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Evaluation of the Effectiveness of Wildlife Guards and Right of Way Escape Mechanisms for Large Ungulates in Arizona

Arizona Department of Transportation Research Center

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16. Abstract

Wildlife-vehicle collisions (WVC) can cause motorist fatalities, injuries, and property damage to vehicles. To address safety concerns and reduce WVC in Arizona, the Arizona Department of Transportation (ADOT) has installed fencing in areas with high WVC incidence to limit ungulate access to the right of way (ROW) and to funnel animals to structures suitable for wildlife passage such as overpasses, underpasses, and culverts. Although fencing is effective in reducing WVC, there remains a dearth of information on the effectiveness of escape mechanisms, which allow wildlife to leave the ROW for a safer place, and wildlife guards, which aim to prevent wildlife from entering the ROW. To fill this gap in knowledge applicable to Arizona, this study used data collected using Reconyx HyperFire still cameras on three types of ungulates—elk, deer, and desert bighorn sheep—along three highways: Interstate 17 (elk and deer), State Route 260 (elk and deer), and U.S. Route 93 (bighorn sheep). The overall goal of this study was to determine the most effective designs for ROW escape mechanisms and wildlife guards for each type of ungulate considered. Additionally, the research team used video surveillance to evaluate performance success and elk behavior associated with electrified and nonelectrified wildlife guards in a controlled test site near Payson, Arizona. The team developed a set of design recommendations for escape mechanisms and wildlife guards found effective for elk, deer, and desert bighorn sheep in Arizona.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

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

APPROXIMATE CONVERSIONS FROM SI UNITS

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

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

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LIST OF ACRONYMS AND ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ADOT	Arizona Department of Transportation
AGFD	Arizona Game and Fish Department
CI	confidence interval
DCG	double cattle guard
DMG	double modified guard
L-R	likelihood ratio
NCHRP	National Cooperative Highway Research Program
PS	painted stripes
PVC	polyvinyl chloride
ROW	right of way
SCG	single cattle guard
SMG	single modified guard
SR	State Route
TI	traffic interchange
WVC	wildlife-vehicle collision
ZC	ZapCrete
ZG	ZapGuard
ZM	ZapMat

LIST OF SPECIES

Animal	**Scientific Name**
bear	*Ursus spp.*
desert bighorn sheep	*Ovis canadensis nelsoni*
elk	*Cervus canadensis*
mule deer	*Odocoileus hemionus*
white-tailed deer	*Odocoileus virginianus*

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EXECUTIVE SUMMARY

Wildlife-vehicle collisions (WVC) can cause motorist fatalities and injuries and property damage to vehicles. To address safety concerns and reduce WVC in Arizona, the Arizona Department of Transportation (ADOT) has installed fencing in areas with high WVC incidence to limit access by ungulates (large mammals with hooves) to the right of way (ROW) and funnel animals to structures suitable for wildlife passage, such as overpasses, underpasses, and culverts. Although fencing combined with wildlife passages is effective in reducing WVC, there remains a dearth of information on the effectiveness of escape mechanisms, which allow wildlife trapped in the ROW to leave for a safer place, and wildlife guards, a type of lateral access control measure that allows vehicular access but aims to prevent wildlife from entering the ROW.

To fill this gap in knowledge for Arizona, this study used data collected from Reconyx HyperFire still cameras to evaluate the effectiveness of ROW escape mechanisms and wildlife guards for elk, deer, and desert bighorn sheep along three highways: Interstate 17, State Route 260, and U.S. Route 93. The overall goal of this study was to determine the most effective designs, based on their relative performance, from among the ROW escape mechanisms and wildlife guards already in use on those highways for each type of ungulate considered in the study. Additionally, the research team used video surveillance to evaluate performance success and elk behavior associated with electrified and nonelectrified wildlife guards at a controlled test site near Payson, Arizona.

Based on the findings of this study, the research team recommends that ADOT consider the following guidance when planning for escape mechanisms and wildlife guards in areas with known presence of elk, deer, and/or desert bighorn sheep.

ESCAPE MECHANISMS

Type

- Install escape ramps instead of slope jumps in areas where elk, deer, and bighorn sheep could become trapped in the ROW.

Design and Materials

- For elk, provide a ramp height of 6 ft from the base of the ramp to the top of the ramp.
- For deer, provide a ramp height of 5 ft, with the option to add a crossbar if deer are documented entering the ROW via escape mechanisms. The height may be increased to 6 ft in areas where elk also reside to reduce the risk of elk entering the ROW.
- For desert bighorn sheep, provide a ramp height of 5 to 6 ft from the base of the ramp to the lip of the ramp, with a horizontal crossbar placed 18 to 20 inches above the lip of the ramp.
- Integrate the escape ramp into the topography or provide a gradual slope with a maximum incline of approximately 4:1 leading up to the opening.

- Provide a level landing pad clear of vegetation and rocks.
- Provide an opening that is a minimum of 10 ft wide, void of tree branches and vegetation.
- Install an impermeable membrane on the face of the ramp to keep soil from sloughing off.
- Avoid ramp fill that does not compact well, such as cinders and gravel.
- When spacing out escape ramps, consider the presence of wildlife guards as potential escape opportunities for elk, deer, and bighorn sheep.

Maintenance

- Incorporate the checking of escape ramps during fence inspections.
- Clear escape ramp openings and landing pads of vegetation and debris when necessary.
- Repair areas where soil is sloughing off the lip of the ramp. Replace or reinforce soil retention materials where needed.
- Remove soil from the base of the escape ramp on the outside of the ROW that may effectively reduce the height that animals need to jump to get into the ROW.

WILDLIFE GUARDS

Type

- Continue the use of standard ADOT double cattle guards or a guard type of equivalent width and functionality, such as round-bar guards or grates.
- In areas where electrified guards are preferred over standard double cattle guards, consider either a wide stand-alone electrified guard or a combination of electrified and nonelectrified guards.
- Consider installing wildlife guards instead of painted stripes that mimic wildlife guards, which were found to be ineffective.
- Avoid the use of shallow guards, such as guards with plates welded to the bottom of the guards to reduce the risk of wildlife falling through them. Shallow guards were found to be ineffective in deterring ungulates.

Design and Materials

Nonelectrified Wildlife Guards

- Employ guards with a minimum width of 16 ft to keep elk, deer, and bighorn sheep from easily jumping over them. This is the same as the default width of ADOT double cattle guards.

- Incorporate fences or other options to keep ungulates from walking along the vault ledges.

Electrified Wildlife Guards

- To reduce the potential for injury to cyclists, consider electrified wildlife guards as an alternative to standard cattle guards in areas that cyclists frequent.
- Provide a push-button shutoff or access gate that allows pedestrians with pets and equestrians to either deactivate or bypass the electrified wildlife guard. If an access gate is used, consider a design in which the gate closes automatically to reduce the likelihood of the gate being left open and allowing animals to access the ROW.
- Use a wider electrified wildlife guard (12 to 16 ft wide) when designing a stand-alone wildlife guard; use a narrower electrified guard (6 to 8 ft wide) when the electric guard is combined with a nonelectrified version.
- When combining electrified and nonelectrified wildlife guards, place the electrified guard on the non-ROW side of the nonelectrified guard to increase the potential for shock when animals pause to investigate the nonelectrified guard.
- Use the highest-voltage energizer available that meets power supply and cost needs but is also safe for humans. In areas where electricity cannot easily be provided, one may consider using a relatively small solar panel to power an electro mat.
- Use highly durable materials such as electrified concrete in areas with high traffic volumes and heavy loads. Less durable designs, such as those made from composite materials, can be used on side roads with minimal traffic (in locations where a gate cannot be used).
- To increase the barrier to wildlife entering the ROW at lateral access roads, consider adding electrified wildlife guards as supplements to single cattle guards during fencing retrofits designed to guide animals to existing structures.

Maintenance

- Assign maintenance personnel that are trained or specialize in electrical operations and maintenance to regularly monitor, maintain, and repair electrified wildlife guards.
- Install equipment that provides fault codes to ADOT personnel when power is lost to electrified guards.

In addition, the research team identified some pertinent findings from other studies throughout North America that ADOT may wish to consider in the design, implementation, and maintenance of escape mechanisms and wildlife guards. See Chapter 6 for details on these recommendations.

CHAPTER 1. INTRODUCTION

Wildlife-vehicle collisions (WVC) can cause motorist fatalities and injuries and property damage to vehicles (Huijser et al. 2008). The rising incidence of collisions between vehicles and wildlife, especially large ungulates (hooved mammals) such as elk, deer, and desert bighorn sheep, poses a safety concern for motorists and an ongoing challenge for the Arizona Department of Transportation (ADOT). From 2007 to 2009, researchers documented more than 100 collisions with elk and deer along a 30-mile stretch of Interstate 17 (Gagnon et al. 2013). Collisions with wildlife continue to rise; from 2002 to 2012, collisions with elk and deer increased more than 100 percent along a 60-mile segment of State Route 260 (Gagnon et al. 2017b).

ADOT continues to strive to provide safe roadways for increasing numbers of motorists. To address safety concerns and reduce WVC in Arizona, ADOT has installed wildlife fencing in areas with high WVC incidence to limit ungulate access to the right of way (ROW) and funnel animals to structures suitable for wildlife passage. In four locations in Arizona, wildlife fencing has been credited with a reduction in WVC of as high as 97 percent for elk and desert bighorn sheep (Gagnon et al. 2010, Dodd et al. 2012, Gagnon et al. 2015, Gagnon et al. 2017a).

While mounting evidence supports the effectiveness of fencing and wildlife passage structures in reducing WVC, there remains a dearth of information on the effectiveness of the escape mechanisms and lateral access control measures that are often used in conjunction with fencing along roadways. Escape mechanisms allow wildlife to leave the ROW for a safer place, and lateral access control measures, also referred to as wildlife guards, prevent wildlife from entering the ROW. The need for information on these measures and on their effectiveness for various species extends well beyond Arizona (Huijser et al. 2015). Recognizing the lack of adequate and reliable data regarding escape mechanisms and wildlife guards, the American Association of State Highway and Transportation Officials (AASHTO) commissioned the Transportation Research Board's National Cooperative Highway Research Program (NCHRP) to conduct a study on this topic, NCHRP 25-25/Task 84 (Huijser et al. 2015). The Huijser et al. 2015 report identified gaps in knowledge, underscored the need for comparative studies, and revealed the need to evaluate the species-specific suitability of existing escape mechanisms and wildlife guards.

To fill the gap in knowledge for Arizona, this study evaluated the effectiveness of ROW escape mechanisms and wildlife guards for elk, deer, and desert bighorn sheep along three highways: Interstate 17 (I-17), State Route 260 (SR 260), and U.S. Route 93 (U.S. 93). Both elk and deer are present along I-17 and SR 260, while U.S. 93 has only desert bighorn sheep. The overall goal of this study was to determine, from among the designs already in use on those highways, the most effective ROW escape mechanisms and wildlife guards for each of the three ungulate species. Additionally, the study evaluated performance success and elk behavior associated with wildlife guards at a controlled test site along SR 260 near Payson, Arizona, and documented potential maintenance concerns with current escape mechanisms and wildlife guards.

CURRENT STATE OF THE PRACTICE

When implementing ungulate-proof fencing to exclude wildlife from roads and guide them to wildlife passage structures, it is also important to provide a way for the wildlife to escape the ROW if they are trapped inside a fence. This can be accomplished through breaks in the fencing, washouts, open gates, or cattle guards; at the ends of fences; or by other means (van der Ree et al. 2015). Equally important is for motorists to have access to the roadway from driveways, on- and off-ramps, or lateral access roads in areas where wildlife is excluded, and traditional gates are not feasible. ROW escape mechanisms and wildlife guards serve these two purposes, respectively. This section describes the current state of the practice at ADOT for both ROW escape mechanisms and wildlife guards.

Right of Way Escape Mechanisms

ADOT has implemented three types of wildlife escape mechanisms: one-way gates, escape ramps (also called jump-outs), and slope jumps.

One-way gates were originally designed to allow ungulates to escape the ROW without being able to get back into it. In both controlled and field tests, one-way gates were effective at allowing deer passage in the proper direction (Reed et al. 1974b). Anticipating that elk would use one-way gates in a similar manner as deer would, ADOT installed one-way gates along SR 260 to allow elk to escape the ROW. In 2001, the Arizona Game and Fish Department (AGFD) and ADOT initiated an evaluation of the effectiveness of fencing and underpasses in reducing WVC while promoting highway permeability by elk (Dodd et al. 2007). Although it was not a formal part of the research study, AGFD also gathered information on the use of one-way gates and escape mechanisms that were incorporated in the first phase of SR 260 reconstruction. AGFD documented that one-way gates were ineffective at allowing elk to escape the ROW and occasionally allowed Coues white-tailed deer to enter the ROW. More recently, these gates were also found to be a source of wildlife mortality (Sielecki 2007). Based on this information and recommendations from AGFD, ADOT no longer employs one-way gates as escape measures for ungulates.

Escape ramps (mounds of soil with a steep drop where ungulates can jump out of the ROW but cannot easily jump in) are becoming more popular as a mechanism for allowing deer to escape from fenced roadways (Bissonette and Hammer 2000, Siemers et al. 2015). ADOT currently constructs escape ramps from wood (see Figure 1), concrete (see Figure 2), or gabion baskets (see Figure 3). Anecdotal information gathered from the first escape ramps along SR 260 indicated that if the ramp height was too low, another type of ungulate, elk, used them to enter the ROW, creating a motorist hazard. If the ramp height was too high, elk became trapped in the ROW, also creating a motorist hazard.

Figure 1. Wooden Escape Ramp

Figure 2. Concrete Escape Ramp

Figure 3. Gabion Basket Escape Ramp

Wooden plank escape ramps used on the first phase of SR 260 presented maintenance issues as boards warped, allowing ramp fill material to erode and compromise the structure. These maintenance concerns prompted AGFD to work with ADOT to modify the escape ramp design, ultimately leading to a robust concrete retaining wall design that was implemented for the next phases of SR 260 and have so far withstood erosion. However, the effectiveness of these concrete structures as one-way escape mechanisms for elk and deer has not been evaluated.

In 2003, ADOT began experimenting with gabion basket escape ramp structures as an alternative to costly concrete designs along U.S. 93 (McKinney and Smith 2007). Gabion basket escape ramps consist of stacked wire mesh baskets filled with rocks (see Figure 3). Although the first gabion baskets were inexpensive, preliminary data indicated that the escape mechanism design was inadequate for preventing bighorn sheep from accessing the ROW, and researchers recommended increasing the ramp height in the future. The heightened versions were installed as escape mechanisms for bighorn sheep on U.S. 93 and for elk and mule deer on I-17. At both locations, soil retention partially failed, exposing the wire mesh along the leading edge of the ramp. This presented a maintenance problem and posed a danger to ungulates as their legs could become caught if they attempted to use the deteriorated escape mechanism (Gagnon et al. 2016, Gagnon et al. 2017a). To address soil retention issues, the gabion basket escape ramps installed on SR 260 in 2013 used a revised design to prevent backfill from sloughing off, incorporating fine wire mesh and landscape fabric into the approved design drawings. The installation was completed in fall 2013, and the updated design has yet to be evaluated.

As an alternative to escape ramps and one-way gates, ADOT designed and constructed slope jumps during the 2004 expansion of SR 260. Slope jumps consist of a segment of shorter fencing that traverses

a slope with the uphill side of the slope jump toward the highway and the downhill side away from the highway (see Figure 4). The premise of slope jumps is to take advantage of existing topography where physics would easily allow a deer or elk to jump down the slope (over a lowered segment of fence) and out of the ROW, but where the animal would have difficulty gaining enough momentum to jump up the slope (over the fence) and into the ROW (Gallagher et al. 2005). Presently, there are no empirical data regarding slopes and heights that effectively prevent ungulates from entering the ROW via slope jumps or using them to escape. The slope jumps along Arizona highways (SR 260 and I-17) are the first of their kind to be implemented; as such, they provide an opportunity to test the effectiveness of this design and determine its utility for future ADOT projects.

Figure 4. Slope Jump Escape Mechanism

Wildlife Guards

Currently, ADOT installs wildlife guards where gates would not be feasible, such as where a break in wildlife fencing is needed to allow vehicles to enter or exit the highway. Where these breaks occur, wildlife guards are placed in the roadway to make the road surface difficult for ungulates to traverse. These devices are located at motor vehicle access points that have relatively high traffic volume. Traditionally, single cattle guards are used to limit livestock access (see Figure 5). However, because of speculation and anecdotal evidence that ungulates sometimes leap single cattle guards, many state transportation departments, including ADOT, install costly double-deep cattle guards (see Figure 6). Conversely, to reduce construction costs, other state departments of transportation have installed

painted stripes that mimic cattle guards. Little information exists on the effectiveness of these alternatives to single cattle guards.

Standard ADOT single and double cattle guards can be a safety hazard to both humans and animals (Peterson et al. 2003). Discussions with ADOT Risk Management and Maintenance personnel both indicated that standard ADOT cattle guards pose a particularly high risk for cyclists, whose tires could slide on the metal cattle guards and result in injury. This points to the need to identify alternatives to standard cattle guards that are safe for cyclists and pedestrians but that also deter wildlife and livestock from accessing the ROW.

More recently, electrified wildlife guards have been implemented in Canada and in several U.S. states, including Arizona, Utah, California, New Mexico, Alaska, Oregon, and Texas (see Figure 7). There is ongoing interest in their use as an alternative to more traditional cattle guard designs (Reed et al. 1974a, VerCauteren et al. 2009, Allen et al. 2013). Electricity provides an additional physical and psychological barrier; however, some studies have shown that the effectiveness of electrified guards in excluding ungulates from roads is limited (Seamans and Helon 2008, Cramer and Flower 2017). Although one might think that electrified wildlife guards could also be unsafe for humans, current designs use electrical pulses that are not harmful to humans with shoes on. To address pedestrians with pets or equestrians, ADOT has used either a push-button option that shuts down the electrified wildlife guard for a set period of time, allowing for safe passage, or a gate adjacent to the guard that allows the user to bypass the guard altogether.

An obvious outcome of wildlife interactions with electrified barriers is that the animals receive a physical shock. However, there is also speculation that animals can sense whether a device is activated. No research has been conducted on whether deer can sense electric fields associated with mats or fences (Seamans and Helon 2008), and the same holds true for other ungulates. Thus, an evaluation of electrified wildlife guards is warranted to determine their effectiveness at minimizing ungulate access into the ROW.

Studies have shown that traditional single cattle guards, extra-wide cattle guards, deer grates, and electrified barriers all deter deer access to the ROW while allowing uninhibited vehicular access (Reed et al. 1974a, Belant et al. 1998, Peterson et al. 2003, Allen et al. 2013, Cramer and Flower 2017). Although there are some studies on the effectiveness of cattle guards and grates at keeping deer from entering the ROW, minimal or anecdotal information exists on their effectiveness for other ungulate species (Cramer and Flower 2017).

Figure 5. ADOT Standard Cattle Guard

Figure 6. Two ADOT Standard Guards Installed Side-by-Side to Create a Double Cattle Guard

Figure 7. Electrified Mat

CHAPTER 2. STUDY AREA

The research team evaluated wildlife guards and escape mechanisms along three ADOT highways (SR 260, U.S. 93, and I-17) and at a test site (Risser Ranch). The selection of specific wildlife guards and escape mechanisms for evaluation was informed by preliminary data that were collected from earlier studies (Dodd et al. 2007, Dodd et al. 2012, Gagnon et al. 2016, Gagnon et al. 2017a). The development of the Risser Ranch test site and the installation of the camera monitoring system were undertaken through a joint effort among AGFD, the ADOT Environmental Planning Group, CrossTek LLC, and Risser Ranch. Figure 8 shows the individual study area locations.

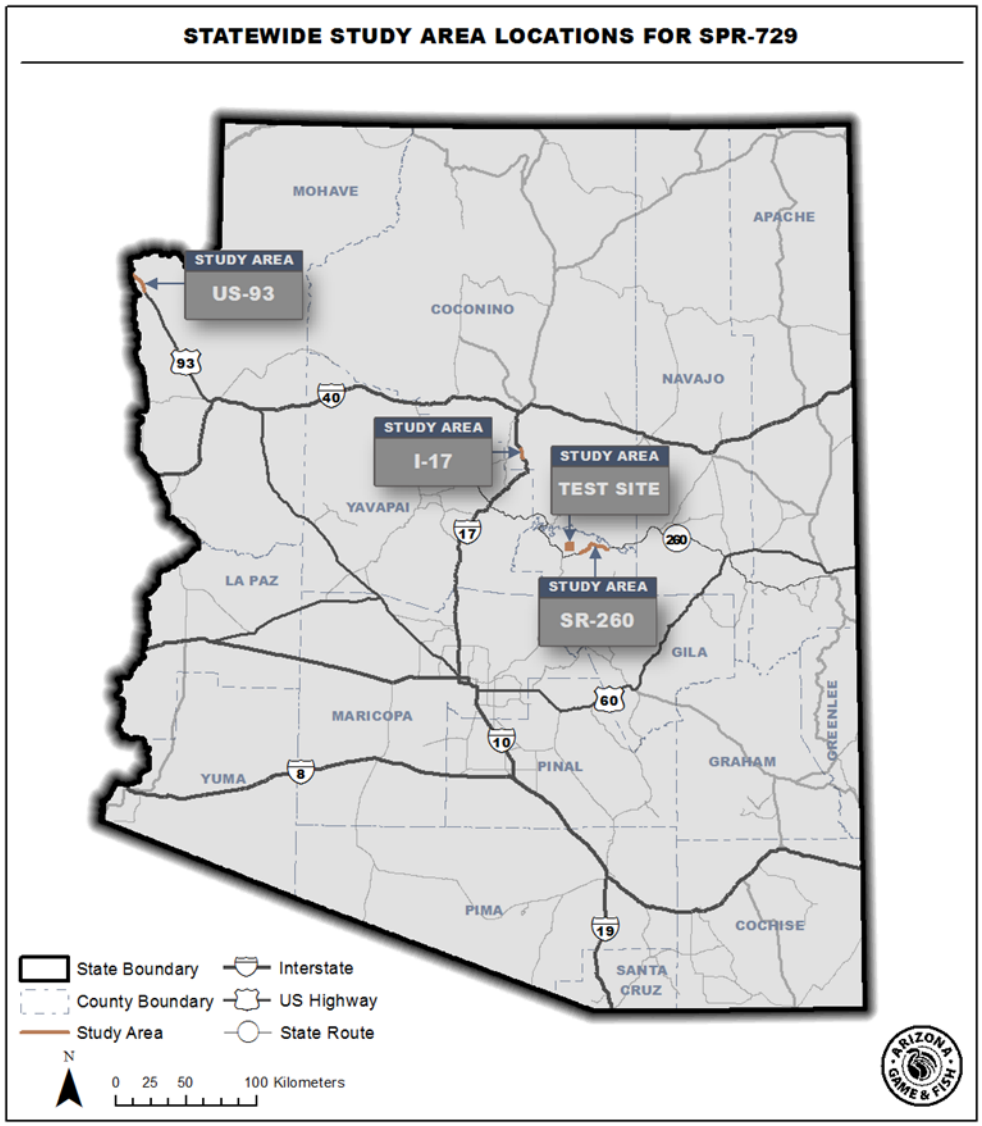

Figure 8. Location of the Three Study Areas and Test Site
(Source of Map Imagery: Esri)

State Route 260

SR 260 is the main highway from the Phoenix metropolitan area to the White Mountains. Traffic fluctuates seasonally, with peaks in traffic volumes in the summer reflective of motorists traveling to summer homes or cooler recreational opportunities. SR 260 sees more than 2 million motorists each year, and traffic levels are expected to increase as Arizona's population continues to grow. In 2000 ADOT began reconstruction of SR 260 from mileposts 260 to 277; the project was conducted in five phases, completed in 2014. This 17-mile stretch of road includes the first wildlife passage structures and associated wildlife guards and escape mechanisms in Arizona. The primary goal of the wildlife features on SR 260 was to mitigate elk-vehicle collisions, but these features benefit deer and other wildlife species as well. The research team focused its evaluation on the mitigation of elk- and deer-vehicle collisions along SR 260, measuring the effectiveness of two types of wildlife guards (double cattle guards and electrified cattle guards) and several types of escape mechanisms (wood, concrete, and gabion basket escape ramps of various heights, as well as slope jumps).

U.S. Route 93

U.S. 93 is the primary transportation route between the Phoenix metropolitan area and Las Vegas, Nevada. U.S. 93 crosses the Colorado River 70 miles northwest of Kingman, Arizona, and 20 miles southeast of Las Vegas. In the fall of 2010, ADOT completed the reconstruction of U.S. 93 from mileposts 2 to 17, which included the first three wildlife overpasses in Arizona and the first of their kind designed for desert bighorn sheep. With this reconstruction project and the Hoover Dam Bypass, 17 miles of fencing intended to keep sheep out of the ROW and funnel them to wildlife passage structures was also completed. ADOT also installed numerous gabion basket escape ramps and single and double cattle guards at lateral access roads and on- and off-ramps. The research team evaluated the effectiveness of the fencing with installed escape mechanisms and wildlife guards for mitigating collisions between vehicles and desert bighorn sheep.

Interstate 17

I-17 is the primary route connecting the Phoenix metropolitan area to Flagstaff, and is the main highway artery serving northern Arizona, connecting with I-40. Each year, I-17 is traveled by millions of tourists visiting national parks and recreation areas, including the Grand Canyon National Park, Petrified Forest National Park, Sunset Crater Volcano National Monument, and Glen Canyon National Recreation Area. In 2011, ADOT and AGFD completed a transportation enhancement project to address elk-vehicle collisions along I-17 by retrofitting existing ROW fencing, increasing its height from 42 inches to approximately 96 inches. The I-17 fencing project was approximately 6 miles long, with a southern terminus at Woods Canyon Bridge (milepost 319) and a northern terminus at the Munds Park interchange at milepost 324. The fencing links four structures that are potentially suitable for safe elk passage across the interstate corridor. Within the limits of the I-17 fencing project, numerous gabion basket escape ramps and a handful of slope jumps were constructed as escape mechanisms to allow elk to exit the ROW, and eight electrified mats serving as wildlife guards were installed at the Schnebly Hill Road and Fox Ranch Road

interchanges. The effectiveness of these structures in mitigating elk-vehicle collisions was evaluated by the research team.

Risser Ranch Test Site

In many cases, wildlife interactions with wildlife guards along a fenced ROW are infrequent and sporadic, reducing the ability to gather robust information on them. A test site can help supplement this information, and when combined with data collected in the field, can help inform decisions and recommendations. In addition, a test site can allow for testing of experimental treatments that may have value to future wildlife-vehicle collision mitigation efforts but have not yet been implemented in a real-world scenario.

The Risser Ranch test site near Payson, Arizona, consists of a 100-by-100-ft fenced area bisected by a partition fence. An entrance allows elk into one end, and the layout then provides elk with two options for moving beyond the partition fence to the remainder of the enclosure, which is baited with alfalfa and water (see Figure 9). These two treatment areas can be individually opened and closed to test one or two types of wildlife guards at a time, thus allowing a testing schedule to assess elks' ability to cross them. The effectiveness of each treatment in repelling elk is documented via video surveillance (see Figure 10). If elk breach a wildlife guard, they have the opportunity to leave through the two treatment areas throughout the night; however, if the elk become reluctant to cross back over the wildlife guard and become trapped, two gates open automatically during daytime to allow them to escape. Elk in this area consist of resident and migratory herds that mix on a regular basis, like the animals that occupy SR 260 and I-17.

Figure 9. Entrance to Test Site Near Payson

Figure 10. Video Surveillance Camera Orientation at a Wildlife Guard Treatment

CHAPTER 3. METHODS

To gather data on the effectiveness and design of escape mechanisms and wildlife guards for elk, deer, and bighorn sheep, the research team utilized three primary sources:

- **Still cameras.** Data from the cameras showed whether elk, deer, or bighorn sheep utilized an escape mechanism or wildlife guard to access or leave the ROW.
- **ArcGIS Survey123.** This geospatial tool collected information to help researchers determine heights and structure characteristics that contribute to wildlife using the escape mechanism or wildlife guard to access or leave the ROW.
- **Video from a controlled test site.** This information helped researchers measure the relative effectiveness of wildlife guards in a variety of configurations. The research team also collected information pertaining to maintenance problems or issues to guide future design of these structures.

STILL CAMERA DATA: COLLECTION, REVIEW, AND ANALYSIS

The research team placed still cameras at 32 ROW escape mechanisms and 13 wildlife guards, for a total of 45 cameras. The cameras were distributed among the locations within the study area as follows:

- **I-17:** seven escape mechanisms, four wildlife guards.
- **U.S. 93:** six escape mechanisms, three wildlife guards.
- **SR 260:** 19 escape mechanisms, six wildlife guards.

Figures 11, 12, 13, and 14 show the location of each camera. Cameras were attached to adjacent fencing using custom-made boxes designed to reduce the chance of theft or vandalism (see Figure 15).

Researchers used Reconyx HyperFire still cameras, which use a motion sensor to detect animals and have a night vision feature to capture images in low lighting. Cameras were positioned to begin capturing images as animals approached the escape mechanisms from either inside or outside of the ROW (see Figure 16). Once an animal was detected, the camera captured a burst of three images each second until the animal left the camera's field of view. Because of the limitations of battery life and image storage capacity, cameras were checked approximately every six weeks to replace batteries, collect image data, verify that camera orientation was correct, and ensure that vandalism or theft had not occurred. Images were backed up twice to avoid loss in the event of storage equipment failure. If a camera was stolen or vandalized, researchers replaced the camera as soon as possible to minimize disruption in data collection.

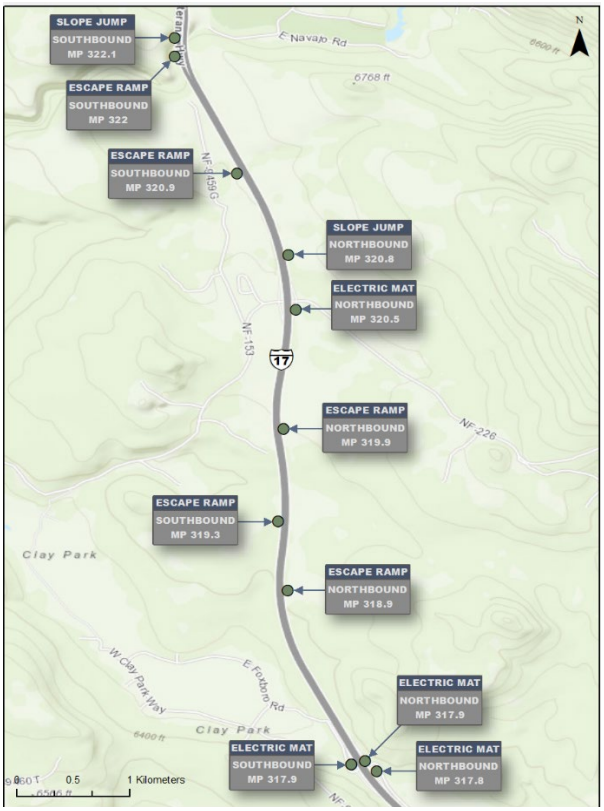

Figure 11. Location of Escape Mechanisms and Wildlife Guards Monitored Along Interstate 17
(Source of Map Imagery: Esri)

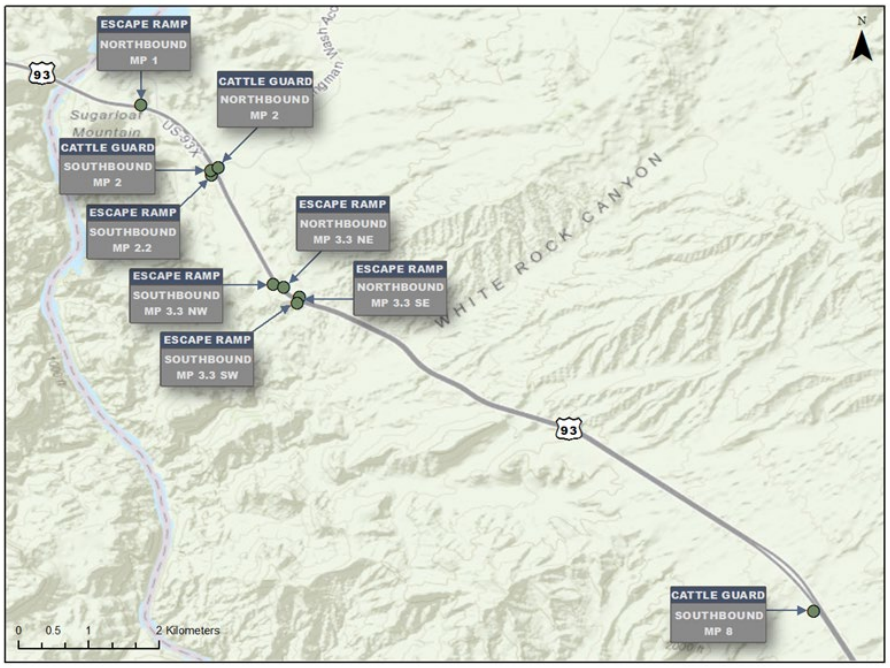

Figure 12. Location of Escape Mechanisms and Wildlife Guards Monitored Along U.S. Route 93
(Source of Map Imagery: Esri)

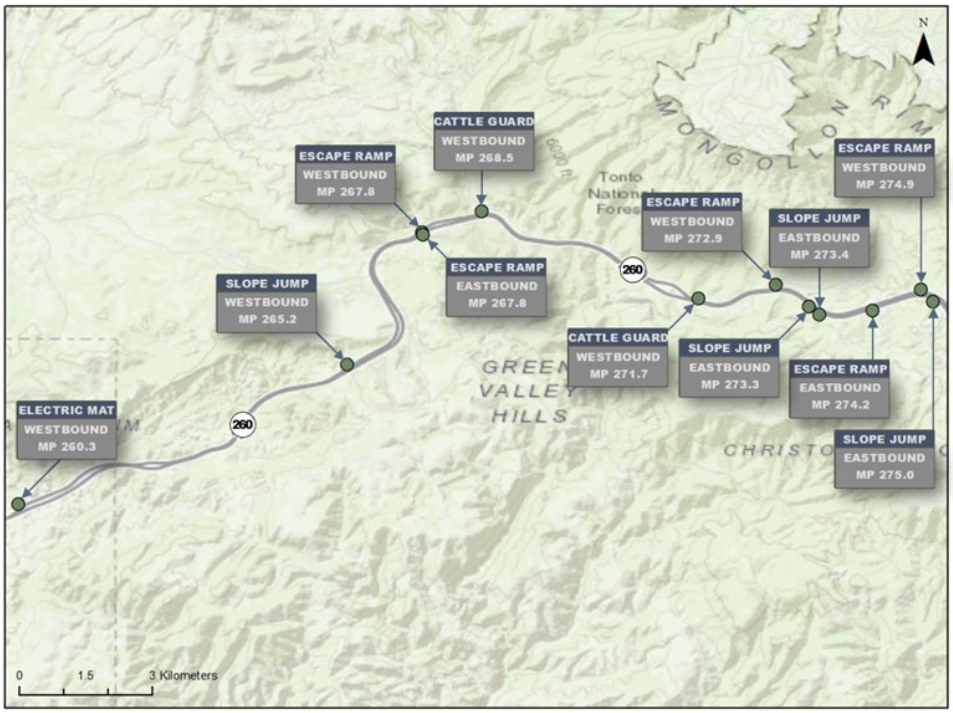

Figure 13. Location of Escape Mechanisms and Wildlife Guards Monitored Along State Route 260 (Mileposts 260 to 275)
(Source of Map Imagery: Esri)

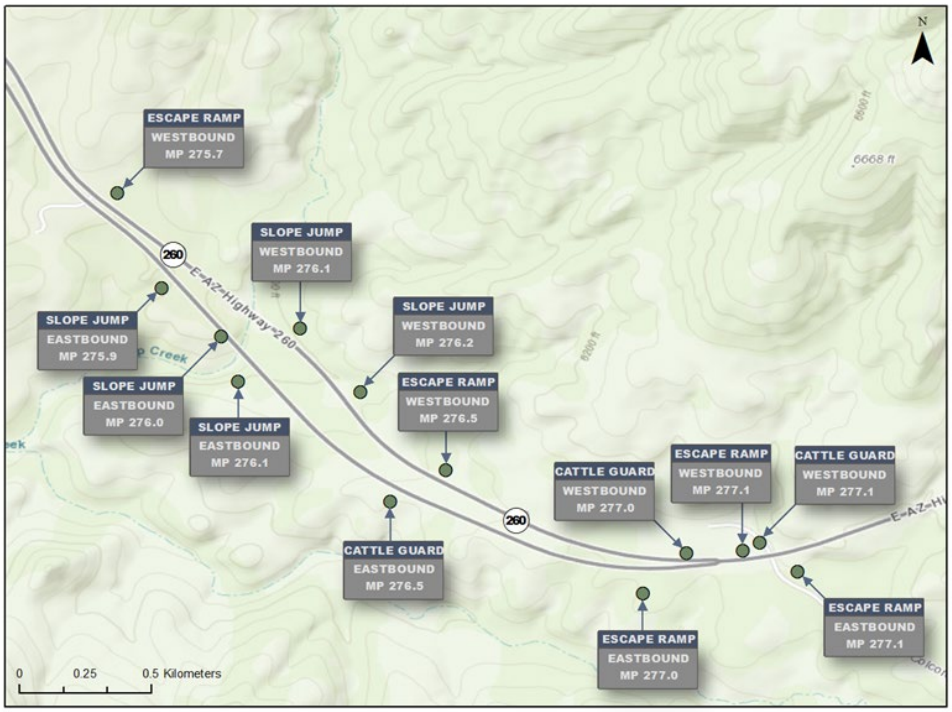

Figure 14. Location of Escape Mechanisms and Wildlife Guards Monitored Along State Route 260 (Mileposts 275.7 to 277.1)
(Source of Map Imagery: Esri)

Figure 15. Camera Box Mounted to Wildlife Fencing

Figure 16. Camera View of Animal Approaching an Escape Mechanism

The research team monitored escape mechanisms and wildlife guards for this study from 2015 to 2018. To increase observations and provide the best available information for analysis and recommendations for future implementation of escape mechanisms and wildlife guards, the research team included the data collected for two related ADOT studies:

- SPR-689 (Gagnon et al. 2016), which gathered data on elk on I-17 from 2012 to 2014.
- SPR-710 (Gagnon et al. 2017a), which gathered data on desert bighorn sheep on U.S. 93 from 2011 to 2015.

The research team also used AGFD funding to monitor escape ramps and wildlife guards along SR 260 from 2012 to 2015, as well as to fill in the gaps in time between the completion of the I-17 and U.S. 93 studies and the start of this project in 2015. Cameras installed during these previous studies were left in place, and data were collected and analyzed in an identical manner throughout both previous studies and the current project. At the start of this study, the research team added cameras to additional escape ramps and wildlife guards to increase sampling efforts.

Data collected from the cameras were used to calculate the escape rate (the number of times animals successfully exited the ROW as a proportion of total approaches) and the repel rate (the number of times animals were kept from entering the ROW as a proportion of total approaches). For example, if elk approached an escape ramp from within the ROW 100 times and exited the ROW 75 times, the escape rate would be 0.75, or 75 percent. Because the purpose of escape mechanisms is to allow animals to escape the ROW once trapped inside, escape mechanisms should have a high escape rate. Conversely, if elk approached the same escape ramp from outside the ROW 100 times and did not enter the ROW on 90 of those occasions, then that escape mechanism would have a repel rate of 0.90, or 90 percent. An effective escape ramp will maximize the threshold where animals can escape the ROW relatively easily while simultaneously repelling them from entering the ROW. This study attempted to define this threshold for the three species studied. Because wildlife guards are intended to keep animals out of the ROW, the primary metric of effectiveness for wildlife guards is the repel rate. The goal of data collected and analyzed in this manner was to determine the structural attributes of escape mechanisms (such as height) and wildlife guards (such as width or design) that maximize the potential for animals to escape the ROW and to be deterred from entering the ROW.

In this study, escape mechanisms were evaluated at heights ranging from 53 to 78 inches for elk and deer, as well as with and without a crossbar for bighorn sheep, to determine which height and configuration best allowed escape from the ROW without allowing entrance to the ROW. Several configurations of wildlife guards were evaluated—a single cattle guard, a single electrified mat, a single cattle guard combined with painted stripes, and a double cattle guard—to determine the best method for keeping elk, deer, and bighorn sheep from entering the ROW.

ARCGIS SURVEY123: DATA COLLECTION, REVIEW, AND ANALYSIS

To collect the structural attributes of an individual escape mechanism or wildlife guard, the team created an ArcGIS Survey123 mobile application that compiles location data, photos, and attributes of

each structure. These attributes included height, width, composition, slope and substrate of landing pad, height of adjacent fence, crossbar presence, and other information that may be pertinent to a structure's effectiveness (see Figure 17).

Once the structural attributes were collected and entered into a database, the research team used logistic regression to identify the structural attributes that were associated with the highest escape and repel rates for each species and structure type (Agresti 1996). This information, combined with other data obtained through literature reviews, was used to help provide recommendations on the desirable designs of escape mechanisms and wildlife guards.

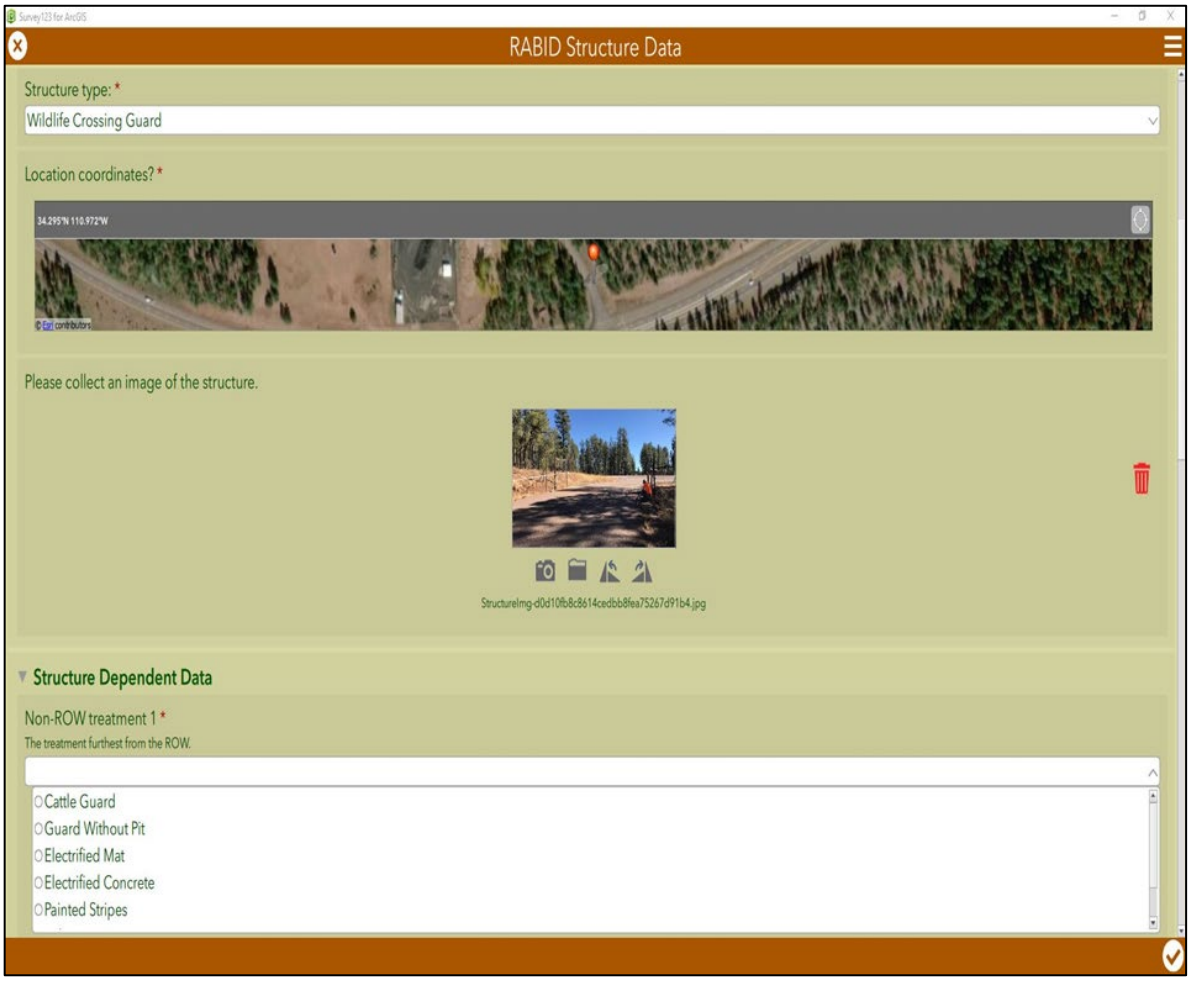

Figure 17. Screen Shot of Survey123 Mobile App Used to Collect Structural Attribute Data

CONTROLLED TEST SITE: DATA COLLECTION, REVIEW, AND ANALYSIS

At the controlled test site, the research team used video surveillance systems to collect data on elk behavior with multiple wildlife guard configurations. When elk entered the enclosure, the video system was triggered via photo beams, and the cameras began recording elk activity to a digital video recorder.

Four cameras were oriented to collect video when elk entered the test site and to document interactions with wildlife guards within the enclosure as elk attempted to reach bait and water on the other side of the wildlife guards at the back of the enclosure (see Figure 18). Infrared illuminators were activated via photocell to allow researchers to document elk activity during nighttime and low-light conditions. Cameras continued to record activity while elk were present and for two minutes after they left the enclosure. Cameras were checked approximately every two weeks to ensure correct camera and photo-beam orientation and to switch out the digital video recorder for image review.

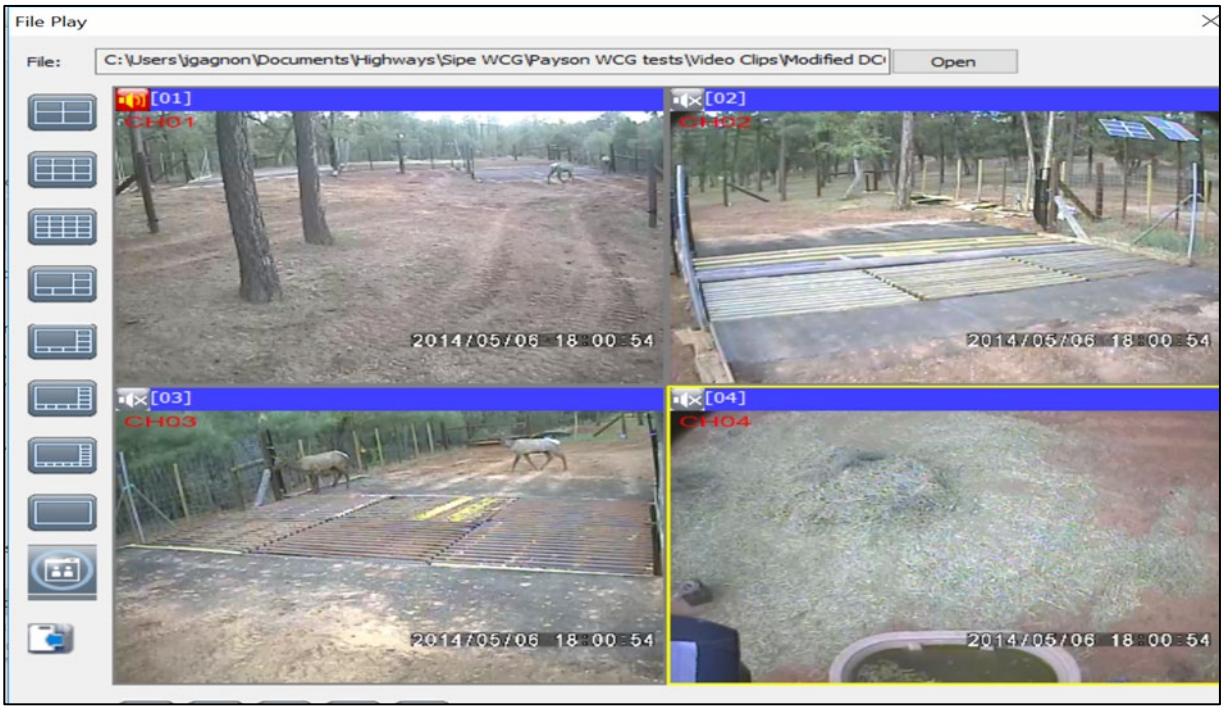

Figure 18. Video Camera Orientations Showing, top to bottom and left to right, (1) Entry Point into Test Site, (2 and 3) Wildlife Guard Treatments, and (4) Bait and Water

The objective of the test site layout was to evaluate the willingness of elk to attempt to cross various wildlife guard options to determine which designs or combination of designs most effectively deterred elk from entering the bait site area. Treatments included asphalt only (control), painted stripes, electrified mats and concrete, single and double cattle guards, and various combinations of these treatments. To entice elk to enter the test site enclosure and attempt to cross a wildlife guard treatment, the research team and CrossTek LLC (a wildlife mitigation consulting firm that assisted with the test site) ensured that bait and water were available at the bait site daily.

The test site layout included two treatment locations to allow two treatments to be tested side by side (see Figure 19). The research team used camera data to calculate the repel rate for each wildlife guard design or combination of designs implemented at the two treatment locations. This information allowed for a paired comparison of wildlife guard designs and a determination of the elk's preferred design to

access the bait site. The repel rates were calculated for each treatment type, as well as the probability and associated odds that an elk would cross one wildlife guard type over another.

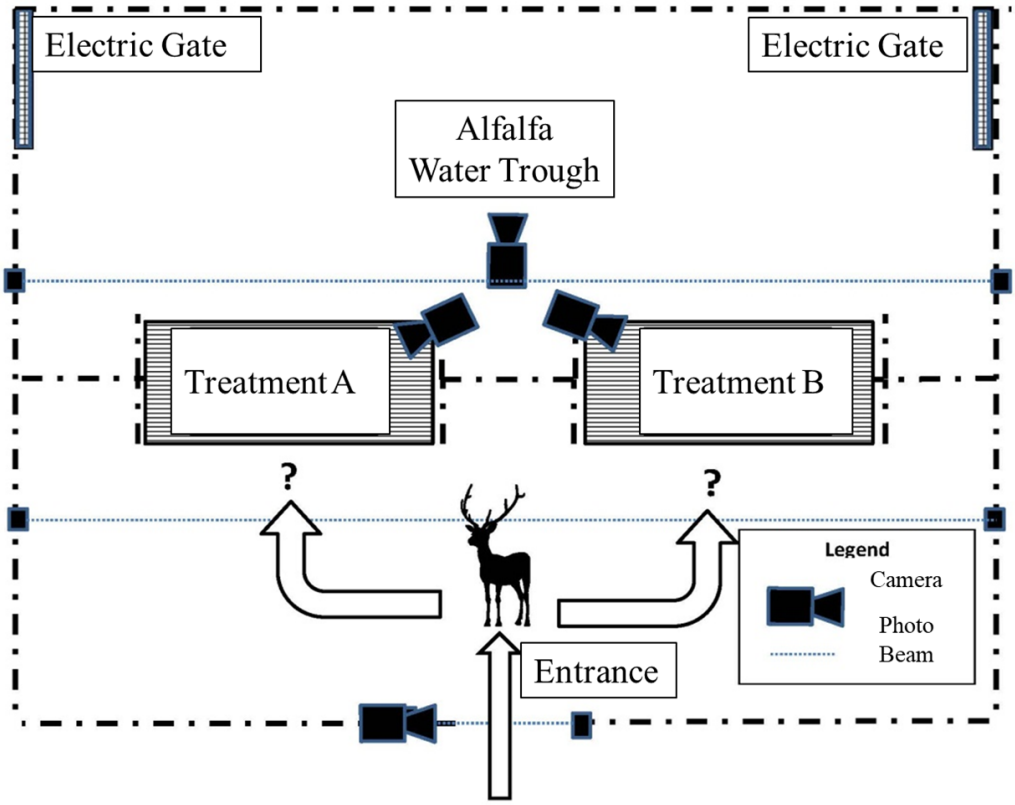

Figure 19. Layout of the Elk Wildlife Guard Test Site and Video Cameras at Risser Ranch

The evaluation and comparison of various combinations of wildlife guard types ended up being limited by the difficulty in implementing potential modifications to the guards and asphalt at the test site; thus, only selected comparisons were made. In addition, the test site evaluation of ADOT standard single and double cattle guards used modified versions of the guards created by CrossTek LLC. In these modified guards, welded black plates were placed inside the cattle guards to keep elk from falling all the way through the grates (potentially leading to injury) while still visually mimicking a cattle guard (see Figure 20).

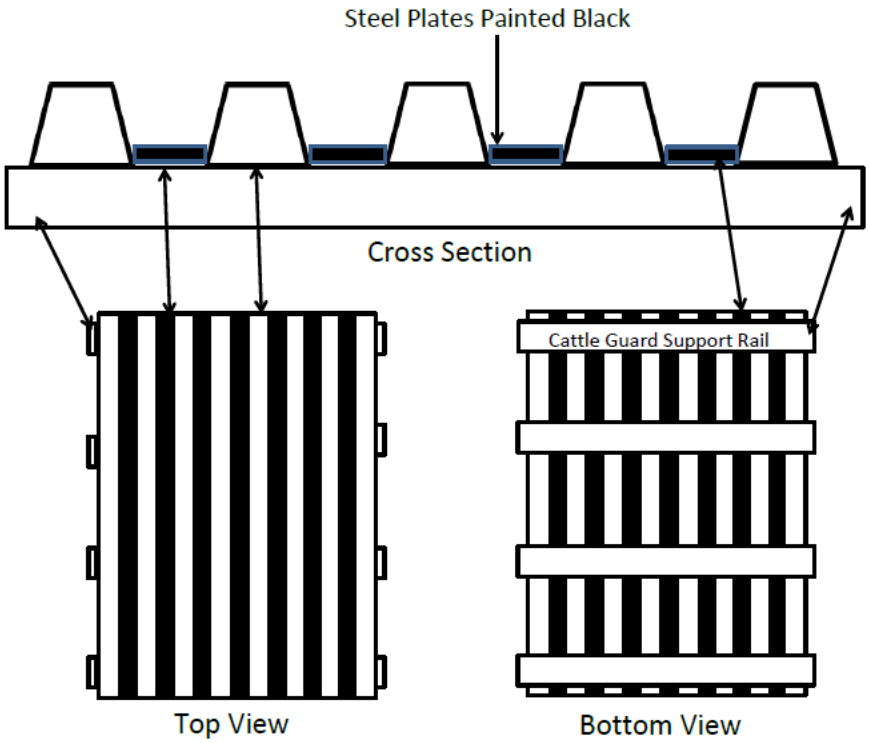

Figure 20. Cattle Guard Modified to Prevent Elk Injury, Showing Cross Section, Top, and Bottom Views

In addition to evaluating wildlife guards, the research team initially proposed that escape mechanism height and type be evaluated at the test site as well. The team ultimately decided this was not feasible due to the additional materials and heavy equipment that would have been needed at Risser Ranch. As an alternative means of increasing sample size, the team placed cameras on additional escape mechanisms along SR 260.

GENERAL MAINTENANCE AND DESIGN CONCERNS

The research team collected photographic examples of maintenance and design concerns associated with various escape mechanisms and wildlife guards used in Arizona. One example is shown in Figure 21. In addition to maintenance and design issues, the research team also sought out examples of escape mechanisms and wildlife guards from other states. These examples were combined and used to help inform current maintenance decisions and recommendations for possible future design changes that would maximize wildlife use and minimize maintenance needs. These issues are discussed in detail in Chapter 4.

Figure 21. Escape Mechanism in Need of Maintenance

CHAPTER 4. DATA ANALYSIS AND RESULTS

This chapter discusses the results of evaluating the effectiveness of escape mechanisms and wildlife guards for elk, deer, and bighorn sheep. The effectiveness of escape mechanisms and wildlife guards is assessed through two metrics: escape rate (the proportion of animals that approached from within the ROW and successfully escaped the ROW) and repel rate (the proportion of animals that attempted to enter the ROW but turned away without entering). To determine these rates, the research team reviewed 1.8 million photos of animals interacting with escape mechanisms and wildlife guards in the three study areas. The photos include 1.3 million images collected in this study from 2015 through 2018 combined with 0.5 million collected in previous ADOT research studies (see Chapter 3) from 2011 through 2015.

To determine important factors that account for the effectiveness of escape mechanisms and wildlife guards, the research team used ArcGIS Survey123 to collect structural attributes of all structures monitored. They then compared the escape and repel rates associated with each attribute. The team also conducted a logistic regression analysis to determine what attributes increased the odds of a successful escape from the ROW by elk, deer, and bighorn sheep. With ADOT's assistance, the research team identified seven locations where modifications to the structural attributes of existing escape mechanisms or wildlife guards were clearly needed. These modifications provided cases for estimating optimal heights of escape mechanisms and widths of wildlife guards.

In addition to the field camera data collection, the research team gathered 1056 hours of video of elk interacting with multiple types of electrified wildlife guards (electrified concrete, electrified cattle guards, and electrified mats) and nonelectrified wildlife guards (painted stripes, single cattle guards, and double cattle guards) at the controlled test site at Risser Ranch. Data on the effectiveness of each of these wildlife guards and on combinations of the various types of electrified and nonelectrified wildlife guards are reported in this chapter.

Throughout the study, the research team also took note of design and maintenance concerns related to escape mechanisms and wildlife guards in Arizona. This chapter provides examples of these design and maintenance concerns.

STILL CAMERA DATA RESULTS

As noted above, of the 1.8 million photos collected for this analysis, 1.3 million were from this study and 501,898 were collected prior to this study. These photos included a total of 11,788 elk, deer, and bighorn sheep interactions with escape mechanisms and 5128 interactions with wildlife guards, for a total of 16,916 events. The still camera data results in this section are presented first by species, then by each species' use of individual escape mechanisms and wildlife guards.

Elk

Escape Mechanisms

Escape Ramps. The research team collected data on 999 elk approaches to escape ramps from inside the ROW, resulting in 343 successful escapes (a 0.34 escape rate). Elk approached escape ramps from outside the ROW 4376 times and did not enter the ROW on 4277 occasions, for an overall repel rate of 0.98. Table 1 shows variation in escape and repel rates by sex and age class of elk. The Unknown Age/Sex category indicates that the species was identified but the sex and/or age of the species could not be verified.

The escape rate for cow elk exiting the ROW was 0.10 escapes/approaches higher, or 34.5 percent higher than the rate for bull elk, while the repel rate for bulls (0.95) that approached the escape ramp from outside the ROW was 0.03 lower than for cows (0.98). When comparing use of the escape ramps by month, 78.3 percent of all entries into the ROW by bulls via an escape ramp occurred in June and October and 68.5 percent of all cow entries into the ROW occurred in April and October. These monthly peaks coincide with peaks in elk-vehicle collisions in April, June, and October within the study areas and on other Arizona roadways (Dodd et al. 2007, Gagnon et al. 2012, Gagnon et al. 2017b).

Table 1. Escape Rates and Repel Rates for Elk Use of Escape Ramps

Rate Type	Total Approaches	Adult Bull Rate	Adult Cow Rate	Juvenile Rate	Rate for Unknown Age/Sex	Overall Rate
Escape Rate	999	0.29	0.39	0.24	0.18	0.34
Repel Rate	4277	0.95	0.98	0.99	1.00	0.98

In seven locations, researchers modified the height of existing escape mechanisms during the study. These locations included areas where elk had been documented to easily enter the ROW via an escape mechanism (see Figure 22) or where heights of escape mechanisms appeared too low (less than 60 inches) to effectively preclude elk from entering the ROW. The research team made modifications that included adding boards along the top edge of the escape mechanism (see Figure 23) or removing dirt mounds at the base of the escape mechanism to increase the height an elk would have to jump to enter the ROW. Three of these locations were on SR 260 and four were on I-17. After the modifications, monitoring was resumed at the new heights. In some instances, multiple modifications were made to the same escape mechanism to find the optimal height that would allow elk to escape the ROW relatively easily but discourage them from entering the ROW.

Figure 22. Elk Using an Escape Ramp in the Wrong Direction to Enter the ROW

Figure 23. Board Added Along the Top of an Escape Ramp to Increase Its Height

The dataset included escape ramp heights ranging from 53 to 78 inches. For analysis, escape ramps were divided into three groups by height: less than 60 inches, 60 to 72 inches, and more than 72 inches. The purpose of this analysis was to determine the optimal escape ramp height for elk. Comparative analysis of escape and repel rates indicates that the higher an escape ramp, the lower the escape rate of elk approaching from inside the ROW, and the higher the repel rate of elk approaching from outside the

ROW (see Table 2 and Figure 24). The intersection of escape and repel rates in Figure 24 shows where an optimal height may be achieved and provides a decision tool to assist in future escape ramp design.

Table 2. Elk Escape Rates and Repel Rates by Escape Ramp Height

Escape Ramp Height (inches)	Approaches from Inside ROW	Escapes	Escape Rate	Approaches from Outside ROW	Times Repelled	Repel Rate
< 60	712	263	0.37	2545	2464	0.97
60-72	129	40	0.31	903	886	0.98
> 72	158	40	0.25	928	927	1.00

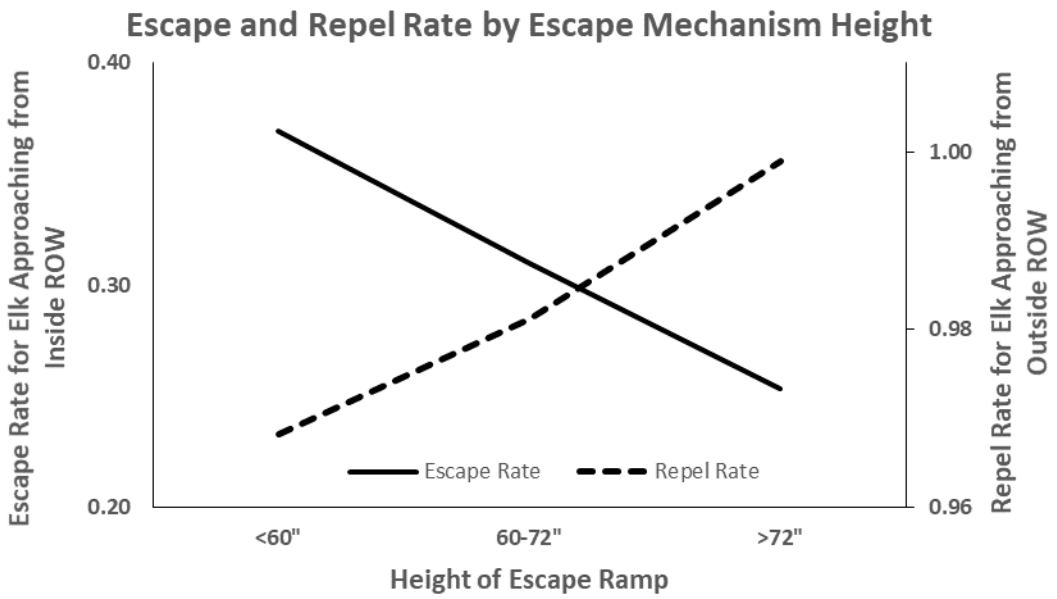

Figure 24. Comparison of Elk Escape Rates and Repel Rates by Escape Ramp Height

The research team evaluated concrete and gabion basket ramps that overlapped in height measurements (54 to 66 inches). Escape and repel rates for gabion basket ramps were similar to those for ramps with a concrete retaining wall (see Table 3). While there were also wooden escape ramps in one section of the study area, they were not analyzed in this study.

Table 3. Elk Approaches, Escape Rates, and Repel Rates by Escape Ramp Type

Escape Ramp Type	Approaches from Inside ROW	Escapes	Escape Rate	Approaches from Outside ROW	Times Repelled	Repel Rate
Concrete	714	265	0.37	2231	2139	0.96
Gabion Basket	127	38	0.31	933	927	0.98

Slope Jumps. The research team documented 24 elk escapes from the ROW out of 278 approaches to slope jumps within the ROW (see Figure 25), which is a 0.09 escape rate. Of 1289 elk that approached from outside the ROW, four entered the ROW and 1285 were repelled, for a repel rate of 1.00. Since 23 of the 24 escapes occurred at a single slope jump where the slope was minimal or nearly flat and only one escape occurred at a slope jump with a slope, the research team did not have enough data to determine an optimal slope. Although the slope jumps deterred elk from entering the ROW, they did not sufficiently facilitate elk in exiting the ROW. The lack of elk use of slope jumps led the research team to discontinue monitoring slope jumps after March 2018.

Figure 25. Elk Successfully Exiting the ROW Using a Slope Jump

Wildlife Guards

The research team collected data on 3852 approaches of elk at the 13 wildlife guards across the three study areas. Elk that approached the wildlife guards from outside the ROW (3231) were repelled at a rate of 0.80 (see Table 4). The effectiveness of all guard types in repelling elk, or keeping them out of the ROW, was much higher for cows (0.90), juveniles (0.86), and elk of unknown sex (0.98) than for bulls (0.53). The proportion of elk that were able to escape the ROW via a wildlife guard after approaching from within the ROW was 0.66 (see Table 5). Bulls negotiated the wildlife guards and entered the ROW on almost half of attempts (see Figure 26). It is likely that the low repel rate for bulls can be explained by individual bulls learning how to cross the cattle guards and then continuing to cross over time. This observation is anecdotal, but it is supported by photos of bull elk with distinct antler configurations crossing on more than one occasion.

Overall, electrified mats were marginally effective at hindering elk movement into the ROW (0.50 repel rate), while single and double cattle guards achieved overall repel rates of 0.80 and 0.85, respectively (see Table 4). Interestingly, however, the escape rates for each wildlife guard increased from 0.49 for an electrified mat to 0.81 for a single cattle guard and 0.83 for a double cattle guard (see Table 5).

Table 4. Repel Rates for Elk that Approached Wildlife Guards from Outside the ROW by Sex and Age Class

Wildlife Guard Type	Total Approaches	Adult Bull Rate	Adult Cow Rate	Juvenile Rate	Rate for Unknown Age/Sex	Overall Rate
Electrified Mat	498	0.41	0.55	0.29	0.96	0.50
Single Cattle Guard	65	0.48	1.00	NA	0.94	0.80
Double Cattle Guard	2668	0.56	0.97	0.96	0.99	0.85
All Types Combined	**3231**	**0.53**	**0.90**	**0.86**	**0.98**	**0.80**

Table 5. Escape Rates for Elk that Approached Wildlife Guards from Inside the ROW by Sex and Age Class

Wildlife Guard Type	Total Approaches	Adult Bull Rate	Adult Cow Rate	Juvenile Rate	Rate for Unknown Age/Sex	Overall Rate
Electrified Mat	318	0.71	0.43	0.65	0.00	0.49
Single Cattle Guard	31	0.89	0.60	1.00	0.71	0.81
Double Cattle Guard	272	0.98	0.57	0.73	0.31	0.83
All Types Combined	**621**	**0.89**	**0.47**	**0.67**	**0.20**	**0.66**

Figure 26. Bull Elk Crossing a Double Cattle Guard

Deer

Escape Mechanisms

Escape Ramps. Deer use of escape mechanisms was minimal compared to elk use. The research team identified 324 approaches of deer from inside the ROW, resulting in 41 successful escapes (an escape rate of 0.13). Of 756 deer that approached escape ramps from outside the ROW, four deer used the escape ramp to enter the ROW and the rest turned away (a repel rate of 1.00; see Table 6). The height of the escape ramps used in the 41 deer escapes ranged from 53 to 78 inches, while the highest escape ramp used by the four deer that entered the ROW was 66 inches (5.5 ft). Due to the low number of deer that used an escape ramp, the evaluation by ramp type and determination of escape ramp heights appropriate for deer was not conducted.

Table 6. Escape Rates and Repel Rates for Deer Use of Escape Ramps

Rate Type	Total Approaches	Adult Buck Rate	Adult Doe Rate	Juvenile Rate	Rate for Unknown Age/Sex	Overall Rate
Escape Rate	324	0.15	0.12	0.00	0.15	0.13
Repel Rate	756	1.00	1.00	1.00	0.98	1.00

Slope Jumps. Of 448 approaches from within the ROW, the research team documented 40 escapes via a slope jump (0.09 escape rate). In many areas where the existing ROW fencing had been retrofitted to a height of 8 ft to focus specifically on elk, deer climbed under the fencing or climbed through breaks in the fencing rather than jumping over it. Only one deer was documented using a slope jump. Eight of 618 deer that approached a slope jump from outside the ROW entered the ROW through it (0.99 repel rate). After March 2018, the research team ended the monitoring period for slope jumps a year early due to low utilization.

Wildlife Guards

Deer approached wildlife guards on 173 occasions. Of 94 deer that approached from outside the ROW, 76 turned away (0.81 repel rate), whereas 21 of 79 deer that approached from within the ROW found their way out via a wildlife guard (0.27 escape rate; see Tables 7 and 8). Of a total of 39 crossings from either inside or outside the ROW, 38 were documented at electrified mats located on SR 260 and I-17, and only one crossing was documented at a double cattle guard. The information deduced from the limited number of deer observations is insufficient to provide general guidance on an effective wildlife guard design for deer. It was observed, however, that electrified mats appeared to allow deer to enter or leave the ROW relatively easily (see Figure 27). The research team identified a couple of potential reasons for this, including that the electrified mats may have been working intermittently throughout the study, thereby allowing deer to enter or leave the ROW. Additionally, the electrified mats were only 6 ft wide, which may not have provided deer with enough exposure to the charged and grounded sections of the electrified guard.

Table 7. Repel Rates for Deer that Approached Wildlife Guards from Outside the ROW

Wildlife Guard Type	Total Approaches	Adult Buck Rate	Adult Doe Rate	Juvenile Rate	Rate for Unknown Sex/Age	Overall Rate
Electrified Mat	29	0.26	0.33	NA	0.83	0.38
Single Cattle Guard	1	NA	1.00	NA	NA	1.00
Double Cattle Guard	64	1.00	1.00	NA	1.00	1.00
All Types Combined	**94**	**0.71**	**0.93**	**0.96**	**0.99**	**0.81**

Table 8. Escape Rates for Deer that Approached Wildlife Guards from Inside the ROW

Wildlife Guard Type	Total Approaches	Adult Buck Rate	Adult Doe Rate	Juvenile Rate	Rate for Unknown Sex/Age	Overall Rate
Electrified Mat	75	0.57	0.00	NA	0.00	0.27
Double Cattle Guard	4	0.00	0.00	NA	1.00	0.25
Both Types Combined	**79**	**0.54**	**0.00**	**NA**	**0.04**	**0.27**

Figure 27. Deer Crossing an Electrified Mat

Bighorn Sheep

Escape Mechanisms

Escape Ramps. Along U.S. 93, which has only gabion basket-style escape ramps, the research team collected data on 564 approaches of bighorn sheep from inside the ROW, resulting in 426 successful escapes (a 0.76 escape rate). Bighorn sheep approached escape ramps from outside the ROW 2129 times and did not enter the ROW on 2080 occasions, for an overall repel rate of 0.98.

Modifications were made to escape ramps between 2011 and 2015 to determine the impact on the ramps' effectiveness. During the bighorn sheep crossing project along U.S. 93 from 2011 to 2015, the research team noted the presence of sheep in the ROW as well as unexpected sheep-vehicle collisions (Gagnon et al. 2017a). The team suspected that sheep were entering the ROW via escape mechanisms and installed cameras at select escape mechanisms to record these entries. After confirming that sheep were accessing the ROW at these locations (see Figure 28), the research team stretched wire across the opening of the ramp to deter sheep from jumping into the ROW while still allowing sheep to exit the ROW by passing under or over the wire (see Figure 29). Continued monitoring of the escape ramps with wire showed that sheep still tried to jump up and were stopped by the wire, presumably because they could not see it (see Figure 30). To help accentuate the wire, the research team added polyvinyl chloride (PVC) pipe to the wire (see Figure 31). The research team presented these preliminary findings to ADOT, and ADOT Maintenance staff added an adjustable horizontal metal crossbar to the escape ramp in place of the wire/PVC (see Figure 32).

The current study monitored the performance of this final version of the escape ramps (with the metal bar added). Data collected before and after the modifications allowed for a comparison of escape ramp effectiveness with and without a barrier (wire, PVC, or metal bar).

Figure 28. Bighorn Sheep Using an Escape Ramp to Access the ROW

Figure 29. Bighorn Sheep Using an Escape Ramp with Wire to Exit the ROW

Figure 30. Wire Preventing Bighorn Sheep from Using an Escape Ramp to Enter the ROW

Figure 31. Bighorn Sheep Using an Escape Ramp with PVC that Accentuates the Wire

Figure 32. Bighorn Sheep Using an Escape Ramp with a Bar

The results indicate that the addition of the horizontal metal bar still allowed a relatively large percentage of sheep (61 percent, or a 0.61 escape rate) to escape the ROW while almost completely eliminating bighorn sheep entrances into the ROW (0.98 repel rate overall). Even though the addition of the bar to the ramps only increased the repel rate by 0.02, this small increase is important, as these modifications correlated with a 54.5 percent decrease in sheep-vehicle collisions along U.S. 93 (Gagnon et al. 2017a). It is important to note that the escape rate went down substantially, from 0.94 to 0.61. This lowered escape rate is an acceptable tradeoff, as adding the bar helped keep sheep out of the ROW to begin with and led to an overall reduction in accidents while still allowing sheep to escape, albeit at a lower rate. The overall results of these modifications are presented in Tables 9 and 10.

Table 9. Escape Rates for Bighorn Sheep Before and After Escape Ramp Modification

Escape Ramp Status	Total Approaches	Adult Ram Rate	Adult Ewe Rate	Juvenile Rate	Rate for Unknown Sex/Age	Overall Rate
Before modification (without barrier)	247	0.95	0.95	0.88	0.00	0.94
After modification (with barrier—wire, PVC, or bar)	317	0.59	0.65	0.50	0.33	0.61

Table 10. Repel Rates for Bighorn Sheep Before and After Escape Ramp Modification

Escape Ramp Status	Total Approaches	Adult Ram Rate	Adult Ewe Rate	Juvenile Rate	Rate for Unknown Sex/Age	Overall Rate
Before modification (without barrier)	500	0.99	0.96	0.97	0.92	0.96
After modification (with barrier—wire, PVC, or bar)	1629	1.00	0.98	0.98	0.99	0.98

Slope Jumps. Because there were no slope jumps in areas where bighorn sheep were present, no data were collected to determine slope jump effectiveness for this species.

Wildlife Guards

From 2011 to 2015, the research team and ADOT Maintenance staff noted that sheep were entering and exiting the ROW via the single cattle guards (a non-ADOT standard cattle guard) at the on- and off-ramps of the Kingman Wash traffic interchange (TI) by either jumping the cattle guard or walking the ledge along the edge of the cattle guard (see Figure 33). In an attempt to reduce access to the ROW by sheep, ADOT painted stripes on the ROW side of the cattle guards to mimic a double cattle guard and discourage sheep from jumping over the cattle guard and onto the painted stripes (see Figure 34). The research team added cameras to two of the cattle guards in 2012. A previous study conducted by the research team on bighorn sheep along U.S. 93 found that these painted stripes did not deter sheep from crossing the single cattle guards (Gagnon et al. 2017a; see Figure 35).

In 2015 ADOT modified the wildlife guards at the four on- and off-ramps at Kingman Wash TI, installing a second single cattle guard alongside the initial cattle guard to create a double cattle guard (like those used for elk along SR 260) and added a fence to block access to the ledge that the sheep had used to cross the cattle guard (see Figure 36).

Figure 33. Bighorn Sheep Walking a Cattle Guard Ledge at Kingman Wash TI

Figure 34. Painted Stripes Mimicking an Additional Cattle Guard

Figure 35. Bighorn Sheep Jumping a Cattle Guard at Kingman Wash TI Despite Painted Stripes

Figure 36. Double Cattle Guard with Fencing

The research team evaluated sheep interactions with single cattle guards measuring 8 ft wide plus painted stripes, as well as two cattle guards combined, or a double-deep cattle guard, measuring 16 ft wide. Prior to the installation of the double cattle guards, the research team documented 122 crossings of the cattle guard out of 933 attempts, for a repel rate of 0.87. After the double cattle guard was added in 2016, not only did the approaches taper off significantly (to 65), crossings were completely eliminated. This raised the repel rate to 1.00 and reflected 100 percent success (see Table 11). Since the modification of these cattle guards, along with the modified escape ramps mentioned in the previous section, there has not been a bighorn sheep-vehicle collision documented by either AGFD or ADOT along U.S. 93 since 2014.

Table 11. Repel Rates for Bighorn Sheep at Cattle Guards Before and After Modifications

Wildlife Guard Type	Total Approaches	Repel Rate
Single Cattle Guard with Stripes	933	0.87
Double Cattle Guard	65	1.00

STRUCTURAL ATTRIBUTES OF ESCAPE MECHANISMS

The research team used an ArcGIS Survey123 mobile application to gather structural attribute data from all 45 structures (escape mechanisms and wildlife guards) in the study area. This section reports on escape ramp attributes for elk and bighorn sheep; deer were not included because of the small sample size. Wildlife guards are not discussed in this section because there are no variations in their sizes or attributes (i.e., they are all the same width and length).

Important Structural Attributes of Escape Ramps for Elk

Of the 10 structural attributes of escape mechanisms shown in Table 12, five were statistically significant (p-value < 0.05) in determining the odds of elk using escape ramps with a particular structural attribute and characteristic (listed in the Options column). If the odds ratio for a structural attribute is greater

than 1.0, it means the elk used escape ramps characterized by the first option. For example, the odds of an elk using an escape ramp with no landing pad obstruction (clear) versus with vegetation were 2.65:1, which means an escape ramp with a clear landing pad was 2.65 times more likely to be used by elk than a ramp with vegetation present. The statistical significance of the calculated odds ratio for each of the structural attributes was tested using the likelihood-ratio (L-R) chi-square test at p-value < 0.05 with a 95 percent confidence interval (CI). It can be surmised from the results that elk used escape ramps with clear and level landing pads, a ramp height below 72 inches, with a concrete retaining wall versus gabion basket, and integrated into the topography (versus stand-alone or distinct). Table 12 also shows that the other five attributes the research team evaluated had no effect on the odds of a successful escape by elk.

Table 12. Logistic Regression Analysis of Elk Escapes by Structural Attributes of Escape Ramps

Structural Attribute	Options	L-R Chi-Square	P-Value	Odds Ratio	95% CI	Preference
Landing Pad Obstruction	Clear vs. Obstructed by Vegetation	38.23	< 0.01*	2.65	1.92-3.64	Clear
Landing Pad Slope	Flat-Gradual vs. Sloped	24.71	< 0.01*	2.10	1.57-2.82	Flat-Gradual
Ramp Height	< 72" vs. > 72"	11.93	< 0.01*	2.05	1.34-3.13	< 72"
Retaining Wall Type	Concrete vs. Gabion	8.64	< 0.01*	1.63	1.17-2.29	Concrete
Topographic Integration	Integrated vs. Distinct	8.64	< 0.01*	1.63	1.27-2.29	Integrated
Landing Pad Compaction	Hard Packed vs. Loose	0.42	0.51	1.18	0.71-1.97	None
Ramp Fill Material	Cobble vs. Soil	0.05	0.82	1.14	0.37-3.53	None
Ramp Compaction	Hard Packed vs. Loose	0.25	0.62	1.13	0.69-1.83	None
Landing Pad Length	< 10' vs. > 10'	0.06	0.81	1.03	0.76-1.41	None
Ramp Opening Width	< 15' vs. > 15'	0.06	0.98	1.01	0.65-1.55	None

* Statistically significant (p-value < 0.05).

Important Structural Attributes for Bighorn Sheep

Of the 10 structural attributes of escape mechanisms used by sheep to escape the ROW, five were statistically significant (p-value < 0.05). The odds of sheep using an escape ramp were approximately 4:1, increasing to 19:1 as each of the following conditions were met: when a bar was absent, when the total ramp height was below 72 inches, when the landing pad and escape ramp soil were hard-packed, and when the approach to the ramp was sloped. The remaining five attributes did not significantly affect the odds of a successful escape by sheep (see Table 13). Sheep likely use the ramps with hard-packed soil due to their sure-footedness in rocky terrain with distinctly higher topography than the surrounding

area to allow for higher visibility. Although the odds of sheep using an escape ramp without a bar are higher, a bar approximately 20 inches high may still be necessary to limit sheep access to the ROW.

Table 13. Logistic Regression Analysis of Bighorn Sheep Escapes by Structural Attributes of Escape Ramps

Structural Attribute	Options	L-R Chi-Square	P-Value	Odds Ratio	95% CI	Preference
Horizontal Bar	Absent vs. Present	50.35	< 0.01*	19.32	5.89-63.43	Bar Absent
Total Height with Bar	< 72" vs. > 72"	37.71	< 0.01*	8.57	3.74-19.62	< 72"
Approach Slope	Sloped vs. Flat	36.4	< 0.01*	6.83	3.82-13.79	Sloped
Landing Pad Compaction	Hard Packed vs. Loose	29.22	< 0.01*	4.96	2.70-9.12	Hard Packed
Ramp Compaction	Hard Packed vs. Loose	23.72	< 0.01*	4.42	2.31-7.82	Hard Packed
Divider Fence	Present vs. Absent	1.46	0.23	1.62	0.75-3.48	None
Landing Pad Obstruction	Clear vs. Obstructed by Vegetation	1.45	0.23	1.62	0.75-3.47	None
Topographic Integration	Integrated vs. Distinct	0.74	0.39	1.47	0.62-3.51	None
Horizontal Bar Height	< 20" vs. > 20"	0.67	0.41	1.36	0.64-2.92	None
Landing Pad Slope	Flat vs. Sloped	0.07	0.8	1.15	0.37-3.57	None

* Statistically significant (p-value < 0.05).

CONTROLLED TEST SITE RESULTS

The controlled test site was used only for elk. The research team's video surveillance system collected 1055 hours, 31 minutes, and 47 seconds of elk interactions with wildlife guards installed at the test site. The test results presented in this section are only for elk that entered the bait site and made a choice to cross the wildlife guard; the results exclude elk that entered and were trapped in the bait site. Overall, the research team evaluated eight wildlife guard types (plus two combination treatments) at the test site (see Table 14).

The research team documented 5472 approaches by elk to the wildlife guard types described in Table 14, resulting in 2626 non-crossings (a repel rate of 0.48). Table 15 shows the repel rates by wildlife guard type, arranged from least effective to most effective for all elk. Given the propensity of bulls to cross wildlife guards (as previously shown in the still camera data), the research teams used two categories to evaluate the repel rates of herds that approached wildlife guards at the test site—herds with at least one bull present (3048 approaches) and herds with cows only (3559 approaches). Herds with bulls present showed a 0.45 repel rate and herds with cows only showed a 0.48 repel rate, indicating no obvious bias was caused by having bulls present.

Table 14. Wildlife Guard Types Evaluated at the Controlled Test Site

Type	Abbreviation	Description
Control (No Guard Present)	C	Control—No treatment; asphalt only
Nonelectrified	PS	Painted stripes—White stripes painted across black asphalt in attempt to mimic a cattle guard
Nonelectrified	SCG	Single cattle guard—Typical single cattle guard used by ADOT to exclude livestock from roads
Nonelectrified	DCG	Double cattle guard—Combination of two SCG side-by-side
Nonelectrified	SMG	Single modified guard—Single cattle guard with welded steel plates
Nonelectrified	DMG	Double modified guard—Double cattle guard with welded steel plates
Electrified	ZC	ZapCrete—Conductive concrete with alternating charged and grounded sections
Electrified	ZM	ZapMat—Composite boards with alternating charged and grounded copper strips
Electrified	ZG	ZapGuard—Electrified single cattle guard
Electrified	ZM/ZG	Combination of ZapMat and ZapGuard side-by-side
Electrified	ZC/SMG	Combination of ZapCrete and single modified guard

Table 15. Repel Rates for Elk at the Controlled Test Site by Type of Wildlife Guard

Wildlife Guard Type	Approaches	Adult Bull Rate	Adult Cow Rate	Juvenile Rate	Overall Rate
Control (No Guard Present)	862	0.01	0.04	0.04	0.04
Painted Stripes	647	0.08	0.09	0.13	0.09
Single Modified Guard	932	0.48	0.21	0.13	0.20
Double Modified Guard	368	0.13	0.58	0.45	0.52
ZapCrete	903	0.52	0.71	0.58	0.66
ZapMat (Single Electric Mat)	503	0.69	0.78	0.83	0.78
ZapCrete with Single Modified Guard	630	0.80	0.85	0.90	0.87
ZapGuard (Single Electric Guard)	105	0.97	0.85	1.00	0.89
Single Cattle Guard	200	0.92	0.97	1.00	0.97
ZapMat with ZapGuard	59	1.00	0.96	NA	0.97
Double Cattle Guard	263	1.00	0.98	1.00	0.98
All Treatments	**5472**	**0.40**	**0.49**	**0.48**	**0.48**

As shown in Table 16, the research team conducted a pairwise comparison to demonstrate the differences in repel rates when elk were given a choice of two (paired) wildlife guards at the same time. The number in a cell represents the difference in repel rate or repels to approaches between the wildlife guard listed in the top row and the repel rate for the paired wildlife guard in the first column. Note that these numbers are not the difference between individual repel rates presented in Table 14.

For example, when ZapCrete (ZC) is paired with ZapMat (ZM), the difference in the repel rates is 0.14. This means that when elk are given a choice of crossing ZC or ZM, the repel rate or the rate at which elk will not cross ZC is 0.14 crossings/approaches higher than the repel rate for ZM. Another example is when elk are given a choice of crossing ZM when paired against painted stripes (PS), the repel rate of the ZM is 0.29 repels/approaches higher than PS, meaning elk prefer to risk crossing PS versus ZM to access the bait.

Table 16. Pairwise Comparison of Elk Repel Rates at the Controlled Test Site

Paired Guard Type	PS	SMG	SCG	DMG	DCG	ZM	ZG	ZM/ZG	ZC	ZC/SMG
C	0.04	*	*	*	*	*	*	*	0.86	*
PS	--[1]	*	0.96	*	*	0.29	*	*	*	*
SMG	--	--	*	0.24	*	0.12	*	*	*	0.92
SCG	--	--	--	*	0.03	*	*	*	*	*
DMG	--	--	--	--	*	0.17	0.40	0.55	*	*
DCG	--	--	--	--	--	*	*	*	*	*
ZM	--	--	--	--	--	--	–0.13	*	0.14	0.58
ZG	--	--	--	--	--	--	--	*	*	*
ZM/ZG	--	--	--	--	--	--	--	--	*	*
ZC	--	--	--	--	--	--	--	--	--	*

* Pairwise comparison not conducted.
[1] A dashed line indicates either a self-pairing (not conducted) or a pairing presented elsewhere in the table.

Researchers analyzed the effectiveness of each wildlife guard type over time (days 1 to 2, 3 to 4, and beyond) (see Figure 37). The electrified wildlife guards had higher repel rates in most instances than the nonelectrified versions (see Figure 38). Of the nonelectrified wildlife guards (see Table 14), the single and double cattle guards maintained a consistently high repel rate over time, while the painted stripes and single modified cattle guard showed a reduction in repel rate to less than 0.10 within four days (see Figure 39). All types that included electrified components (see Table 14) achieved a repel rate greater than 0.60, and in some cases these types increased in effectiveness over time. The most effective electrified configuration over time was the ZapMat combined with the ZapGuard. Both the ZapGuard alone, and the ZapCrete and single modified cattle guard combined, increased the repel rate to more than 0.90 (see Figure 40).

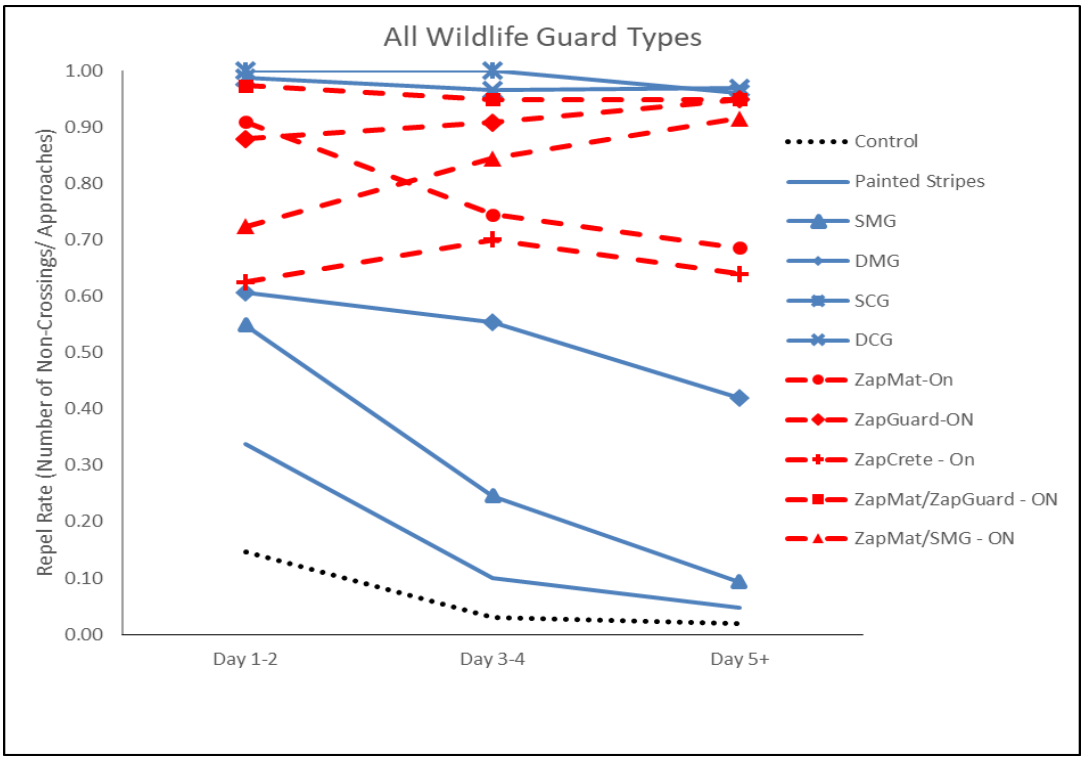

Figure 37. Elk Repel Rates Over Time for Wildlife Guards at the Controlled Test Site

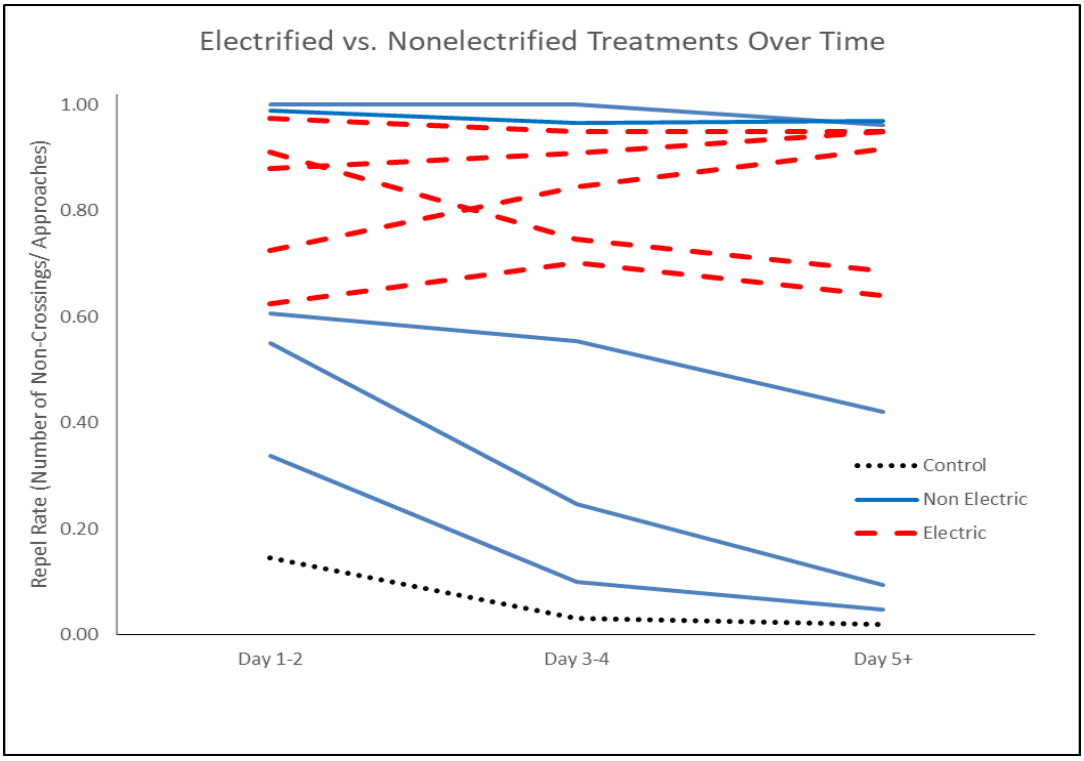

Figure 38. Elk Repel Rates Over Time for Electrified and Nonelectrified Wildlife Guards

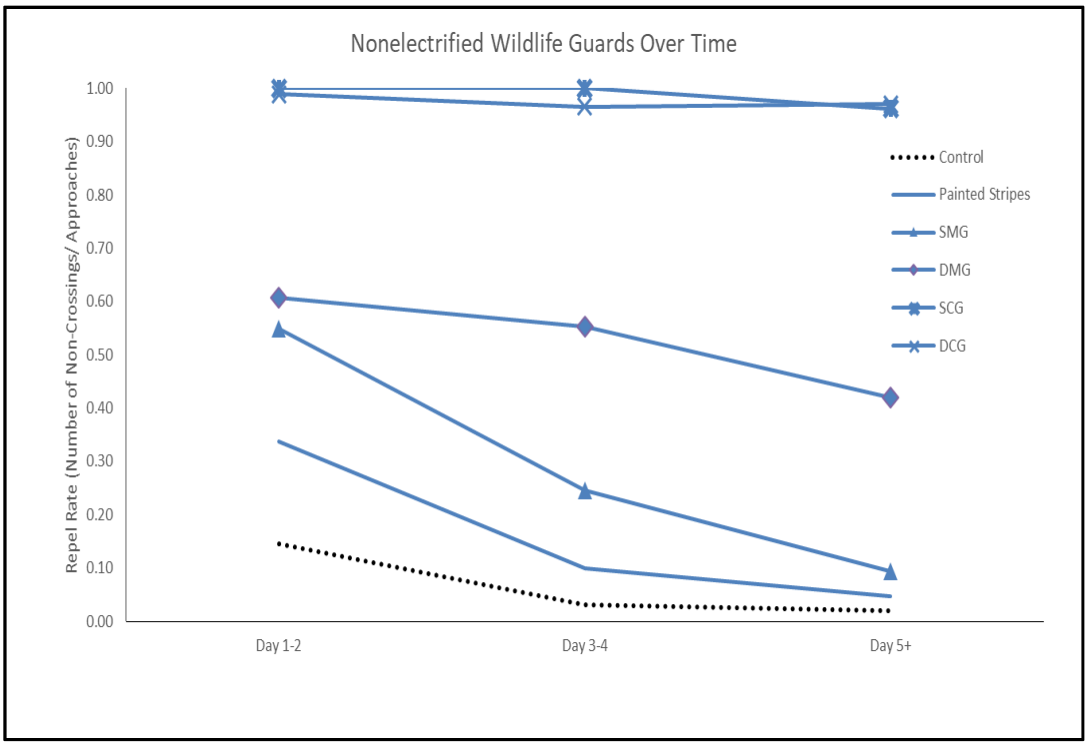

Figure 39. Elk Repel Rates Over Time for Nonelectrified Wildlife Guards

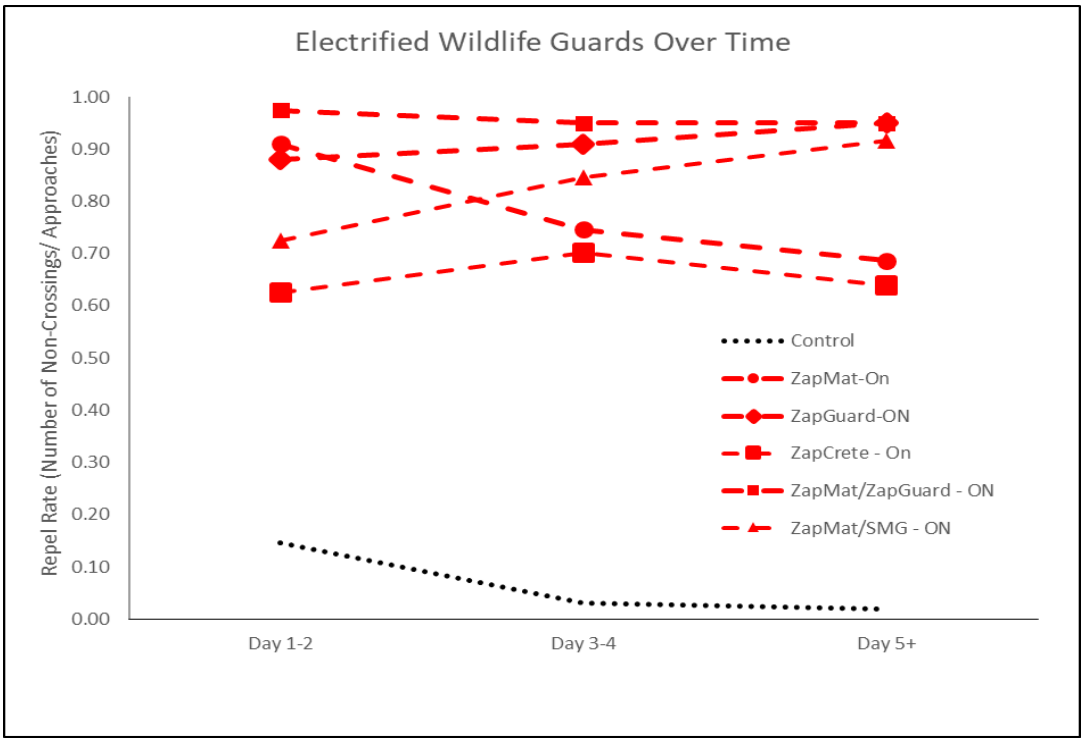

Figure 40. Elk Repel Rates Over Time for Electrified Wildlife Guards

The research team tested multiple configurations of the electrified wildlife guards, including different sizes and different voltage energizer levels (see Table 17). The options for these configurations included composite planks with charged embedded copper strips (ZapMat (ZM)), concrete with charged steel mesh (ZapCrete (ZC)), and electrified standard ADOT single cattle guards (ZapGuard (ZG)). The energizers included small (lowest voltage), medium (voltage levels between small and large), and large (highest voltage). The electrified versions of the wildlife guards had a repel rate of 0.83 (all treatments combined) when turned on compared with only 0.47 when turned off.

Table 17. Electrified Wildlife Guard Treatment Configurations Evaluated at Controlled Test Site

Treatment ID	Description
ZM-5P	5-plank electric mat
ZM-6P	6-plank electric mat
ZM-9P	9-plank electric mat
ZG	Electrified SCG
ZM/ZG-9P	9-plank electric mat with electrified SCG
ZM/ZG-3P	3-plank electric mat with electrified SCG
ZC-1	ZapCrete—no mesh
ZC-2	ZapCrete with expanded metal mesh
ZC-3	12' x 24' ZapCrete-Sim, 4 isolated 3' x 24' pads
ZC-3-A	ZC-3 with energizer A
ZC-3-B	ZC-3 with energizer B
ZC-3-C	ZC-3 with energizer C
ZC-4-A	9' x 24' ZapCrete-Sim, 3 isolated 3' x 24' pads, with energizer A
ZC-4-B	Same as ZC-4-A but with energizer B
ZC-4-C	Same as ZC-4-A but with energizer C
ZC/SMG-1	ZapCrete and single modified guard
ZC/SMG-2	8' x 24' ZapCrete-Sim, 2 isolated 3' x 24' pads, directly in front of single modified guard (7' x 24')—no energizer
ZC/SMG-2-A	Same as ZC/SMG-2 but with energizer A
ZC/SMG-2-B	Same as ZC/SMG-2 but with energizer B
ZC/SMG-2-C	Same as ZC/SMG-2 but with energizer C
ZC/SMG-3	8' x 24' ZapCrete-Sim, 3 isolated 3' x 24' pads, directly in front of single modified guard (7' x 24')—no energizer
ZC/SMG-3-A	Same as ZC/SMG-3 but with energizer A
ZC/SMG-3-B	Same as ZC/SMG-3 but with energizer B
ZC/SMG-3-C	Same as ZC/SMG-3 but with energizer C
ZC-5-A	9' x 24' ZapCrete-Sim, 3 isolated 3' x 24' pads
ZC-5-B	Same as ZC-5-A but with energizer B
ZC-5-C	Same as ZC-5-A but with energizer B

The breakdown of repel rates for each electrified configuration, each with a minimum of 10 approaches from outside the test site enclosure, are shown in Table 18. The repel rates for the electrified mats tested increased from 0.60 (five-plank) and 0.43 (six-plank) to 0.89 for the nine-plank mat, indicating that width may increase effectiveness by exposing elk to additional charged and grounded sections of the electrified mat. The importance of width for electrified wildlife guards is further supported by the evidence that the combinations of electrified and nonelectrified wildlife guards had higher repel rates than stand-alone electrified wildlife guards. These combined versions expose wildlife to a higher potential for shock as they attempt to cross the wildlife guard. The addition of small, medium, and large energizers to the base electrified wildlife guard type also changed the repel rates (see Table 19).

Table 18. Elk Repel Rates for Electrified Wildlife Guards Evaluated at the Test Site and Treatment Rankings

Treatment ID	Approaches	Crossings	Repel Rate	Ranking (1 = highest repel rate)
ZC/SMG-1	38	1	0.97	1
ZC/SMG-2-B	169	19	0.89	4
ZC/SMG-2-C	207	19	0.91	3
ZC/SMG-3-B	83	19	0.77	8
ZC/SMG-3-C	123	24	0.80	7
ZC-1	28	1	0.96	2
ZC-2	93	27	0.71	9
ZC-3	15	5	0.67	10
ZC-3-A	201	67	0.67	10
ZC-3-B	282	99	0.65	11
ZC-3-C	21	4	0.81	6
ZC-4-B	239	101	0.58	13
ZC-5-C	25	3	0.88	5
ZG	105	12	0.89	4
ZM/ZG-9P	56	2	0.96	2
ZM-5P	161	64	0.60	12
ZM-6P	23	13	0.43	14
ZM-9P	319	35	0.89	4

Table 19. Effects of Different Energizers on Repel Rates of Elk

Energizer	Approaches	Crossings	Repel Rate
A (small)	201	67	0.67
B (medium)	773	238	0.69
C (large)	376	50	0.87

MAINTENANCE AND DESIGN CONCERNS

During this project, the research team documented multiple maintenance and design concerns associated with the types of escape mechanisms and wildlife guards examined in this study. This section gives examples of those design and maintenance concerns.

Escape Mechanisms

For escape mechanisms, a key maintenance concern was inadequate soil retention. Causes included no method of retaining soil, retention failure due to excessively porous soil, failure of soil retention material, noncompatible substrate on the ramp surface, and soil and debris buildup at the base of a ramp from flood events. Design concerns included ramps short enough to allow wildlife to easily enter the ROW, and obstacles that may hinder wildlife use of ramps (see Figures 41 to 47).

Figure 41. Escape Ramp with a Noncompatible Substrate and No Soil Retention Method

Figure 42. Soil Loss Around an Expanded Metal Mesh Retainer

Figure 43. Soil Loss from Failing Wooden Plank Retaining Wall

Figure 44. Ramp Placed Near Drainage, Allowing Buildup of Water-Deposited Sediment

Figure 45. Retaining Wall Too Short to Keep Elk from Entering the ROW (Height Less Than 48 Inches)

Figure 46. Erosion, Lack of Soil Retention, and Short/Buried Guide Fence

Figure 47. Retaining Mesh Above Lip of Ramp, Creating Potential Escape Obstacle

Wildlife Guards

The research team also documented maintenance and design concerns regarding wildlife guards during field visits in Arizona. These concerns included excessive spacing between the two cattle guards in a double cattle guard; areas within the wildlife guard where animals could walk, either related to design or to dirt filling the cattle guard; and materials unsuitable for heavy traffic (see Figures 48 to 51).

Figure 48. Large Distance Between Double Cattle Guards and Short Fence

Figure 49. Ledge Allowing Animals to Access the ROW via a Wildlife Guard

Figure 50. Cattle Guard Partially Filled in with Dirt

Figure 51. Electrified Mat Material Damaged by Traffic Over Time

CHAPTER 5. DISCUSSION AND CONCLUSIONS

Complete elimination of ROW access by elk, deer, and bighorn sheep is both challenging and unlikely, because these animals have the physical ability to leap up escape ramps and to jump over wildlife guards used for WVC mitigation efforts. The presence of an incentive to jump up an escape ramp or cross a wildlife guard is a key factor in whether animals will attempt to access the ROW at these locations. The higher the incentive to cross, the more substantial the barrier must be. For example, higher-quality browse (edible vegetation) on the ROW side of the exclusionary fence compared to outside of the right of way can entice animals to risk crossing an escape mechanism in the wrong direction or traversing a wildlife guard. Similarly, in migration corridors, animals must move between seasonal ranges for survival, causing them to take higher risks to reach those ranges by attempting to gain access via escape ramps or wildlife guards.

To contribute to the complexities of designing effective escape mechanisms and wildlife guards, there appear to be differences in motivation and ability within species at both the gender and individual level. The data from this study indicate that bull elk are more likely than cow elk to cross wildlife guards (nearly 50 percent of bull elk approaches to wildlife guards resulted in a crossing, versus only 10 percent for cows). Possible explanations include differences in physical capabilities, differences in desire to access the ROW for preferred foraging opportunities, or cow elk's greater aversion to risk. It is also possible that a small number of individual bulls regularly crossed the cattle guards, thereby artificially inflating the crossing rates in this study. This is a reasonable assumption since in previous studies, elk-vehicle collisions were reduced by more than 87 percent following the implementation of mitigation measures that included escape ramps and wildlife guards (Gagnon et al. 2010, Dodd et al. 2012, Gagnon et al. 2015).

Because of the complexities of using information on species, incentives, and interspecific variation to design escape mechanisms and wildlife guards for a given WVC mitigation project, each project should be evaluated on a case-by-case basis in collaboration with local wildlife experts. When in doubt, the safest strategy is to use the most conservative approach that minimizes wildlife access to the ROW while still allowing an acceptable level of animals to escape the ROW. This chapter discusses applicable approaches for elk, deer, and bighorn sheep based on this conservative assumption.

ESCAPE MECHANISMS

Type

Current escape mechanism options include escape ramps, slope jumps, and one-way gates. This study showed that escape ramps are substantially more effective than slope jumps in allowing wildlife trapped in the ROW to escape. This finding is also supported by research from Bissonette and Hammer (2000), who evaluated the effectiveness of one-way gates compared to escape ramps and concluded that escape ramps are the most effective mechanism for allowing animals trapped in the ROW to escape while limiting access to the ROW. Currently, escape ramps are the best option for future WVC mitigation efforts.

Design and Materials

Based on our evaluation of various escape ramp designs, it appears that there are a few specific escape ramp design needs for elk, deer, and desert bighorn sheep, with the remainder of design recommendations applicable across all three species. These design needs are outlined below along with recommended materials for escape ramp construction.

Currently, it appears that 6 ft is a height that works well for keeping the majority of elk off ADOT roads while still allowing elk to escape the ROW. This height could be lowered slightly to increase escape attempts, but not without the potential tradeoff of a small increase in elk entering the ROW. Raising the height higher than 6 ft quickly reduces the elk's desire to use the escape ramp to exit the ROW. Elk staying within the ROW longer, however, risk collisions with vehicles.

Deer use of escape ramps during this study was minimal, with a successful escape rate of only 13 percent of 324 attempts to escape the ROW. This low escape rate indicates that escape ramps originally designed for elk, at approximately 6 ft, may be too high for deer. This finding is corroborated by other studies on deer use of escape ramps (Huijser et al. 2015, Huijser et al. 2016, Kintsch et al. 2020). Escape ramp designs for deer that are lower than 6 ft and provide an option for a horizontal bar to reduce deer entering the ROW may be appropriate to consider, similar to a subset of those evaluated by Siemers et al. (2015). Where both elk and deer are present, designing the escape ramp for elk is recommended since elk are a higher motorist safety concern due to their large body size.

Along U.S. 93, ADOT and AGFD implemented escape ramps for desert bighorn sheep that were similar in design to those used on SR 260 for elk. However, the sheep's climbing and leaping abilities allowed them to easily access the ROW, and the escape ramps required subsequent design modification. Adding a horizontal bar approximately 18 to 20 inches above the top of a ramp that is between 5 and 6 ft high almost completely eliminated sheep access to the ROW while still effectively allowing egress. This design modification to the ramps not only helped reduce sheep-vehicle collisions along U.S. 93 but has also been adopted in Nevada along I-11 (see Figure 52).

For all three species, general features of an effective escape ramp design include a clear landing pad, an unobstructed opening (free from tree branches and vegetation), and where possible, integration into the landscape. If the topography does not allow integration and a ramp is required to be stand-alone, then a slope with a maximum incline of 4:1 is recommended to allow animals to gradually ascend to the opening rather than requiring them to climb up a steep slope to access it.

Using impermeable materials for soil retention on escape ramps is essential. These materials could include concrete, properly treated and supported wood, landscape bricks, composite materials, or other durable, low-maintenance materials (see Figures 53 to 56). If gabion baskets are used, adding an impermeable surface or membrane to the face of the ramp can help reduce soil sloughing off. Using ramp fill material that packs well may also help reduce future maintenance requirements; avoid using material such as cinders or gravel.

Maintenance

Once escape ramps are constructed, continued maintenance is essential to helping them serve their purpose of allowing animals to escape the ROW while simultaneously hindering access to the ROW. Incorporating regular checks of escape mechanisms into an agency's fence inspections can help ensure long-term functionality. Maintenance activities include repairing retention material, replacing fill that is sloughing off, and removing soil from the base of ramps to retain effective height.

Figure 52. Escape Ramp with Horizontal Bar to Limit Bighorn Sheep Access from Outside the ROW; Inset Photograph Shows Horizontal Bar Detail

Figure 53. Escape Ramp Using Concrete to Retain Soil Along State Route 260 in Arizona

Figure 54. Montana Example of Escape Ramp Using Landscape Blocks to Retain Soil on U.S. Route 93

Figure 55. New Mexico Example of Escape Ramp Using Properly Treated and Supported Lumber to Retain Soil Along Interstate 40

Figure 56. Escape Ramp Using Composite Material to Retain Soil Along State Route 260 in Arizona

WILDLIFE GUARDS

Type

The research team's evaluation of multiple wildlife guard types in both field and control settings indicate that the best options for reducing elk, deer, and bighorn sheep access to the ROW include ADOT double cattle guards (essentially two ADOT standard cattle guards installed side-by-side) and wider electrified wildlife guards or combinations of electrified and nonelectrified guards. Painted stripes were completely ineffective, and wildlife guards with welded plates beneath them (to reduce the risk of animals falling through the guards) were ineffective after a couple of days.

Design and Materials

Nonelectrified Wildlife Guards

Ungulates in this study crossed wildlife guards by jumping over them, walking along the vault ledge, or walking across the guards. Elk and sheep tended to jump guards that were narrower, such as single cattle guards. With wider guards, such as double cattle guards, elk walked across them, or partially walked across and then jumped over the remainder of the guard. Using two ADOT standard guards, or double cattle guards, of a combined width of 16 ft was the most effective approach for deterring elk and eliminating access to the ROW by bighorn sheep. Although our monitoring of wildlife guards documented very little deer activity, other studies have shown that deer have the ability to cross wildlife guards in the same manner as elk, thereby supporting the conclusion that a double-wide wildlife guard (16 ft wide) is effective for ungulates (Cramer and Flower 2017).

Wildlife guards for ungulates can be further improved upon by implementing design options to keep animals from walking on them. These options include using round bars instead of flat bars, similar to the design implemented in Nevada along I-11 (see Figure 57), or using a grate material rather than bars (see Figure 58), an approach that has been successfully used to deter ungulates in Florida and Montana (Peterson et al. 2003, Allen et al. 2013, Kintsch et al. 2020). Guardrail, fencing, or angle iron can be used to exclude ungulates from the vault edge or to reduce their ability to gain a foothold; these approaches were implemented along U.S. 93 for bighorn sheep (see Figure 59) and along U.S. 550 in New Mexico (see Figure 60). A similar concept for reducing access to the vault ledge by using rubber bumpers was suggested by Allen et al. (2013).

Electrified Wildlife Guards

Based on our field and test site evaluations of electrified guards, a 12-ft or wider electrified wildlife guard or a combination of electrified and nonelectrified guards are viable options to deter elk from entering the ROW. This idea is also supported by a wildlife guard evaluation by Cramer and Flower (2017) that documented that elk access to bait sites was virtually eliminated once electrified mats were powered on. Deer, however, have shown mixed responses to electrified guards. In our study, more than 60 percent of deer crossed the electrified mats, possibly due to the narrow width of the guards (which reduces the potential for shock), occasional system malfunction, or a combination of both. This lack of

electrified wildlife guard effectiveness on deer is consistent with findings by Cramer and Flower (2017), who also documented that electrified mats were not effective on mule deer. (As in the current study, data on deer were collected in a field setting, versus a controlled setting for elk.) In contrast, electrified guards evaluated by Seamans and Helon (2008) were successful in repelling deer, but this study was conducted in a controlled environment, which may have decreased the potential for guard malfunction. No studies on desert bighorn sheep interactions with electrified wildlife guards have been conducted.

To increase the barrier to wildlife entering the ROW at lateral access roads, consider adding electrified wildlife guards as supplements to single cattle guards during fencing retrofits designed to guide animals to existing structures. When combining electrified and nonelectrified wildlife guards, the electrified guard should be placed on the non-ROW side of the nonelectrified guard to increase the potential for shock when animals pause to investigate the nonelectrified guard. In our evaluation of electrified wildlife guards, it was found that the larger the energizer, the more effective the guard was at repelling elk. With this in mind, the highest-voltage energizer available that meets power supply and cost needs but is also safe for humans is the best option for electrified guards.

Materials for electrified guards should be selected based on traffic volume and vehicle loads. For example, an electrified guard made of composite material on SR 260 did not hold up well to high traffic volumes and heavy traffic loads, whereas a similar design did hold up well on low-use forest roads. An electrified concrete guard was installed in place of the composite guard on SR 260 in late 2018 and currently appears robust enough for this application (see Figure 61). To further ensure the safety of pedestrians (with or without pets) and equestrians, the addition of temporary shutoff systems (see Figure 61) or side access gates can allow crossing when needed.

Maintenance

Regular maintenance of wildlife guards will help ensure that ungulates have limited opportunities to access the ROW. Maintenance of nonelectrified guards will be the same as for current ADOT cattle guards, including cleaning out vaults to limit opportunities for animals to walk on silt that has accumulated below the guards. Electrified wildlife guards will require personnel that are trained or specialize in electrical operations and maintenance to regularly monitor, maintain, and repair the guards. Equipment that automatically provides fault codes to ADOT personnel when power is lost to electrified wildlife guards could help identify malfunctions more quickly.

Figure 57. Wildlife Guard with Round Bars to Deter Wildlife Located on an Arizona-Nevada Joint Project Along Interstate 11; Inset Photograph Showing Round Bar Detail

Figure 58. Montana Example of Grate-Style Wildlife Guard Along U.S. Route 93; Inset Photograph Showing Grate Detail

Figure 59. Wide Wildlife Guard to Deter Jumping, with Guardrail or Fence to Prevent Walking on the Vault Edge, Along U.S. 93; Inset Photograph Showing Fencing Detail

Figure 60. New Mexico Example of Wide Wildlife Guard to Deter Jumping, with Angle Iron Welded to the Vault Edge to Reduce Walking on the Vault Edge, Along U.S. Route 550; Inset Photograph Showing Welded Angle Iron Detail

Figure 61. Electrified Concrete Wildlife Guard with Push-Button Power Delay for Pedestrian Crossing Along State Route 260; Inset Photograph Showing Push-Button Detail

CHAPTER 6. RECOMMENDATIONS

This chapter uses the results from this study to provide recommendations for escape mechanisms and wildlife guards for elk, deer, and desert bighorn sheep. Additionally, the research team presents recommendations based on applicable findings from other studies to provide the best available information for successful escape mechanism and wildlife guard application along Arizona roadways. These recommendations are provided for ADOT's consideration during the design and construction phases of roadway projects that require WVC mitigation strategies for motorist safety.

ESCAPE MECHANISMS

Based on the results of this study, the research team makes the following recommendations for escape mechanisms for elk, deer, and bighorn sheep:

Type

- Install escape ramps instead of slope jumps on projects where there is a need to allow elk, deer, and bighorn sheep that could be trapped in the ROW an opportunity to escape.

Design and Materials

- For elk, provide a ramp height of 6 ft from the base of the ramp to the top of the ramp.
- For deer, provide a ramp height of 5 ft, with the option to add a crossbar if deer are documented entering the ROW via escape mechanisms. The height may be increased to 6 ft in areas where elk also reside to reduce the risk of elk entering the ROW.
- For desert bighorn sheep, provide a ramp height of 5 to 6 ft from the base of the ramp to the lip of the ramp, with a horizontal crossbar placed 18 to 20 inches above the lip of the ramp.
- Integrate the escape ramp into the topography or provide a gradual slope with a maximum incline of approximately 4:1 leading up to the opening.
- Provide a level landing pad clear of vegetation and debris.
- Provide an opening that is a minimum of 10 ft wide, void of tree branches and vegetation.
- Install an impermeable membrane on the face of the ramp to keep soil from sloughing off.
- Avoid ramp fill that does not compact well, such as cinders and gravel.
- Consider the presence of wildlife guards as potential escape opportunities for elk, deer, and bighorn sheep when spacing out escape ramps.

Maintenance

To address maintenance concerns, the research team recommends:

- Incorporate the checking of escape ramps during fence inspections.
- Clear escape ramp openings and landing pads of vegetation and debris when necessary.
- Repair areas where soil is sloughing off the lip of the ramp. Replace or reinforce soil retention materials where needed.
- Remove soil from the base of the escape ramp on the outside of the ROW that may effectively reduce the height that animals need to jump to get into the ROW.

WILDLIFE GUARDS

Based on the results of this study, the research team makes the following recommendations for wildlife guards for elk, deer, and bighorn sheep:

Type

- Continue the use of standard ADOT double cattle guards or a guard type of equivalent width and functionality, such as round-bar guards or grates.
- In areas where electrified guards are preferred over standard double cattle guards, consider either a wide stand-alone electrified guard or a combination of electrified and nonelectrified guards.
- Consider installing wildlife guards instead of painted stripes that mimic wildlife guards, which were found to be ineffective.
- Avoid the use of shallow guards, such as guards with plates welded to the bottom of the guards to reduce the risk of wildlife falling through them. Shallow guards were found to be ineffective in deterring ungulates.

Design and Materials

Nonelectrified Wildlife Guards

- Employ guards with a minimum width of 16 ft to keep elk, deer, and bighorn sheep from easily jumping over them. This is the same as the default width of ADOT double cattle guards.
- Incorporate fences or other options to keep ungulates from walking along the vault ledges.

Electrified Wildlife Guards

- To reduce the potential for injury to cyclists, consider electrified wildlife guards as an alternative to standard cattle guards in areas that cyclists frequent.
- Provide a push-button shutoff or access gate that allows pedestrians with pets and equestrians to either deactivate or bypass the electrified wildlife guard. If an access gate is used, consider a

design in which the gate closes automatically to reduce the likelihood of the gate being left open and allowing animals to access the ROW.

- Use a wider electrified wildlife guard (12 to 16 ft wide) when designing a stand-alone installation; use a narrower electrified guard (6 to 8 ft wide) when the electric guard is combined with a nonelectrified version.
- When combining electrified and nonelectrified wildlife guards, place the electrified guard on the non-ROW side of the nonelectrified guard to increase the potential for shock when animals pause to investigate the nonelectrified guard.
- Use the highest-voltage energizer available that meets power supply and cost needs but is also safe for humans. In areas where electricity cannot easily be provided, one may consider using a relatively small solar panel to power an electro mat.
- Use highly durable materials such as electrified concrete in areas with high traffic volumes and heavy loads. Less durable designs, such as those made from composite materials, can be used on side roads with minimal traffic (in locations where a gate cannot be used).
- To increase the barrier to wildlife entering the ROW at lateral access roads, consider adding electrified wildlife guards as supplements to single cattle guards during fencing retrofits designed to guide animals to existing structures.

Maintenance

- Assign maintenance personnel that are trained or specialize in electrical operations and maintenance to regularly monitor, maintain, and repair electrified wildlife guards.
- Install equipment that provides fault codes to ADOT personnel when power is lost to electrified guards.

RECOMMENDATIONS FROM OTHER STUDIES

The following recommendations are based on findings from other studies conducted by the research team in Arizona, Nevada, and New Mexico, along with findings documented by other researchers throughout North America.

Escape Mechanisms

- Select escape ramps for WVC mitigation projects rather than one-way gates. Escape ramps are more effective than one-way gates at allowing animals to escape the ROW.
    - Although early research in a controlled environment showed promise for one-way gates (Reed et al. 1974b), escape ramps are more effective than one-way gates in field settings (Bissonette and Hammer 2000, Dodd et al. 2007).

- Locate escape ramps approximately 0.5 miles apart in general, but also consider placing ramps in areas where ROW breaches may be more likely, such as near fence ends or drainages that could wash out the fence during extreme weather events.
    - Spacing escape ramps at regular intervals allows ungulates opportunities to encounter escape ramps often when trapped inside the ROW. However, under circumstances where ROW breaches are more likely to occur, placement of escape ramps in these potential problem areas could present an immediate opportunity for animals to escape (Bissonette and Hammer 2000).
- Confer with local wildlife experts and ADOT Maintenance personnel on escape ramp placement to meet both wildlife needs and maintenance access needs.
    - Local wildlife experts can identify areas where heavier use by wildlife may occur, such as daily or seasonal migration corridors (Bissonette and Hammer 2000). They can also help optimize placement of limited escape ramps, as was done in collaboration with AGFD along multiple ADOT roadways (such as U.S. 93, SR 260, I-17, SR 77, SR 86, and South Mountain Freeway).
    - Discussions with ADOT Maintenance following the completion of escape ramps along SR 260 pointed to the need to confer with maintenance personnel to ensure that the locations of planned escape ramps are conducive to maintenance access.
- Include a perpendicular guide fence to direct animals toward the ramp opening.
    - Although the research team did not gather evidence to support the presence of guide fencing to direct wildlife to escape opportunities, anecdotal evidence suggests that guide fencing can improve the performance of escape ramps. Consider perpendicular guide fences as an option for future designs until additional evidence on their effectiveness, or lack of effectiveness, can be documented.

Wildlife Guards

- Where possible, explore round bars or grates as an option in place of flat bars to keep animals from walking across them.
    - Round-bar guards and grate materials have been shown to be effective alternatives to typical cattle guards with flat tops; these alternative designs can reduce the potential for animals to walk on the bars (Peterson et al. 2003, Allen et al. 2013, Kintsch et al. 2020). However, round bars may not be as safe as grates for pedestrians, so consider on a case-by-case basis (Peterson et al. 2003, Huijser et al. 2015).
- Regularly inspect wildlife guards for silt buildup. If the silt is close enough to the surface for ungulates to walk on (less than 24 inches from the surface), it should be cleaned out.

- Wildlife guards with deeper pits are a more substantial barrier to ungulates than wildlife guards with shallower pits (Huijser et al. 2015).

- Consider electrified wildlife guards, or combinations of nonelectrified and electrified versions, in areas where collisions with both hooved and padded-foot animals are a concern.
    - Standard cattle guards are not effective on padded-foot animals such as bears (Allen et al. 2013) and utilizing electrified guards can simultaneously address collisions with both padded-foot and hooved animals.

Wildlife Fencing

- Consider ungulate exclusion fencing that is a minimum of 8 ft high, made of woven or welded wire fence material with openings that are a maximum of 4 inches wide. Posts made of resilient, low-maintenance materials are preferred.
    - This type and design have shown the best results for both wildlife-vehicle collision reduction and lower long-term maintenance (Clevenger et al. 2001, Dodd et al. 2012, Huijser et al. 2015, Gagnon et al. 2017a).

- Consider modifications or additions to ungulate exclusion fencing to address smaller animals on a case-by-case basis.
    - Adding smaller wire mesh at the base of ungulate-proof fencing, and in some instances burying the fencing to reduce burrowing underneath it, can reduce reptile, amphibian, and small mammal roadkill (van der Ree et al. 2015).

- Recommend maintenance conduct inspections of the large ungulate exclusion fencing looking for breaches just prior to migration periods as that would be the most likely time for higher numbers of animals to approach the fencing. Inspecting large ungulate exclusion fence for damage after a large storm event is also recommended.
    - This recommendation extends beyond the traditional annual maintenance checks, but it is important to consider in areas with ungulate exclusion fencing to reduce hot spots in wildlife-vehicle collisions at these locations. This approach has been used successfully in other Arizona studies (Dodd et al. 2012, Gagnon et al. 2016).

- Provide gates for public access and have maintenance personnel ensure that gates that are left open by motorists are closed as soon as possible to reduce the potential for wildlife to access the ROW. Add signs to promote the closure of gates.
    - During previous studies along SR 260, I-17, and U.S. 93 (Dodd et al. 2012, Gagnon et al. 2016, Gagnon et al. 2017a), gates were left open by recreationalists and needed to be closed. Although this is not ideal, in areas where gates were not provided, fences were regularly cut for access, creating a more time-consuming maintenance issue. Providing

signs like the signs on SR 260 that say “Close the Gates to Prevent Wildlife-Vehicle Collisions” can significantly reduce the number of times gates are left open.

- Terminate ungulate exclusion fencing in areas where end runs by wildlife are minimized, or block access at fence ends, reducing the number of animals that enter the ROW via the fence ends.
    - Reducing the number of animals that have access to fence ends by terminating fences at wildlife crossings, in rugged terrain, or in other habitats that limit wildlife movement, or by adding wildlife guards at the ends of the fence can reduce the number of animals that enter the ROW to begin with (Huijser et al. 2008, Siemers et al. 2015, Gagnon et al. 2019).

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