such significant barriers and there is such a limited application of passage structures and little insight on the benefits to promoting connectivity and gene flow.

1.2 RESEARCH JUSTIFICATION

US 89 is the primary highway route connecting Flagstaff/Interstate-40 with Utah to the north, and serves the Navajo Nation and popular recreation areas north of Flagstaff (e.g., Sunset Crater and Wupatki national monuments, Grand Canyon National Park, Page, Lake Powell, etc.). The final *US 89 Antelope Hills – Junction US 160 Environmental Assessment* (ADOT 2006) addressed alternatives for the reconstruction of US 89. The environmental assessment (EA) reported that traffic volume along US 89 (currently averaging 7,500 vehicles/day; ADOT 2006) is projected to double in 20 years. The majority of the existing highway is a 2-lane roadway with limited passing lanes. Under the preferred alternative, US 89 would be widened to a 4-lane divided highway; the center median along three miles through Wupatki National Monument would be 30 ft wide, while from there to Gray Mountain the median would be 84 ft wide.

As documented in the EA, the primary environmental effect of the proposed US 89 reconstruction on pronghorn populations would be to increase the barrier effect associated with the widened highway and increased traffic, contributing to a higher degree of population fragmentation. It is recognized that a “wide, naturally vegetated overpass structure over US 89 may facilitate pronghorn movement across the US 89 corridor” (ADOT 2006:76). The EA also addressed secondary impacts from highway reconstruction on pronghorn, citing the loss of connectivity and genetic viability.

The EA states:

> “ADOT in consultation with FHWA will make a good faith effort to find the funding for a proposed 3-year research project to determine pronghorn movements north of I-40 in Arizona that will be completed at a minimum 1 year prior to final design for projects between milepost 442.0 to milepost 458.0 (Navajo Indian Reservation boundary). ADOT’s Environmental Planning Group (EPG) will coordinate the pronghorn research project and will establish at the beginning of the research project a Wildlife Connectivity Technical Advisory Committee (WCTAC) consisting of representatives from FHWA, NPS, NFWD (Navajo Fish and Wildlife Department), and AGFD. The NPS, as a cooperating agency, has committed to maintain connectivity for pronghorn and other species as part of its requirements under the NPS Organic Act (16 US Code 1–4) and NPS policy. The WCTAC will review data from the research project, provide recommendations to ADOT and FHWA on the appropriateness of a pronghorn crossing structure, and identify the potential location and conceptual design of a crossing structure, if warranted for consideration prior to final project design. The WCTAC will also address wildlife connectivity in general for the project (ADOT 2006:76).”

In November 2004 (following issuance of the draft EA), EPG commissioned a research concept paper to implement the research project addressed in the EA. In November 2006, the Arizona Department of Transportation (ADOT) and the Arizona Game and Fish Department (AGFD) executed an Interagency Agreement between for the research project (Project JPA07-004T) with funding provided by ADOT’s Arizona Transportation Research Center. This research project is significant from several perspectives. First, it epitomizes the incremental process in addressing wildlife connectivity and permeability needs embodied in *Arizona’s Wildlife Linkages Assessment* (Arizona Wildlife Linkages Workgroup 2006). General connectivity needs identified in the assessment (e.g., Linkage No. 17; Deadman Mesa to Gray Mountain) were proactively addressed in the EA process for US 89. This led to the commitment to obtain information to make data-driven decisions on the need and best location(s) for passage structures to promote pronghorn permeability that could be built during highway reconstruction. Further, compared to previous ADOT-funded research on wildlife-highway relationships along SR 260, SR 64, and Interstate-17, there was no overarching highway safety issue associated with wildlife-vehicle collisions (Dodd et al. 2006, 2007*a*, 2009); rather, this research project was predicated solely on addressing ecological needs for pronghorn connectivity.

1.3 RESEARCH OBJECTIVES

This research project will add greatly to the understanding of pronghorn movements in relation to highways and traffic volume. Given the degree to which highways are known to limit pronghorn permeability, the depressed nature of current pronghorn populations and the fact that US 89 will be reconstructed in the future to accommodate increasing traffic volume, the challenge is to determine if and how pronghorn meta-populations in northern Arizona can be reconnected to maintain population viability. The overarching goal of this research project was to apply insights gained on current pronghorn movements and permeability across US 89 in developing strategies to enhance connectivity in future highway reconstruction. The specific objectives of this research project were to:

1) Assess pronghorn movement patterns and distribution relative to US 89 and determine current permeability across the highway corridor.
2) Investigate the relationships of pronghorn highway crossing and distribution patterns to vehicular traffic volume.
3) Assess the influence of fencing on pronghorn highway crossing patterns and permeability.
4) Investigate pronghorn-vehicle collision patterns along US 89.
5) Establish a baseline to assess the degree to which US 89 and other northern Arizona highways have affected gene flow and genetic diversity within and among pronghorn populations.
6) Develop recommendations to enhance pronghorn highway permeability.

2.0 STUDY AREA

The focus of this research project was a 28-mile stretch of US 89 starting approximately 15 miles northeast of Flagstaff, Coconino County, Arizona (lat 35°22'–35°46'N, long 111°20'–111°40'W). The study section stretches from milepost (MP) 430.0 at the northern end of the Coconino National Forest (NF) near the entrance to Sunset Crater National Monument, to MP 458.0 at the Navajo Nation boundary north of Gray Mountain (Figures 1 and 2). A 3-mile portion of the highway crosses through Wupatki National Monument near the center of the study area (Figures 1 and 2). US 89 is classified as a Rural Principal Arterial highway; these highways are considered the state's principal corridors for statewide travel— they carry the highest volume of long distance trips in Arizona (ADOT 2006).

In 1999, US 89 from MP 430.0 to 442.0 was reconstructed to a 4-lane divided highway. From MP 442.0 north, the section of US 89 proposed for reconstruction in the *US 89 Antelope Hills – Junction US 160 Environmental Assessment* (ADOT 2006) is predominantly a 2-lane roadway with occasional passing lanes and lateral road access turnouts. Within the study area, the planned design standards north of MP 442.0 include:

- A 5-lane undivided roadway with two lanes in each direction and a two-way continuous left-turn lane centered on the existing centerline in the Antelope Hills section (MP 442.0 to MP 443.0).

- A 4-lane divided section with 30-foot median width, widening centered about the existing centerline on the Wupatki National Monument section (MP 443.0 to MP 445.4).

- A 4-lane divided section with 84-foot median width, widening to the west of the existing centerline with the exception of between MP 445.4 and MP 447.0 and between MP 451.7 and MP 453.2, where the roadway will be widened to the east to avoid impacting existing business for the Wupatki National Monument to Gray Mountain section (MP 445.4 to MP 456.0).

Land ownership adjacent to the highway corridor includes U.S. Forest Service (USFS) (Coconino NF) lands on the south half interspersed with scattered small private land parcels, National Park Service (NPS) (Wupatki National Monument) lands in the center of the study area, and a "checkerboard" pattern of Arizona State Trust and private land (primarily Babbitt Ranch) holdings on the north half of the study area (Figures 1 and 2).

2.1 PHYSICAL SETTING

The study area is located at the southwestern extent of the Colorado Plateau physiographic province, and lies within the San Francisco Peaks Volcanic Field (Hansen et al. 2004). The study corridor lies adjacent to US 89. One end is at 6,890 ft elevation near the Sunset Crater National Monument turnoff atop Deadman Mesa on the east flank of the San Francisco Peaks. It steadily drops off to the north along Deadman Flats and

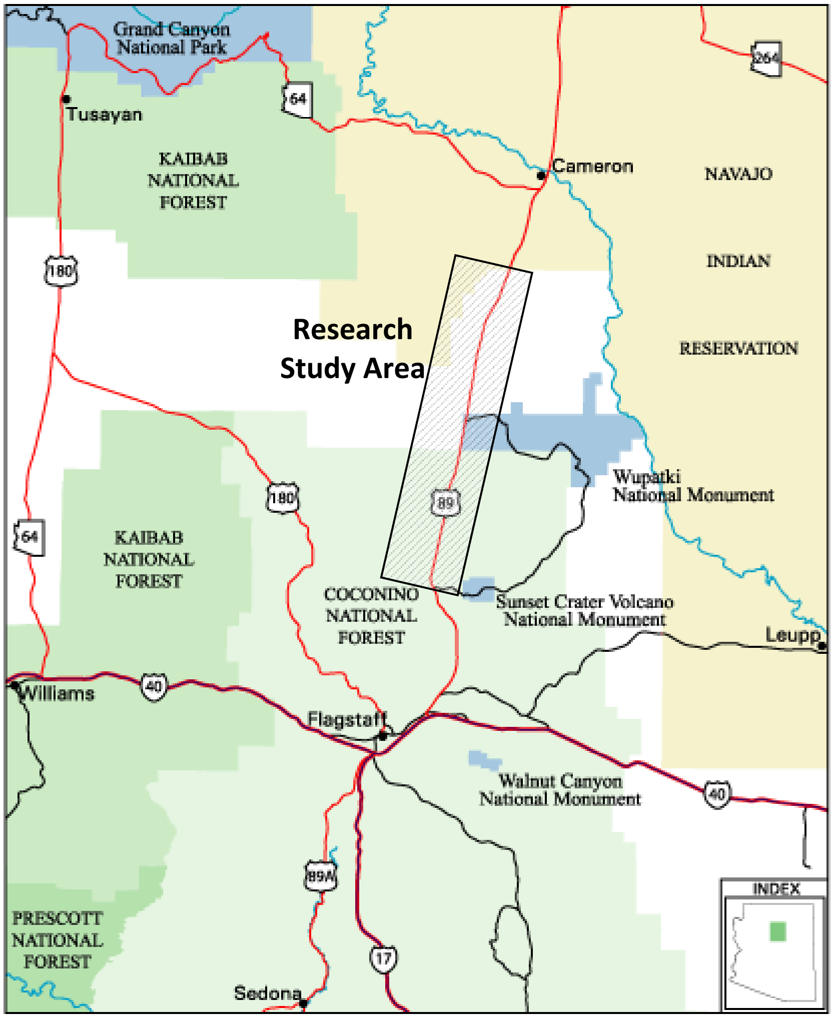

Figure 1. Location of the US 89 research study area in north central Arizona (map from Hansen et al. 2004).

continues to Gray Mountain at the northern extent of the study area to an elevation of 4,900 ft. The geology and topography within the study area are a diverse and complex mix of mesas, basalt flows, cinder cones extending northward through much of the study area (Figure 2), rolling hills, and arroyos, all interspersed with relatively flat grassland areas. At the northern extent lie broken bluffs and sparsely vegetated badlands associated with the Painted Desert. The eastern extent is defined by cliffs and bluffs above the Little Colorado River and the broken lowlands of the Wupatki Basin (Hansen et al. 2004). This diversity in elevation and topography has a significant influence on vegetative community composition (Hansen et al. 2004), which in turn influences pronghorn distribution and habitat use (Ockenfels et al. 1997, Bright and van Riper 2000). The numerous manmade stock tanks and some springs that are scattered throughout the area also influence pronghorn distribution (Bright and van Riper 2000).

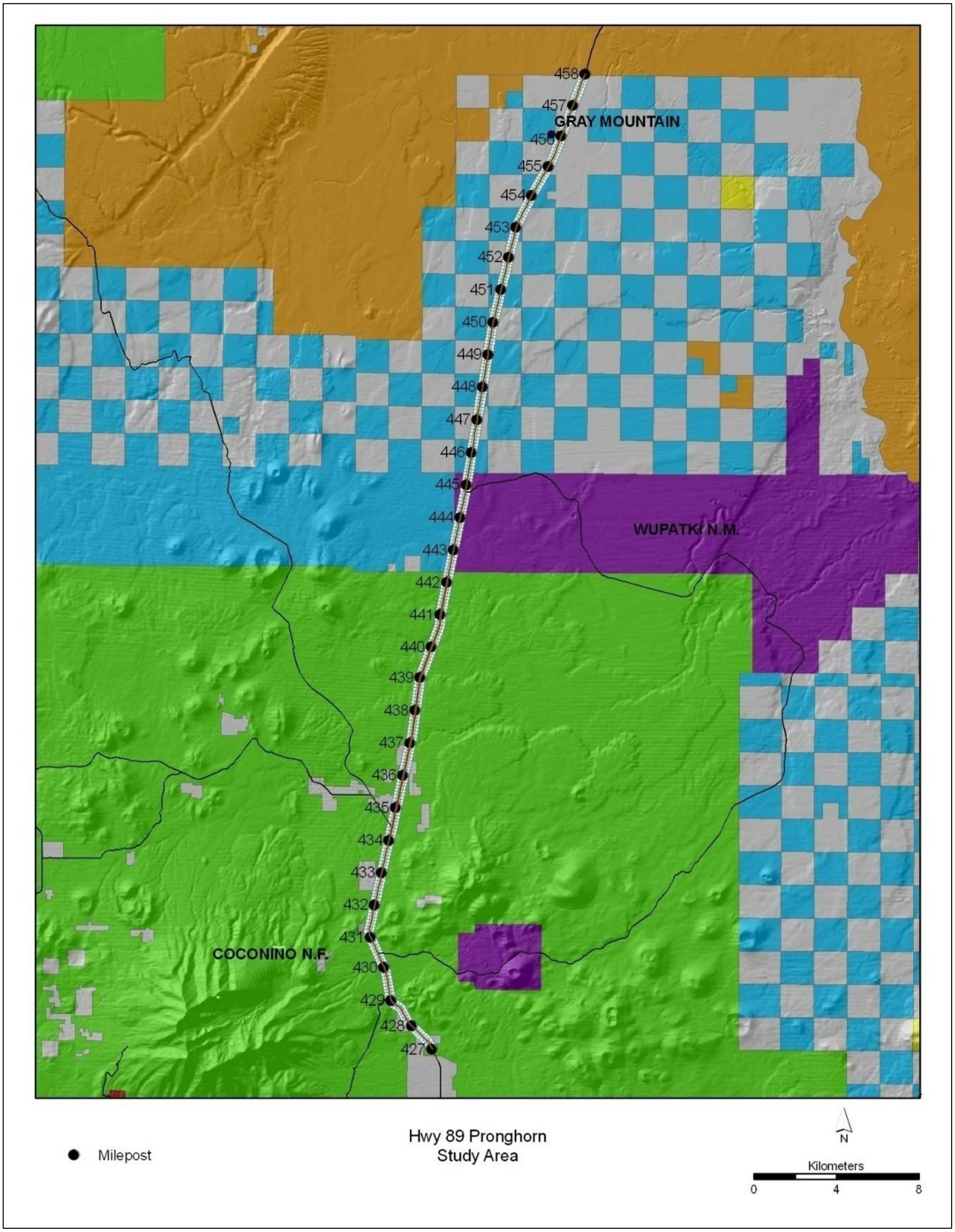

Figure 2. Study area stretch of US 89, extending from MP 430.0 to 458.0

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2.2 CLIMATE

The variation in elevation and topography across the study area affects climatic patterns. Most of the study area is semi-arid, dominated by hot summers and cool winters. At the lower elevations of the area's northern part, precipitation is low and annually averages only 5.2 in, with occasional winter snows that annually average 8.9 in (van Riper and Ockenfels 1998). Summer thunderstorms account for the majority of precipitation in the northern portion of the area (Hansen et al. 2004). Here, summer temperatures often exceed 100^{o} F and winter lows typically hover around freezing but can occasionally dip to 10^{o}F after winter storms. At the southern end of the study area, with higher elevations and the nearby San Francisco Peaks, precipitation is considerably higher and more consistent, averaging 19.8 in, with considerable snowpack accumulating during winter (van Riper and Ockenfels 1998). Due to the presence of the San Francisco Peaks south of the study area, windy conditions often prevail which further exert an influence on pronghorn distribution and habitat use.

2.3 VEGETATION

Vegetation within the study area is diverse and exhibits characteristics of the Montane Coniferous, Plains, Great Basin Grassland, and Great Basin Desertscrub biotic communities (Brown 1994, Hansen et al. 2004). Dominant plant species in the southern portion include a ponderosa pine and limited pinyon pine overstory with sagebrush, rabbit brush, cliffrose, and Apache plume in the understory, interspersed with small grasslands composed primarily of blue grama and other grasses. At lower elevations, the vegetation is dominated by oneseed juniper woodlands with cliffrose, Apache plume, and other shrubs, along with blue grama and other grasses (Figure 3). Juniper woodlands transition to shortgrass prairie/grasslands composed of blue and black grama, galleta, alkali sacaton, and needle and thread grasses, with winterfat and sagebrush interspersed with sparse junipers (Hansen et al. 2004; Figure 3). At the northern extent of the area, desertscrub vegetation is dominated by shadscale, greasewood, rabbit brush, and blackbrush, with Indian ricegrass.

Most of the study area has a long history of livestock grazing, which has altered plant communities, particularly grasslands, and contributed to juniper encroachment (ADOT 2006, Hansen et al. 2004). Though grazed by livestock until the 1980s, Wupatki National Monument supports relatively pristine native bunchgrass grasslands that provide reference conditions for historical grasslands and offer a seed source for dispersal to surrounding habitats (ADOT 2006). Wupatki National Monument constitutes excellent pronghorn habitat for forage and especially cover, particularly when adjacent national forest, state trust and private lands are grazed by livestock (Bright and van Riper 2000; B. Holton, unpublished report, NPS, Flagstaff, AZ).

2.4 PRONGHORN POPULATION

Two distinct pronghorn herds inhabit the study area, one on each side of US 89 (ADOT 2006). Both herds fall within AGFD Game Management Unit (GMU) 7, and as such are surveyed and managed as a single population. However, based on movement studies by

Figure 3. Characteristic juniper woodland (top) and shortgrass prairie/grasslands (bottom) associated with the US 89 research study area (photos from Hansen et al. 2004).

Ockenfels et al. (1997), van Riper and Ockenfels (1998), and Bright and van Riper (2000), who documented limited passage across US 89, these herds have become virtually separate and isolated. The herd on the west side of US 89 ranges westward to US 180. The herd to the east ranges to the Little Colorado River and south to Interstate-40. The current (2007–2008) population estimate for GMU 7 is approximately 600 animals (AGFD unpublished Pronghorn Hunt Recommendations, Game Branch, Phoenix). From 2003 to 2008 surveys of the population from fixed wing aircraft found an average of 220 pronghorn in 42 groups with an average ratio of 36 males (bucks):100 females (does):40 young (fawns). The general population trend has been downward and is a source of concern, particularly given the large numbers of animals (males) harvested by sport hunting (AGFD unpublished Pronghorn Hunt Recommendations, Game Branch, Phoenix). Since 2003, the fawns:doe ratio on the west side of US 89 has averaged 0.45 compared to only 0.27 on the east side.

2.5 TRAFFIC VOLUME

Average annual daily traffic (AADT) volume on this portion of US 89 (sampled at Gray Mountain) was estimated at 5,600 vehicles/day in 2006 and 7,300 in 2007 (unpublished data, ADOT Data Management Section). Since March 2007, traffic volume has been continuously measured by a permanent automatic traffic recorder (ATR) installed near the center of the study area just north of Wupatki National Monument. This ATR measured an actual AADT of 6,310 vehicles/day in 2008. Traffic volumes were highest during daytime hours (Figure 4). Between 10:00 and 17:00, hourly traffic volume exceeded 430 vehicles/hr, equivalent to a volume of 10,000−11,600 vehicles/day. Monthly traffic volume was highest during May−August when it averaged 60% higher than volume during the lowest traffic months of December−February. Passenger cars accounted for 81% of all vehicles traveling along US 89 (2007-2008), though commercial trucks accounted for up to a third of the traffic during early morning hours (midnight to 03:00). Vehicular speeds averaged 72.5 mph though the posted speed at the ATR and along most of the study area stretch of US 89 is 65 mph.

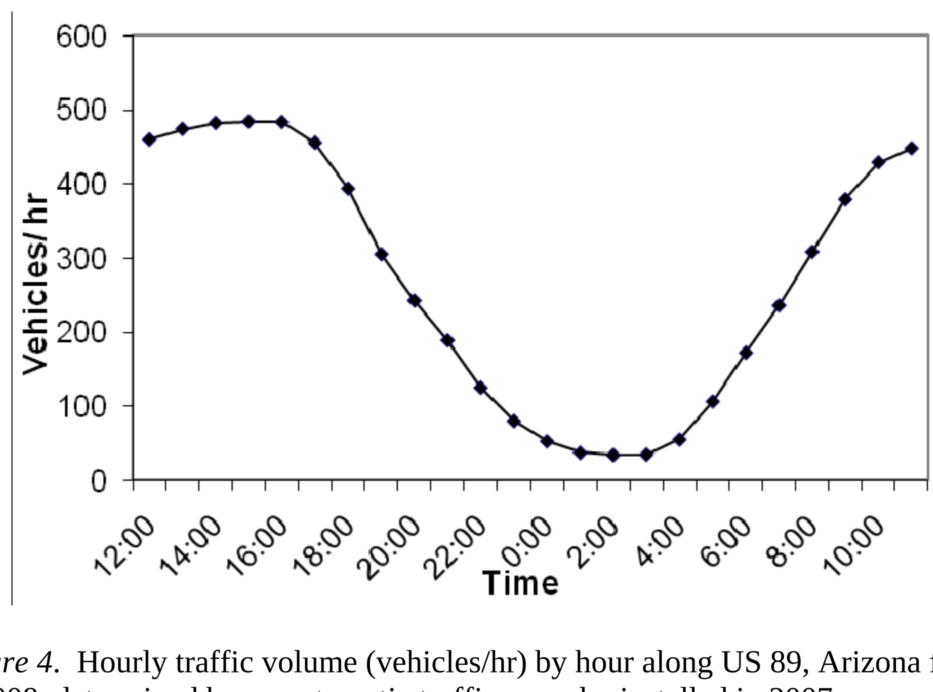


Figure 4. Hourly traffic volume (vehicles/hr) by hour along US 89, Arizona from 2007 to 2008, determined by an automatic traffic recorder installed in 2007.

3.0 METHODS

3.1 PRONGHORN CAPTURE AND GPS TELEMETRY

The research team captured pronghorn using a net gun fired from a helicopter (Firchow et al. 1986, Ockenfels et al. 1994; Figure 5). A fixed-wing aircraft and numerous ground spotters using optics equipment were employed to search for pronghorn during capture to minimize helicopter searching. Pronghorn were primarily captured during the winter (December−January) to minimize heat-related stress on animals, as well as deleterious effects on females that could occur if captured later in their pregnancies. The team's capture objectives were to: 1) instrument as nearly an equal number of pronghorn on each side of US 89 as possible, 2) spread the collars among as many different herds along the length of the study area as possible, and 3) capture animals within five miles of US 89.

Upon capture, pronghorn were immediately blindfolded and untangled from the capture net. Animals were fitted with a GPS collar and marked with a numbered, colored ear tag (Figure 5). Tissue samples were taken from the animals' ears with a paper punch and preserved for future genetic analysis. The research team instrumented the pronghorn with store-on-board GPS receiver collars (Model TGW-3500; Telonics, Inc., Mesa, AZ) programmed to receive 12 GPS fixes/day, with one fix every 90 min between 04:00−22:00; the GPS units had a battery life of 11 months. All collars had VHF beacons, mortality sensors, and programmed release mechanisms to allow recovery.

3.2 GPS DATA ANALYSIS OF PRONGHORN MOVEMENTS

Once the GPS collars were recovered and data downloaded, the research team employed ArcGIS Version 8.3 Geographic Information System (GIS) software (ESRI, Redlands, California) to analyze the data similar to analyses done for elk by Dodd et al. (2007*d*, 2009) and white-tailed deer (Dodd et al. 2009). The team used GPS data to calculate daily distance traveled by the collared pronghorn by sex and season, as well as individual minimum convex polygon[1] (MCP) home ranges comprised of all GPS fixes (White and Garrott 1990). Differences in means were assessed by analysis of variance (ANOVA), and means were reported with ±1 standard error (SE).

3.2.1 Calculation of Passage Rates

The team divided the study length of US 89 into 280 sequentially numbered 0.1-mile segments corresponding to the units used by ADOT for tracking wildlife-vehicle collisions and highway maintenance, and identical to Dodd et al. (2007*d*, 2009). The number and proportion of GPS pronghorn fixes within 0.15, 0.30, and 0.60 mile of US 89 were calculated for each animal, as well as the proportion of three-dimensional (3-D) or two-dimensional (2-D) fixes that were acquired.

[1] Constructed by connecting the outermost fixes.

Figure 5. Helicopter capture of pronghorn by net gunning (top; note the net over the pronghorn), blindfolded and GPS-collared female to which an ear tag is being applied (center), and the marked pronghorn being released near the US 89 study area (R. Ockenfels photos).

The team drew lines connecting all consecutive GPS fixes and inferred a highway crossing where lines between fixes crossed the highway through a given segment (Dodd et al. 2007*d*, 2009). Animal Movement ArcView Extension Version 1.1 software (Hooge and Eichenlaub 1997) was used to assist in determining where pronghorn had crossed. The research team compiled crossings by individual animals by highway segment, date and time, and calculated crossing rates for individual pronghorn by dividing the number of crossings by the days a collar was worn. As stated earlier, it turned out there was only one crossing detected.

Passage rates for individual collared pronghorn were used as the relative measures of highway permeability (Dodd et al. 2007*d*, 2009). An approach was considered to have occurred when an animal traveled from a point outside the 0.15-mile buffer zone to a point within 0.15 mile of US 89, determined by successive GPS fixes. The approach zone corresponded to the road-effect zone associated with traffic-related disturbance (Rost and Bailey 1979, Forman et al. 2003) previously used for elk and white-tailed deer by Dodd et al. (2007*d*, 2009). Pronghorn that directly crossed US 89 from a point beyond 0.15 mile were counted as an approach and a crossing.

3.2.2 Calculation of Approaches and Weighted Approaches

Based on previous pronghorn telemetry research adjacent to US 89 (Ockenfels et al. 1997, van Riper and Ockenfels 1998, Bright and van Riper 2000), the research team anticipated that there might be few pronghorn crossings or approaches to within 0.15 mile, especially when compared to the 11,052 crossings by 100 elk along SR 260 (Dodd et al. 2009). As such, the team used the number of approaches by pronghorn to within 0.30 mile to determine the distribution of animals adjacent to US 89 for the purposes of assessing the need for and potential location(s) of passage structures. Use of this greater approach distance also was deemed appropriate given the relatively open nature of pronghorn habitat, pronghorn reliance on visual stimuli in risk avoidance (Gavin and Komers 2006), and pronghorn mobility over long distances compared to other ungulates (Yoakum and O'Gara 2000).

To account for the number of individual pronghorn that approached each highway segment adjacent to US 89, as well as evenness in crossing 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 the $-(p_i \ln p_i)$ for each pronghorn that had approaches in the segment, where each p_i is defined as the number of individual collared pronghorn approaches within each segment divided by the total number of pronghorn approaches in the segment. SDI were used to calculate weighted approach frequency estimates for each highway segment, multiplying uncorrected approach frequency × SDI. Weighted approaches better reflected animal approach frequency, number of approaching animals, and equity in distribution among approaching pronghorn (cf. Dodd et al. 2006, 2007*a*).

Pronghorn highway approaches were determined for animals approaching from each side of US 89, and both sides combined. The research team tested the hypothesis that the observed spatial approach distribution (by 0.10-mile segments) did not differ from a discrete randomly generated approach distribution using a Kolmogorov-Smirnov test (Clevenger et al. 2001; Dodd et al. 2006, 2007*d*), a test that is sensitive to both the difference in ranks and shape of the distributions.

3.2.3 Determination of Linear Approach Distance along Highway

To assist with the assessment of the number and spacing of passage structures that might be necessary to promote pronghorn passage across US 89, the research team compiled the linear distance adjacent to US 89 between the 0.1-mile segments in which pronghorn approached that were the furthest apart. This linear approach distance measured how far animals ranged along the length of US 89; for example, an animal that had approaches within segments 21 through 175, spanning 154 0.1-mile segments, had a linear approach distance of 15.4 miles.

3.3 PRONGHORN MOVEMENTS AND FENCING REMOVAL

Around 2004, barbed wire was removed from a short 0.1-mi section of the ROW fence between MP 444.1 to MP 444.2 on Wupatki National Monument to facilitate pronghorn crossing, though the fence T-posts were left in place. As detailed in the *US 89 Antelope Hills – Junction US 160 Environmental Assessment* (ADOT 2006), there is no conclusive evidence that pronghorn have crossed at this point aside from a few pronghorn tracks being found on both sides of the highway in this location. As part of its pronghorn GPS telemetry tracking, the research team assessed whether animals approached and/or crossed US 89 at this point to a higher degree than the adjacent sections of highway.

In November 2008, ADOT and NPS personnel removed 1.5 miles of ROW fencing on each side of US 89 within Wupatki National Monument, including the T-posts. This unprecedented large-scale fence removal is anticipated to have a greater impact on promoting pronghorn highway crossings than the section modified at MP 444.1 to 444.2. Also, ROW fencing along a 0.5-mile stretch of US 89 immediately north of Wupatki National Monument was modified in 2009 by ADOT and Babbitt Ranches. Due to the presence of livestock here, the fence was pulled back from the ROW >100 yards to allow pronghorn the opportunity to cross fences and roadways individually. Unfortunately, the second phase of the pronghorn telemetry was completed when these fence modifications were made, limiting the tracking of animal response. Twelve pronghorn were captured in late November 2008 and instrumented with GPS receiver collars, seven on the east side and five on the west side of US 89 to assess potential pronghorn response to the removal of ROW fence. The GPS collars from these animals will be recovered in December 2010 and movements in relation to the fence modification will be analyzed in a separate report.

3.4 TRAFFIC VOLUME AND PRONGHORN DISTRIBUTION

The research team had access to traffic volume data from a permanent ATR programmed to record hourly traffic volumes. ADOT's Data Management Section assisted the research team in installing the ATR in March 2007 at a central location in the study area, just north of Wupatki National Monument. As was done for elk by Gagnon et al. (2007*b*) and white-tailed deer by Dodd et al. (2009), the research team combined traffic and GPS data by assigning traffic volumes for the previous hour to each pronghorn GPS location using ArcGIS® Version 9.1 (ESRI, Redlands, California, USA). This allowed the team to correlate traffic volumes with pronghorn actions/movements during any given one-hour time interval.

The research team examined how the proportion of pronghorn relocations at different distances from the highway varied with traffic volume by calculating the proportion of relocations in each 330-ft (0.0625 mi) distance band, out to a maximum of 3,300 ft (0.625 mi), similar to Gagnon et al. (2007*b*) for elk and Dodd et al. (2009) for white-tailed deer except that previous analyses were limited to 2,000 ft. To avoid bias due to differences in the number of relocations for individual pronghorn, the proportion of relocations occurring in each distance band for each animal was used as the sample unit, rather than total relocations. The team then calculated a mean proportion of pronghorn relocations for all animals within each 330 ft-distance band at varying traffic volumes (vehicles/hour): <100, 101−200, 201−300, 301−400, 401−500, and 501−600 (Gagnon et al. 2007*b*). Pronghorn distribution and highway impact were compared to those for elk (Gagnon et al. 2007*b*) and white-tailed deer (Dodd et al. 2009).

3.5 PRONGHORN-VEHICLE COLLISIONS

To track wildlife-vehicle collisions (WVC) involving pronghorn, the research team primarily relied on accident report forms provided by Department of Public Safety (DPS) highway patrolmen in the Flagstaff District, including the recording of roadkills where no accident was reported. This information was augmented by periodic searches of the highway corridor by the research team for evidence of WVC. WVC records were compiled and summarized by highway reconstruction section by year. Lastly, ADOT's long-term statewide roadkill database (1990−2006) was queried for past WVC involving pronghorn along the study stretch of US 89.

3.6 IDENTIFICATION OF PASSAGE STRUCTURE SITES

Of the 28 miles of US 89 (280 0.1-mile segments) within the study area, 12 miles (MP 430.0 to 442.0) were upgraded to a 4-lane divided highway in 1999. It is expected that the remaining 16-mile length from MP 442.0 to 458.0 will be upgraded in the future. FHWA guidelines permit ADOT to extend active construction activities up to 5% of the project length in each direction beyond project limits. Therefore, with the 42 miles (MP 442.0 to 484.0) of reconstruction addressed under the final *US 89 Antelope Hills – Junction US 160 Environmental Assessment* (ADOT 2006), construction activities could extend 2 miles beyond the south end of the reconstruction zone, to MP 440.0. As such, the research team assessed the potential for pronghorn passage structure sites from MP 440.0 to 458.0 and excluded the remainder of the study area to the south.

Sawyer and Rudd (2005) identified several important considerations for locating the most suitable sites for pronghorn passage structures. In its assessment of potential passage structure sites, the research team considered each criterion identified by Sawyer and Rudd (2005), but recognized that the 0.1-mile segment scale was too small and cumbersome to discern and analyze differences among segments. Dodd et al. (2006, 2007*b*) reported that the 0.6 mile (1 km) scale was optimum for making recommendations for wildlife passage structures based on telemetry or WVC data. Making recommendations at this scale also allows ADOT engineers latitude to determine the best technical location for passage structures along the segment. Thus, for analysis of the criteria identified by Sawyer and Rudd (2005), the team aggregated the 180 0.1-mile segments from MP 440.0 (one 0.1-mile segment added) to 458.0 into 30 0.6-mile segments for analysis.

Sawyer and Rudd (2005) identified pronghorn abundance as a primary criterion for the consideration of passage structure sites. The research team applied this observation on the entire study stretch of US 89 and separately on individual segments. Sawyer and Rudd (2005: 17) stressed that passage structures were more appropriate in linking populations with “abundant numbers (i.e., hundreds)” and exhibit a high likelihood of encountering passage structures, than small isolated populations that may not benefit to the same degree. Since the pronghorn population adjacent to US 89 exceeds 600 animals, with the herds on both sides of the highway still viable and reproducing, the research team determined that there is a sufficient population to evaluate passage structure sites. Thus, the team used the other segment-specific criteria identified by Sawyer and Rudd (2005) with minor modifications to rate each of the 30 0.6-mile segments, considering GPS telemetry findings with other pertinent factors, as follows:

Pronghorn distribution − this rating was based on the mean (of 0.1-mile segments within each 0.6-mile rating segment) number of different GPS-collared pronghorn relocated within the 0.3-mile approach zone on either side of US 89. Ratings were:

0	No animals approaching
1	1−2 animals approaching
2	3−5 animals approaching
3	6−8 animals approaching
4	9−10 animals approaching
5	>10 animals approaching

Pronghorn approaches – this criterion was considered the most important and indicative of where animals potentially would approach and cross US 89 via a passage structure, and was based on the mean number of approaches for the six 0.1-mile segments on both sides of the highway. Ratings were:

0	No approaches
1	1−10 approaches
2	11−20 approaches
3	21−30 approaches
4	31−40 approaches
5	41−60 approaches
6	>60 approaches

Land status – this criterion reflected the ability to conduct construction activities outside the ADOT ROW, such as creating approaches with fill material for overpasses. Ratings were:

0	State Trust
1	Private
2	Federal – NPS (natural ecosystem focus)
3	Federal – USFS (multiple-use focus)

Human activity – ideally, no human activity should occur within the vicinity of a passage structure; however, road access, businesses, visitor pullouts, and other activities do occur adjacent to US 89. Ratings were:

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

Fencing – fencing, especially of the highway ROW has a significant impact on permeability. This criterion relates to the ability to eliminate or mitigate fencing associated with a potential passage structure, and is closely tied to land ownership. Ratings were:

0	Private lands near homes/businesses
1	State Trust land
2	Private land
3	Private lands with cooperative landowner (Babbitt Ranch)
4	USFS lands
5	NPS lands (no livestock grazing, no fencing needed)

Topography – the ability to situate overpasses oriented along existing ridgelines that pronghorn can traverse, or locate underpasses in association with wide gentle drainages is desirable. Ratings were:

0	Terrain not suited for a passage structure (steep, broken)
1	Topography marginal for a passage structure (flat)
2	Topography could accommodate a passage structure (drainage)
3	Topography ideally suited for passage structure (ridgeline or wide, gentle drainage or basin)

Median width (not identified in Sawyer and Rudd 2005) – the selected alternative median width has a large bearing on the potential distance that a passage structure would need to span, as well as the distance animals would have to traverse in crossing the highway. Ratings were:

1	84-ft median planned or existing
2	30-ft median planned
3	No median planned

4.0 RESULTS

The research team instrumented and tracked 37 pronghorn (20 females, 17 males) with GPS receiver collars from January 2007 to December 2008. Most animals were captured in January and December 2007 as part of two separate telemetry phases, though two animals were captured in August 2007 following the independent death of two females (both apparently by dogs near private land). The team was able to instrument 19 pronghorn with collars on the west side of US 89 and 18 on the east side, meeting its objective for distributing collars equally.

GPS collars were affixed to pronghorn an average of 266.2 days (±30.6 SE), during which time the collars accrued 118,181 GPS fixes (Figure 6) for a mean of 3,194.1 fixes/pronghorn (±376.1). Of the GPS fixes, a mean of 86.6% were 3-D fixes and 13.4% were lower accuracy 2-D fixes.

4.1 PRONGHORN MOVEMENTS, DISTRIBUTION, AND APPROACHES

4.1.1 Pronghorn Movements and Distribution

Of the GPS fixes accrued (Figure 6), 1,125 (1.0%) occurred within 0.15 mile of US 89, or an average of 33.1 (±7.9) fixes/animal; eight pronghorn did not approach the highway to within 0.15 mile. Within 0.30 mile of the highway, there were 3,794 pronghorn fixes (3.2% of all fixes) for an average of 102.5 (±20.4) fixes/animal; six animals did not approach to within 0.30 mile of US 89. Pronghorn approached to within 0.60 mile of the highway 10,230 times (8.7% of all fixes), with a mean of 276.5 (±46.6) fixes/animal; four pronghorn never approached to within 0.60 mile of US 89 during the study.

Over the duration of GPS tracking, pronghorn (n = 37) travelled an average of 3.2 miles (±0.07) each day. Males (n = 17) travelled slightly further each day (3.3 miles; ±0.10) than females (3.1 miles; ±0.10; n = 20), though the difference was not significant (P = 0.177).

MCP home ranges for all pronghorn with sufficient fixes to estimate home ranges(n = 30) averaged 71.1 mile^2 (±6.8). Male (n = 12) MCP home ranges (76.7 mile^2; ±10.3) were considerably large than females' (n = 18) which averaged 66.1 mile^2 (±9.0); however, the difference was not significant (P = 0.668). There was no significant difference between home ranges on each side of US 89 (P = 0.605).

4.1.2 Pronghorn Highway Crossings and Permeability

Only one GPS-collared pronghorn crossed US 89 during the nearly two years of tracking, a female that crossed 12 times in June 2007; none of the other 36 collared pronghorn crossed the highway. This animal was apparently travelling to water tanks on the east side of the highway from the west side of US 89 where it resided the vast majority of the

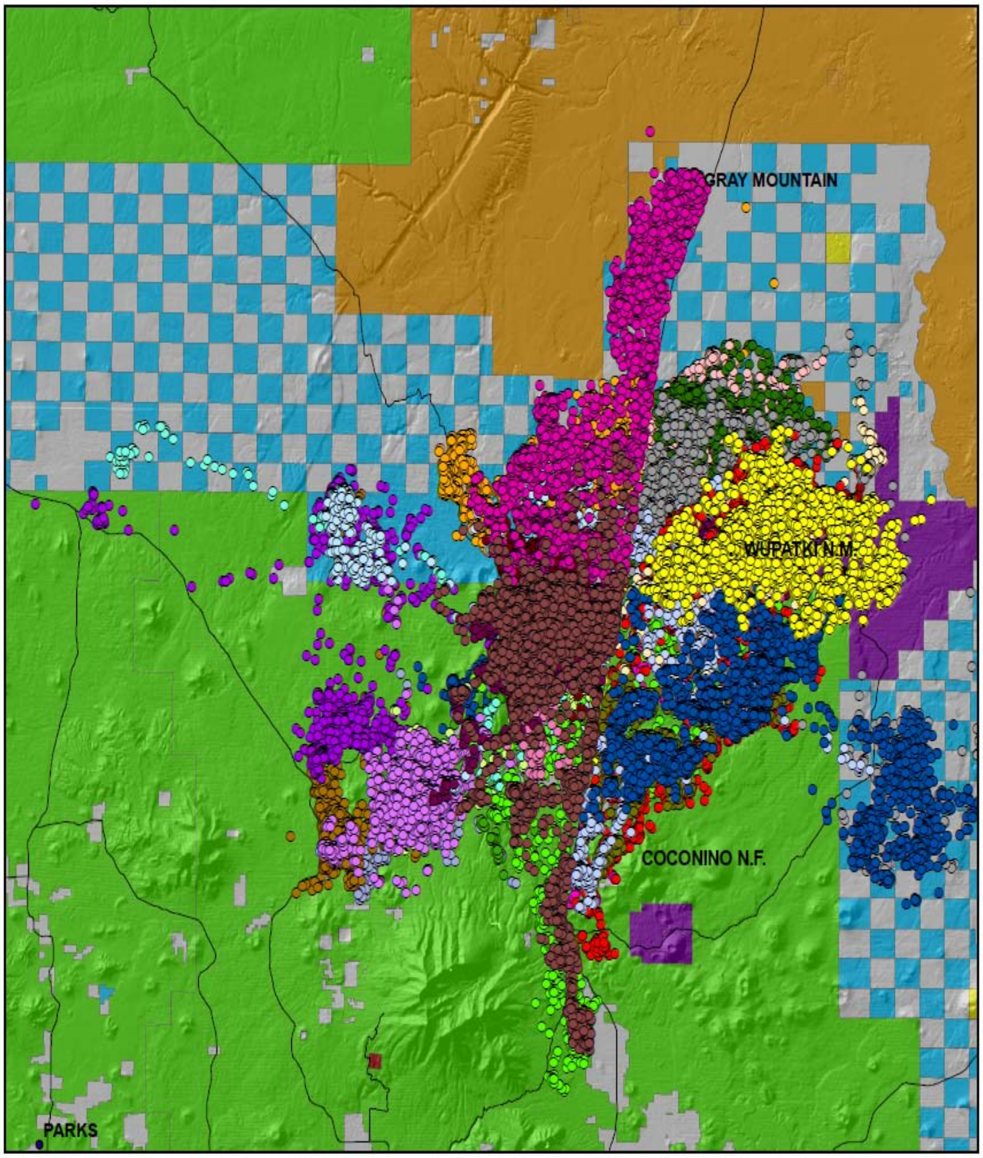


Figure 6. Distribution of GPS fixes for 37 pronghorn accrued from 2007 to 2008 adjacent to US 89, Arizona. Each color represents an individual collared pronghorn.

time. The crossing rate for this animal was 0.05 crossings/day, and the crossing rate averaged 0.001 crossings/day among 30 pronghorn that approached US 89 to within 0.15 mile. The mean pronghorn passage rate was negligible (0.006 crossings/approach; n = 30).

4.1.3 Pronghorn Approaches

The frequency of approaches that pronghorn made to within 0.30 mile of US 89 yielded considerably more information than crossings to assist in determining the locations of potential passage structures. The number of approaches differed considerably on each side of the highway, though not significantly (P = 0.103). There was three times the number of approaches from the west side compared to the east side. On the west side, 18 pronghorn approached the highway 2,875 times (Figure 7), for a mean of 159.7 (±34.3) approaches/animal. There was an average of 9.0 approaches/0.1-mile segment, and a range of 0 to 134 approaches among the segments. Among segments, the number of different approaching pronghorn ranged from 0 to 13 and averaged 1.7. The observed approach distribution did not occur in a random distribution (Kolmogorov-Smirnov d = 0.309, P< 0.001).

On the east side of US 89, 13 pronghorn approached the highway 952 times (Figure 7), with a mean of 73.9 (±21.5) approaches/pronghorn. Among 0.1-mile segments, pronghorn approaches averaged 3.1/segment and ranged from 0 to 55 approaches. The number of different pronghorn approaching the highway at a given segment from the east side ranged from 0 to 5, and averaged 0.8/segment. The observed distribution of approaches from the east also differed from a discrete random distribution (Kolmogorov-Smirnov d = 0.249, P< 0.001).

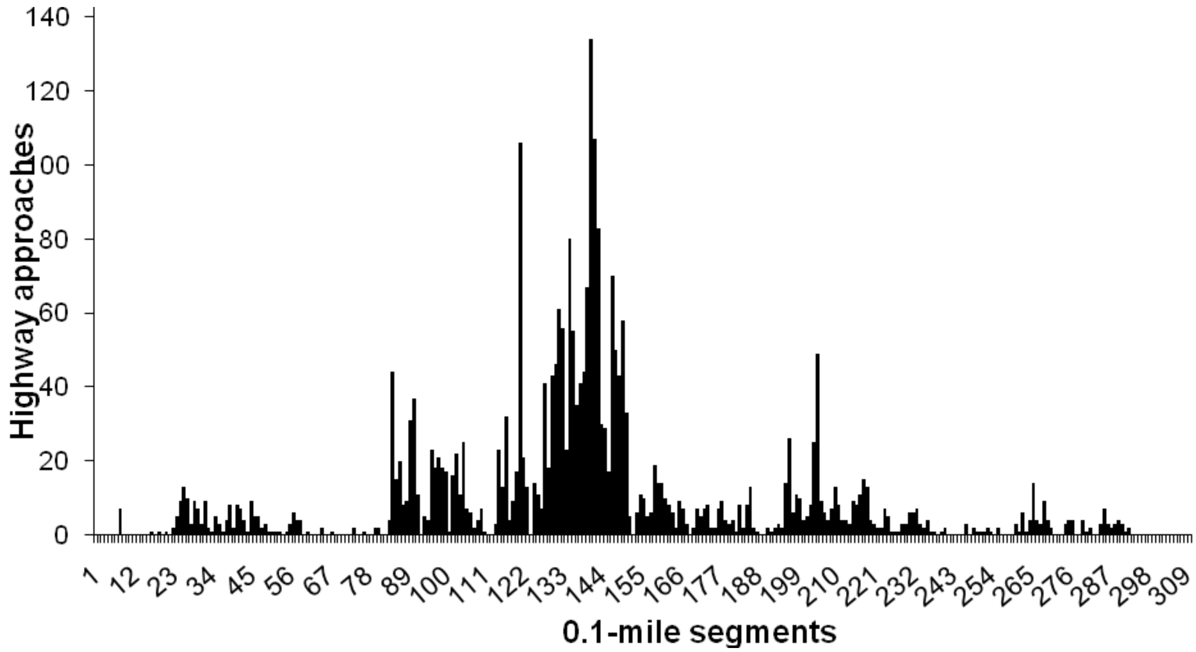
On the west side of the highway, the SDI-weighted pronghorn approaches totaled 3,435.2, and averaged 11.1/segment (Figure 8). The weighted distribution of approaches (Figure 8) lacked several of the peaks in approach frequency for unweighted approaches between segments 89−111 and 199−221 (Figure 7), as relatively few animals accounted for these unweighted approach peaks. Conversely, the large peak in approaches between segments 122 and 155 (Figure 7) increased substantially when weighted by SDI (Figure 8) reflecting the large number of different collared pronghorn that approached in this area, 15 of the total 18 that approached on the west side of US 89. Beyond segment 220 (through 310) there were no weighted approaches (Figure 8).

On the east side of the highway, SDI-weighted approaches decreased from the unweighted approach total to 682.2, averaging 2.2 approaches/segment (Figure 8), and reflected the fact that many of the approaches were made by relatively few animals. This was particularly true for the large peak in approaches between 50 and 57 (Figure 7). Like the west side of the highway, there were no weighted approaches beyond segment 220.

With weighted approaches by pronghorn from both sides of US 89 combined, totaling 5,035.2 approaches (16.2/segment), a significant peak accounting for nearly half (47%) of the approaches occurred at the north end of the Coconino NF between segments 130 and 150 (MP 441-442), or only 7% of the length of the study area (Figure 9). Of 31 total pronghorn that approached the highway, 22 (71%) approached US 89 in this 2-mile zone.

4.1.4 Linear Approach Distance along Highway

GPS-collared pronghorn (n = 31) were recorded within 0.30 mile of the highway along a mean linear distance of 6.5 miles (±0.8) adjacent to US 89. The linear distance in which pronghorn approached the highway on the east side (7.9 mile; ±1.2; n = 13) was greater than animals approaching on the west side (5.6 mile; ±1.1; n = 18), though the difference was not significant (P = 0.169). Likewise, though the mean linear distance in which approaches occurred adjacent to the highway by males (7.7 miles; ±1.5; n = 13) was higher than by females (5.7 miles; ±0.9; n = 18), the difference was not significant (P =



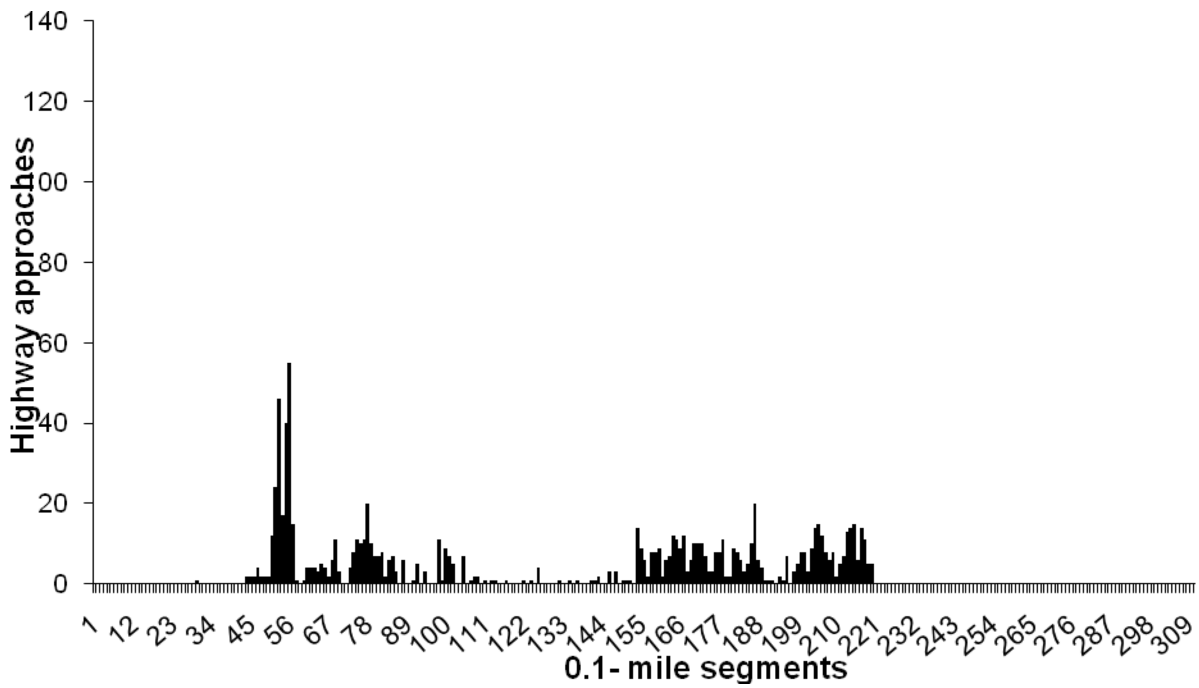


Figure 7. Frequency distribution among 0.1-mile segments of approaches to within 0.3 mile of US 89 made by 18 pronghorn on the west side of the highway (top) and by 13 pronghorn on the east side of the highway (bottom). Both distributions differed from a discrete random distribution.

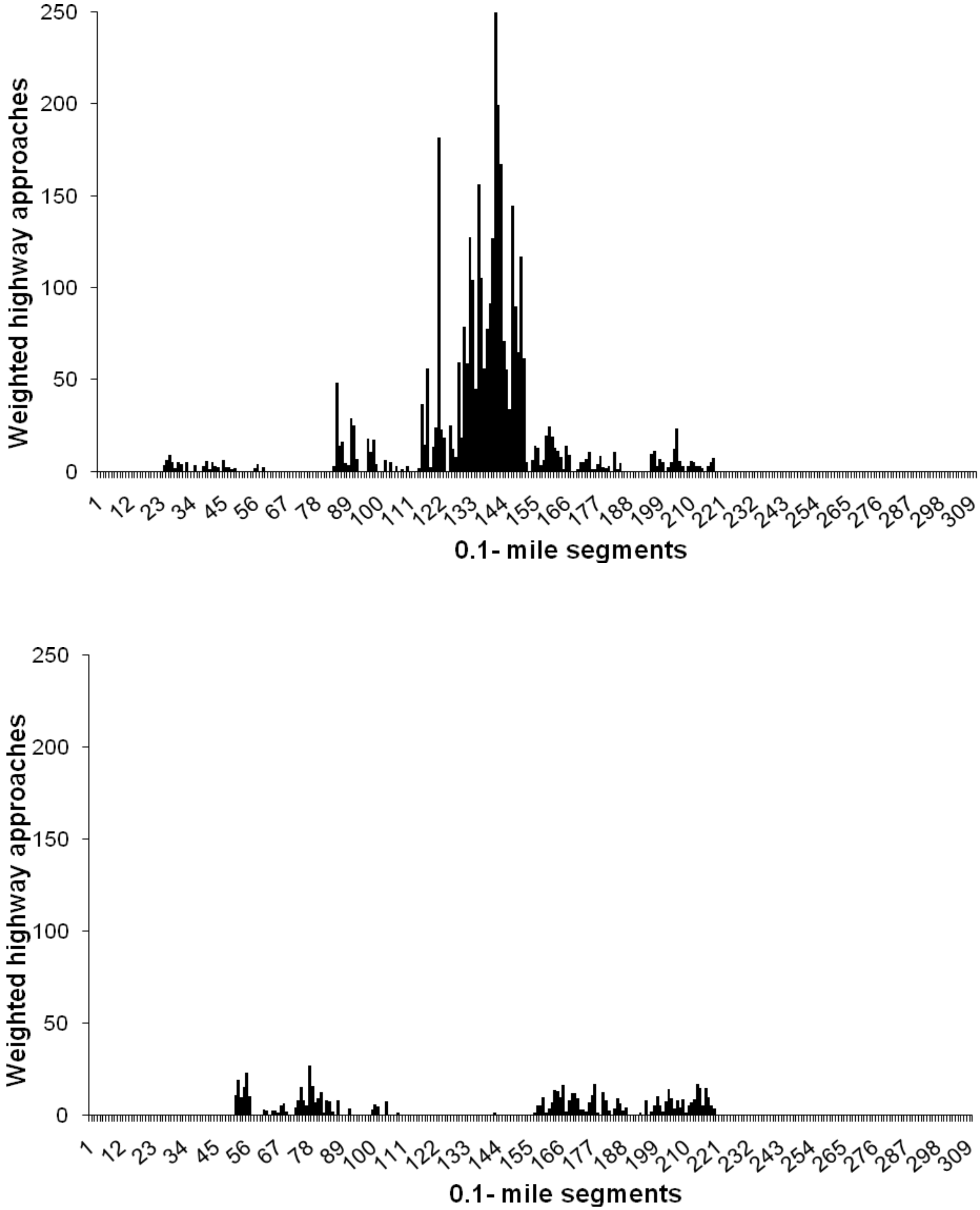


Figure 8. Frequency distribution among 0.1-mi segments of Shannon diversity index-corrected weighted approaches to within 0.3 mi of U.S. Highway 89, Arizona made by 18 pronghorn on the west side of the highway (top) and by 13 pronghorn on the east side of the highway (bottom). Weighted approaches reflect animal approach frequency, number of approaching animals, and equity in distribution among approaching pronghorn.

= 0.231). This linear distance reflects the extent that pronghorn approach and use the habitat adjacent to US 89, and has a bearing on the number and spacing of potential passage structures.

4.2 PRONGHORN MOVEMENTS AND FENCING REMOVAL

At and adjacent to the 0.1-mile segment (172; MP 444.1 to MP 444.2) where barbed-wire fencing was removed from ROW fence T-posts within Wupatki National Monument, no pronghorn crossings were recorded. At the segment where fence was modified and 0.1 mile on either side, approaches to within 0.3 mile of the highway averaged 6.3 approaches/segment. This compared to a mean of 7.0 approaches/segment in the adjacent half-mile stretch to the north of the modified fence, and a mean of 5.8 approaches/segment a half mile to the south. Similarly, there was no discernable increase in approaches to within 0.15 mile of US 89 that could better reflect an "intent" or attempt to cross the highway; two approaches occurred at the 0.1- mile segment where fence was modified compared to a mean of 2.0 approaches/segment a half mile to the south, and 1.6 approaches/segment for a half mile to the north. As such, it does not appear that pronghorn responded with increased highway crossings or approaches to this limited section where fencing was modified. This underscores the importance of the effort to remove fence along three miles of ROW in November 2008 and its prospect for achieving improved pronghorn passage, as well as the two-year commitment to monitor pronghorn response to this fence removal.

4.3 TRAFFIC VOLUME AND PRONGHORN DISTRIBUTION

The distribution analysis was based on 10,100 pronghorn GPS relocations recorded within 3,300 ft of US 89. Frequency distributions of mean probabilities of pronghorn occurring in distance bands showed minimal shift in distribution away from the highway at increasing traffic volume until traffic reached 500 vehicles/hr (Figure 10). Among all traffic volumes up to 500 vehicles/hr, mean distribution probabilities were constant (Table 1), varying minimally (<15%) among traffic volume classes. At distances between 0 to 990 ft from the highway, the mean distribution probabilities at traffic volumes up to 500 vehicles/hr were <0.15. At traffic volumes between 500 and 600 vehicles/hr, mean pronghorn distribution probabilities between 1,320 and 2,970 ft declined 17% compared to lower traffic volume classes, and increased 73% in the 2,970 to 3,330 ft class (Table 1, Figure 10). The mean probability of female pronghorn occurring within 1,980 ft of US 89 across all traffic volumes (0.45) was slightly lower than the probability for males (0.49). The most apparent difference between sexes occurred at 3,300 ft from the highway, where the female distribution probability across all traffic volumes (0.17) was higher than the mean male probability (0.11).

4.4 PRONGHORN-VEHICLE COLLISIONS

During the project from 2007 to 2008, no WVC involving pronghorn were recorded by DPS highway patrolmen or the research team along US 89. Further, no pronghorn

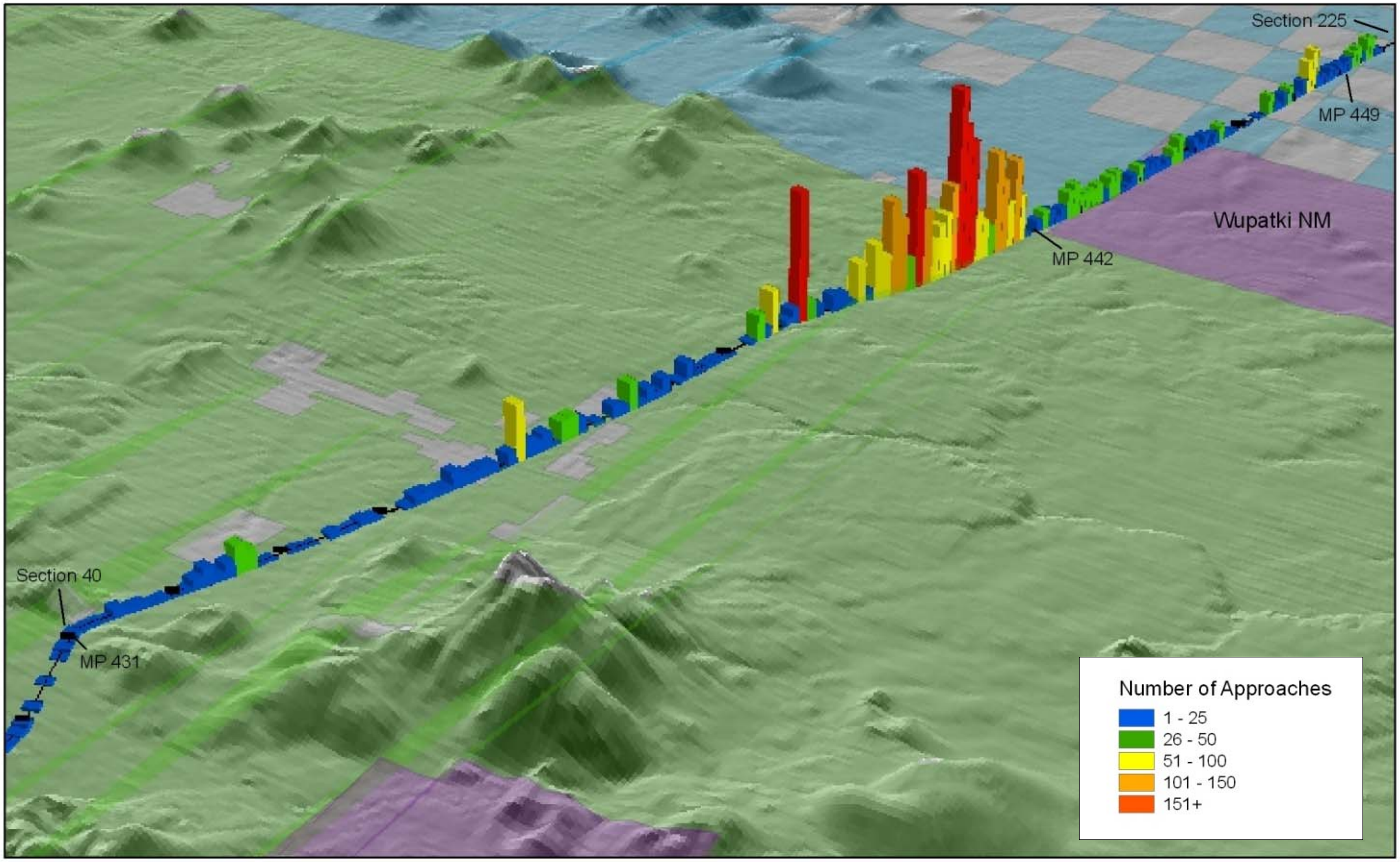


Figure 9. Combined frequency distribution among 0.1-mile segments of weighted approaches to within 0.3 mile of US 89 made by 31 pronghorn on both sides of the highway.

records were found in ADOT's long-term statewide roadkill database for the period 1990−2006.

4.5 IDENTIFICATION OF PASSAGE STRUCTURE SITES

The distribution of weighted approaches by pronghorn along US 89 (Figure 9) alone suggests locations where passage structures might be appropriate. When combined with other criteria such as identified by Sawyer and Rudd (2005), ratings of 0.6-mile segments between MP 440.0 to 458.0 for suitability to passage structures ranged from 5−26 points (Appendix A, Figure 11). The highest rated 0.6-mile segment (0.1-mile segments 142-147) on the Coconino NF boundary south of Antelope Hills corresponded to the stretch of highway with the highest mean weighted pronghorn approaches (116.1 approaches/segment), highest mean number of different pronghorn (10.3/segment), and favorable land ownership, all of which make this site highly suited for a pronghorn passage structure. The second highest rated segment was immediately to the north (148-153), scoring 24 points. The adjacent segment corresponded to the area encompassing the private lands at Antelope Hills with relatively few weighted approaches (23.2/segment) and different pronghorn (3.8/segment), coupled with high human activity and poor prospect for addressing fencing needs, all contributing to its low rating for passage structure suitability (Figure 11; Appendix A). The next four highest rated segments (18-19 points) were those on Wupatki National Monument (segments 160-183) up to the segment with the main park entrance road and visitor pullout that rated lower (17 points). North of Wupatki National Monument between segments 196−219, three of four 0.6-mile segments rated >10 points (Figure 11), with the one at segments 202−207 corresponding to the minor peak in pronghorn approaches (Figure 9). Beyond segment 220, there were no weighted crossings and no more than a single different pronghorn that approached the 0.1-mile segments.

Table 1. Mean combined probabilities that GPS-collared pronghorn (*n* = 31) found within distance bands from the highway at varying traffic volumes. Probabilities were determined from pronghorn telemetry and traffic counting conducted along U.S. Highway 89, Arizona, from 2007−2008.

Distance from highway (ft)	Probability of occurring in distance band by traffic volume (vehicles/hr)					
	<100	100−200	200−300	300−400	400−500	500−600
300−990	0.15	0.13	0.15	0.14	.014	0.14
990−1,980	0.33	0.35	0.35	0.33	0.33	0.27
1,980−2,970	0.40	0.40	0.38	0.38	0.37	0.34
2,970−3,300	0.12	0.13	0.11	0.15	0.16	0.26

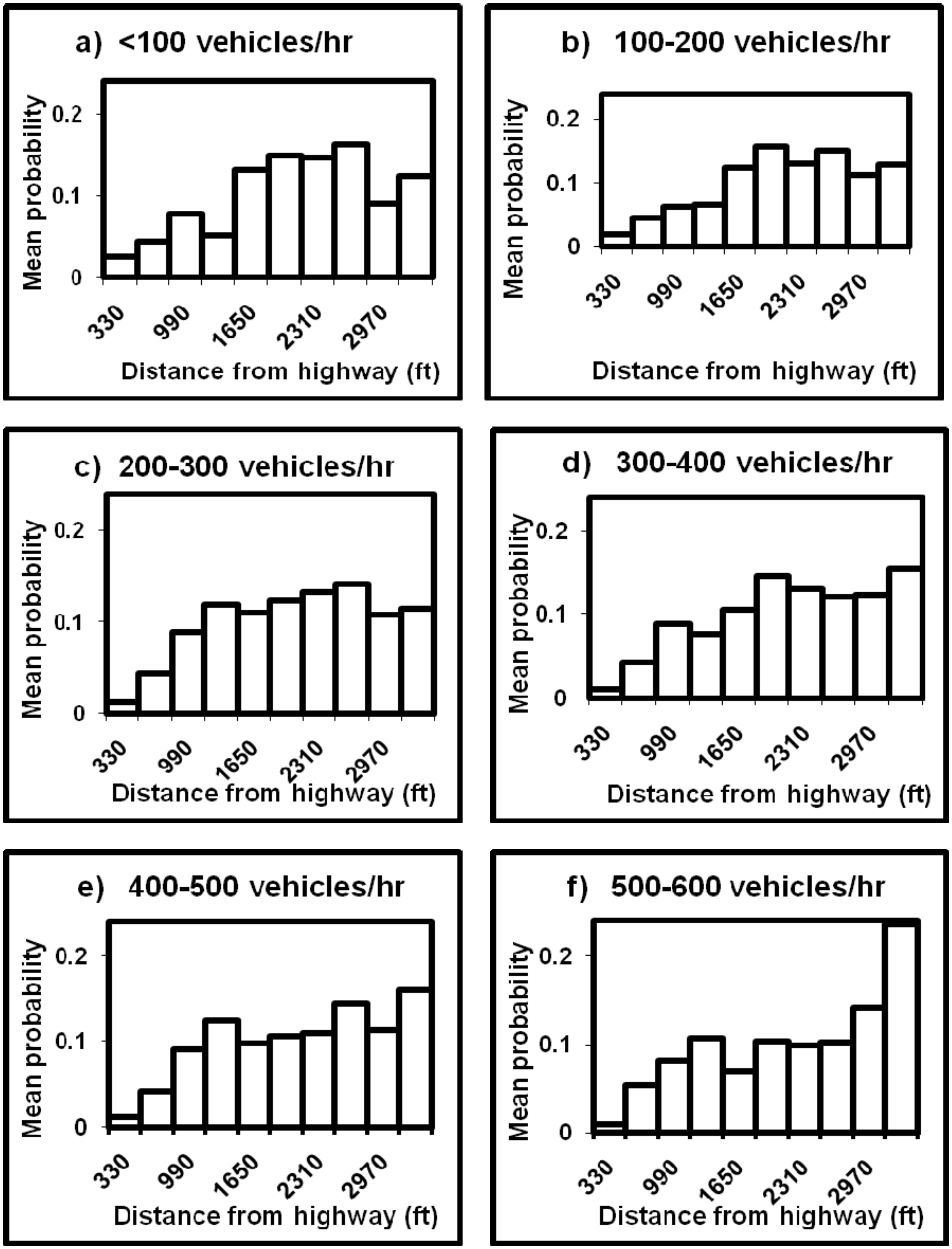


Figure 10. Mean probabilities that GPS-collared pronghorn (*n* = 31) occurred within each 330-ft distance band from the highway at varying traffic volumes: a) <100, b) 100−200, c) 200−300, d) 300−400, e) 400−500, f) 500−600 vehicles/hr.

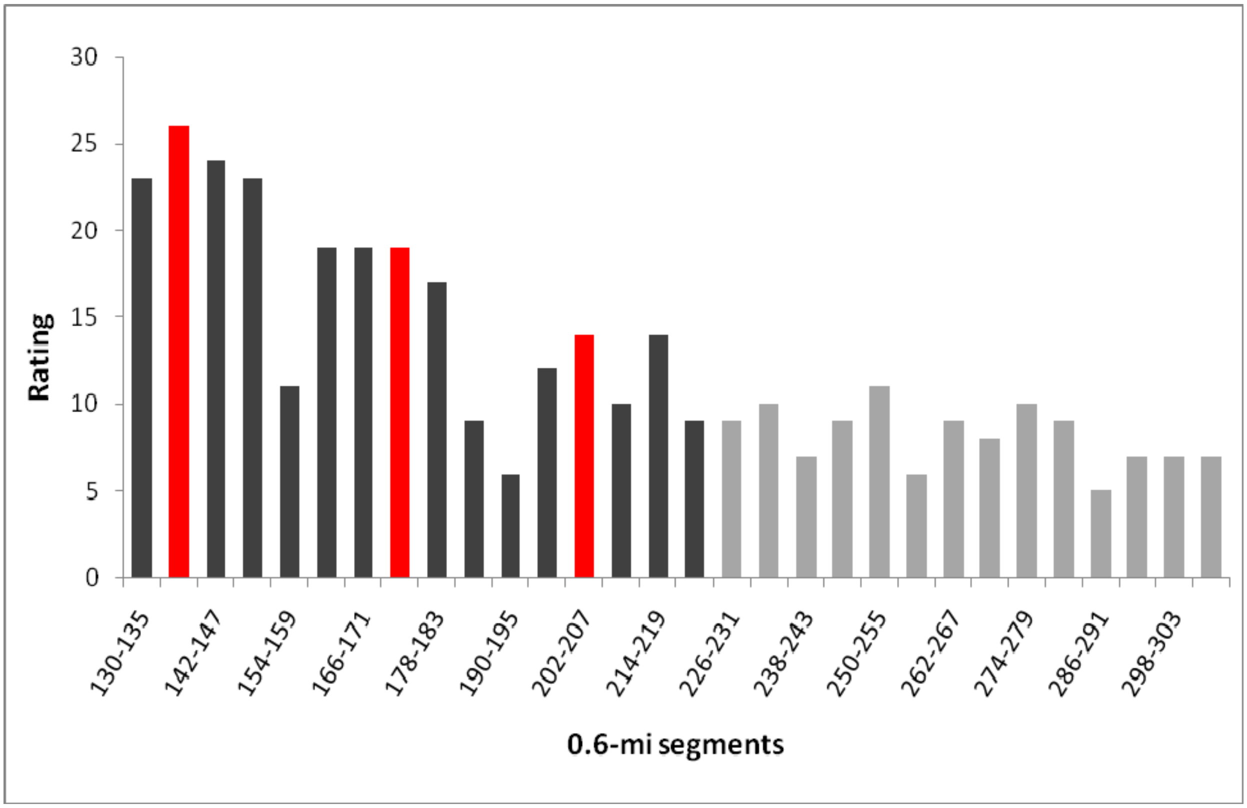


Figure 11. Ratings of suitability for pronghorn passage structures based on seven criteria by 0.6-mile segment between US 89 mileposts 440.0 and 458.0 (Appendix A). Red bars denote the three recommended segments for pronghorn passage structures based on ratings, weighted approaches, and approximate 3.2-mile spacing between passage structures. Gray bars denote segments where no weighted pronghorn crossings were recorded.

5.0 DISCUSSION

Dodd et al. (2006) advocated utilizing WVC and roadkill data where it exists as a surrogate to costly GPS telemetry movement information to plan and identify locations for wildlife passage structures; they found that the spatial incidence of WVC was strongly associated with GPS-determined highway crossings. However, in the instance of a species like pronghorn where highways constitute passage barriers to the degree that pronghorn-vehicle collisions do not occur, GPS telemetry data is essential to developing informed, data driven recommendations for passage structure placement. And where traditional VHF-telemetry studies were instrumental in first demonstrating the degree to which northern Arizona highways constituted barriers to pronghorn movement (Ockenfels et al. 1997, van Riper and Ockenfels 1998, Bright and van Riper 2000, Hart et al. 2008), these studies provided only limited insights on the best locations for potential passage structures when compared to GPS telemetry. Dodd et al. (2007*d*) stressed how GPS telemetry has revolutionized wildlife movement studies, particularly those intended to quantify wildlife permeability across highways, as GPS yields tremendous amounts of unbiased movement data. In this study, the mean number of GPS relocations for individual pronghorn (n = 3,194) exceeded the relocations of all animals combined on most previous Arizona VHF telemetry projects, with the exception of Ockenfels et al. (1994) that relocated 47 animals 4,996 times.

5.1 PRONGHORN PERMEABILITY

With the insights gained from previous northern Arizona telemetry studies (Ockenfels et al. 1997, van Riper and Ockenfels 1998, Bright and van Riper 2000, Hart et al. 2008), the research team expected that the US 89 pronghorn passage rate would be low compared to elk (Dodd et al. 2007*d*, 2009; 0.43−0.88 crossings/approach) and white-tailed deer (Dodd et al. 2009; 0.03−0.16 crossings/approach). However, the negligible pronghorn passage rate (0.006 crossings/approach) where only one of 30 animals that approached US 89 ultimately crossed was even lower than anticipated. The lone female crossed at the driest time of the year (June 2007), apparently crossing the highway six times to utilize stock tanks on the east side and returned each time. Unfortunately, these movements occurred outside of the breeding season such that no genetic benefit was realized. US 89 can be considered a near-total barrier to the passage of pronghorn, and thus has effectively subdivided the GMU 7 herd into two isolated populations. The future reconstruction of US 89 between MP 442.0 and 458.0 to a 4-lane divided highway with an 84-ft median will certainly exacerbate this barrier effect, as predicted by wildlife highway avoidance models (Jaeger et al. 2005, Hart et al. 2008).

The impact of isolation on the separate herds on each side of US 89 is difficult to assess. Current genetic assessment of the populations on each side of US 89 and comparison to other populations is now underway. This assessment is similar to those done elsewhere for bighorn sheep (Epps et al. 2005) and meso-carnivores (Riley et al. 2006), and will help quantify the impact of highway-induced genetic isolation and drift. Genetic samples collected during the capture of pronghorn on this project are being analyzed as part of a cooperative effort between ADOT, AGFD, and Northern Arizona University's

Department of Biology (ADOT Project SPR-659, *Genetic Variation of Pronghorn Across US Highway 89 and State Route 64*). This genetic assessment will constitute a baseline from which to conduct future assessments of the genetic effectiveness of passage structures, argued for by Corlatti et al. (2009) as being warranted to justify the high cost of such structures.

The GMU 7 pronghorn population may be exhibiting symptoms of isolation. Though the populations on each side of US 89 are largely isolated from each other, there likely remains some level of gene flow and interaction with pronghorn further to the west and east, though the distance that GPS-collared animals travelled away from the US 89 corridor over two years was limited (Figure 6). The research team's observations, as well as those of other pronghorn biologists familiar with the US 89 populations (R. Ockenfels and B. Holton, personal communications) were that the eastern herd has noticeably declined over the past ten or more years. During the initial capture effort in January 2007, a winter snowstorm pushed and concentrated over 350 animals from the northern slopes of the San Francisco Peaks to within a mile of the west side of US 89. On the east side, only 30-40 different animals were found within five miles of US 89, similar to the number found in December 2007 during the subsequent second capture. When animals were captured for previous VHF telemetry studies in 1992−1994 (Ockenfels et al. 1997, van Riper and Ockenfels 1998), "hundreds" of pronghorn were seen on the east side and within five miles of US 89 (R. Ockenfels, personal communication). The pronghorn recruitment rate (fawns:doe) on the east side of US 89 has averaged 40% lower than on the west side since 2003. This is a source of concern for a population exhibiting a downward population trend (AGFD unpublished Pronghorn Hunt Recommendations, Game Branch, Phoenix) and not benefitting from population replenishment and genetic flow from the potential "source" population on the west side of US 89.

In spite of these population and isolation concerns, the findings of this study serve to illustrate that the population's numbers adjacent to US 89 remain sufficient to benefit from potential passage structures that would promote connectivity, an important consideration stressed by Sawyer and Rudd (2005). Furthermore, the movement, distribution, and weighted approach data suggest that it is likely that pronghorn would encounter and use one or more passage structures, which would ultimately successfully enhance permeability.

5.2 TRAFFIC VOLUME AND PRONGHORN DISTRIBUTION

Pronghorn distribution among all distances and across all traffic volumes up to 500 vehicles/hr remained constant. Only at 500−600 vehicles/hr (equivalent to 12,000−14,400 AADT) did a change in distribution occur. At this traffic volume the probability of pronghorn being 3,300 ft from US 89 was nearly double that at 100 vehicles/hr or lower. Mean probabilities of occurrence of white-tailed deer also showed minimal shift in distribution away from SR 260 at increasing traffic volume, with the mean probability of a deer occurring within 660 ft of the highway remaining constant from approximately 0.32 at <100 vehicles/hr to 0.28 when traffic was >600 vehicles/hr (Dodd et al. 2009). In contrast to both pronghorn and deer, elk along SR 260 exhibited dramatic shifts in distribution across distance bands with increasing traffic, including a >50% reduction in the probability of being within 660 ft of the roadway as traffic increased from <100 to 600 vehicles/hr. However elk exhibited higher probabilities of occurrence closer to the road when traffic volumes were at their lowest (Gagnon et al. 2007*b*). Elk utilized lush meadows adjacent to SR 260 for feeding (Manzo 2006; Dodd et al. 2007*b*) and were relocated within 0.6 mile of the highway at twice the expected frequency of occurrence (Dodd et al. 2007*d*). In the absence of such attractive habitats adjacent to US 89, pronghorn appear to lack an incentive or attractant to "tolerate" even the impact of relatively low traffic volumes. Whereas Reeve (1984) reported that regular vehicular traffic produced minimal disturbance among pronghorn due to habituation, the research team believes that pronghorn along US 89 are consistently negatively impacted by traffic volume even at low levels, which is seldom during the daytime when pronghorn are most active (Figure 3). Daytime traffic volumes along US 89 typically exceed the 10,000 vehicles/day level where highways become strong barriers to wildlife passage and traffic repels animals from the roadway, as hypothesized by Mueller and Berthoud (1997).

Just as Reeve (1984) found females with young to be more sensitive to vehicular traffic and Gavin and Komers (2006) reported that female pronghorn in spring and herds with young exhibited higher proportions of vigilant behavior, a 54% higher proportion of female relocations compared to males occurred at the furthest distance (3,300 ft) from US 89 that was assessed. This suggests that females may be more sensitive to traffic-associated impacts from the highway.

5.3 STRATEGIES TO PROMOTE PRONGHORN PERMEABILITY

As detailed by Sawyer and Rudd (2005), several factors support the continued pursuit and development of strategies for wildlife passage structures along the US 89 study area, including:

- Pronghorn populations on each side of US 89 are sufficient in numbers (particularly on the west side) and remain viable with reproduction, though they may be exhibiting signs of isolation indicating the future action to promote permeability is warranted; pronghorn population status warrants action and it is expected that the population will benefit and respond to management actions.

- US 89 represents a near-total barrier to the passage of pronghorn across the highway; without intervention, especially as the highway is upgraded, the impact of the highway barrier effect will increase and further limit pronghorn movement.

- The distribution and movement of pronghorns along US 89, the numbers for weighted approaches, and the counts for different animals using highway segments suggest that pronghorn will likely use passage structures. Peak use zones and areas of pronghorn concentration near US 89 ensure that a significant portion of the population will encounter passage structures once built.

- Land ownership is conducive to potential passage structure construction and integrated management of ROW fences, both of which are critical to the success of promoting permeability.

In developing its strategies to promote pronghorn permeability along US 89, the research team addressed the following considerations:

- Number of passage structures and spacing needed to accommodate pronghorn passage.

- Locations and priorities for potential passage structures.

- Role of ROW fencing and options.

- Types of passage structures and specific design criteria.

5.3.1 Number and spacing of passage structures

The spacing of wildlife passage structures has a potentially significant impact on their ability to promote highway permeability (Olsson 2007, Bissonette and Adair 2008, Dodd et al. 2009). Bissonette and Adair (2008) recommended spacing of 2.0 miles between passage structures to accommodate pronghorn permeability based on isometric scaling of home ranges. Using this criterion for the stretch of US 89 evaluated for passage structures (MP 440.0 to 458.0), approximately nine passage structures would be required. If the target highway stretch was shortened by 9 miles to eliminate the 0.1-mile segments where no weighted approaches by pronghorn occurred (segments 221−310), four to five passage structures would be required to promote pronghorn permeability.

The mean linear distance that pronghorn travelled adjacent to US 89 over the duration of the project was 6.5 miles, while the daily distance traveled by individual pronghorn averaged 3.2 miles. These movements reflect the "flattening" effect that US 89 has on the configuration of pronghorn home ranges and the linear distance travelled along this impermeable highway corridor (Figure 12). Ockenfels et al. (1997) reported elongated home ranges reflecting constriction along transportation corridors compared to more typical pronghorn home range shapes (O'Gara and Yoakum 1992). Clevenger et al. (2001) noted that animals travelled parallel to a highway after encountering the roadway corridor. On the other hand, recommendations made by Bissonette and Adair (2008) reflect uniformly shaped home ranges that were bisected by highways.

The research team believes that 3.2-mile spacing between passage structures more realistically reflects empirical pronghorn movements along US 89. This recommended spacing reflects the mean daily distance traveled by pronghorn and is half the mean linear distance travelled along US 89 by collared pronghorn. This distance ensures that a passage structure would be encountered no further than 3.2 miles in either direction along the average linear travel distance. Using a passage structure spacing of 3.2 miles over the entire 16.8-mile stretch of highway, five passage structures would be required.

Excluding the 9-mile stretch of highway where no weighted pronghorn approaches occurred, two to three passage structures would be required to promote pronghorn permeability.

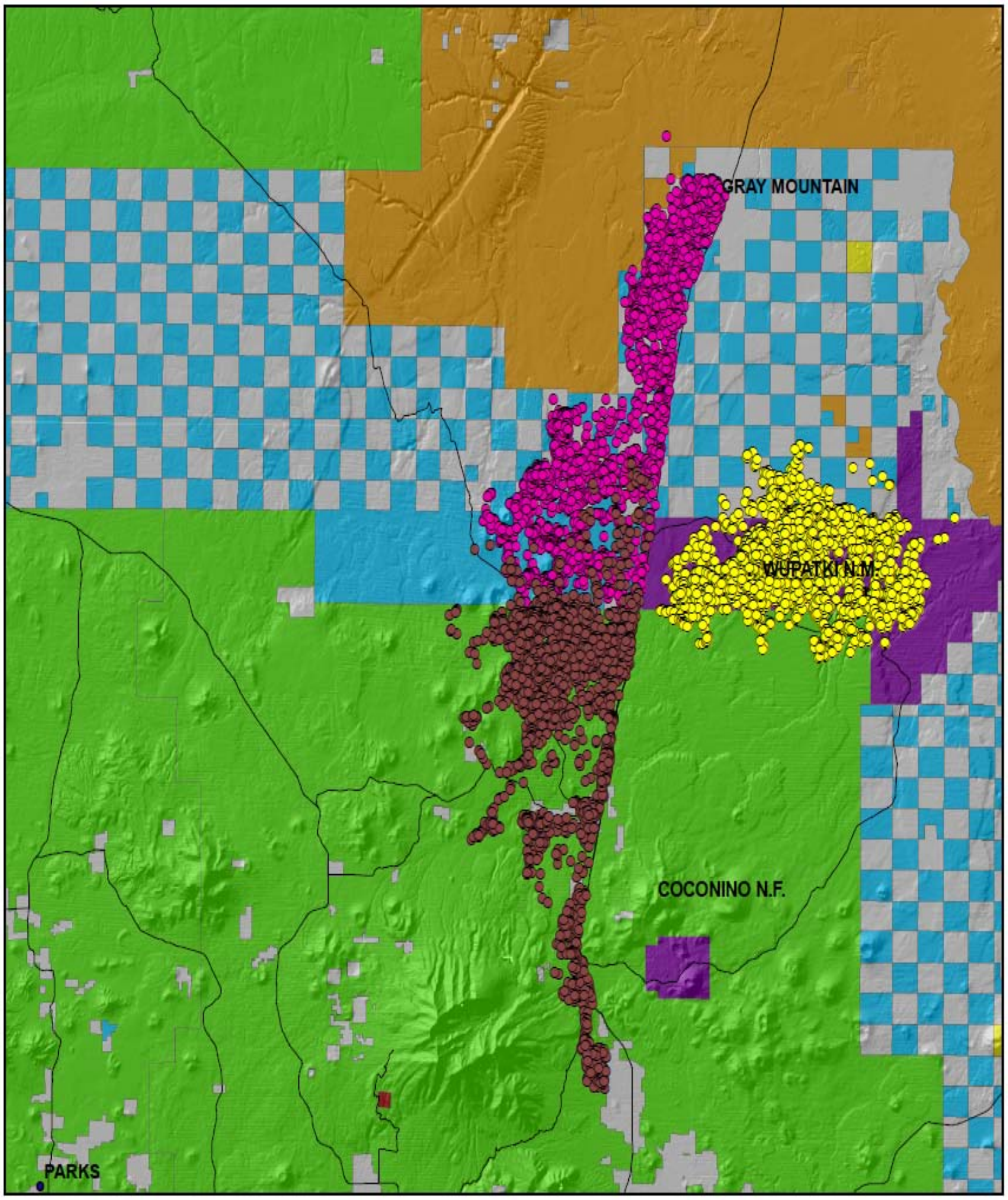


Figure 12. Comparison of GPS fix distributions for three representative pronghorn adjacent to US 89, with the pronghorn on the east side of the highway (yellow) never approaching the highway and thus not flattening the distribution linearly along the impermeable barrier as with the two pronghorn on the west side of the highway.

5.3.2 Locations and Priorities for Potential Passage Structures

Applying a spacing distance of 3.2 miles, priority sites for passage structures were identifed based on the rating of 0.6-mile segments. In identifying locations for potential passage structures, the research team excluded the 9-mile northernmost stretch of US 89 where no weighted pronghorn approaches occurred (Figure 7).

<u>Coconino National Forest - Antelope Hills Site</u>

Both the distribution of weighted pronghorn approaches (Figure 9) and ratings by 0.6-mile segment (Figure 11; Appendix A) unequivically show segments 136-141 (MP 440.6−441.1) to be the best stretch for a passage structure along US 89. This segment exhibited the largest peak in approaches and numbers of different pronghorn approaching the highway (Figure 9; Appendix A). This site appears to function as a “crossroads” for pronghorn moving adjacent to US 89 in either direction; 13 of 18 (72%) GPS-collared animals on the west side had approaches within this 0.6-mile segment, and six of 13 (46%) on the east side.

The concentration of pronghorn at this site likely reflects several factors. First, the area is situated on the ecotone or transition between juniper woodland and short grass prairie/grasslands (Figure 13). This zone reflects a transition from the fairly broken terrain to the south to the generally flat terrain vegetated by grasslands to the north (Figures 9 and 13). Though pronghorn are adapted to using open flat to undulating or rolling topography (Yoakum 1980), they do use broken and steeper terrain (Ockenfels et al. 1994). This vegetative and terrain transition zone near the Coconino NF boundary affords pronghorn refuge from winter storms and winds amongst junipers and behind leeward ridges, cinder cones, and other terrain. During summer, woodland cover is used for shading (Ockenfels et al. 1994), though pronghorn typically avoid dense woodlands (Ockenfels et al. 1994, Bright and van Riper 2000). This transition area also reflects higher vegetative diversity and composition, which has a strong influence on pronghorn populations (Ockenfels et al. 1994, Yoakum 1980). Areas with high shrub diversity have been shown to be important for fawning cover (Bright and van Riper 2000). The concentration of pronghorn in the vicinity of the Coconino NF boundary could also reflect differences in livestock management practices and potential competition with pronghorn on USFS, State Trust, and private lands (McNay and O’Gara 1982; B. Holton, unpublished report, NPS, Flagstaff, AZ).

This area of highest concentrated pronghorn distribution is along the US 89 section that was reconstructed to a 4-lane divided highway in 1999 (Figure 13). As such, erecting a passage structure here would constitute a “retrofitting” effort, though this would be permissible if done as part of an adjacent highway reconstruction project. The terrain at this site is generally a large west to east running ridge that slopes downward to the east; there are large cut slopes on the west side of the highway (Figure 13). This site would be conducive to the construction of an overpass for pronghorn passage.

Wupatki National Monument Site

Approximately three miles to the north of the Coconino National Forest – Antelope Hills site is the 0.6-mile segment (segments 172−177; MP 444.2−444.7) situated amongst the four relatively high-rated segments on Wupatki National Monument (Figure 11). Though this segment lacks the high frequency of weighted pronghorn approaches that occurred to the south, there were nonetheless approaches made by 11 different pronghorn. One of this site's most attractive features is the ease of addressing ROW fencing issues since no livestock graze here; the majority of the ROW fence on Wupatki National Monument has already been removed to facilitate pronghorn passage. The high quality of pronghorn habitat associated with the location also makes this site a favorable location for a crossing structure.

Roadway reconstruction plans for this area include a 4-lane divided highway with a 30-ft median, 54 ft less than the median planned north of Wupatki National Monument (ADOT 2006); this is another attractive aspect of this site as it requires a shorter span for a potential passage structure. The terrain within this segment ranges from a gentle shallow basin up to a gentle incline along the highway that culminates at a fairly flat ridgeline running west to east, with cut slopes on each side of the highway (Figure 14). This segment has two potential passage structure sites, one in the basin near a drainage that would support a wide underpass/viaduct type structure and the other at the ridge crest that would be more conducive to an overpass (Figure 14).

Babbitt Ranch Site

A peak in weighted pronghorn approaches occurred at segments 202−207 (MP 447.2−447.7; Figure 9), at which five different GPS-collared pronghorn approached the highway. This segment spans both private lands owned by Babbitt Ranches and State Trust land. The terrain in the segment is a broad flat basin typical of open pronghorn habitat (Figure 15). The segment lacks the topographic relief found at the other two priority passage structure sites (Figure 15). The rating for this segment (Figure 11) reflects the fact that Babbitt Ranches has taken a highly proactive role in pronghorn management and has expressed a desire to cooperate in the evaluation of potential passage structures and further modification of ROW fencing. A viaduct-type structure would be appropriate at this relatively flat basin site.

5.3.3 Role of ROW Fencing and Options

Hart et al. (2008) concluded that the lack of pronghorn response to fence modification treatments intended to promote passage across the railroad corridor through Petrified Forest National Park reflected several factors, including heavy rail traffic that deterred animals from approaching the corridor. However, the relatively short extent of the modified fence (0.6 mile) and the fact that T-posts were not removed contributed to the lack of measurable response by pronghorn. Thus, it is not surprising that pronghorn did not cross or approach US 89 at the 0.1-mile section where the barbed wire was removed but T-posts were left standing, though this fence had been modified for several years compared to the fence modifications Hart et al. (2008) assessed that were in place for only six months. The removal or modification of nearly two miles of ROW fence on Wupatki

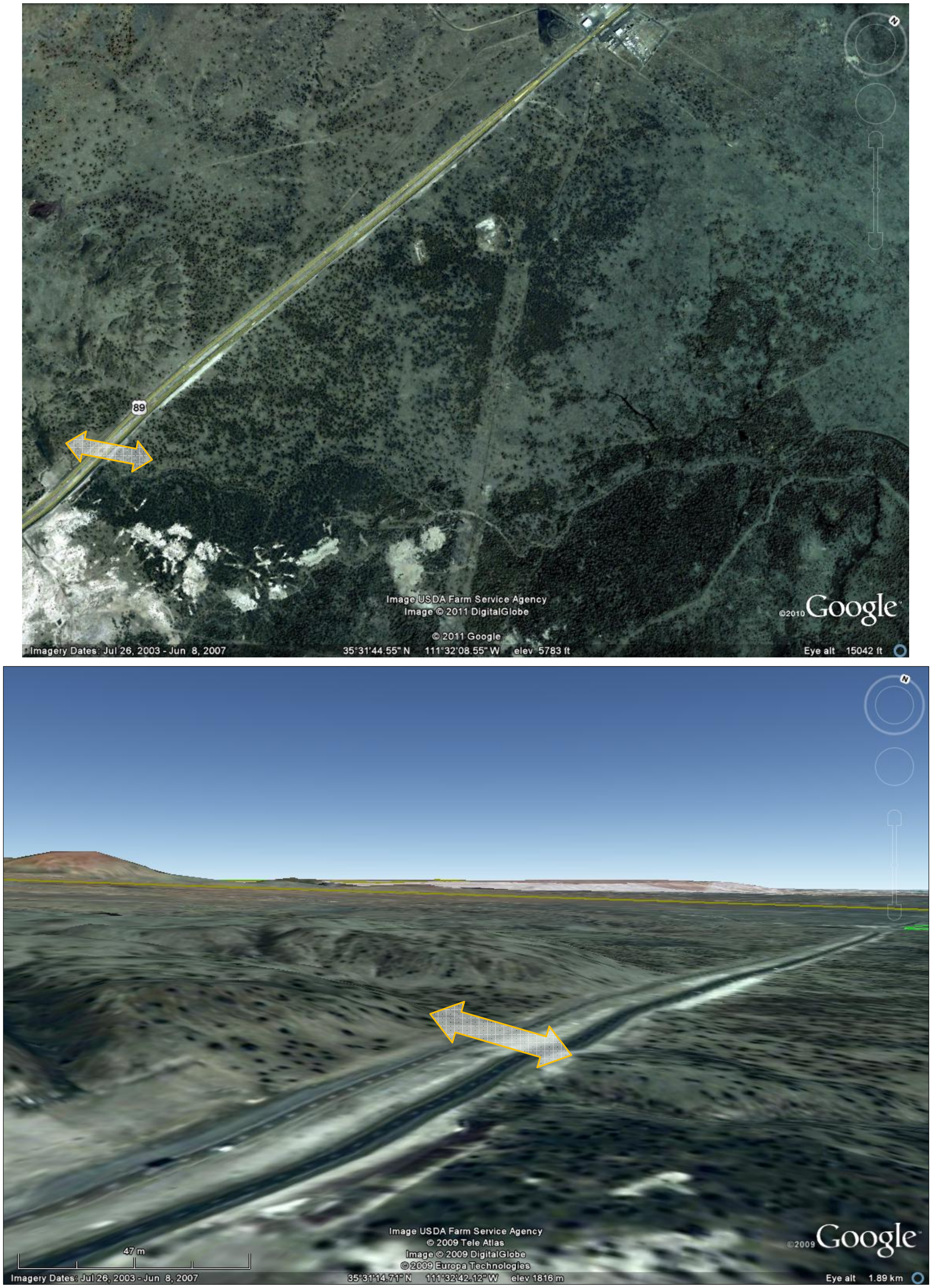
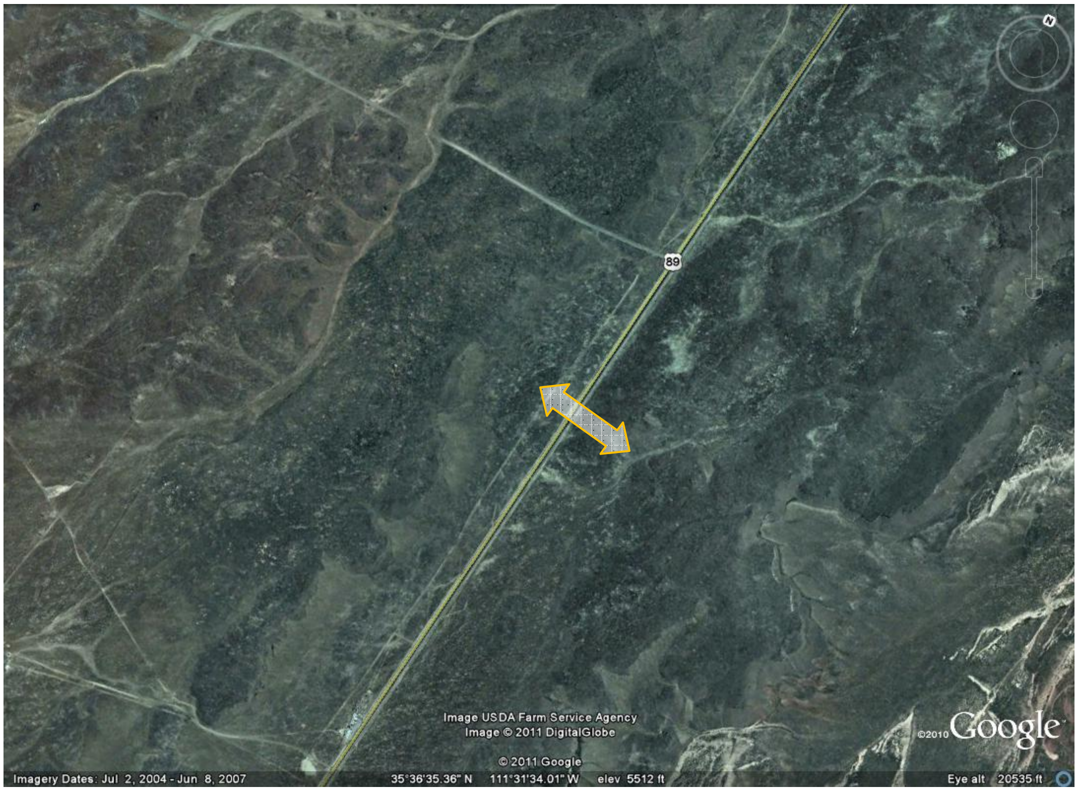


Figure 13. Aerial view (top) and enlarged oblique view (bottom) from GoogleEarth© depicting the proposed Coconino NF - Antelope Hills pronghorn passage structure site on US 89 between MP 440.6 and 441.1.

Figure 14. Aerial view (top) and enlarged oblique view (bottom) from GoogleEarth© depicting the potential Wupatki National Monument pronghorn passage structure sites between US 89 MP 444.2 and 444.7.



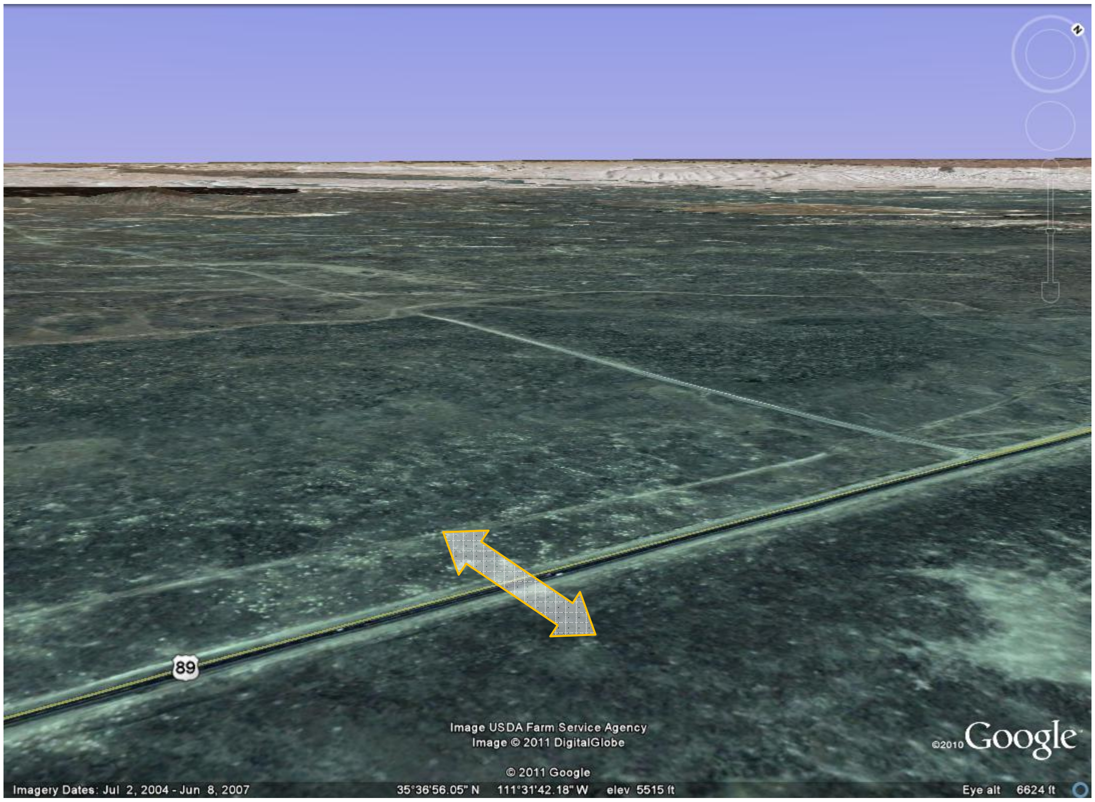


Figure 15. Aerial view (top) and enlarged oblique view (bottom) from GoogleEarth© depicting the Babbitt Ranch site between US 89 MP 447.2 and 447.7.

National Monument and Babbitt Ranches should provide a more thorough and conclusive evaluation of the ability to promote highway passage by eliminating or reducing the barrier effect of fences.

Whereas pronghorn evolved in open plains/grassland environments where speed and mobility was their defense against predators (Hart et al. 2008), this species has exhibited limited ability to adapt to fences like elk, deer, and other species have. And whereas fencing has been instrumental in preventing at-grade highway crossings and funneling animals to passage structures to reduce WVC and promote permeability (Clevenger et al. 2001, Dodd et al. 2007*c*), such an approach may not be necessary for pronghorn since they make few at-grade highway crossings and have few collisions with vehicles in Arizona. Sawyer and Rudd (2005:18) stressed the advantage of avoiding fences altogether in association with passage structures to promote pronghorn use. They stated that "ideally, a crossing structure should be located in an area with no fencing. If fencing is required, then (the) crossing structure(s) should be located in area(s) where fence design is pronghorn-friendly … and do not inhibit pronghorn movements to and from the structure." With the absence of livestock on Wupatki National Monument, ROW fencing is not needed, a significant advantage for promoting pronghorn permeability. On the Coconino NF and Babbitt Ranch lands, creative approaches such as pulling fences back 0.25 to 0.5 mile or resting pastures and removing fencing (B. Cordasco, Babbitt Ranches, personal communication) or raising/removing the bottom strand of barbed-wire fences (Hart et al. 2008) could minimize the impact of ROW fences. ROW fencing in association with passage structures is not needed to preclude at-grade pronghorn crossings of US 89. Fencing would play less of a physical funneling role (e.g., compared to elk; Dodd et al. 2007*c*) than providing a visual clue as to a path of least resistance across the highway barrier, provided no fencing is used at the mouth of the passages.

5.3.4 Types of Passage Structures and Specific Design Criteria

The focus of this project was to first identify the need for passage structures along US 89, which the research team believes is apparent (e.g., Figure 9), and then determine best locations for passage structures. Determining the appropriate types of structures for application at these sites is best left to ADOT's engineers. This is partly the reason for evaluating 0.6-mile segments: they provide technical latitude in specific site placement. And though the specific site characteristics will dictate what type of potential structure (e.g., underpass, viaduct, overpass) might be appropriate from engineering and cost standpoints, a few general criteria are important for consideration as specific structures are considered.

Structural design characteristics have a significant bearing on the eventual use and acceptance of passage structures by wildlife (Foster and Humphrey 1995; Clevenger and Waltho 2003; Gordon and Anderson 2003; Ng et al. 2004; Dodd et al. 2007*b*, 2009). Most important is the requirement that any type of structure that is considered for pronghorn passage be as open and wide as possible (Ruediger 2002, Sawyer and Rudd 2005), with special attention paid to avoiding obstructed line-of-sight views through or across the structures (Foster and Humphrey 1995, Sawyer and Rudd 2005, Dodd et al.

2007*a*, 2009). This species' adaptation to an open plains/grassland environment has resulted in a strong survival reliance on visual stimuli and avoidance of dense habitats and situations that restrict their view or mobility (Hart et al. 2008). While Yoakum (2004) questioned the ability to achieve pronghorn use of passage structures across high traffic volume roadways due to behavioral characteristics (e.g., highway avoidance), Sawyer and Rudd (2005) concluded that properly designed and located structures could be effective. They favored wide (>60 ft between bridge supports) and high (>24 ft) open-span bridge/underpass structures to overpasses, and in recognizing the lack of insights for pronghorn passage, believed underpasses to have wider application and lower cost, while also helping address drainage needs. The research team stresses that topography and the maximization of visual continuity for pronghorn are also critical concerns that may make overpasses attractive and/or applicable along certain US 89 locales. Most wildlife underpasses implemented along SR 260 that have proven so successful in promoting elk and deer passage (Dodd et al. 2009) would not function well for pronghorn passage; nor are similar topographic features prevalent along US 89 in which to situate underpasses, a strong selling point made by Sawyer and Rudd (2005) in recommending underpasses. Given a paucity of topographic situations in which to construct SR 260-type underpasses, including at all three priority US 89 passage structure sites, the research team envisions the potential application of either overpasses or open, elevated roadways/viaducts under which animals pass (Figure 16). Aside from their greater cost, the main drawback of such an underpass or viaduct would be traffic-associated noise emanating from the elevated roadway.

With the impact evident from the high daytime traffic on US 89, including the visual and noise impact on pronghorn (Mueller and Berthoud 1997), comprehensive measures to reduce the traffic-associated impact could create "quiet zones" along the highway in the areas of passage structures. Such quiet zones could facilitate pronghorn approaching (and successfully crossing) the highway and play a potentially significant role in promoting passage. A comprehensive set of measures should include incorporation of highway design, noise barriers that don't restrict movements, and pavement treatments (Kaseloo and Tyson 2004). In conjunction with passage structure construction, for instance, highway approaches to the structure could be recessed below grade to reduce the noise impact while supporting overpass construction. Soil berms or sound walls adjacent to passage structures may be warranted to help reduce traffic impact, as well as to shield traffic from pronghorn sight and vice versa. Such barriers could reduce traffic noise by as much as half, depending on their height (FHWA 2001). Further, shielding vegetation atop berms could further reduce traffic-associated noise, as would rubberized asphalt pavement near passage structures. Without a comprehensive effort to reduce traffic's noise and visual impact, the success of passage structures could be compromised by continued deterrence of pronghorn from the highway at high traffic volumes (Mueller and Berthoud 1997, Yoakum 2004).

One type of structure referenced by Sawyer and Rudd (2005) as having potential for use as a pronghorn passage is CON/SPAN® pre-cast concrete arches, which can span 60 ft

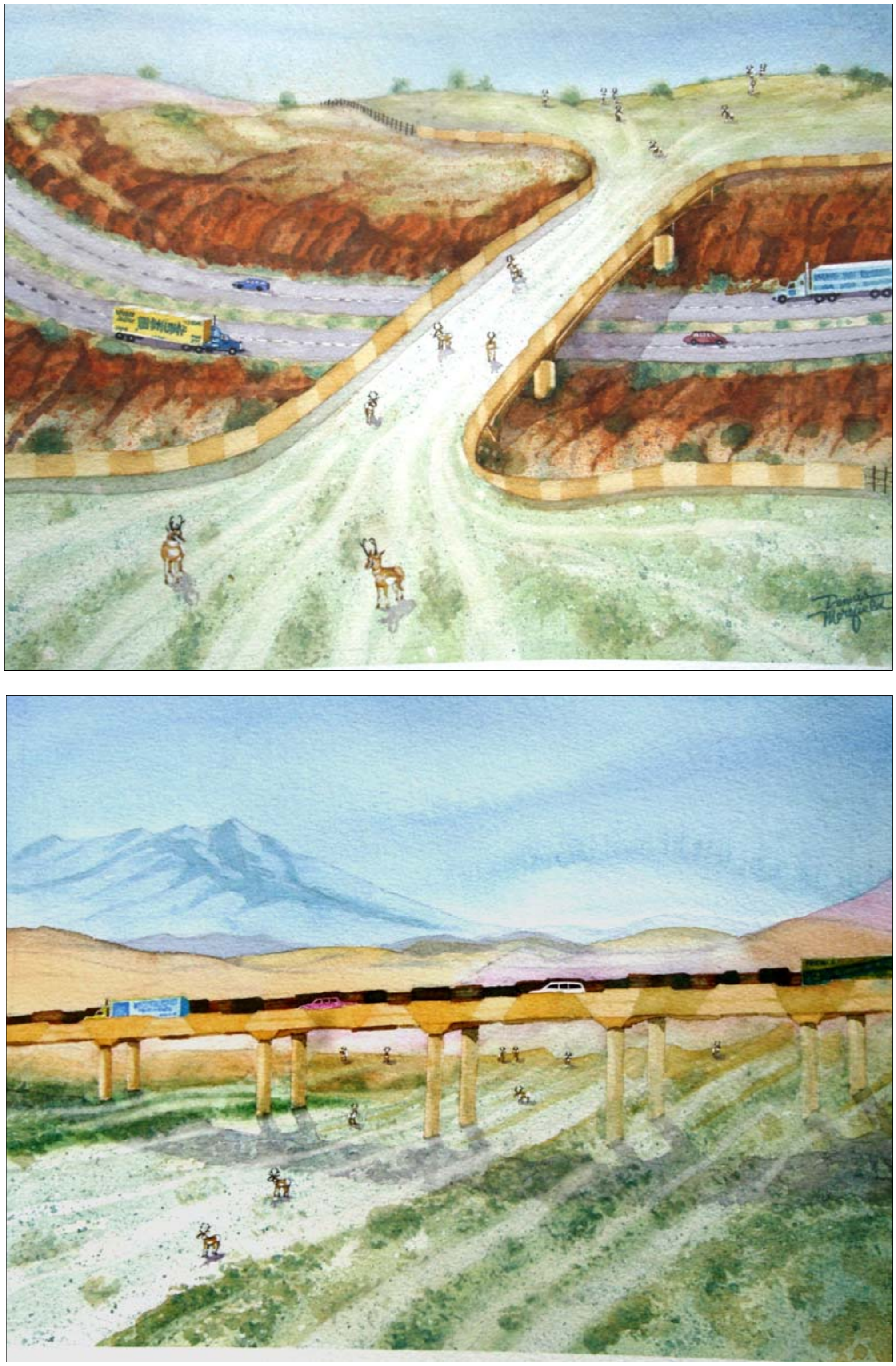


Figure 16. Renderings of potential pronghorn passage structures that emphasize openness and unobstructed views for crossing pronghorn, including an overpass capitalizing on existing terrain (top) and an elevated roadway/viaduct over gentle terrain (bottom).

and have various heights up to 24 ft and widths up to and exceeding 100 ft; additional height can be achieved by extending the pedestal walls upon which the barrels rest. Such a structure is potentially attractive for the Coconino NF- Antelope Hills site as it can quickly be dropped into place in a retrofit application with minimal disruption to traffic flow, is more cost effective than traditional bridge applications, and can maintain existing sloping ridgeline integrity by side-by-side installation with arches of different heights (Figure 17). Furthermore, the headwalls could be flared to maximize openness, with a width of 100 ft or more to create a wide, open overpass on which pronghorn would cross over US 89 (Figure 17).

A construction products company provided an estimate of the cost to erect a typical pre-cast concrete arch overpass at the Coconino NF-Antelope Hills site (MP 440.9) and conceptual plan sheets (Appendix B). The estimated cost for the construction of a 100-ft wide overpass is estimated at $542,725 (≅ $700,000 including installation but excluding fill atop the structure). This structure could be erected at the site in a matter of days.

Figure 17. Rendering of a CON/SPAN® pre-cast concrete arch application for a wildlife overpass at MP 440.9 along US 89. The bottom rendering depicts separate 32-ft spans (21 ft high) over each set of lanes, looking south, and the inset depicts the top of the overpass, looking east (note: fencing would need to be erected atop the walls).

6.0 CONCLUSIONS AND RECOMMENDATIONS

This project used a data-driven approach to quantifying pronghorn permeability across US 89, as well as determining the best locations for potential passage structures to enhance permeability. The study was particularly important given the lack of WVC data involving pronghorn, data that typically can serve as a surrogate to GPS-telemetry data for other ungulate species. The key conclusions and recommendations from this research project follow below.

Recommendations are highlighted using the symbol: ☞

6.1 PRONGHORN PERMEABILITY

- US 89 constitutes a near-total barrier to the passage of pronghorn, with only one of 37 animals having crossed the highway in two years of GPS telemetry tracking.
- The pronghorn highway crossing rate averaged only 0.001 crossings/day among 30 pronghorn that approached US 89 to within 0.15 mile. The pronghorn passage rate was negligible; only 0.006 crossings/approach.
- Due to the barrier effect and consequent few crossings by pronghorn, no collisions with vehicles were recorded during the study, nor were any pronghorn-vehicle collision records found in ADOT roadkill databases dating back to 1990.
- The barrier effect associated with US 89, coupled with the continued viability and size of the pronghorn population points to the need for and potential benefit of passage structures to promote permeability and maintain population viability.

6.2 POTENTIAL PASSAGE STRUCTURE LOCATIONS AND SPACING

- Based on weighted approaches by GPS-collared pronghorn to within 0.3 mile of US 89, combined with several other factors analyzed at the 0.6-mile segment scale, potential locations for pronghorn passage structures were objectively rated. Pronghorn approaches to US 89 did not occur in a random manner, but rather exhibited peak approach zones.
- Bissonette and Adair (2008) recommended spacing of 2.0 miles between passage structures to accommodate pronghorn permeability based on theoretical isometric scaling of home ranges. However, based on the empirical findings from this project, the research team arrived at a different recommendation:

    ☞ The research team recommends a spacing of 3.2 miles between passage structures which reflects: 1) the mean daily movement distance of pronghorn, 2) half the mean linear approach distance by pronghorn along US 89 determined over the duration of tracking, and 3) the "flattening" effect of the highway on pronghorn home ranges that abut US 89.

- Based on the weighted pronghorn approaches and other rating factors, as well as the research team's spacing recommendation, three sites are recommended for potential passage structures between MP 440.0 and 458.0.

  - ☞ The highest priority for a passage structure was the section of US 89 between MP 440.6 and 441.1 (segments 136−141), the Coconino NF - Antelope Hills site. This site had the largest peak in pronghorn approaches and numbers of different pronghorn approaching the highway, with 72% of GPS-collared animals on the west side approaching the highway here, and 46% of the animals on the east side approaching it. This site falls within a portion of US 89 that has already been reconstructed to four lanes, but is close enough to the future reconstruction stretch for passage structure construction be permissible here.

  - ☞ The Wupatki National Monument passage structure site (MP 444.2−444.6; segments 172−177), located three miles to the north of the Coconino NF-Antelope Hills site, is situated amongst four relatively high rated segments on Wupatki National Monument. This site is attractive due to the ease of addressing ROW fencing issues since no livestock grazing occurs here, and the planned highway median is considerably narrower (54 ft) than other sites' medians.

  - ☞ A third passage structure is recommended at the Babbitt Ranch site (MP 447.2−447.7, segments 202−207), three miles north of the Wupatki National Monument site. This site spans both private lands belonging to Babbitt Ranches and State Trust land. The rating for this segment reflects Babbitt Ranches' proactive role in pronghorn management, including further modification of ROW fencing.

  - ☞ Where passage structures are considered, long-term land tenure must be secure to ensure that the structures yield their intended benefit in promoting pronghorn passage relative to the cost. Structures constructed on USFS and NPS lands are secure, while strategies such as conservation easements or long-term cooperative agreements may be needed on private or State Trust lands to ensure similar long-term benefit.

6.3 IMPACT OF TRAFFIC AND NOISE

- Pronghorn distribution among all distances and across all traffic volumes up to 500 vehicles/hr remained constant. Only at 500-600 vehicles/hr (equivalent to 12,000−14,400 AADT) did a change in distribution occur. At volumes between 500 and 600 vehicles/hr, mean pronghorn distribution probabilities between 1,320−2,970 ft declined 17% compared to lower traffic volume classes, and increased 73% in the 2,970−3,330-ft class. In the absence of attractive habitats adjacent to US 89, pronghorn appear to lack an incentive to approach any closer.

- Traffic, at even low volume, consistently has a negative impact on pronghorn. Daytime traffic volumes along US 89 typically exceed 10,000 vehicles/day, the level at which highways become strong barriers to wildlife passage and traffic repels animals from the roadway, as hypothesized by Mueller and Berthoud (1997). Pronghorn are primarily active during daytime hours when traffic volume peaks on US 89.

  ☞ A comprehensive set of measures to reduce traffic-associated noise impact should be considered to create "quiet zones" along the highway at passage structure locations to facilitate pronghorn highway approaches and crossings. These measures could include recessing the roadway below grade, integrating noise barriers such as berms, vegetation, and sound walls, and applying pavement treatments like rubberized asphalt. Without a comprehensive effort to reduce noise and visual impact, the success of passage structures could be compromised.

6.4 ROLE OF FENCING

- Because pronghorn have exhibited limited ability to adapt to fences like other ungulate species, ROW fences contribute significantly to the highway barrier effect. And while fencing has been instrumental in funneling other animals to passage structures to promote permeability, such an approach may not be necessary for pronghorn because they seldom cross the highway. Rather, fencing in conjunction with passage structures may be more useful in providing a visual clue as to a path of least resistance across the highway barrier, provided no fencing is used at the mouth of the passages.

  ☞ Ideally, passage structures should be located in areas with no ROW or livestock pasture fencing near the highway as fencing presents an impediment to free passage by pronghorn to and across the highway.

  ☞ Where ROW and livestock pasture fencing is needed (e.g., outside Wupatki National Monument) to prevent livestock access to US 89, creative approaches should be used to minimize the barrier effect of fencing on pronghorn. Near passage structures, fences can be pulled back from the highway ¼–½ mile to separate fencing and highway barriers. A better approach still would be the long-term resting (or temporary removal) of livestock pastures adjacent to passage structures with the removal of fencing at the mouths of passage structures.

6.5 PASSAGE STRUCTURE DESIGN CRITERIA

- Site specific characteristics associated with different passage structure locations will dictate what type of structure (e.g., underpass, viaduct, overpass) would be appropriate from engineering and cost standpoints. However, structural design characteristics will have a significant bearing on pronghorns' eventual use and acceptance of the passage structures.

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

- To date, no passage structure designed specifically to accommodate pronghorn passage has been constructed in North America. As such, limited guidelines or insights exist as to what type(s) of structure is best suited to promoting pronghorn permeability. The research team believes that overpasses and/or large elevated viaducts have the best potential for promoting permeability. Relative to the three recommended locations for passage structures, the team recommends the following structure types.

  - ☞ The terrain at the Coconino NF-Antelope Hills site is suited to the construction of an overpass for pronghorn passage. Since this stretch of US 89 has been reconstructed, a retrofit application here is appropriate. The application of CON/SPAN® pre-cast concrete arches may hold potential for this site, as they can be dropped into place with minimal traffic disruption, cost less than traditional bridges, and side-by-side installation with arches of different heights could maintain existing sloping ridgeline integrity. The headwalls could be flared to maximize openness, with a 100-ft width to create a wide, open overpass.

  - ☞ Due to the limited experience and insights on what structures will best promote pronghorn permeability and whether they will successfully be used along US 89 due to traffic impact and other factors, the research team recommends that implementation of the Coconino NF-Antelope Hills structure (MP 440.9) be considered prior to US 89 reconstruction under an experimental enhancement grant. Thus, insights would be gained on the efficacy of a passage structure at the highest priority site where the prospect for success is highest. Further, the estimated cost ($542,725, not including fill) and ease of construction (just a few days) of a CONSPAN® pre-cast concrete arch overpass makes an enhancement grant possible. Additional funding for an enhancement grant could be pursued from various partners including FHWA, AGFD (Heritage Funds), Arizona Antelope Foundation, and others.

  - ☞ At the Wupatki National Monument site, the variation in terrain will support either an overpass near a ridgeline or an elevated viaduct in a basin.

  - ☞ At the Babbitt Ranch site, where the terrain is predominately flat, an elevated viaduct would function best in promoting permeability.

6.6 MONITORING

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

  - ☞ Should US 89 pronghorn passage structures be implemented, funding should be provided to conduct thorough evaluation of their use by pronghorn and other animals, as well as their contribution to promoting permeability.

  - ☞ Monitoring should be conducted in a scientifically rigorous manner under a before-after-control experimental design (Hardy et al. 2003, Roedenbeck 2007).

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APPENDIX A

RATINGS OF SUITABILITY FOR PRONGHORN PASSAGE STRUCTURE SITES BASED ON SEVEN CRITERIA BY 0.6-MILE SEGMENT BETWEEN US 89 MILEPOST 440.0 AND 458.0

0.6-mi Segment	Mileposts	Pronghorn Distribution[1]		Pronghorn Approaches[2]		Land Status[3]		Human Activity[4]	Fencing[5]	Terrain[6]	Median Width[7]		TOTAL RATING
130−135	440.0−440.5	6.0	3	60.0	5	USFS	3	3	4	3	30’	2	**23**
136−141	440.6−441.1	10.3	5	63.0	6	USFS	3	3	4	3	30’	2	**26**
142−147	441.2−441.7	9.3	4	57.0	5	USFS	3	3	4	3	30’	2	**24**
148−153	441.8−442.3	7.2	3	32.5	4	USFS	3	3	4	3	0	3	**23**
154−159	442.4−442.9	3.8	2	17.3	2	Pvt/ST	1	0	0	3	0	3	**11**
160−165	443.0−444.5	6.2	3	16.8	2	NPS	2	3	5	2	30’	2	**19**
166−171	444.6−442.1	6.0	3	13.0	2	NPS	2	3	5	2	30’	2	**19**
172−177	444.2−444.7	5.1	2	11.7	2	NPS	2	3	5	3	30’	2	**19**
178−183	444.8−445.3	5.2	3	11.2	2	NPS	2	1	5	2	30’	2	**17**
184−189	445.4−445.9	2.8	2	12.3	2	SL	0	2	1	1	84’	1	**9**
190−195	446.0−446.5	1.5	1	2.7	1	SL	0	1	1	1	84’	1	**6**
196−201	446.6−447.1	0.5	1	17.0	2	Pvt	1	3	3	1	84’	1	**12**
202−207	447.2−447.7	2.2	2	27.2	3	Pvt/SL	1	3	3	1	84’	1	**14**
208−213	447.8−448.3	4.3	2	13.5	2	SL	0	3	1	1	84’	1	**10**
214−219	448.4−448.9	4.3	2	20.7	3	Pvt	1	3	3	1	84’	1	**14**

220−225	449.0−449.5	1.2	1	4.7	1	SL	0	3	2	1	84’	1	**9**
226−231	449.6−450.1	1.0	1	2.5	1	Pvt	1	1	3	1	84’	1	**9**
232−237	450.2−450.7	1.0	1	3.8	1	Pvt/SL	1	2	3	1	84’	1	**10**
238−243	450.8−451.3	0.5	1	0.7	1	SL	0	2	1	1	84’	1	**7**
244−249	451.4−451.9	0.4	1	0.8	1	Pvt	1	2	2	1	84’	1	**9**
250−255	452.0−452.5	1.0	1	1.0	1	Pvt	1	3	3	1	84’	1	**11**
256−261	452.6−453.1	0.3	1	0.8	1	SL	0	1	1	1	84’	1	**6**
262−267	453.2−453.7	0.8	1	5.0	1	Pvt/SL	1	2	2	1	84’	1	**9**
268−273	453.8−454.3	0.7	1	3.0	1	SL	0	2	2	1	84’	1	**8**
274−279	454.4−454.9	0.5	1	1.8	1	Pvt/SL	1	2	3	1	84’	1	**10**
280−285	455.0−455.5	0.8	1	1.7	1	Pvt	1	2	2	1	84’	1	**9**
286−291	455.6−456.1	1.0	1	3.7	1	Pvt	1	0	0	1	84’	1	**5**
292−297	456.2−456.7	1.0	1	0.5	1	Pvt	1	1	1	1	84’	1	**7**
298−303	456.8−457.3	1.8	1	0	0	Pvt	1	2	1	1	84’	1	**7**
304−310	457.4−458.0	0.4	1	0	0	Pvt	1	2	1	1	84’	1	**7**

[1]*Pronghorn distribution* − mean number of different GPS-collared pronghorn among the 0.1-mile segments relocated within the 0.3-mile approach zone on either side of US 89. Ratings were:

0	No animals approaching	3	6−8 animals approaching
1	1−2 animals approaching	4	8-10 animals approaching
2	3−5 animals approaching		

[2]*Pronghorn approaches* – mean number of approaches for the six 0.1-mile segments on both sides of the highway. Ratings were:

0	No approaches	4	31−40 approaches
1	1−10 approaches	5	41−60 approaches
2	10−20 approaches	6	61−80 approaches
3	21−30 approaches		

[3]*Land status* – land ownership, affecting ability to conduct construction activities outside the ADOT ROW. Ratings were:

0	State Trust (SL)	2	Federal – NPS (natural ecosystem focus)
1	Private (Pvt)	3	Federal – USFS (multiple-use focus)

[4]*Human activity* – relative degree of human activity within each segment. Ratings were:

0	Significant human activity	2	Limited human activity
1	Moderate human activity	3	No human activity

[5]*Fencing* – criterion relates to the ability to eliminate or mitigate fencing associated with potential passage structures. Ratings were:

0	Private lands near home/businesses	4	USFS lands
1	State Trust land	5	NPS lands (no livestock grazing or need for fence)
2	Private land		
3	Private lands with cooperative landowner (Babbitt Ranch)		

[6]*Terrain/topography* – the degree to which terrain/topography will facilitate construction of passage structures. Ratings were:

0	Terrain not suited for a structure	2	Topography could accommodate a structure
1	Topography marginal for a structure	3	Topography ideally suited for a structure

[7]*Median width* – the width of planned (or existing) median affecting the span distance of a passage structure. Ratings were:

1	84-ft median planned
2	30-ft median planned
3	No median planned

APPENDIX B

CON/SPAN® PRE-CAST CONCRETE OVERPASS COST ESTIMATE AND CONCEPTUAL PLAN SHEETS FOR THE COCONINO NATIONAL FOREST – ANTELOPE HILLS PASSAGE STRUCTURE SITE (MP 440.9)

CONTECH
BRIDGE SOLUTIONS INC.

12725 W Indian School Road E-101
Avondale, AZ 85323
PHONE (602) 377-5347
FAX (623) 512-4901
www.contechbridge.com

TO:	Norris Dodd
DATE:	10/5/09
PROJECT:	US 89 Overpass: Coconino NF – Antelope Hills
RE:	Precast Bridge Wildlife Overpass

The following is an engineer's estimate of construction materials. A formal quotation can be issued after obtaining additional details about the project. We will then fabricate the Precast Concrete Bridge Sections as follows, all in accordance with the plans and specifications:

Items Included in Price:

- CON/SPAN Precast Culvert System
- Precast Headwalls
- Precast Wingwalls
- Mounting Hardware
- Joint Sealing Material
- Structural Design
- Field Installation Supervision
- Installation Drawings for Foundation and Structure

CULVERT *Contractor to unload, set, grout structure and apply joint primer with sealer.*

Precast CON/SPAN Bridge System

(2) Barrel 32' X 10' CON/SPAN Precast Arches	= **$3,200/LF**
(4) Precast Headwalls- 2' Height at Crown of Arch	= $ 30,000
(4) Precast Wingwalls, 25' long	= $ 64,000

Cast-In-Place Concrete - Installed *(quantities are estimated)*

Footings and pedestal walls, 3.07 cy/lf	= **$ 1,228/LF**
Wing wall footings	= $ 5,925

Respectfully submitted,

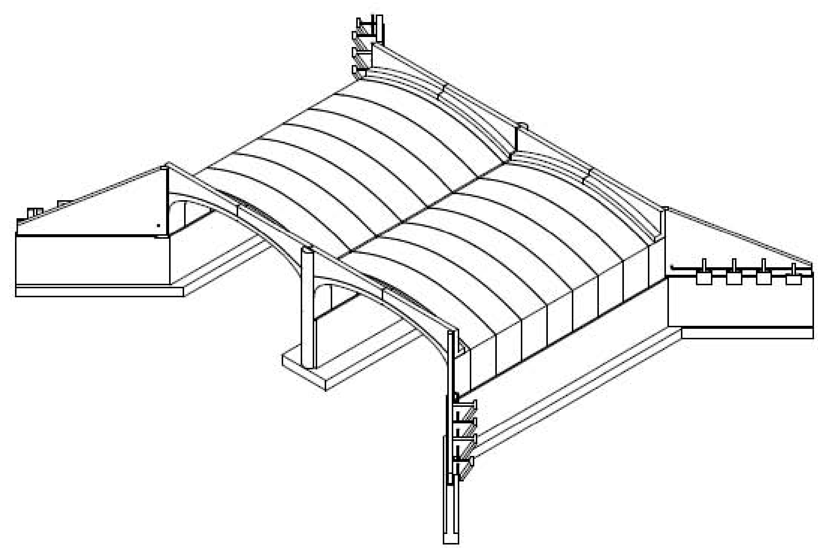
Tara Anderson

Tara Anderson
Project Consultant

US 89 Overpass: Coconino NF - Antelope Hills

(2) cells: northbound and southbound traffic

32' Span x 21' Rise



ISOMETRIC VIEW

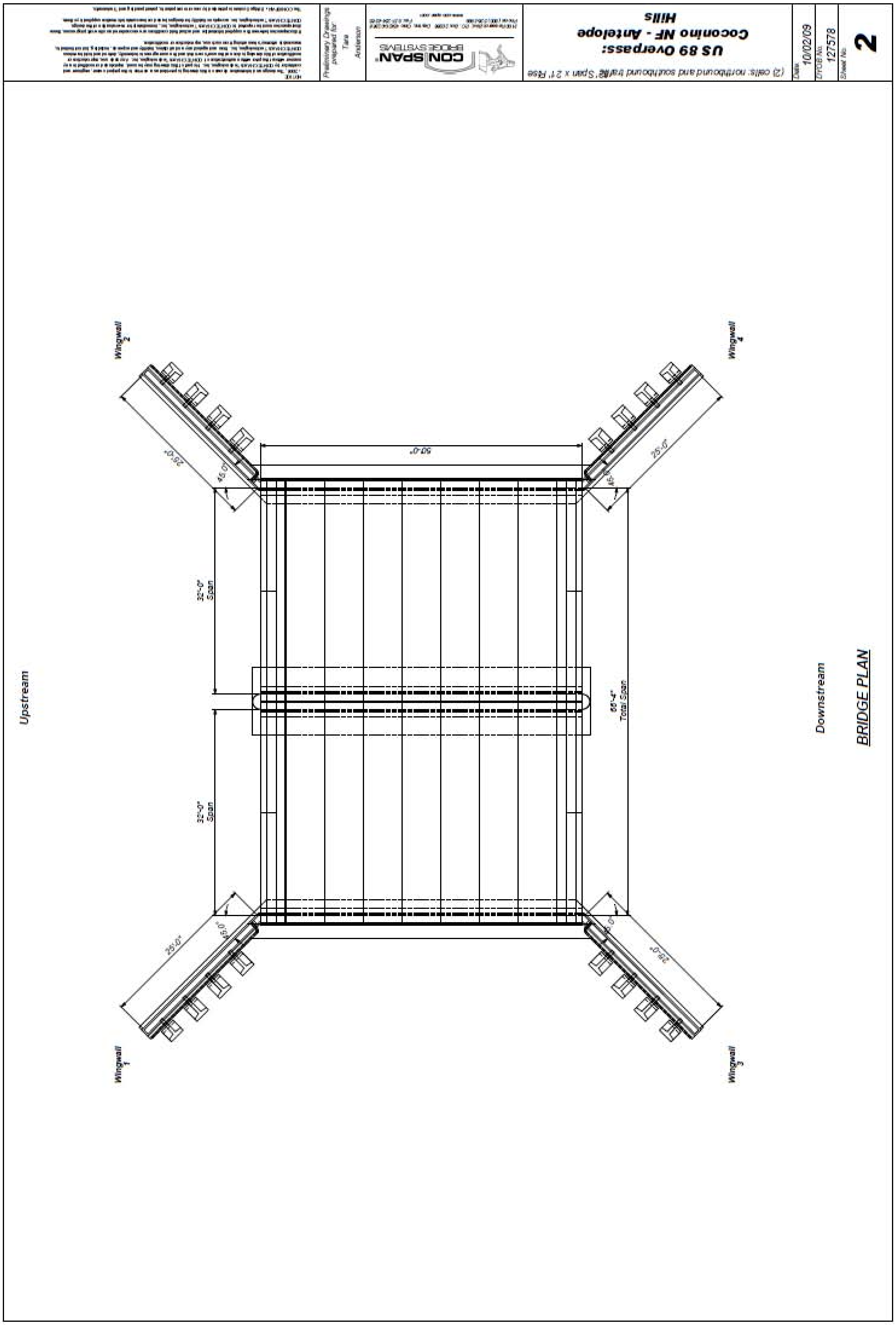
Preliminary Drawings prepared for: Tara Anderson

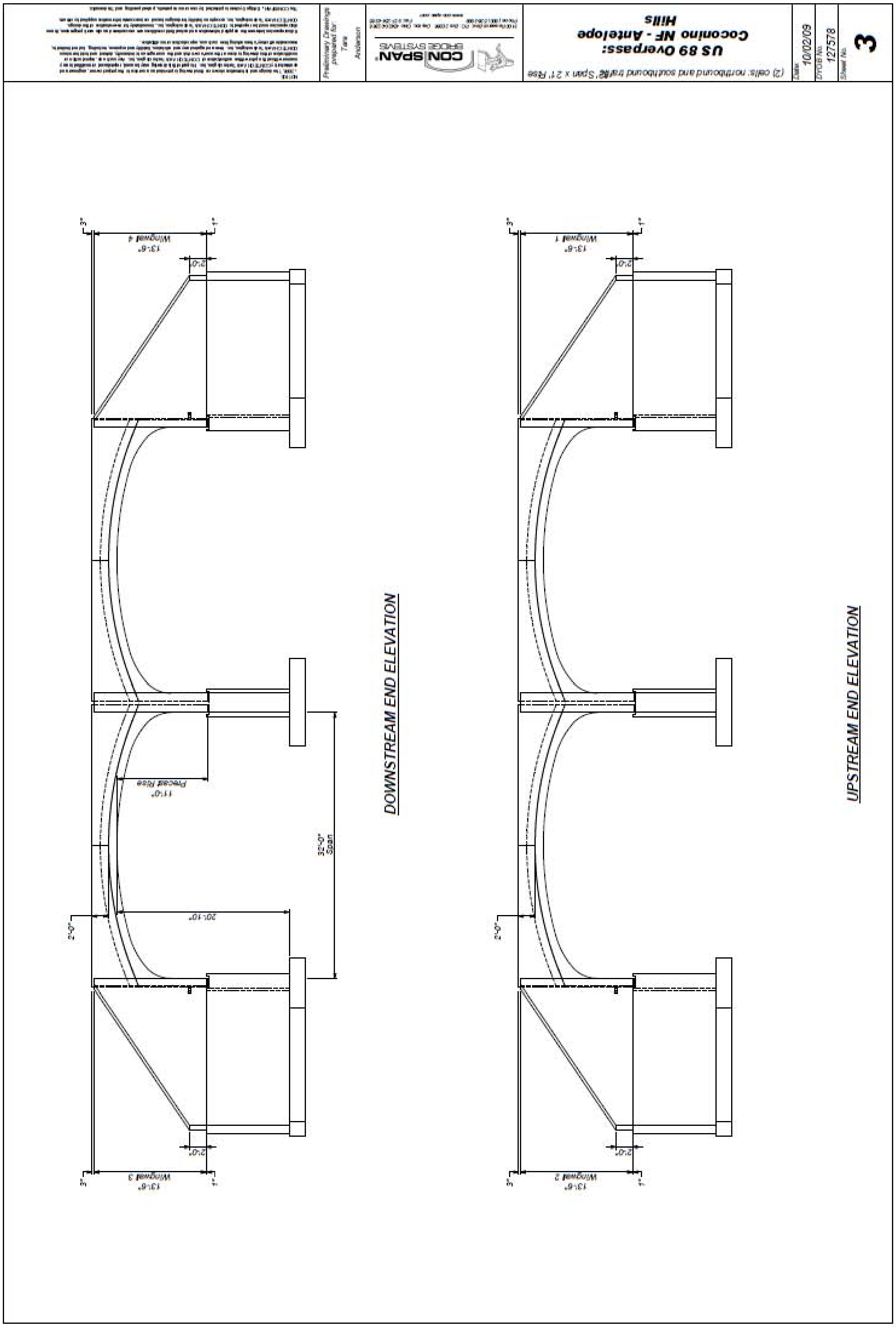
CON/SPAN® BRIDGE SYSTEMS

(2) cells: northbound and southbound traffic 32' Span x 21' Rise

US 89 Overpass: Coconino NF - Antelope Hills

Date	10/02/09
DYOB No.	127578
Sheet No.	1


US 89 Overpass: Coconino NF - Antelope Hills
(2) cells: northbound and southbound traffic 32' Span x 21' Rise
Date 10/02/09
127578
Sheet No. 2
CON/SPAN BRIDGE SYSTEMS
Preliminary Drawings prepared for: Tara Anderson
Upstream
Downstream
BRIDGE PLAN
Wingwall 1
Wingwall 2
Wingwall 3
Wingwall 4
50'-0"
32'-0" Span
32'-0" Span
66'-4" Total Span
25'-0"
45.0°


DOWNSTREAM END ELEVATION
UPSTREAM END ELEVATION
2'-0"
3"
1"
13'-6"
Wingwall 3
Wingwall 4
Wingwall 2
Wingwall 1
2'-0"
20'-10"
11'-0"
Precast Rise
32'-0"
Span
Preliminary Drawings prepared for:
Tara
Anderson
CON/SPAN
BRIDGE SYSTEMS
US 89 Overpass:
Coconino NF - Antelope
Hills
(2) cells: northbound and southbound traffi32' Span x 21' Rise
Date
10/02/09
DYOB No.
127578
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3