Synthesis of Animal-Vehicle Collision Mitigation Measures

Final Report 612

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<tr><td colspan="6">16. Abstract
In all western states, domestic animal and wildlife populations are increasing as well as the vehicular traffic volumes. Consequently, increases in animal-vehicle collisions have been reported by many states. The purpose of this report is to provide a synthesis of animal-vehicle collision mitigation measures utilized by other states and to provide a cost-effective recommendation for ADOT to further reduce animal-vehicle collisions. Preparation for this report included assembling documented studies currently underway and existing reports, and conducting a survey among selected states and countries to learn what practices have been used for solving or alleviating animal-vehicle collisions.</td></tr>
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SI* (MODERN METRIC) CONVERSION FACTORS

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

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

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List of Acronyms

ADOT	Arizona Department of Transportation
ATRC	Arizona Transportation Research Center
BCMoT	British Columbia Ministry of Transportation and Infrastructure
BLM	Bureau of Land Management
DOT	Department of Transportation
FHWA	Federal Highway Administration
GIS	Geographic Information System
ICOET	International Conference on Ecology & Transportation
ROW	Right of Way
USDA	United States Department of Agriculture
USDOT	United States Department of Transportation

1.0 INTRODUCTION

Animal-vehicle collisions in Arizona have a large effect on highway safety and the local economy. Due to growth in wildlife and vehicular traffic throughout Arizona, the number of animal-vehicle collisions has a potential to increase. Accidents involving wildlife can result in significant damage to transport trucks and other motor vehicles and produce long traffic delays. This is especially true in remote areas where alternative highway routes are not readily available (Sielecki 2005). The Arizona Department of Transportation (ADOT) is currently studying various measures to reduce animal-vehicle collisions.

Each year more than 200 motorists are killed and 29,000 more are injured in animal-vehicle collisions in the United States (Bies 2007). The insurance industry estimates the annual cost to society for these fatalities and injuries is $200 million. The nationwide average for vehicle repair costs incurred from animal-vehicle collisions is approximately $2,000. With continued urban sprawl and suburban development the costs associated with animal-vehicle collisions is likely to increase (Peterson et al. 2003).

The purpose of this report is to provide a synthesis of animal-vehicle collision mitigation measures utilized by other states and agencies and to provide a cost-effective recommendation for ADOT to further reduce animal-vehicle collisions. Preparation for this report included documenting studies currently underway and existing reports, and conducting a survey among selected states and countries to learn what practices have been used for solving or alleviating animal-vehicle collisions.

2.0 BACKGROUND

In 2005, Arizona had an estimated population of 6,044,985, which is an increase of 17.8% from the year 2000 census (Arizona Workforce Informer 2007). This population increase has led to an increase in vehicular traffic and may potentially add to the number of animal-vehicle collisions throughout Arizona causing both economic and highway safety concerns. While the number of households in the U.S. grew by 72% between 1969 and 2001, household vehicle miles traveled shot up by 193% (Oberstar 2005).

ADOT has actively taken actions and measures to reduce animal-vehicle collisions. For example, a research report titled *Evaluation of Measures to Minimize Wildlife-Vehicle Collisions and Maintain Permeability across Highways: Arizona Route 260* (Dodd et al. 2007) reports the results of a study conducted on ways to minimize the incidence of wildlife-vehicle collisions along Arizona State Route 260.

In all western states, elk populations and vehicular traffic volumes are increasing. Consequently, increases in elk-vehicle collisions have been reported by many states. The reported number of elk-vehicle collisions in 2003 in Arizona was 396. However, it is estimated that the actual number of elk killed in highways may be two to three times that reported (Ruediger et al. 2005). Arizona's efforts in studying wildlife habitat fragmentation due to highway systems and possible solutions will go a long way in reducing animal-vehicle collisions statewide.

A number of states in the United States have also taken a leadership role in addressing wildlife ecology and transportation through policy, procedure, planning, project development, design, construction, and maintenance. However, these states vary in the treatment of animal-vehicle collisions due to lack of national uniform standards and guidelines for mitigation. The International Conference on Ecology and Transportation (ICOET) has demonstrated that some European countries are ahead of the United States in this area of science and research (Bank et al. 2002).

Animal-vehicle collision mitigation studies and measures fall into two categories: those for wildlife and those for domestic animals or livestock. In 2003, deer were struck in three out of four animal-vehicle collisions that caused human fatalities, but collisions with other animals such as cattle, horses, dogs and bears also led to fatalities (Huijser et al. 2007). The average adult elk weighs 600-850 pounds. This indicates that an elk-vehicle collision has the potential to be much more serious than a deer-vehicle collision (Ruediger et al. 2005). The traditional high and strong fencing and cattle guards have proven to work for some animals, but there are new measures that have been proposed and studied throughout the world to mitigate the number of animal-vehicle collisions on highways. Recent studies include how to cost-effectively apply various fencing material to different locations.

2.1 Animal Behavior

Understanding livestock and wildlife behavior is necessary before designing and implementing an effective animal exclusion method.

2.1.1 Livestock

Cattle, horses, and mules have panoramic vision: they can see everything except what is directly behind them. Cattle also have very limited depth perception. While a cow may see a fence nearby, it cannot judge its distance. Livestock, especially cattle, are curious creatures that often investigate fence oddities and use stationary structures to rub against (AgrAbility Project 2002). Often cattle rub against fencing poles causing damage to fencing and creating gaps for cattle to wander onto adjacent property or highway right-of-ways, creating the potential for animal-vehicle collisions.

2.1.2 Wildlife

Wildlife behavior is related to the "fight-or-flight response." Wildlife feel safe when there is space or a boundary around them. Once that boundary is violated the animal's response is unpredictable. Even if an animal sees a vehicle, it may still jump in front of it, or it may not even recognize the vehicle as a danger and may bolt in front of it, greatly increasing the chance of a collision. Wildlife also tend to travel in groups and if one animal crosses the road, there may be others that follow.

Humans may see roads as being a dangerous place for animals, but wildlife is attracted to the road, highway right-of-way, and roadside ditches, for many reasons including:

- Grasses growing within the highway right-of-way can increase feeding.
- Removal of snow in the winter can provide for ease of movement.
- More wind on the road and right-of-way provides relief from biting insects.
- Product spillage (such as grain) from vehicles can create temporary food sources.

(Wildlife Collision Prevention Program 2007)

2.2 Arizona's Current Practices and Studies

ADOT has actively taken measures to reduce both domestic and wildlife animal-vehicle collisions through policies, guidelines, and research.

2.2.1 ADOT's Design Guidelines and Standards

The *ADOT Roadway Design Manual* (ADOT 2007a) and the *Construction Standard Drawings* (ADOT 2007b) provide standardized preparation and implementation procedures for highway design and construction throughout Arizona. Specific guidelines and drawings have been developed for right-of-way fencing and cattle guards to keep domestic animals from entering the right-of-way and interfering with traffic.

Roadway Design Manual

Sections 313 and 314 of the *Roadway Design Manual* are ADOT's guidelines for right-of-way fencing and cattle guards.

> *313 – Right-of-Way Fence*
> Fencing is provided along the ADOT right-of-way to physically identify the right-of-way and to impede unauthorized access onto the right-of-way.
>
> All controlled access highways shall have right-of-way fencing except where walls or other physical barriers adequately define the right-of-way or where public access to the highway is permitted.
>
> Non-controlled access highways in rural areas should be fenced. In fringe-urban areas, highways should be fenced unless access to adjacent properties is so frequent that only short runs of fencing could be provided.
>
> In urban areas, those state highways which also function as arterial streets generally should not be fenced since access to the adjacent properties may be expected to be provided at frequent intervals along the highway.
>
> The construction standard drawings include the standard types of fences generally used by ADOT. The types of fencing to be included in the plans depends upon a number of factors and the selection should involve representatives from the ADOT district, the right-of-way group, and the environmental planning and enhancement group.
>
> *314.1 – Cattle Guards*
> Cattle guards, with or without gates, may be required to prevent livestock from interfering with roadway traffic or to maintain range control. To prevent cattle from entering the right-of-way, the construction of cattle guards may be required at side roads and private entrances. When placed near traffic interchanges on a crossroad, cattle guards without gates should be placed at or near the access control line to prevent livestock entering the main roadway. Only under unusual circumstances will cattle guards be justified in urban areas. The number of units required should be determined by the width of the roadway.

Construction Standard Drawings

The following are ADOT's construction standard drawings for cattle guards and fencing.

- C-11.10 Roadway Cattle Guard (3 Sheets)
- C-11.20 Cattle Guard, Drainage
- C-12.10 Fence Woven Wire with Gates (5 Sheets)
- C-12.20 Fence, Chain Link Types 1 and 2 with Gates (3 Sheets)
- C-12.30 Fence, Chain Link Cable Barrier (3 Sheets)

ADOT's construction standard drawings for cattle guards and fencing are very similar to other states. ADOT doesn't, however, have a standard detail for wildlife fencing. Due to the size and agility of wildlife, wildlife fencing must be higher and more specialized than typical right-of-way fencing used to contain livestock. Wildlife exclusion systems should be designed for specific species that represent the greatest potential hazard to the motoring public. The structural components of the fencing should be designed to withstand the forces of the largest animals and prevent the smallest animals from breaching gaps in the fence (Sielecki 2005). ADOT is currently testing several types of wildlife fencing. Standards will be considered upon conclusion of various wildlife-vehicle crash studies.

The British Columbia Ministry of Transportation and Infrastructure (BCMoT) has found exclusion fencing to be the most effective means of keeping wildlife off highway right-of-ways. BCMoT's experience with 2.4m (8 feet) high fencing on both sides of right-of-way show it is 97% - 99% effective in preventing wildlife-vehicle accidents (Sielecki 2004). The bottom of the fence may need to be buried to prevent bears and coyotes from digging under the fence and providing access to the highway for other animals (Ruediger et al. 2005).

2.2.2 ADOT's Existing Studies

State Route 260

In a coordinated effort among ADOT, FHWA, the US Forest Service and the Arizona Game and Fish Department, new highway upgrades were implemented to Arizona State Route 260 that addressed traffic and safety concerns. A major goal of this plan is to improve wildlife protection and habitat connectivity in the area. Habitat fragmentation associated with highways and other developments can affect wildlife populations by reducing or eliminating access to important habitat components ranging from critical winter range to key watering sites.

ADOT has employed a comprehensive package of mitigation measures along SR 260. These measures include eleven sets of bridged wildlife underpasses, six sets of larger bridges over streams, wildlife-proof fencing, innovative fencing alternatives, such as steep cut-and-fill slopes and "elk rock" or closely placed rock rip-rap, to deter movement across the highway and encourage use of underpass structures, and escape structures to prevent wildlife from getting trapped within the fenced roadway sections.

Once completed, the SR 260 project will be one of the most comprehensive efforts in North America to reduce the risk of wildlife-vehicle collisions and maintain or enhance wildlife passage across a highway corridor. Current and future research, including a full analysis of the relationship between wildlife passage and design characteristics of all seventeen sets of underpasses and other project features such as fencing and escape structures should contribute substantially to the understanding of wildlife and highway relationships. For more information on SR 260 mitigation measures, see *Evaluation of Measures to Minimize Wildlife Vehicle-Collisions and Maintain Wildlife Permeability Across Highways: Arizona Route 260* (Dodd et al. 2007).

US 93

The realignment of U.S. Highway 93 in Arizona and Nevada, entitled the Hoover Dam Bypass Project, includes the construction of 3.5 miles of new roadway and a bridge across the Colorado River. The Arizona Game and Fish Department, with funding from FHWA and ADOT, placed collars on thirty bighorn sheep to study their migration patterns. The realignment of U.S. Highway 93 has been designed to mitigate impacts on bighorn habitat by including wildlife crossings, jump-outs and fencing. The corridor study of impacts of construction and mitigation measures on desert bighorn sheep are ongoing.

3.0 OPPORTUNITIES

Reducing the risk of collisions between motor vehicles and animals will mean fewer human injuries and fatalities, less money spent on vehicle repair and insurance costs, and reduced mortality in wildlife and livestock populations. In addition, allowing safe passage for wildlife will also ensure that animals have access to all necessary habitats and resources and that connectivity among different populations is maintained (Lloyd and Alexis 2005).

Each highway project needs to be evaluated individually because not all mitigation measures will have the same set of factors including project location, area habitat, and roadway design. When wildlife is considered during the planning process for roadway design the overall cost will be minimized. Designers and agencies should work with the entities that manage landscapes surrounding project areas to minimize animal crossings and maintain the landscape structure cues that bring animals to mitigated crossing locations (Barnum 2003). ADOT's animal exclusion solutions should meet these five goals to be considered effective:

1. Improve public safety
2. Reduce animal mortality
3. Maintain wildlife habitat and connectivity
4. Protect threatened populations of wildlife species
5. Be cost-effective

Developing a comprehensive and efficient strategy for addressing the environmental, economic, and social costs of animal-vehicle collisions must therefore be based on an understanding of where conflicts between wildlife and highway operations are most severe (Lloyd and Alexis 2005). Having identified the scope of the problem and location of the accident hotspots regarding animal-vehicle collisions, more efficient decision making can be developed into solution options and thereby more efficiently use the limited economic resources (Perrin and Disegni 2003). Obtaining crash data from Arizona's traffic records will help to identify problem areas of high animal-vehicle collisions. Determining areas with high concentrations of animal-vehicle collisions can be used in project prioritization for new highways and improvements or retrofits to existing highways. Developing site specific solutions for these problem areas first will create the best cost/benefit ratio. BCMoT uses collision data to provide a detailed historical record of wildlife mortality that is used as a tool for supporting decision-making with regard to the development of wildlife exclusion systems on existing and planned highways (Sielecki 2005).

The use of GIS data by layering state highway systems, structure locations, wildlife habitats, animal-vehicle collision data, land ownership, and livestock operations will assist in determining the appropriate, habitat specific solutions for differing locations. Arizona's Wildlife Linkages working group has already developed and is currently refining the statewide linkage map (ADOT 2004). The GIS data will be used to identify migration patterns and animal behavior. Broad-scale or landscape-level wildlife habitat linkage analysis is critical to improving highway mitigation for wildlife (Ruediger et al. 2005).

3.1 Interagency Coordination

Interagency education, coordination and cross training is an essential and cost-effective method of communicating current efforts, problem areas and possible solutions for animal-vehicle collisions. The streamlining, context-sensitive design, and stewardship programs in state transportation agencies should be used to collaborate and share information (Bank et al. 2002). A common language is also needed for agencies to communicate effectively and efficiently. The U.S. Forest Service has developed a Wildlife Crossings Toolkit with a glossary of common terms used by engineers and biologists on highway issues (USDA 2007).

Europe has devised a communication network that has been developed to coordinate information, enhance wildlife connectivity, and garner support for providing measures of wildlife in the transportation system. The Europeans have used many symposia and journals to spread information related to wildlife and transportation (Bank et al.2002).

Conducted every two years, the International Conference on Ecology & Transportation is designed to address the broad range of ecological issues related to surface transportation development, providing the most current research information and best practices in the areas of wildlife, fisheries, wetlands, water quality, overall ecosystems management, and related policy issues. The mission of the International Conference on Ecology and Transportation is to identify and share quality research applications and best management practices that address wildlife, habitat, and ecosystem issues related to the delivery of surface transportation systems.

3.2 Public Education

Educating the public on issues concerning animal-vehicle collisions will go a long way in reducing the number of collisions and improving highway safety for both the public and wildlife. Increasing public awareness through education can be accomplished by a variety of methods with relatively minimal cost. These methods include, but are not limited to, specific project public involvement or outreach, driver education, public service announcements, and an increase in media exposure.

Colorado has an ongoing education campaign called *Colorado Wildlife on the Move.* It is an effort by state and federal agencies, insurance groups and non-profit organizations to prevent traffic crashes involving wildlife. The educational effort includes the distribution of more than 58,000 *Driver Safety Tip Sheets* at 175 locations in 85 cities across Colorado, with a list of suggestions about how to avoid hitting animals. The most important tip was a reminder to drivers to stay alert and slow down (Southern Rockies Ecosystem Project 2006).

Public involvement during the project planning phase is a great tool for educating the public regarding the importance of highway safety using animal exclusion design measures. The importance of public involvement in the planning process is evident on a highway project in Slovenia where a public opinion survey and public demonstration resulted in the placement of an underpass on the Ljubljana-Postonjana Highway for wildlife/human connectivity and hydraulic needs (Bank et al. 2002). The public must first understand the issue or problem before it can make a good judgment on a solution.

3.3 Solutions to Alleviate Animal-Vehicle Collisions

3.3.1 Cattle Guard

Cattle Guards – The basic objective of a cattle guard is to allow the rancher to pass through a fenced livestock area without having to open and close a traditional gate, while simultaneously keeping the livestock from passing through. Cattle guards also known as deer guards, have been proven extremely effective in containing livestock when properly installed and maintained. Since livestock lack depth perception they will not cross open slatted construction. Painted white strips on black pavement have also been known to contain cattle. Cattle guards require side framing for stability. Typical cattle guards are 6 to 8 feet across and 10 to 16 feet wide over a 2 foot deep pit. Maintenance is required to remove debris accumulated in the pit.

If cattle guards are only required for a short period of time, temporary cattle guard may be used. Temporary cattle guards are a raised platform with slats allowing vehicles to cross, but not livestock.

Cattle guards are widely used to stop deer from crossing as well as cattle. Many cattle guards have been installed at BLM and Forest Service sites throughout the Pacific North-west. Both the Forest Service and BLM believe that the cattle guards have performed beyond expectations, at reasonable cost, with minimal maintenance (Vachowski 1998). Cattle guards reduce deer crossings by at least 95% (Curtis and Sullivan 2001). A study to review deer control devices intended for use on airports concluded that deer would approach cattle guards but rarely attempted to cross them (Seamans 2001). However, in snow country, cattle guards alone may not be as effective from deterring elk and other wildlife from accessing the roadway because snow compaction in cattle guards allows animals to walk across them and into the roadway (Ruediger et al. 2005).

3.3.2 Fencing

Fencing along highway right-of-way is greatly effective in reducing animal-vehicle collisions when it is designed to withstand the largest animal of concern within the area of installation, is properly maintained and frequently inspected. Animal exclusion fencing must be designed for different kinds of affected species. Wildlife exclusion fencing is different than domestic animal (livestock) exclusion fencing.

BCMoT wildlife exclusion fencing specifications are designed to produce a fence with a 15 to 20-year lifespan. Certain locations of wildlife exclusion fencing make daily inspection and maintenance impractical. Wildlife exclusion fencing has proven very effective in reducing wildlife accidents on the Coquihala Highway located between Hope and Marritt in British Columbia, reducing wildlife accidents by 100% (Sielecki 2005).

Fencing for elk and other ungulates should be at least 8 feet tall and used in conjunction with overpasses and underpasses to improve effectiveness. Fencing commonly increases elk use of underpasses or overpasses by 80% or more (Ruediger et al. 2005).

British Columbia has established a Highways Fencing Program to increase motorist and livestock safety. For land owners to be eligible for fence replacement they must operate an active livestock operation adjacent to a highway right-of-way and the fencing must be part of a complete containment system. Fence replacement priorities are given to areas in most need or repair or reconstruction (British Columbia Cattlemen's Association 2007). Fences are used extensively in the United Sates and Europe to keep wildlife off major highways (Bank et al. 2002). A variety of fence types are used. Fencing should be designed to withstand the largest animal of concern within the area of installation. British Colum-bia standard wildlife fencing is 8 feet tall and made of steel or wood posts and wire mesh.

Fencing, combined with underpasses and overpasses as appropriate, is the only broadly accepted method that is theoretically sound and proven to be effective in the reduction of animal-vehicle collisions (Hedlund et al. 2004). Fencing, intercept feeding, and eco-passes are the most promising techniques currently available for reducing deer-vehicle collisions. (Romin and Bissonette 1996).

Fencing can become a trap if not adequately installed or maintained, increasing the probability of an animal being struck by a vehicle. Animals caught within highway right-of-way fencing can become stressed by both traffic and the inability to escape which could result in an animal-vehicle collision (Maine Interagency Work Group 2001). Fence exits from the inside of highway right-of-way, one-way gates, earthen ramps, or funnel fences should be provided to allow wildlife to return to their habitat. Many types of wild-life one-way gates exist. Jump-outs or earthen ramps are a relatively new technology. Their effectiveness is being studied on the new alignment of U.S. Highway 93 in Arizona and Nevada. Because the roadway has not been opened to vehicular traffic, no conclu-sions as to their effectiveness have been determined. Wildlife tends to follow fencing until they find gaps to traverse. Funnel fencing leads wildlife to strategically placed one-way gates.

Roadway geometry plays a large role in determining necessary placement of animal exclusion fencing. If animal at-grade crossings are necessary, they should be located on the designed roadway tangent where driver's line-of-sight is maximized providing motorists adequate time to react if an animal is crossing the highway. For low-volume highways where animal-vehicle collisions do not present a significant safety hazard to animals or drivers, the most cost- and biologically-effective strategy for reducing conflicts is to encourage animals to cross freely at-grade.

3.3.3 Construction

Workmanship and materials are vital components of the construction phase for animal exclusion systems. Attention to design by workers and the use of good quality materials help ensure the systems will operate as designed for an extended period of time (Sielecki 2005). It is important to construct animal exclusion systems using quality workmanship and materials because continuous maintenance is difficult and costly to perform.

Wildlife exclusion systems are most easily incorporated into the design and construction of new highways. In this way, the designs of major structures, such as bridges and culverts, can be modified to maximize their effectiveness for wildlife passage (Sielecki 2005).

3.3.4 Post Construction and Maintenance

Regular maintenance is essential for ensuring that fencing and cattle guards operate properly. Fencing must be continually maintained because it can be easily damaged by weather, erosion, animals and vehicles. Fencing with gaps due to erosion or topographic contours can be traversed by deer and other wildlife. Maintenance of fencing must be frequent in order to be successful in reducing animal-vehicle collisions because animals exploit breaks in the fence (Foster and Humphrey 1995).

Maintenance of cattle guards can be performed less frequently than fencing. If the cattle guard is too short, lacks side guards or wings, or has incorrect spacing between the tread rails, cattle may be tempted to try to jump or walk through it (Vachowski 1998).

3.3.5 Driver Awareness

Road Lighting – According to FHWA road lighting is not effective in reducing wildlife mortality. It does however increase driver awareness, but unless utilities exist near the highway, the cost of implementing this solution is high.

Driver Education – As mentioned in 3.2.1 public education is a relatively inexpensive yet extremely effective way to reduce animal-vehicle collisions.

Animal Detection Devices – Detection systems use radio frequencies and infrared sensors to detect the presence of large animals. The system warns drivers as they are entering an area of the freeway that there is an animal present (Transport Canada 2003).

Reduction in speed limits – Reducing speed limits in areas with potentially high levels of animal-vehicle collisions is effective in reducing collisions (Maine Interagency Work Group 2001). Reduced speeds provide motorists additional time to respond and are a very low-cost solution. Colorado DOT has experimented with night time speed limit reductions in areas with high wildlife activity crossing the roads. This research is ongoing and additional data is needed before a determination can be made as to its effectiveness.

Signing – Sixty percent of drivers will not notice wildlife crossing signage (Perrin and Disegni 2003). Highway signs tend to be so common, often for such long stretches of road, that drivers become complacent to their warnings unless the warning on the sign is reinforced by actual experience and drivers see wildlife in the area (Danielson and

Hubbard 1998). According to Leonard Sielecki, an environmental issues analyst with BCMoT, animal crossing warning signs decline in effectiveness over time. Combining wildlife signs with speed limit signs seems to increase their effectiveness. Including flashing lights also is believed to be effective (Bank et al. 2002).

Thermal Sensors – Solar powered thermal sensors detect the presence of animals, which triggers a fiberoptic wildlife warning sign to reduce the speed limit. This installation has reduced wildlife mortality on a two-lane regional road in Switzerland (Bank et al. 2002).

3.3.6 Infrastructure Adaptation

At-grade crossings – At-grade crossings for livestock and wildlife, combined with active signs, offer a long-shot chance at providing greater safety than uncontrolled crossings marked only with passive signs. At-grade crossings are most promising for highways that cross mule deer migration routes in western states (Hedlund et al. 2004). At-grade crossings should only be implemented where traffic volumes are low (Barnum 2003). The Colorado Department of Transportation has a research project underway titled *Roads and Connectivity in Colorado: Animal-Vehicle Collisions, Wildlife Mitigation Structures, and Lynx-Roadway Interactions* which focuses on a means to maintain an at-grade crossing for wildlife. The research is focusing on a detection system using electromagnetic detection to identify when animals are moving within the right-of-way towards the road. The detection will be used to activate lighting at night to illuminate the roadside for drivers to see the animals more easily. This research is scheduled to be completed in 2008 but may take several years to provide conclusive evidence to validate this type of mitigation.

Cattle Underpasses – Cattle underpasses are used in British Columbia in conjunction with fencing and cattle guards and have proven effective when regular fence maintenance is performed.

Deer Crosswalk - Crosswalks are used in conjunction with fencing to funnel deer to specific crossing locations. Deer crosswalks are dirt paths that run from one-way gates in highway fencing across dirt portions of the right-of-way. Paint is used to delineate crosswalks on the actual roadway surface. Stone river cobble, which is believed to deter deer from leaving the path, is placed along both sides of the dirt path. Complete elimination of deer-vehicle collisions is unlikely with the use of the crosswalk technique. However, they are a lower-cost alternative to overpasses and underpasses (Danielson and Hubbard 1998).

Clearing right-of-way – Roadside clearing may be effective, although there is very limited information supporting it. Roadside clearing must be part of a broader strategy of roadway design and maintenance (Hedlund et al. 2004).

Wildlife Underpasses – Wildlife underpasses are structures that provide grade separation between motor vehicles and animal traffic. Underpasses increase the success of exclusion fencing by increasing the permeability and habitat connectivity across highways. There are many ongoing studies on Arizona's State Route 260 to determine what type of structures and different configurations of the seventeen wildlife underpasses constructed are most used by wildlife. Effective underpasses for elk are the open-span crossings. These are large bridges that have long roadway spans with sloped abutments to the natural ground floor. Engineers and biologists in Canada and Arizona often recommend open-span wildlife crossings as both effective and cost efficient (Ruediger et al. 2005).

Wildlife Overpasses – Wildlife overpasses are sometimes considered green bridges and can be straight or hourglass shaped. They are vegetated highway overpasses which greatly improve habitat connectivity. Wildlife overpasses are costly and therefore should only be placed where existing wildlife habitat exists and connectivity is desired. Overpasses in Europe are considered successful for the largest spectrum of animals. The presence of habitat on overpasses allows for use by everything from insects to large carnivores. Structure size, width, location, and habitat must be considered in the design of overpasses for the target species in the area of application. Overpasses can serve dual purposes, where small volume roads or human recreational activities share the overpass (Bank et al. 2002).

Culverts – A culvert is a conduit covered with embankment around the entire perimeter and can be in the shape of a rectangle, circle or arch. Small animals can pass under an intersecting roadway through a culvert. Culverts are most effective as animal crossings when paired with fencing directing the animals away from the highway right-of-way.

3.3.7 Animal Deterrent

Reflective Devices – Reflectors are less expensive and less intrusive than fencing, however, studies suggest that reflectors do not modify wildlife behavior and are therefore ineffective (Perrin and Disegni 2003).

Wildlife Warning System – Wildlife warning systems alert wildlife at an animal crossing that a vehicle is approaching. Upon activation animals are frightened away from the roadway allowing vehicles to pass safely (Bushman et al. 2001). This system may cause animals to run onto the road, and is only cost effective for small areas.

Animal Repellents – Deer repellents have a limited effect on modifying deer feeding and movement patterns (Hedlund et al. 2004). Animals adapt to the scent and therefore the repellents are ineffective in alleviating animal-vehicle collisions.

3.3.8 Vehicle Systems

Vehicle Mounted Whistles - Research in the United States has indicated that deer whistles and other ultrasonic devices are ineffective in reducing wildlife-vehicle accidents (Curtis and Sullivan 2001).

Night Vision - Night Vision is available as an option on all Cadillac's DeVille 2000 models as well as some other makes/models. Night Vision uses thermal imaging, or infrared, technology to create pictures based on heat energy emitted by objects in the viewed scene. Night Vision uses a refractive optical-lens system to gather infrared energy. Infrared driver vision technology in vehicles may be effective in the future. Its development and implementation will depend on its usefulness in improving driver night vision (Hedlund et al. 2004). This system is available on high-end vehicles only and therefore is of limited use for the general driving public.

4.0 RECOMMENDATIONS

Based on the results of previous studies and reports, the following are recommended cost-effective practices and measures for alleviating the animal-vehicle collisions throughout Arizona.

- Start early – Begin thinking about wildlife and livestock issues and exclusion solutions at the planning stages of design projects.

- Continue Arizona's efforts of interagency coordination, education and cross training for communicating current efforts, problem areas and possible solutions for animal-vehicle collisions. Educate the design team through interagency meetings on specific projects.

- Implement a public education program to increase public awareness. Educate the public on specific projects through project outreach, including open houses, design workshops, and community meetings.

- Determine areas of high animal-vehicle collisions through trend analysis of collision data. Prioritize animal exclusion projects on existing highway systems based on areas of high levels of animal-vehicle collisions. Study areas of high animal vehicle collisions prior to any new roadway or bridge design.

- Design site-specific solutions of animal exclusion projects based on location, area habitat, and roadway design.

- Continue refining GIS data to determine actual wildlife habitats in relation to the Arizona state highway system. Using GIS data, avoid placing highways were large habitats exist.

- Combine the use of animal exclusion fencing, cattle guards and underpasses for maximum habitat continuity and reduction in animal-vehicle collisions.

- Maintain fences through inspections, especially in areas of livestock grazing or known wildlife habitats.

5.0 WEBSITES

The following websites are useful in providing up-to-date material on animal-vehicle collision mitigation measures and studies from around the world.

British Columbia Cattlemen's Association – Highways Fencing Program
http://www.cattlemen.bc.ca/hwy_fencing.htm

Center for Transportation and the Environment
http://itre.ncsu.edu/cte

FHWA – Critter Crossings – Linking Habitats and Reducing Road Kill
http://www.fhwa.dot.gov////environment/wildlifecrossings

International Conference on Ecology and Transportation
http://www.icoet.net

Wildlife Crossings Toolkit
http://www.wildlifecrossings.info

Wildlife-Vehicle Accident Prevention Program
http://www.wildlifeaccidents.ca/

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