CONSTRUCTION GUIDELINES FOR WILDLIFE FENCING AND ASSOCIATED ESCAPE AND LATERAL ACCESS CONTROL MEASURES

Requested by:

American Association of State Highway
and Transportation Officials (AASHTO)

Standing Committee on the Environment

Prepared by:

Marcel P. Huijser, Angela V. Kociolek, Tiffany D.H. Allen, Patrick McGowen
Western Transportation Institute – Montana State University
PO Box 174250
Bozeman, MT 59717-4250

Patricia C. Cramer
264 E 100 North, Logan, Utah 84321

Marie Venner
Lakewood, CO 80232

April 2015

The information contained in this report was prepared as part of NCHRP Project 25-25, Task 84, National Cooperative Highway Research Program, Transportation Research Board.

DISCLAIMER

DISCLAIMER STATEMENT

ACKNOWLEDGEMENTS

This study was requested by the American Association of State Highway and Transportation Officials (AASHTO), and conducted as part of the National Cooperative Highway Research Program (NCHRP) Project 25-25 Task 84. The NCHRP is supported by annual voluntary contributions from the state Departments of Transportation. Project 25-25 is intended to fund quick response studies on behalf of the AASHTO Standing Committee on the Environment. The work was guided by a panel chaired by Todd Williams. Other panel members were Gail Anne D'Avino, Timothy Dexter, Norris Dodd, Jeff Gagnon, Todd Nichols, Kelly McAllister, Stirling Robertson, William C. Ruediger, and Leonard Sielecki, and Bill Ostrum was the FHWA liaison. The project was managed by Nanda Srinivasan and Crawford Jencks from NCHRP.

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EXECUTIVE SUMMARY

This report describes the current state of knowledge and practice regarding the design, implementation and maintenance of wildlife fencing and associated escape and lateral access control measures. The state of knowledge and practice was summarized through a literature review (Chapter 2) and a survey among practitioners and other people who work with wildlife fencing and associated mitigation measures (Chapter 3). The main function of wildlife fencing is to keep wildlife off the highway, but wildlife fencing also helps funnel wildlife to safe crossing opportunities (at-grade, underpasses or overpasses). It is considered good practice to not increase the barrier effect of roads and traffic for wildlife without also providing for safe and effective crossing opportunities for wildlife. Therefore the authors of this report suggest to always combine wildlife fencing with safe crossing opportunities for wildlife.

While underpasses and overpasses are not part of the current report, at grade crossing opportunities are. At grade crossing opportunities may consist of a gap in a wildlife fence (on opposite sides of a highway) where wildlife can or are encouraged to cross. Such at grade crossing opportunities may be accompanied with wildlife guards (bridge grate material) or electric mats or electric concrete embedded in the pavement to keep wildlife from wandering off in the fenced road corridor. In addition, animal detection systems may be considered to further decrease the probability of wildlife-vehicle collisions at fence gaps or fence ends. However, at grade crossing opportunities for large mammals – with or without accompanying animal detection systems - are typically only implemented along relatively low volume highways (a few thousand up to perhaps 14,000 vehicles per day at a maximum). For high volume roads (certainly for highways with more than 15,000 vehicles per day), a physical separation of traffic and wildlife (i.e. through underpasses and overpasses for wildlife) is almost always advisable.

Wildlife fences are typically installed at a wildlife road mortality hotspot. Mortality hotspots for large mammals also represent a serious threat to human safety. However, if wildlife fences are designed, implemented and maintained correctly, they can reduce collisions with large mammals by 80-100%. It is essential though that the mitigated road sections cover the entire length of the hotspot as well as a buffer zones from each end of the hotspot. In addition, wildlife fences and associated measures should be designed with the target species in mind. Different species have different capabilities to climb, jump, dig, or push through, over or under fences or other measures, and the measures should be designed accordingly. Fence end runs by wildlife, intrusions by wildlife into the fenced road corridor at fence ends, and spatial inaccuracies of crash and carcass data may cause short mitigated road sections to be less effective and more variable in their effectiveness in reducing wildlife-vehicle collisions than longer mitigated road sections. Fence end treatments (e.g. wildlife guards with bridge grate material or electric mats or electric concrete) can increase the effectiveness of the mitigation measures in reducing wildlife-vehicle collisions and reduce the variability for short fenced areas, but they do not address potential fence end runs and spatial inaccuracies of the crash and carcass data. Based on cost-benefit analyses (Chapter 4), the authors of this report suggest that mitigated road sections for large mammals should perhaps be at least 3-5 km long, if the objective is to keep the average costs per kilometer mitigated road to a minimum. Shorter mitigated road sections have relatively high costs per kilometer of road. This is mainly because of the costs associated with fence end treatments; the costs for fence end treatments is diluted with increasing length of the road section that is mitigated.

Lateral access control measures allow humans to leave and enter the fenced road corridor at selected locations while (hopefully) maintaining the barrier effect of the wildlife fencing for the species for which the mitigation measures are designed (the target species). Depending on the mode of transportation and the specific use for the human access points, the measures may include various types of gates or carousels (pedestrians, horseback riders and their horse) or wildlife guards or electric mats or electric concrete (motorized vehicles or bicycles). Wildlife guards and electric mats have been found to be a substantial barrier for large ungulates. For non-ungulates (e.g. bear, canid or felid species), electric mats and electric concrete are or appear to be an effective barrier whereas wildlife guards are not.

Regardless of how well a wildlife fence is designed, implemented and maintained, regardless of how effective potential fence end treatments are in keeping wildlife from entering the fenced road corridor, some animals will still end up in the fenced road corridor. Wildlife jump-outs and one-way gates are designed to allow wildlife to escape from the fenced road corridor and get to the safe side of the fence. However, some one-way gate designs can injure or kill animals and one-way gates can also become two-way gates when strong animals (e.g. elk (*Cervus canadensis*) or moose (*Alces aces*), bend the metal tines or when debris keeps them from closing properly. Over the last decade or so wildlife jump-outs have become increasingly common. They appear to function well in certain areas for mule deer, elk and bighorn sheep and are often between 1.5 and 2.1 m high. However, data of what a good design is for other species or what design may be most appropriate if there is more than one target species with different jumping and climbing capabilities, is often lacking and warrants further research.

While large mammals, particularly large ungulates, tend to receive most attention when implementing wildlife fencing and associated measures, amphibian and reptile species may suffer more from direct road mortality with severe consequences for their population survival probability in an area or even within the United States as a whole (Huijser et al., 2008a). Plastic sheeting (potentially attached to a medium mammal fence or a large mammal fence) and barrier walls embedded in the roadbed appear the most effective barriers for reptiles and amphibians. However, a well-functioning physical barrier for tree frogs is lacking, suggesting specific research may be warranted for this species group.

This report contains examples from the literature and from practitioners about the design, implementation and maintenance of wildlife fencing and associated measures (Chapter 2 and 3). However, very little to no comparative studies are available that allow for the identification of what practices can or should be labeled as “best.” While wildlife fencing and several associated measures have been implemented and tested somewhat satisfactory for some species or species groups (notably deer (*Odocoileus* spp.) and e.g. Florida panther (*Puma concolor coryi*)), there may be very little information available for other species or species groups. If the objective is to identify mitigation measures that are “best” then more initiative should be taken for comparative studies that evaluate the effectiveness of the mitigation measures for different species and species groups. These tests should not only include the design characteristics of the measures, but also the implementation and maintenance practices and requirements. Nonetheless, the authors of this report do provide recommendations based on the current knowledge and experience of researchers and practitioners, and identify the most pressing research questions related to wildlife fencing and associated measures (Chapter 5 and 6).

Keywords: access, access road, amphibians, analyses, animal detection systems, barrier, barriers, bears, bicyclists, carousel, cars, cats, cattle guard, corridor, cost-benefit, cyclists, deer, design, ecology, electric mat, electric concrete, electric, elk, escape ramp, equestrian, concrete, fence, fenced, fencing, frogs, gaps in knowledge, highway, horse, horseback riding, human, human access, implementation, infrastructure, jump-out, literature review, maintenance, mitigation, mitigation measures, moose, motorway, mountain lion, one-way gate, pedestrians, recommendations, research, rider, riding, right-of-way, road, road ecology, side road, snakes, survey, swing gate, toads, traffic calming, transportation, tortoises, tree frogs, turtles, ungulates, vehicles, wall, warning signs, wildlife detection systems, wildlife fencing, wildlife guard

1. INTRODUCTION

1.1. Background

While overall highway safety has improved substantially over the last several decades (Insurance Institute for Highway Safety, 2012), wildlife-vehicle collisions have increased by about 50 percent between 1990 and 2004 (Huijser et al., 2008a). The number of collisions with large wild mammals in the United States is estimated at one to two million per year (Huijser et al., 2008a). These collisions result in wildlife mortality, vehicle damage, and in some cases also human injuries and fatalities (Huijser et al., 2009a). In addition, travel delays can result, and crash investigation, debris and carcass removal may take additional resources from law enforcement and transportation agencies.

Transportation agencies need to balance travel needs, human safety, and wildlife conservation within their available budget (Huijser et al., 2008a). Wildlife fencing is one of the most effective and robust mitigation measures to reduce collisions with large mammals (Clevenger et al., 2001; Huijser et al., 2009a). However, fences alone also increase the barrier effect of roads and traffic and may result in a near absolute barrier for wildlife in the landscape. Wildlife fencing reduces or eliminates daily movements within an animal’s home range and hinders seasonal migration and dispersal movements. The latter are essential for the colonization or re-colonization of distant and isolated habitat patches and the strengthening of small and isolated populations and overall population viability of a species in a region. Therefore wildlife fencing is typically combined with safe crossing opportunities. If combined with safe crossing opportunities, wildlife fencing not only reduces wildlife-vehicle collisions but also guides the animals towards these safe crossing opportunities (Dodd et al., 2007a; Gagnon et al., 2010). In addition, if sufficient and appropriate safe crossing opportunities are provided individual animals are less likely to breach the fence and enter the fenced road corridor. Wildlife underpasses and overpasses are a very robust safe crossing opportunity (Clevenger & Huijser, 2011) while animal detection systems or other at grade crossing opportunities should be considered more experimental (Huijser et al., 2009a).

While wildlife fencing is one of the most commonly applied mitigation measures to reduce wildlife-vehicle collisions there are currently no generally agreed upon guidelines with regard to the length of the road sections that should be fenced, where fences should start and end, potential fence-end treatments to prevent fence-end runs, the height and type of wildlife fencing given the target species, escape opportunities for wildlife that end up in the fenced road corridor, or how to address potential gaps in the fence associated with access roads.

This report summarizes the state of knowledge and current practices regarding the implementation of wildlife fences and associated mitigation measures for three different species groups: 1. Large mammals (e.g. deer (*Odocoileus* spp.) size and larger), 2. Medium sized mammals (e.g. coyote (*Canis latrans*), and 3. Reptiles and amphibians. The emphasis lies with practices in the United States and Canada.

1.2. Overview and Purpose of the Mitigation Measures Included in this Report

Wildlife fencing is primarily aimed at reducing wildlife-vehicle collisions through keeping selected species, typically large wild mammal species, from entering the road corridor (Figure 1). Wildlife fencing can also guide wildlife to safe crossing opportunities. Though safe crossing opportunities (e.g. wildlife underpasses and overpasses) are not part of the current project, they can reduce the number of animals that climb over the wildlife fence, go through the wildlife fence, or dig under the wildlife fence. Connecting wildlife fencing between wildlife crossing structures has been found critical to achieving passage structure effectiveness and promoting highway permeability (e.g. Dodd et al., 2007a; Gagnon et al., 2010; Loberger et al., 2013). In addition, fencing, including standard right-of-way fencing or livestock fencing, is best avoided at the approaches of wildlife crossing structures. If a right-of-way fence or livestock fence must be present at the approaches of safe crossing opportunities, it is best to have a smooth top and bottom wire (no barbed wire) so that wildlife can more easily jump the fence or crawl under the fence without injuring themselves. Alternatively top and bottom wires can be run through PVC tubing, and the top two wires or the bottom two wires (assuming there are 4 strands in total) can be combined in PVC tubing, effectively lowering the fence height, and creating more space between the ground and the first wire(s).

Escape ramps or jump-outs (Figure 1) are designed to allow medium and large mammals to safely exit fenced right-of-ways on their own. Jump-outs should be low enough to encourage animals to jump to the safe side of the fence, and they should be high enough so that animals are discouraged from jumping into the fenced road corridor. Other measures that allow animals to escape from the fenced road corridor include one-way gates, tree trunks or branches stacked against the fence, and gates that are opened by wildlife managers who then haze the animals towards the open gate and the safe side of the fence.

Gates, wildlife guards, electric mats, or electric concrete can be implemented at access roads that would otherwise result in gaps in the fence (Figure 1). Gates may be most suitable for very low volume roads with one or very few users while wildlife guards, electric mats or electric concrete may be more appropriate for higher volume roads and multiple users. Wildlife guards, electric mats or electric concrete may also be used on the mitigated highway at fence ends or as a supportive measure for at grade crossing opportunities to reduce the likelihood of large mammals entering the fenced road corridor (Figure 1).

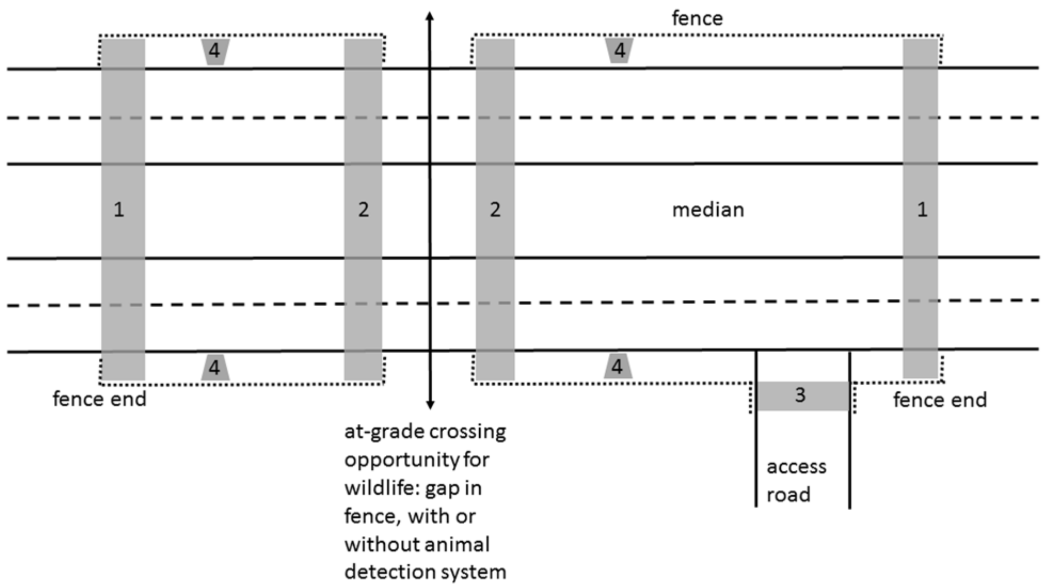

Figure 1: Schematic representation of a divided highway with a median, wildlife fencing and associated escape and lateral access control measures. 1 = fence end treatments (e.g. fence end close to pavement, boulder field between pavement edge and fence and in median, wildlife guard, electric mat or electric concrete embedded in pavement and potentially also between pavement and fence, and in median), 2 = measures to encourage wildlife to cross the highway perpendicular at an at-grade wildlife crossing opportunity (similar measures to a fence end), 3 = access road treatments (e.g. gate, wildlife guard, or electric mat or electric concrete across access road), and 4 = escape opportunities for wildlife allowing them to leave the fenced road corridor and access the safe side of the fence (e.g. escape ramps or jump-outs).

1.3. Organization of the Report

This report on the design, implementation, and maintenance of wildlife fencing and associated escape and lateral access control measures has been organized based on distinct efforts that had their own purpose methodology:

- Literature review summarizing the state of knowledge (Chapter 2)
- Survey of practitioners summarizing the state of practice (Chapter 3)
- Cost-benefit analyses exploring the economic investments and returns for the mitigation measures (Chapter 4).
- Recommendations for design, implementation and maintenance for the mitigation measures based on the previous chapters (Chapter 5).
- Gaps in knowledge and suggestions for future research (Chapter 6).

2. LITERATURE REVIEW

2.1. Organization of Literature Review

The literature review was organized according to the purpose of the different mitigation measures:

- Keep wildlife off the road: wildlife fencing, wildlife guards, gates, boulder fields
- Allow wildlife that ends up in the fenced road corridor to escape to the safe side of the fence: wildlife jump-outs, one-way gates, tree trunks and branches stacked against the fence, gates in combination with hazing by wildlife managers.
- Warn drivers for wildlife that may be in fenced road corridor or at fence ends: standard warning signs, enhanced warning signs, warning signs and animal detection systems
- Allow humans to get in and out of the fenced road corridor.

2.2. Keep Wildlife Off the Road

2.2.1. Fence Location and Length

Wildlife fences are typically installed at locations where concentrations ("hotspots") of wildlife-vehicle collisions occur. To be effective in reducing wildlife-vehicle collisions, the fences need to cover the actual hotspot. However, the fencing needs to extend further than the actual hotspot to prevent animals that approach the road at the hotspot from simply walking to the fence end and crossing at grade (e.g. Bissonette & Rosa, 2011). The radius or diameter of the home range for the target species in combination with the length of the "hotspot" can be used to decide on the appropriate length of the fence (Bissonette & Adair, 2008; Huijser et al., 2008b).

Regardless of the length of a wildlife fence, there may still be a "fence end run" as animals may cross more frequently in the immediate vicinity of fence ends than at road sections that are not fenced (Clevenger et al., 2001; Cserkész et al., 2013). Fence end runs occur because not all animals that approach the fenced road section may choose to use a safe wildlife crossing opportunity (e.g. wildlife underpass, wildlife overpass) that may be present within the fenced road section. Instead, these animals may follow the fence, or they already know where the fence ends, and then cross the road at grade at or near the fence end. While safe crossing opportunities for wildlife fall outside of the scope of this report, safe crossing opportunities may reduce such fence end runs when placed close to or at fence ends (Allen et al., 2013).

Fence end runs may not be considered a problem unless there is also a concentration of wildlife-vehicle collisions at fence ends. However, fence end runs can be reduced if the location and length of wildlife fencing is not only based on wildlife-vehicle collision data (unsuccessful wildlife crossings) but also on successful wildlife crossings as these are not necessarily in the same location (Clevenger et al., 2002; Neumann et al., 2012). As an alternative to using successful wildlife crossing data, the fence may also simply extend beyond a particular habitat that may be associated with the target species; this can also be expected to reduce the probability of fence end runs. Yet another alternative is to accept that wildlife may have a relatively high number of at grade crossings at a fence end and then mitigate that by installing an animal detection system that can activate warning signs for drivers (Huijser et al., 2006).

By definition, road sections with relatively long and contiguous wildlife fencing (e.g. at least several miles or kilometers) are less likely to have a fence end run issue than relatively short road sections with wildlife fencing (e.g. up to several hundred yards or meters). For long road sections the road length around the fence ends where a fence end run may occur is relatively short compared to the total road length than is fenced. In contrast, for short road sections with wildlife fencing the road length around the fence ends where a fence end run may completely overlap the fenced road section.

Wildlife fencing should typically be implemented on both sides of a road with the fence ends ending opposite of each other. If a fence is present on one roadside only, animals that approach from the other side still get on the road, and they may spend more time on the road because a fence on the other side of the road does not allow them to leave the road corridor. Fence ends that do not end on opposite sides of the road (i.e. "staggered") can lead to similar problems, and they may result in an increased probability that animals wander off into the fenced road corridor rather than cross at grade at a fence end.

2.2.2. Where to Start, Where to Stop?

At a micro scale, the location of fence ends may coincide with topography or other landscape features to reduce the probability of fence end runs. Steep slopes (road cut or fill), river crossings, or areas with relatively high levels of human presence and disturbance are good examples of where one may choose to have a fence end.

2.2.3. Fence Material and Dimensions

The fence material and dimensions are discussed for each of the three species groups.

Large Mammals

For ungulates (deer (*Odocoileus* spp.), elk (*Cervus canadensis*) and moose (*Alces alces*)) in the United States and Canada fence height for woven wire mesh fences is typically set at about 2.4 m (8 ft) (Clevenger et al., 2001; Parker et al., 2008; Gagnon et al., 2010; Clevenger & Huijser, 2011; Stull et al. 2011; Huijser et al., 2013a). Fence height is sometimes set lower (e.g. 1.2-1.5 m (4-5 ft)) than 2.4 m (8 ft) if electric fencing is used (Seamans & Vercauteren, 2006; Leblond et al., 2007; Phillips et al., 2011). An electric fence may be lower than a woven wire fence as an electric fence is not only a physical barrier, but also a behavioral barrier (animal that touch the fence experience an electric shock). However, electric fencing may need to be taller (e.g. about 2.1 m (7 ft)) to exclude large mammals similarly to 2.4 m high woven wire fencing (Leblond et al., 2007; Phillips et al., 2011; Clevenger & Huijser, 2011). Opaque fencing is also sometimes thought to be more effective than woven wire mesh fencing allowing for reduced fence height. However, if deer are not naïve and know what may be on the other side of an opaque fence, there may not be any measurable benefit from opaque fencing compared to woven wire mesh fencing, suggesting that fence height would still have to be about 2.4 m (8 ft), even if the deer cannot see through the fence (Stull et al., 2011). If the target species are capable climbers (e.g. black bear (*Ursus americanus*), Florida panther (*Puma concolor coryi*)) fences may need to be taller (e.g. 3.0 m (10 ft)) (Foster & Humphrey, 1995). Note that fence height may have to be adjusted if the fence is positioned on a slope. For example, fence height may be measured about 1 m (3.3 ft) from the fence on the "safe side" of the fence (Kruidering et al., 2005). Finally, the fence should be flush to the ground to prevent animals from crawling under the fence. Special attachments, rubber flaps or chains attached to the main fence may be required at stream crossings (Kruidering et al., 2005). If the target species are able to dig, a buried fence or "apron" may have to be attached to the main fence and dug into the soil, angling away (45°) from the road (Clevenger & Huijser, 2011). The buried fence may consist of a 1.0-1.2 m (4-5 ft) wide galvanized chain-link fence that is attached to the bottom of the actual fence. The buried fence should extend approximately 1.1 m (3.5 ft) under the ground (Clevenger & Huijser, 2011). Note that swaths of large boulders ((>0.75 cm in diameter) have been used as an alternative to wildlife fencing for elk in Arizona (Dodd et al., 2007b).

The mesh size of large mammal woven wire fencing is typically 15-18 cm (6-7 inches) (Kruidering et al., 2005; Clevenger & Huijser, 2011). Oftentimes smaller meshes (8 cm (3 inches)) are used at the bottom of a large mammal fence to also exclude medium sized mammals (Kruidering et al., 2005; Clevenger & Huijser, 2011). Mesh wire is available in different gauges. Thick wire (e.g. 2.5 mm diameter (American Wire Gauge 10) or thicker) is of course more durable than thin wire and results in a greater life span (Kruidering et al., 2005; Clevenger & Huijser, 2011). Most woven wire mesh fencing is galvanized with the highest degree of protection resulting in a life span of at least 15-20 years (Clevenger & Huijser, 2011). For capable climbers such as black bear or the Florida panther, chain-link fencing may be used (Foster & Humphrey, 1995). Smaller mesh sizes prevent these species from being able to place their feet in the meshes when they attempt to climb over the fence. Electric fencing may consist of five strands of rope-like material (about 1 cm (½ inch) in diameter) that conduct electricity, spaced about 25-30 cm apart (Seamans & Vercauteren, 2006; Leblond et al., 2007). When an animal touches the strands they experience an electric shock. This is unpleasant, but not severe enough to harm the animals or humans that may touch the strands. High voltage fences are generally required for bears (*Ursus* spp.) (Clevenger & Huijser, 2011).

The posts of a woven wire mesh fence for ungulates are usually treated wood; diameter 13 cm (5 inches) for line posts and at least 16 cm (6.5 inches) for corner posts (Clevenger & Huijser, 2011). Line posts may be spaced at 4.2-5.4 m (10-18 ft) interval and are typically placed 0.9-1.2 m (3-4 ft) deep in the ground (Giles et al., 2012; Clevenger & Huijser, 2011). Poles made out of recycled plastic ("plastic lumber") may also be considered, especially in wet areas. Rocky substrates sometimes require metal posts set in concrete (Clevenger & Huijser, 2011). The fence material is usually attached with metal staples (e.g. 1.75-inch nine-gauge) (Giles et al., 2012).Chain-link fencing typically requires metal posts (Foster & Humphrey, 1995) while electric fencing requires fiberglass posts (about 10-15 m apart, 1.2 m (4 ft) in ground) (Seamans & Vercauteren, 2006; Leblond et al., 2007). Note that the fence material should always be attached to the "safe side" (not the roadside) of the poles (Kruidering et al., 2005). This reduces the probability that animals exercising force against the fence can make the fence material tear from the poles.

Outriggers are sometimes placed on top of the fence. Outriggers face away from the road (e.g. at 45°) and make it more difficult for an animal to jump or climb into the fenced road corridor (Stull et al., 2011). Outriggers may consist of the same material as the actual fence or they may consist of (barbed) wires (Foster & Humphrey, 1995). In some cases a high tensile cable (e.g. 3/16-inch stainless steel cable with 12-gauge hot rings attached to the fence material) is used on top of fence (Clevenger & Huijser, 2011; Giles et al., 2012). Such a cable is designed to limit damage to the fence from falling trees (Clevenger & Huijser, 2011). 3/16-inch stainless steel top cable electric fences with fiberglass posts tend to be more flexible and may not sustain permanent damage when a tree falls on the fence.

Medium Mammals

Fencing for medium sized mammals alone (e.g. coyote (*Canis latrans*), red fox (*Vulpes vulpes*), gray fox (*Urocyon cinereoargenteus*), feral cats (*Felis catus*), bobcat (*Lynx rufus*), American badger (*Taxidea taxus*) or Eurasian badger (*Meles meles*)) is typically 0.9-1.8 m high (Dorrance & Bourne, 1980; Robley et al., 2007; Rickenbach et al., 2011; Moreno-Opo et al., 2012; Smith et al., 2013). While a height of about 1 m (3.3 ft) appears sufficient for most medium sized mammal species, feral cats and red foxes may require higher fences (1.8 m (6 ft)), unless the fences are electrified (Robley et al., 2007). However, a 1.15 m (4 ft) high fencing combined with a 60 cm (2 ft) curved 'floppy' overhang effectively excluded red fox and feral cat (Moseby & Read, 2007). The floppy overhang resulted in a greater barrier than a 45° straight overhang (Moseby & Read, 2007).

One mesh size used is 10.2 x 5.1 cm (4 x 2 inches) with electrical wires along the bottom (about 9 cm (3.5 inches) above the ground) and at the top to prevent animals from digging under or climbing over (Smith et al., 2013). Other designs had meshes of about 4 x 4 cm (1.6 x 1.6 inches) and also included electrical wires (Rickenbach et al., 2011; Moreno-Opo et al., 2012). Three strands of electric fencing at 10, 15, 20, and sometimes also at 30 cm above the ground have been found to effectively exclude Eurasian badgers (Poole et al., 2002; Tolhurst et al., 2008; Judge et al., 2011).

Eurasian badger fences along roads are normally 1 m (3.3 ft) high, have mesh sizes of 2.5x5 cm (1x2 inches) and are dug into the soil 0.2-0.4 m (07-1.3 ft) (Kruidering et al., 2005). It appears that dig barriers (see large mammal section) are required for species that can dig under fences (e.g. badgers, coyotes). Note that the digging of a trench for a dig barrier may require erosion control measures to reduce the probability that sediments end up in streams (e.g. Clean Water Services, 2008). Erosion control measures will likely add costs to the installation of a dig barrier.

Reptiles and Amphibians

Fencing for amphibians (e.g. frogs, toads, and salamanders) is typically 0.4-0.6 m (1.3-1.6 ft) high, and is buried 0.1 m (0.3 ft) into the ground (Kruidering et al., 2005; Woltz et al., 2008). While small mesh fencing (bend on top to reduce animals climbing over fence) has been used, some amphibian species can still climb a mesh fence or they can go through the meshes (especially young animals), and small mesh fencing can be easily damaged when mowing vegetation in the right-of-way or alongside the fence. Therefore smooth plastic sheets (high-density polyethylene (HDPE)) are now recommended instead for amphibians (Kruidering et al., 2005). Such plastic sheets can be attached to poles that also have a fence for medium sized mammals or large mammals. A barrier can also be incorporated in the road bed; there is no fence sticking up above the ground, but there is a retaining or barrier wall that acts as a fence. The retaining wall or barrier wall typically consists of composite material, recycled plastic, or concrete with a smooth surface, oftentimes with an overhang.

Fences for lizards have been designed with a height of 76 cm (30 inches) and using mesh wire fencing with a mesh size of 0.6x0.6 cm (0.25x0.25 inches) with an additional 15 cm (6 inches) buried into the soil (USDOI, 2002). This fence material was attached to t-posts with metal clips or ties (USDOI, 2002).

Fences for turtles and tortoises are typically 0.30-0.60 m high and are buried 5-20 cm into the ground (Boarman & Sazaki, 1996; Boarman et al., 1997; Guyot & Clobert, 1997; Aresco, 2005; Griffin, 2006; Kruidering et al., 2005; Woltz et al., 2008; AZDOT 2013a). The fence material may consist of woven vinyl erosion control fencing with wooden stakes (Aresco, 2005), but more permanent fencing material can consist of mesh wire fencing (e.g. 1x1 cm (0.4x0.4 inches) or 1.3x1.3 cm(0.5x0.5 inches) or 2.5x5.0 cm (1x2 inches)), sometimes with aluminum flashing (10-15 cm (4-6 inches) wide) at the top, or composite or concrete retaining walls (Boarman & Sazaki, 1996; Ruby et al., 1994; Dodd et al. 2004; Griffin, 2006).

Higher and sturdy barrier walls have been developed where larger reptiles such as American alligator (*Alligator mississippiensis*) are among the target species: 1.1 m (3.6 ft) high with a 15.2 cm (6 inches) overhang (Dodd et al., 2004). This type of barrier worked especially well for larger reptile species such as snakes, turtles and American alligator. However, the concrete barrier or retaining wall was not found to be particularly effective for tree frog species (Dodd et al., 2004). In addition, chain-link fences about 90 cm high (3 ft) with the top angled away from the road have been implemented for the American crocodile (*Crocodylus acutus*) (Brien et al., 2008).

Multi-species Groups Design

If multiple types of fencing are required for different target species they can often be combined into one design (Kruidering et al., 2005). For example, medium sized mammals may require smaller mesh sizes than large mammals the first section from the ground whereas amphibians may require plastic sheeting the first 50 cm from the ground. A buried apron, angled away from the road, may be attached to the fence to discourage animals from digging under the fence.

2.2.4. Fence End Treatments

Angle Fence Away from the Road at Fence End

In many cases a wildlife fence is angled away from the road at a fence end. In some cases the fence angles only slightly away from the road (e.g. 45°) whereas it is 90° (perpendicular) to the road in other cases (Kruidering et al., 2005). There are also examples where the wildlife fence first angles away from the road at 90° and then bends back another 90° essentially paralleling the main fence for some distance (Kruidering et al., 2005). The main purpose of having a wildlife fence angle away from the road is to discourage animals from crossing the road at grade at the fence end; it helps avoid a "fence end run" effect. Note that additional measures (e.g. wildlife guard, electric mat or electric concrete) may need to be installed in the travel lanes to substantially reduce the likelihood that wildlife enters the fenced road corridor at a fence end.

Bring Fence Ends Close to Paved Road Surface

In some cases the fence angles towards the road surface at a fence end. The main purpose of having a wildlife fence angle towards the road surface at a fence end is to discourage animals from wandering off into the fenced right-of-way. An angled fence does not help avoid a fence end run effect though.

Bringing a fence close to the road surface typically results in having the fence and the end post in the "clear zone." The clear zone should be free of obstacles so that drivers whose vehicle has left the paved road surface may still recover and regain control of the vehicle without crashing in to large objects. This means that measures must be taken to prevent cars from crashing into the fence or fence end. Break-away structures may be used to limit the danger to humans (e.g. Gagnon et al., 2010). Alternatively, guard rails or Jersey barriers can deflect vehicles that have left the roadway at fence ends where the fence end has been brought close to the road surface. Note that additional measures (e.g. wildlife guard, electric mat or electric concrete) may need to be installed in the travel lanes to substantially reduce the likelihood that wildlife enters the fenced road corridor at a fence end.

Boulder Fields

Boulder fields may be used at fence ends between the paved road surface and fence ends, and, in case of a divided highway, also in the median. It is an alternative to bringing a fence end close to the paved road surface as boulder fields are believed to discourage wildlife, specifically ungulates, from walking into the fenced road corridor. The suggested size of a boulder field is 50-100 m (165-325 ft) measured in road length from the edge of the fence into the fenced right-of-way (Clevenger & Huijser, 2011). The width of the boulder field (perpendicular to the road) should be equivalent to the distance between the edge of the pavement to the fence.

The boulders should be subangular, quarried rock, with a 20-60 cm (7.8–23.6 inches) diameter with about 75% larger than 30 cm (11.8 inches)) (Huijser et al., 2008a; Clevenger & Huijser, 2011). The boulders should be installed on geofabric at a depth of about 40-50 cm (16-20 inches) (sub-excavated smoothed ground). This should result in the boulders projecting about 20-30 cm (10-12 inches) above the ground in the surrounding area (Clevenger & Huijser, 2011).

Boulder fields next to the shoulder or pavement may not be appropriate at curves or high speed roads as boulder fields are a hazard to cars that have run off the road. However, guard rails or Jersey barriers can be placed in between the pavement and the boulder field to deflect vehicles before they would hit the boulder field. On the other hand the use of a shield (guard rails or Jersey barriers) can be a safety hazard too, and placing a shield for boulder fields and similar objects is a danger to vehicles too and placing these is not a hard guideline or recommendation (AASHTO, 2006). Note that additional measures (e.g. wildlife guard, electric mat or electric concrete) may need to be installed in the travel lanes to substantially reduce the likelihood that wildlife enters the fenced road corridor at a fence end.

Modified Cattle Guards or Wildlife Guards

Cattle guards, modified to discourage wild ungulates from crossing, or wildlife guards can be embedded in the road surface at fence ends. They typically consist of a pit with metal bars or bridge grate material on top. They may extend into the clear zone until they connect with a fence end. They may also be used in combination with fence ends that are close to the road surface or boulder fields. The main purpose of these modified cattle guards or wildlife guards is to discourage wildlife from using the road surface to enter the fenced road corridor. If modified cattle guards or wildlife guards are used at a fence end, the road in which it is embedded typically has a relatively high traffic volume and relatively high traffic speed. This means that a standard cattle guard with large round or flat metal bars may not be suitable or safe (Peterson et al., 2003). Modified bridge grate material may be much more suitable and safe for relatively high traffic volumes and high traffic speed (e.g. Peterson et al., 2003). Wildlife guards that use modified bridge grate material are also safer for pedestrians and cyclists than standard cattle guards (Peterson et al., 2003).

Wildlife fencing should run up to the cattle guard or wildlife guard (perpendicular to the road). Additional sections of wildlife fencing should run alongside the cattle guard or wildlife guard (parallel to the road), for the full width of the guard. The pit under a guard typically has retaining walls, e.g. made out of concrete. The concrete ledges of the retaining walls should be made inaccessible to wildlife as many wildlife species, including deer (*Odocoileus* spp.) can walk on a very narrow ledge between the wildlife fence and the actual guard to access the fenced road corridor (Allen et al., 2013). This means that the sections of fence that cover the width of a guard should connect to the actual surface of the guard. In some cases bulb-outs have been used to make the concrete ledge more difficult to access for wildlife. In other cases a separate section of fencing covered the concrete ledges.

The pit under a cattle or wildlife guard can be a trap for small species that fall through the bars or grate. If possible, openings should be present in the side walls of the pit that allow the animals to escape to the safe side of the fence. This may only be possible if the guard is built in a road bed that is higher than the surrounding area. These openings should be equal or greater than the openings in between the bars or the grate. If openings in the side walls of the pit are not an option, escape ramps that lead up to the surface of the wildlife guard should be provided at the sides of the pit.

If cattle guards or wildlife guards are used to discourage wild North American ungulates such as deer (*Odocoileus* spp.) they should probably be at least 3 m (12 ft) wide (Reed et al., 1974a; Belant et al., 1998) rather than 1.5 m (5 ft) wide (Vercauteren et al., 2009), but double wide guards (5.5-6.1-6.6 m (20-22 ft)) with 45-100 cm (1.5-3.3 ft) deep pits are most likely a greater and more acceptable barrier with 75-100% of deer (*Odocoileus* spp.) not crossing the wider guards (Sebasta et al., 2003; Peterson et al., 2003; Seamans & Helon, 2008; Allen et al., 2013; McAllister et al., 2013). Cattle guards or wildlife guards do not appear to be a substantial barrier to bears (*Ursus* spp.) (Allen et al., 2013).

Painted Wildlife Guards or Cattle Guards

Painted wildlife or cattle guards on the road surface are to mimic a true cattle guard or wildlife guard with the expectation that cattle or wild ungulates will think it is a real cattle guard or wildlife guard (Lehnert & Bissonette, 1997). While painted lines on the road surface are less expensive than real cattle guards or wildlife guards, they are completely ineffective for large ungulates including moose, elk, and mule deer (Cramer, 2013; Cramer et al., 2014). Fence configuration at painted wildlife guards should be similar to that for cattle or wildlife guards.

Electric Mats, Electric Concrete or Electrified Cattle Guards

Electric mats at fence ends are embedded in the roadway and discourage animals enter the fenced road corridor (Seamans & Helon, 2008; Gagnon et al., 2010; Huijser, 2013; Siepel et al., 2013). Whenever an animal steps on the electric mat or electric concrete the animal receives an electric shock. Electric mats, electric concrete or electrified cattle guards are likely a much better barrier to bears (*Ursus* spp.) than cattle guards or wildlife guards that are not electrified (Allen et al., 2013). Electric mats, electric concrete or electrified cattle guards or wildlife guards seem to be a much greater barrier to bears.

Fence configuration at electric mats, electric concrete or electrified cattle guards should be similar to that for cattle or wildlife guards. Note that pedestrians wearing shoes and cyclists will not be shocked when they cross the mat. However, dogs, horses and people without shoes will be exposed to an electric shock unless separate gate or an "off button on a timer" are installed (Clevenger & Huijser, 2011).

2.2.5. Access Road Treatments

Gates

Various types of gates have been developed for access roads. For low vehicle traffic volume, access roads gate types include simple swing gates, swing gates with a lock, and "bump" swing gates, some of them electrified. Carousel gates and gates that are hung on an angle so that gravity closes them automatically have been used for pedestrians and equestrian use.

Gates should typically have the same height as the wildlife fence and should present a similar barrier to the target species as the wildlife fence. For species that can dig under a fence or gate and small sized species, e.g. reptiles and amphibians, a gate should have a snug fit to the ground. A “doorstep” (concrete or wood) and flaps attached to the fence can help reduce the probability that animals dig or crawl under gates.

Modified Cattle Guards or Wildlife Guards

This is similar to the cattle guards and wildlife guards discussed in section 2.2.4. However, access roads typically have lower traffic volume and lower vehicle speed than the road or highway that has been fenced. Therefore, at access roads, cattle guards or wildlife guards may be considered that are only suitable for relatively low traffic volume and low traffic speed.

Painted Wildlife or Cattle Guards

See section 2.2.4

Electric Mats or Electric Concrete

See section 2.2.4.

Barrier Continues Under Road

Barriers for relatively small species (e.g. reptiles and amphibians) may continue under the access road. This measure may consist of a tunnel for reptiles or amphibians under the access road, parallel to the main road or highway. The top of this tunnel may act as a barrier for reptiles or amphibians; they may fall through the openings. Alternatively, the barrier alongside the main road or highway can be extended alongside the access roads for a certain distance (perpendicular to the main road).

2.2.6. Effectiveness in Reducing Collisions

It is critical that a wildlife fence is designed for and tailored to the target species that may have been identified for the project. Proper construction practices are important as well; for example, the wildlife fence should be snug to the ground and properly attached to the posts. While safe crossing opportunities for wildlife (e.g. wildlife underpasses and overpasses) fall outside of the work scope for this project, they can reduce intrusions into the fenced road corridor and thereby increase the effectiveness of the mitigation measures in terms of reducing wildlife-vehicle collisions. Wildlife fences should have a tight fit with the safe crossing opportunities leaving no openings for the target species to enter the fenced road corridor. Fence maintenance is important as well. For example, erosion, falling trees, damage as a result of vehicles crashing into the fence, and vandalism can all result in openings in the wildlife fence. Regular inspections (e.g. once a month) have been suggested to identify and fix potential problems with the mitigation measures (Clevenger & Huijser, 2011).

Wildlife fencing, typically in association with safe crossing opportunities for wildlife can reduce wildlife-vehicle collisions with large ungulates substantially (≥80%) (Reed et al. (1982) 79%; Ward (1982): 90% Woods (1990): 4%–97%; Clevenger et al. (2001): 80%; Dodd et al. (2007a): 87%). However, when wildlife fencing is installed over relatively short road segments (e.g. up to a few kilometers or miles), wildlife fencing may be less effective (58%) in reducing wildlife-vehicle collisions (McCollister & van Manen, 2010). This may be related to "fence end effects" that have the potential, by definition, to be greater for relatively short fenced road sections than for relatively long fenced road sections. In addition, "weak spots" (e.g. mitigated or unmitigated access roads) can further reduce the effectiveness of a wildlife fence in reducing wildlife-vehicle collisions.

Fencing for medium sized mammals can also be effective: various fence designs were 100% or almost 100% effective in excluding species such as Eurasian badger, red fox and feral cat (Poole & McKillop, 1999; Moseby & Read, 2007; Tolhurst et al., 2008; Judge et al., 2011).

Fencing or barrier walls can also be very effective 88-100% effective in reducing collisions with turtles, snakes, and alligators (Boarman & Sazaki, 1996; Dodd et al., 2004; Aresco, 2005). However, it is more challenging to construct effective fencing for frogs and toads, particularly tree frogs (Dodd et al., 2004).

2.2.7. Wildlife Mortality as a Result of Wildlife Crashing into Fences

In some areas birds flying into fences are a concern that may have to be addressed. The birds concerned tend to be relatively large, heavy and low flying such as different grouse species and large owls (Fitzner, 1975; Catt et al., 1994; Baines & Summers, 1997; Martínez et al., 2006; Wolfe et al., 2007; Summers et al., 2010; Stephens et al., 2012). Attaching markers to wildlife fences to make them more visible to the birds can help reduce these strikes by 49-91% (Dobson, 2001; Baines & Andrew, 2003; Stephens et al., 2012).

In addition, predators can use fences to corner and kill prey species. In one instance a wildlife fence blocked access to steep terrain that bighorn sheep (*Ovis canadensis*) had traditionally used to escape predators. The bighorn sheep still fled towards the steep terrain but now crashed into the wildlife fence, allowing the chasing predators to more easily corner and kill the bighorn sheep. Colored fabric was attached to the wildlife fence to make the fence more visible to the bighorn sheep (Huijser et al., 2008c). The expectation was that bighorn sheep would have a reduced probability of crashing into the fence after it was made more visible.

2.2.8. Landscape Aesthetics

Wildlife fences may affect landscape aesthetics. High fences, especially chain-link fences, and metal posts tend to generate the highest level of concern (Clevenger & Huijser, 2011). The fencing material can be plastic coated (e.g. black or dark green in color) to reduce the visual impact of a fence (Clevenger & Huijser, 2011). Shrubs and low trees in front of a fence, perhaps on both the roadside and the safe side, can also help a fence blend into the landscape (Clevenger & Huijser, 2011). However, shrubs and trees that are close to the fence may increase maintenance effort because of falling branches or trees and cutting branches or trees that allow wildlife to more easily climb the fence. On the other hand, shrubs and trees may shade out grasses and herbs and may reduce mowing and fence damage as a result of the mowing practices.

In other cases a fence may be lowered along selected road sections where wildlife presence may be relatively low (e.g. in front of buildings and paved surfaces that offer no or little food and cover). Fences may also be lower if they are constructed adjacent to a low-lying area or a trench on the safe side of the fence which makes the fence a greater barrier to wildlife that may consider jumping into the fenced road corridor (Clevenger & Huijser, 2011).

2.2.9. Costs

The costs for 2.4 m (8 ft) high wildlife fencing along US Highway 93 on the Flathead Indian Reservation in Montana varied depending on the road section concerned: US$26, US$38, US$41 per meter (3.28 ft) fence length in 2006 (material and installation combined) (Personal communication Pat Basting, Montana Department of Transportation) (Huijser et al., 2008c). A finer mesh fence was dug into the soil and attached to the wildlife fence for some fence sections at an additional cost of US $12 per meter (per 3.28 ft) fence length (Personal communication Pat Basting, Montana Department of Transportation). Fencing along the Trans-Canada Highway in Banff National Park (the portion of the project known as phase 3-B, constructed in 2006-2007) was estimated at CAD $75 in 2006 per meter (per 3.28 ft) fence length (personal communication, Terry McGuire, Parks Canada) (Huijser et al., 2008c). This fence was 2.4 m (8 ft) high, had pressure-treated wooden posts and a dig barrier. A 2.4 m high wildlife fencing with galvanized steel posts was estimates at $82.10 per meter (per 3.28 ft) fence length (Giles et al., 2012). In British Columbia 2.4 m high wildlife fence with heavy gauge wire and a mix of wood and steel posts across flat to rolling terrain with no rock outcroppings was estimated at CAD$ 35-45/m (Ministry of Transportation and Infrastructure, 2011). In rocky terrain where drilling is required the costs increase to CAD$75-85 /m (Ministry of Transportation and Infrastructure, 2011). Plastic coating that makes a chain-link fence less noticeable in the landscape may add costs. An electric fence (5 KV, 4-5 strands of rope with 25 cm (10 inches) spacing) was estimated at $9-11 per meter (per 3.28 ft) fence length, including installation (Seamans & Vercauteren, 2006; Leblond et al., 2007), excluding electricity bills required to keep the fence operational. Costs for medium mammal fencing were estimated at AUD $8.81 per m (per 3.28 ft) for a 115 cm (3.8 ft) high fence to AUD $12.43 per m (per 3.28 ft) for a 180 cm high fence with two electric wires (Moseby & Read, 2006), though it is not clear if these costs relate to fence length or road length (the latter with fencing on both sides of the road). Costs for materials for turtle and tortoise fences were estimated at about $10 per meter (3.28 ft) fence length (Ruby et al., 1994; Langen, 2012). Note that additional cost data were obtained in the survey (Chapter 3) and that the cost-data were used in the cost-benefit analyses (Chapter 4).

The costs for the material and labor for the installation of boulders at the fence end at one location was estimated to cost CAD $65,000 (installed in 2005, cost estimate for 2007) (Bruce Leeson, personal communication). The reported cost of a specially designed double wide (about 6 m) wildlife guard with bridge grate material was about $30,000 (Pat Basting, Montana Department of Transportation, personal communication). Electric mats (material only) have been estimated at $550 (3.0×1.2-m (9.8x3.9 ft)) (Seamans & Helon, 2008). However, an electric mat does require electricity to maintain its function. Therefore electric mats, electric concrete or electrified wildlife guards are most feasible if electricity is present at the location already, but in many cases power is obtained from solar panels. In addition, there are operating costs for electric mats, electric concrete and electrified wildlife guards. Costs for single- and double-panel (i.e. single or double wide) gates have been estimated at $300–360 and $350–550, respectively (Pat Basting, Montana Department of Transportation, personal communication).

2.2.10. Maintenance

Maintenance can be reduced best by having a well-designed and well-built fence. Naturally a sturdy fence requires less maintenance than a fence that is constructed less robust. Thick and durable posts (treated wood, metal, potentially set in concrete), tick and galvanized wires for the mesh fencing, and a solid attachment of the fencing material to the posts (especially in areas with high snow loads) are essential to reducing maintenance (Gagnon et al., 2010; Clevenger & Huijser, 2011; Giles et al., 2012). Most large mammal fences are projected to have a life span of about 20-30 years (Huijser et al., 2009a; Clevenger & Huijser, 2011). A strong wire at the top of the fence may reduce damage from trees that may fall on the fence. Erosion (especially on slopes), flooding, heavy snow fall and snow accumulation, freeze and thaw cycles, digging by animals, vehicles that leave the roadway and crash into the fence, and vandalism can all damage the fence. If the damage allows animals to enter the fenced right-of-way the main purpose of the fence is jeopardized. Therefore it is important to check the status of the fence regularly (e.g. every month or every few months) (Clevenger & Huijser, 2011).

Shrubs and trees that are close to a fence can reduce the impact of a wildlife fence on landscape aesthetics, and they may make it more difficult for large ungulates to jump over a fence, but shrubs and trees may also result in higher levels of maintenance to fences (falling trees or branches) and animals that can climb shrubs and trees may use them to cross the fence more easily (Clevenger & Huijser, 2011). In addition, shrubs and trees that are close to the fence may hinder access for maintenance and increase maintenance costs. Removal of dead trees and shrubs before installation and at regular times after installation can help reduce damage to the fence from falling trees. If an electric fence is used, vegetation must be kept short to present leakage of electricity (Clevenger & Huijser, 2011). The vegetation alongside fences is typically kept short (regular mowing), especially if the fences are relatively short to begin with (e.g. medium mammal fences and reptile or amphibian fences) (Dodd et al., 2004).

Because of fence and vegetation maintenance, it is generally recommended to place wildlife fences along roads within the right-of-way that is owned or managed by the transportation agency (Kruidering et al., 2005). This will allow access for workers and mowing or cutting of vegetation.

Substantial snow accumulation could make a boulder field less of a barrier to ungulates. It appears though that if snow levels reach that level that walking will be extremely hard for large ungulates anywhere and that they may depend on browsing shrubs and trees rather than eating grasses and forbs in the fenced road corridor.

The pit under a wildlife guard may fill with snow in areas with high snowfall (Belant et al., 1998). However, it appears that ungulates would still sink in the snow as the snow in the pit is unlikely to have been substantially compacted. Plowing a wildlife guard is probably required to keep the access road open to vehicles and to keep the wildlife guard from being hidden under the snow for both people and wildlife. Special care must be taken not to let snow accumulate on the side, on top of the wildlife guards. This snow may harden and may allow for ungulates to access the fenced road corridor. Similar snow plowing is required for electric mats and electric concrete, but these measures – at least electric mats - can be virtually maintenance free otherwise and do stand up to snowplows (Keller, 2008).

Swing gates may be blocked if snow accumulates on the ground. This can be mitigated by placing the swing gate on a platform (e.g. 1 m (3.28 ft)) above the ground with steps on either side of the fence. Alternatively the gate can be split into two panels, similar to a "French door." The upper and lower half of the gate can be locked together in summer, and unlocked in winter. This allows the lower panel to stay in place, buried under the accumulated snow, while the upper half can open above the snow level.

2.3. Allow Wildlife to Escape the Fenced Road Corridor

2.3.1. General Considerations

Measures that allow animals to escape from the fenced road corridor may function best if they are set a bit further back from the road with some cover (vegetation or topography) to block visual disturbance originating from the road (i.e. vehicles). In some cases short sections of wildlife fencing are placed perpendicular to the escape opportunities to encourage animals to investigate and use the escape measures. Escape opportunities have also been "off-set" in the wildlife fence so that an animal that moved alongside the fence (at least from one direction) would end up "bumping" into the escape opportunity (Reed et al., 1974b). If the fence moved back away from the road after about 12 m (40 ft) a second escape opportunity, for animals traveling from the opposite direction, may be installed (Reed et al., 1974).

There are no established standards for the spacing of escape opportunities. It has been recommended though that the number of escape opportunities for large ungulates should be four per mile road length (two on each side of the road) (AZDOT, 2013a). Others have recommended a spacing of 400 m (0.25 mi) between escape opportunities for large ungulates.

2.3.2. Passive One-Way Gates

One-way gates for large ungulates typically consist of spring loaded steel tines (Reed et al., 1974b). The gates are installed in a wildlife fence and allow large mammals that are caught in the fenced right-of-way to push themselves through the spring loaded steel tines that are pointing towards the safe side of the fence (i.e. away from the road). The direction of the tines, their range of motion, and the springs minimize, at least theoretically, the probability that large animals can travel from the safe side of the fence into the fenced road corridor.

In some cases the tines do not start until 30-90 cm (1-3 ft) above the ground level. This allows for snow or debris to accumulate or vegetation to grow without immediately affecting the opening or closing of the tines (Reed et al., 1974b). In some cases the fence material continues under the tines, in other cases there may be an opening under the lowest tines which allows small species and young animals to crawl under the one-way gate. Note that an opening under the tines allows for two-way travel by definition. Dimensions that have been used for the opening in the fence for a one-way gate are 104 cm (41 inches) but the actual opening that the animals would have to fit through was 71 cm (28 inches) (Reed et al., 1974b). The tines were set closer together at the bottom (10 cm (4 inches)) than in the middle (13 cm (5 inches)) or top (15 cm (6 inches)) of the one-way gate.

Between 33-49% of the mule deer (*Odocoileus hemionus*) that were in the fenced road corridor and that approached one-way gates used the gates to leave the fenced road corridor (Bissonette & Hammer, 2000). However, in other cases use was much lower at 16% (Lehnert et al., 1996).

While one-way gates are designed to only allow animals to pass from the fenced road corridor to the safe side of the fence, animals do sometimes succeed in using the gate to access the fenced right-of-way. Depending on the design 0, 3.8 and 6.0% of all passages were in the wrong direction (Reed et al., 1974). Some species (e.g. elk (*Cervus canadensis*) and moose (*Alces alces*) can bend the tines out of shape and can transform a one-way gate into a two-way opening (Reed et al., 1974). To reduce death or injuries to animals trying to get into the fenced road corridor (e.g. Huijser et al., 2008a; Sielecki, 2008) the tines of some one-way gates have curved ends or plastic disks or balls to prevent spiking the animals (Sielecki, 2008). However, animals' hoofs and legs may catch in the open curved ends. Therefore only solid disks or balls at the ends of the tines are now recommended (Sielecki 2008).

One way escape gates have also been designed for medium sized mammals such as the Eurasian badger (Kruidering et al., 2005). These one-way gates are made out of aluminum and are set at an angle so that gravity automatically closes the gate. These gates are vulnerable to damage and debris keeping the gates from closing properly. To minimize debris and vegetation growing around such one-way gates they have been installed on concrete slab.

2.3.3. Active One-Way Gates

In some cases swing gates are installed along highways that area patrolled by wardens or rangers. As part of their job, if animals are found inside the fenced road corridor, wardens or rangers can open the nearest gates and walk toward the animals, pushing them to the opened gate. A wider double gate is more effective than a single gate, especially for larger species such as elk or moose.

An alternative that does not require wildlife managers to be present is animal-activated self-opening electronic gates (Gagnon et al., 2010). If an animal approached the gate it would trip a sensor. The gate would then open (out of sight of the animal so that it does not scare them) and then close two minutes after the last detection (Gagnon et al., 2010).

2.3.4. Wildlife Jump-outs or Escape Ramps

Wildlife jump-outs or escape ramps are hills that are positioned in the fenced road corridor and allow animals to walk up the slope and an opening in the fence. The hill can be constructed out of soil or rocks (e.g. in wire cages (gabions)). The height of the jump-outs should be low enough for the target species to readily jump down to the safe side of the fence. At the same time the jump-outs should be high enough to discourage animals that are on the safe side of the fence to jump up into the fenced road corridor. This implies that finding an optimum height for the target species is important. However, there is very little information available on the appropriate height of jump-outs. The backing for the wildlife-jump-outs has been made out of wooden planks, concrete walls or stacked interlocking concrete stones. In some cases metal sheeting has been attached to the backing to reduce the likelihood of bears climbing up the wall into the fenced road corridor (Huijser et al. 2008c)

Wildlife jump-outs that were about 1.5 m (5 ft) high appear to be used much more readily (about 7.9-11.0 times more) by mule deer than one-way gates (Bissonette & Hammer, 2000). Wildlife jump-outs that were between 1.7-2.4 m (5.6-7.9 ft) high were used by about 25-60% of the mule deer that appeared on top of the jump-outs but none or almost none of the white-tailed deer that were present on top of the jump-outs jumped down to safety (Huijser et al., 2013b; Marcel Huijser, Personal Communication November 1013). Recommended wildlife jump-out height for mule deer, white-tailed deer and elk is 1.7-1.8 m (5.5-6.0 ft) (AZDOT, 2013a; b). Others have set the height at 2.0 m (6.5 ft) in combination with a horizontal plank that stuck out from the edge (Siepel et al., 2013). However, these jump-outs did not function well for mule deer and it was suggested to remove the either the horizontal plank or reduce the height of the jump-outs (Siepel et al., 2013).

A jump-out can be made to appear higher for animals that may be interested in jumping up into the fenced road corridor and lower for animals that may be interested in jumping down to the safe side of the wildlife fence. The area in front of the "backing," on the safe side of the fence, may be dug out in an area up to 1.5-1.8 m ((5-6 ft) from the backing (AZDOT, 2013a; b). The soil may be deposited on the "landing pad" which may start 1.5-1.8 m from the backing. Similarly the top of the jump-out can be made to appear higher by adding soil on top of the jump-out starting about 2.4 m (8 ft) away from the edge of the top of the jump-out (AZDOT, 2013a; b). Alternatively, a metal bar or wooden plank may be attached about 46 cm (18 inches) close to the edge of the jump-out (Siemers et al., 2013). This still allows animals that are on top to step over the bar or plank before jumping down, while animals wanting to jump up would also have to clear the bar or plank.

Wildlife jump-outs should be almost maintenance free. However, some backing may not be strong enough for the pressure from the material that makes up the hill, and some vegetation maintenance may be required to keep the vegetation on top and at the bottom short enough so that animals walk to the top of a jump-out and land safely. Loose sand, rather than compacted soil or rocks at the bottom of jump-outs may also facilitate use and safe landings for the animals. In addition both the top and bottom of a jump-out should be relatively flat (AZDOT, 2013a; b). Jump-outs may need to be signed to minimize use by humans as they could injure themselves.

The cost for earthen escape ramps varied between $2,000 (Bissonette & Hammer, 2000), and $6,250 (Huijser et al., 2009a). Other large escape ramps were $40,000 each (AZDOT, 2013a; b), but costs were reduced by reducing the size of jump-outs that were built later. Jump-outs can also be made less expensive by integrating them into the existing road bed, especially near underpasses where the roadbed is high. In those situations no hills are required. The jump-out simply consists of a barrier wall at a gap in the fence (AZDOT, 2013a; b). Alternatively, the headwall of a wildlife underpass can also serve as a wildlife jump-out (AZDOT, 2013a; b). The wildlife fence can also be lowered to 1.2-1.5 m (4-5 ft) if the fence is positioned on a steep slope angling down away from the road AZDOT, 2013a; b). This construction is referred to as a "slope-jump" (AZDOT, 2013a; b).

Wildlife jump-outs have also been constructed for medium sized mammals such as the Eurasian badger. These are about 1 m (3.28 ft) high (Kruidering et al., 2005). If barriers for reptiles and amphibians are integrated into the roadbed (i.e. not a fence but a barrier wall) then amphibians and reptiles can escape to the safe side of the barrier wall anywhere, along the entire length of the barrier, by falling or jumping off the barrier wall.

2.3.5. Branches Stacked Against Fence

In some cases natural objects such as tree stumps, tree branches or brush have been stacked against the fence (on the road side) until it reaches the top of the fence. This allows small- and medium-sized species (e.g. Iberian lynx (*Lynx pardinus*)) to climb up to the height of the fence and exit the fenced road corridor.

2.3.6. Lower Fences with Outrigger

If an outrigger is attached to a relatively low wildlife fence (2.1 m (6.8 ft) high), and if the outrigger faces away from the road, then deer (*Odocoileus virginianus*) are more likely to jump to the safe side of the fence than into the fenced road corridor (Stull et al., 2011).

2.4. Warn Drivers and Traffic Calming in Fenced Road Corridor

2.4.1. Warning signs

Warning signs in combination with wildlife fencing make most sense at fence gaps and at fence ends. In this context fence gaps are openings in the wildlife fence on opposite sides of the road. These gaps are typically not associated with access roads. The fence gaps are designed to allow wildlife to cross the road at grade at a specific location; the fence gap. Fence ends are not designed to allow wildlife to cross the road; a fence end is typically located at a location where animals may find it difficult to approach the road in order to reduce the likelihood of a fence end run (see 2.2.).

Measures that discourage animals from wandering off in the fenced road corridor at fence ends have been described in section 2.2.4. For at grade crossing opportunities at fence gaps it is advisable to also consider measures that discourage animals from wandering off in the fenced road corridor. Measures between the edge of the pavement and the fence line may include bringing the end posts of the fence closer to the paved road surface, boulder fields, wildlife guards, electric mats or electric concrete (see section 2.2.4.) (Lehnert & Bissonette, 1997). Contrary to fence ends, it is not advisable though to have fences angle away from a gap in a wildlife fence; the purpose is to encourage animals to approach and cross the road at the fence gap, the purpose is not to guide them away from the fence gap. Measures on the road surface may include painted wildlife guards, wildlife guards, electric mats or electric concrete as long as the specific design allows for the traffic volume and vehicle speed of the highway that is to be mitigated (see section 2.2.4.) (Lehnert & Bissonette, 1997).

The width of the wildlife crossing area of a fence gap on the actual road surface varies substantially: 9-10-60-90-92-100-200-220-250-300 m (30-33-197-295-302-328-656-722-820-984 ft) (Taskula, 1997; Lehnert & Bissonette, 1997; Muurinen & Ristola 1999; Strein et al., 2008; Strein, 2010). In some cases the wildlife fence (or a lower right-of-way fence) may angle towards the road which may help funnel wildlife towards the actual crossing area (Lehnert & Bissonette, 1997). The mouth of the funnel can be wider than the actual crossing area on the road surface. If a fence end run effect cannot be avoided through careful placement of the fence end in relation to the topography and other landscape features, one may consider an at grade crossing opportunity. The width of this crossing opportunity depends on how far out the fence end run effect is detectable.

At grade crossing at fence gaps, fence ends, or stand-alone animal detection systems have been implemented for highways with a traffic volume that varies: 1,447-1,777-2,538-2,545-2,578-3,360-5,120-7,370-8,700-13,000 vehicles per day (Kistler 1998; Kinley et al. 2003; Mosler-Berger & Romer, 2003; Gordon et al., 2004; Huijser et al. 2006; 2009b; Strein et al., 2008; 2010; Dai et al. 2009; Gagnon et al. 2010; Sharafsaleh et al. 2012). At grade crossings are typically implemented for 2-lane roads, they are only rarely implemented for 4-lanes roads. When traffic volume and road width increase it becomes less and less desirable to continue to allow animals to cross at grade or encourage animals to cross at grade, with or without associated mitigation measures. It seems that at grade crossing opportunities are mostly designed for roads with a traffic volume <5,000 vehicles per day, and rarely for roads that have a traffic volume of

>13,000 vehicles per day. While there is no established standard, at grade crossing opportunities may not be suitable for roads with a traffic volume >15,000 vehicles per day because higher traffic volumes are associated with an increase in rear-end collisions, especially when vehicles start hitting their brakes.

Drivers should typically be warned for the potential presence of wildlife on or near the road at fence gaps, and, if fence ends runs are present, also at fence ends. Warning signs can include standard wildlife warning signs, enhanced warning signs (Lehnert & Bissonette, 1997) or warning signs associated with an animal detection system (Taskula, 1997; Muurinen & Ristola, 1999; Mosler-Berger & Romer, 2003; Gordon et al., 2004; Strein et al., 2008; Strein, 2010). Warning signs may make a driver more alert and may allow the driver to reduce the stopping distance (Figure 2). Standard or enhanced warning signs (with or without advisory or mandatory speed limit reductions) may also lead to lower vehicle speed (Pojar et al., 1975; Al-Ghamdi & AlGadhi, 2004; Sullivan et al., 2004). Drivers tend to reduce their speed somewhat (<5 km/h) (Kistler 1998, Muurinen & Ristola 1999, Hammond & Wade 2004, Huijser et al. 2006) or more substantially (≥5-22 km/h) in response to activated signs of animal detection systems (Kistler 1998, Kinley et al. 2003, Gordon et al. 2004, Gagnon et al. 2010, Sharafsaleh et al. 2012). The greatest reductions in vehicle speed seem to occur when the signs are associated with advisory or mandatory speed limit reductions or if road conditions and visibility for drivers are poor (Kistler 1998, Muurinen & Ristola 1999).

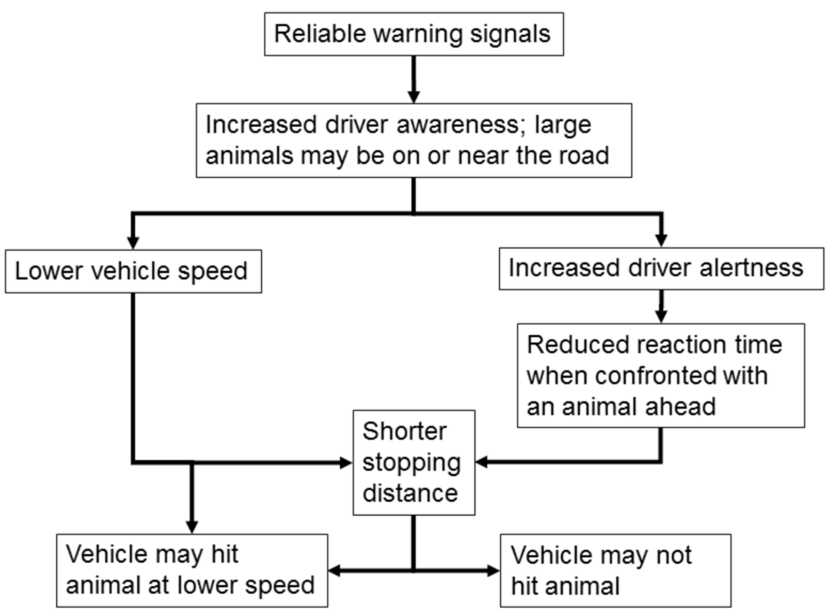

Figure 2: Warning signs must be reliable before they can be effective. They can reduce wildlife-vehicle collisions through increased alertness of the driver, reduced vehicle speed, or both.

The majority of studies of the effectiveness of standard and enhanced signs in reducing wildlife-vehicle collisions concluded that they were not effective (e.g. Pojar et al. 1975, Coulson 1982, Rogers 2004, Meyer 2006, Bullock et al. 2011). However, some have found standard warning signs to be effective (34% reduction in collisions) immediately after installation (Found & Boyce 2011) or at a gap in a fence with a crosswalk painted on the road surface (37 - 43%) (Lehnert & Bissonette 1997). Seasonal warning signs can reduce collisions, though their effectiveness varies substantially (9-50%) (Sullivan et al. 2004, CDOT 2012). The effectiveness of animal detection systems is also variable, but they appear to result in a greater reduction in collisions than seasonal warning signs: 33-97% reduction in collisions with large mammals (Mosler-Berger & Romer 2003, Huijser et al. 2006, Dai et al. 2009, Strein 2010, Gagnon et al. 2010, MnDOT 2011, Sharafsaleh et al. 2012).

2.4.2. Traffic Calming

In addition to warning signs that may be combined with advisory or mandatory speed limit reduction, traffic calming measures may be implemented for at grade wildlife crossing opportunities. Traffic calming may include speed bumps or a series of rumble strips that increase in height closer to the at grade crossing opportunity. Note that speed bumps may only be suitable for roads that have a low traffic volume.

2.5. Allow Humans to Get In and Out of the Fenced Road Corridor

2.5.1. General

Mitigation measures such as wildlife fencing in combination with safe crossing opportunities for wildlife are most effective in reducing wildlife-vehicle collisions when they are implemented over relatively long distances (see section 2.2.). Land use and human presence and activities in the surrounding landscape not only influence if wildlife fencing will be constructed and over what road length. They also influence the number, location and type of access points where humans can get in and out of the fenced road corridor. In addition transportation agency personnel or their contractors need to regularly inspect structures, and conduct repairs when needed. Access points can be considered a weak point in the fenced road corridor. Therefore it is best to minimize the number of access points. In some cases a frontage road or trail may be constructed on the safe side of the fence to minimize the number of access points to the main fenced road corridor. For example, if there are four access roads within as relatively short distance on the same side of the main highway, the number of access points could be reduced from four to one through a frontage road at the safe side of the fence that connects the four access roads.

2.5.2. Non-Motorized Use (Pedestrians, Bicyclists, Equestrian)

While there are many forms of non-motorized use, here we only include access points for pedestrians, bicyclists and equestrian use. The suitability of different types of access facilities for the three user groups is summarized in Table 1. There is no access facility that is optimal for all user groups. Therefore, if multiple user groups need to have access at a certain location, multiple access facilities may be provided adjacent to each other.

Table 1: The suitability of different types of access facilities in and out of fenced road corridors for pedestrians, bicyclists, and equestrian use.

Access facility type	Pedestrians	Bicyclists	Equestrian use
Walk through gate	+	-	-
Swing gate at grade	+	±	±
Swing gate with steps	+	-	-
Swing gates with lock chamber	+	±	±
Carousel	+	±	+
Wildlife guard (bars)	-	±	-
Wildlife guard (grate)	+	+	-
Wildlife guard (electrified)	-	±	-
Electric mat or electric concrete	±	±	-

Walk-Through Gates

Walk-through gates consist of a gap in a fence, wide enough to pass a human. On one end of the gap the fence simply stops. On the other side of the gap the fence splits and “embraces” the gap. When viewed from above this fence end looks like the letter “Y” with the other fence end ending halfway in between the arms of the “Y”. Walk-through gates allow humans to walk through a fence line without opening or closing a gate and without crawling or climbing. These types of openings do require a human to turn several times as the person winds through the walk-through gate. These types of gates are recommended where foot traffic is expected to be relatively high (AZGFD, 2011). Because several sharp turns are required to pass through the fence it is not suitable for bicyclists or equestrian use. Similarly, this type of gate is thought to be a substantial barrier for large wild ungulates as their backs may not allow for sharp turns.

Swing Gates

Swing gates at grade consist of a gate that can be opened by a human. A swing gate is hinged on one side and attached to a fence post. Locked gates are only useable by people who carry the key and are only suitable if the human use is restricted to very few individuals. Gates that are unlocked may be opened by any person, but they are more likely to be left open (accidentally or on purpose). Therefore self-closing gates are sometimes constructed, though these cannot necessarily present a gate from being propped open on purpose. Self-closing gates may have springs or they may be hung at an angle so that gravity automatically closes the door. In areas with snow accumulation swing gates may not be usable in winter. In those types of areas swing gates have been placed on a platform (e.g. 1 m (3.28 ft) above the ground. This requires pedestrians to walk up several steps to the platform (on either side) before they can open the gate. In other situations a “lock chamber” has been integrated into the access point. A lock chamber has two swing gates with a fenced “neutral area” (the “lock chamber”) in between.

Swing gates with a lock chamber may be required where there is a relatively high risk of the target species escaping when a gate swings open or if a gate is left open accidentally.

Swing gates tend to be awkward for bicyclists and equestrian use. People will typically have to get off their bicycle or off their horse and then move their bicycle or lead their horse through the gate. Gates with steps are even more difficult to use for these groups.

Carousels

A carousel or rotating "door" allows for relatively easy passage for pedestrians. It may be awkward for cyclists and they may still have to get off their bicycle, but large carousels have been designed for equestrian use and they seem to function well; people can stay mounted on their horse when moving through the carousel (Huijser, 2012).

Wildlife guards

Wildlife guards with bars (flat, round, or with edges pointing upwards) are awkward and sometimes even dangerous and unpassable for pedestrians and equestrian use. When bridge grate material is used a wildlife guard may be passable for pedestrians but by its very design it should not be readily passable for horses. Bicyclists have fewer problems with wildlife guards, but some wildlife guards can still be a barrier if the bars do not allow the bicycle wheels to easily and safely roll across them.

Electric mats, Electric Concrete or Electrified Wildlife guards

Electric mats or electric concrete integrated into the access road or trail are not a physical obstacle to pedestrians, bicyclists or equestrian use. However, if the user does not wear shoes that do not conduct electricity or if the user (humans or horses) touches the electrified surface with its skin, the user will receive an electric shock.

While it is possible for pedestrians or cyclists to safely cross an electric mat, electric concrete or electrified wildlife guard a separate access facility is typically provided for these groups. By definition, Electric mats, electric concrete and electrified wildlife guards are not suitable for equestrian use.

2.5.3. Motorized Use

Motorized use is very varied. Here we discuss access points with passenger cars, pick-up trucks, All Terrain Vehicles (ATVs), and motorcycles in mind. Table 2 summarizes the suitability of different types of access facilities for motorized use with regard to not having to stop the vehicle, not having to reduce the speed of the vehicle, being able to remain in or on the vehicle, and the comfort of driving through the access facility. There is no access facility that is optimal for all user groups. Wildlife guards made out of bridge grate material (electrified or not) and electric mats or electric concrete are the most suitable access facilities for motorized use (Table 2).

Table 2: The suitability of different types of access facilities in and out of fenced road corridors for motorized vehicles.

Access facility type	Vehicle does not have to stop	Vehicle does not have to slow down	People remain in / on vehicle	Comfortable to drive through/over
Swing gate (manual open/close)	-	-	-	+
Swing gate (automatic open/close)	±	-	+	+
Wildlife guard (bars)	+	-	+	-
Wildlife guard (grate)	+	+	+	+
Wildlife guard (electrified)	+	+/-	+	+
Electric mat or electric concrete	+	+	+	+

Swing Gates

Swing gates typically require a person to get out of or off their vehicle twice for each passage; once to open the gate, once to close the gate. Therefore swing gates are only suitable for very low volume roads where the users share an interest in leaving the gates closed. Some gates allow for automatic opening or closing (sensors, "bump" gates etc.). They may still require vehicle to come to slow down to a near stop, but people can remain in the vehicle and the gate is less likely to be left open on purpose.

Wildlife Guards

Wildlife guards with bars are suitable for motorized vehicles, but they are often constructed in such a way that vehicles have to slow down substantially and it is generally uncomfortable to drive across. Wildlife guards constructed out of bridge grate material, when constructed correctly, do not require vehicles to slow down and are comfortable to drive across.

Electric Mats, Electric Concrete or Electrified Wildlife Guards

Electric mats or electric concrete embedded in the road surface and electrified wildlife guards made out of bridge grate material do not require vehicles to slow down and are comfortable to drive across.

3. SURVEY

3.1. Organization of Survey

This chapter was organized according to species groups and the purpose of the different mitigation measures. The species groups were:

- Large or medium mammals.
- Amphibians and reptiles.

For each of these two species groups the survey results were organized around the purpose of the different mitigation measures:

- Keep wildlife off the road.
- Allow wildlife that ends up in the fenced road corridor to escape to the safe side of the fence.
- Prevent wildlife from entering the fenced road corridor at fence gaps and fence ends.
- Allow humans to get in and out of the fenced road corridor.
- Allow wildlife to cross the road at grade.

The respondents were also asked to submit design plans or “as-built” technical drawings of the mitigation measures. The design plans or technical drawings were discussed in the last section of this chapter.

3.2. Methods

3.2.1. The Target Population

We invited a wide range of practitioners involved with road ecology projects in North America to participate in the survey. The researchers sent the survey invitation to employees from transportation agencies in each state and province in the United States and Canada, the Federal Highway Administration (including FHWA Transportation Liaisons from the Community of Practice), Transport Canada, and University Transportation Centers that focus on environmental issues, the USDA Forest Service, the US Bureau of Land Management, the US Fish and Wildlife Service, the US Army installations with wildlife exclusion issues, and selected key researchers in the field of road ecology. These contacts were obtained through Dr. Cramer’s and WTI’s databases on past surveys, the AASHTO Standing Committee on the Environment website for committee members, the Canadian Ministry of Transportation, Federal Highways contacts, and through the Wildlife, Fisheries, and Transportation (WFT) Listserv (CTE, 2014). The researchers encouraged the target population to send the survey invitation on to other individuals that may have experience with or knowledge of wildlife fencing and associated measures.

3.2.2. Survey Development and Review

The survey questions focused on the following topics:

1. The design and material characteristics for wildlife fences and associated escape and lateral access control measures (e.g. fence-end treatments, jump-outs, and cattle guards, wildlife guards, electric mats, electric concrete, driver warning systems). Note that the researchers distinguished between large mammals (including large ungulates) and medium mammals, and reptiles and amphibians.
2. Construction costs for wildlife fencing and associated escape and lateral access control measures.
3. Maintenance needs including maintenance regimes, maintenance history, durability of the mitigation measures, maintenance costs, and other maintenance issues or experiences.
4. Local climate and environment (e.g., snow loads) that may influence the design and material characteristics of the mitigation measures.
5. Landscape aesthetics of the mitigation measures, particularly wildlife fencing (fence type and dimensions).
6. Wildlife habitat connectivity issues with fencing (i.e. stand-alone application or combined with safe crossing opportunities).
7. Potential negative side effects of wildlife fencing and associated mitigation measures on non-target species (e.g. barrier effect for non-target species, mortality of low flying birds).
8. Measures that allow for human access through wildlife fencing (access roads, non-motorized access).
9. Mitigation measures designed to reduce or manage fence-end runs by wildlife, including design and materials, construction costs and maintenance needs, history and costs.
10. Design plans or as-built drawings (electronic copies), if available.
11. Past and current monitoring efforts on these mitigation measures, including parameters measured and any potential documentation of the results (e.g., reports, articles).

The survey design allowed respondents to skip questions if they so desired. Not every respondent answered every question. The survey design also allowed multiple responses for some questions, if appropriate. Therefore, results are sometimes reported as number of *respondents* (up to one answer per respondent) and other times reported as number of *responses* (a possibility of multiple responses per respondent).

The survey questions are included in the attachment (Attachment A). The survey was deemed exempt from review by the Institutional Review Board at Montana State University. The survey was opened on 23 April 2014 and closed on 13 June 2014. Several reminders were sent to the target population while the survey was still open.

3.3. Respondents

There were 137 respondents that answered at least one question of the survey. The researchers did not calculate a response rate as the number of people who received the invitation to participate in the survey was unknown.

Almost half of all respondents were employees from state or provincial transportation agencies (Figure 3). Respondents from federal or national natural resource management agencies, state or provincial natural resource management agencies, private or consulting businesses and universities each represented between 9-13% of all respondents (Figure 3).

The vast majority of all respondents came from the United States or Canada (91%) (Figure 4), representing 33 states and 4 provinces (Table 3).

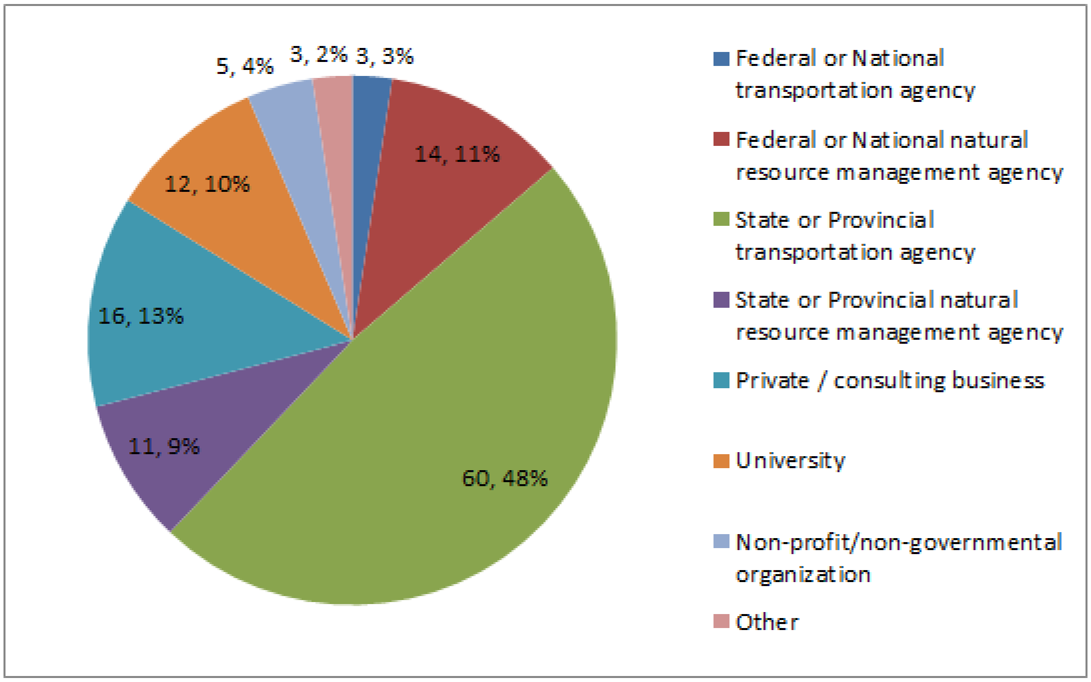

Figure 3: Respondent affiliation (n = 125).

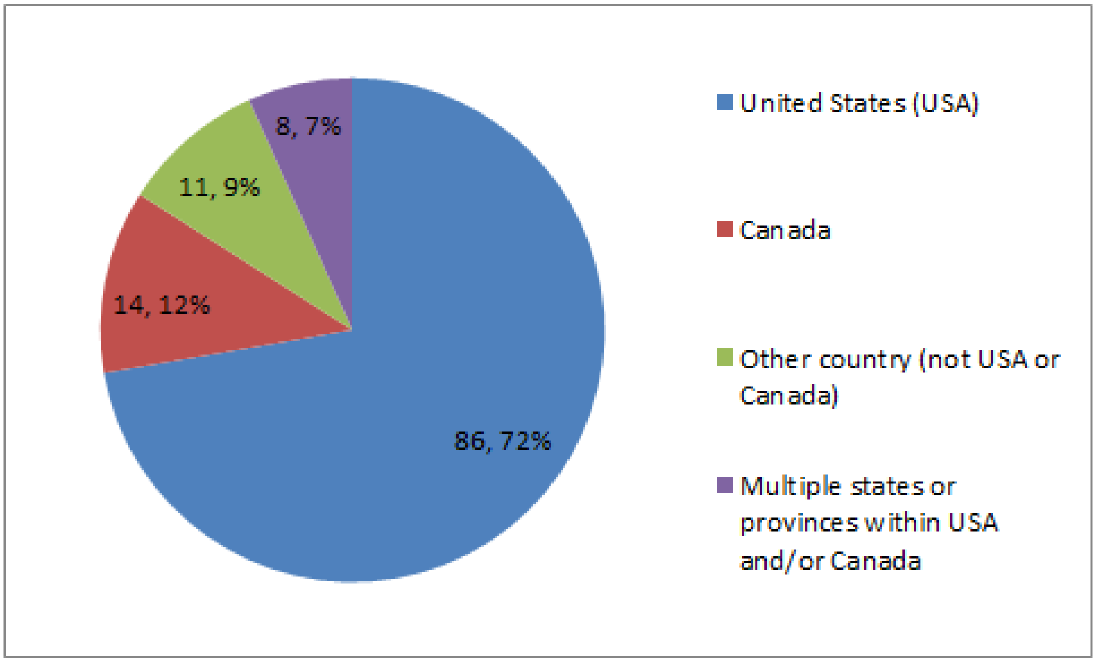

Figure 4: Country representation of respondents (n = 119).

Table 3: US state and Canadian province representation.

		Number of respondents
United States	Alabama	1
	Arizona	3
	California	12
	Colorado	3
	Connecticut	1
	Florida	3
	Georgia	1
	Idaho	4
	Iowa	1
	Kentucky	5
	Maine	2
	Maryland	1
	Massachusetts	4
	Michigan	1
	Minnesota	2
	Montana	7
	Nebraska	2
	Nevada	2
	New Hampshire	1
	New York	1
	North Carolina	3
	North Dakota	1
	Ohio	2
	Oregon	9
	Pennsylvania	2
	Rhode Island	2
	South Dakota	1
	Utah	2
	Vermont	1
	Virginia	2
	Washington	1
	Wisconsin	1
	Wyoming	2
		86
Canada	Alberta	1
	British Columbia	7
	New Brunswick	3
	Ontario	3
		14

The vast majority of the respondents had actual personal knowledge or experience with the design, implementation or evaluation of wildlife fencing or associated measures (Figure 5).

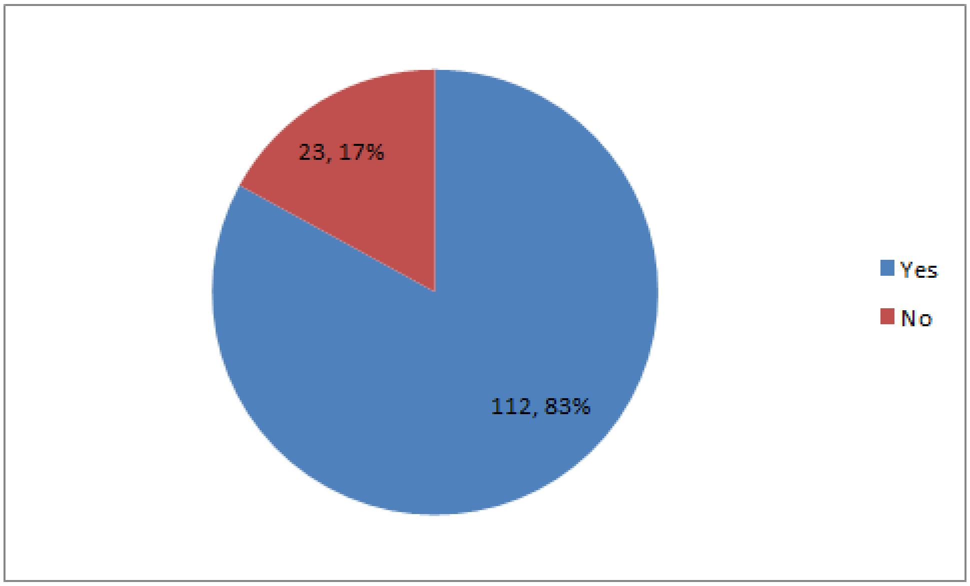

Figure 5: Number and percent of respondents personally involved with the design, implementation, maintenance, or evaluation of wildlife exclusion fencing project(s) along roadways (n = 135).

The information presented in the following chapters of the report are primarily based on closed-ended responses (i.e., based on answer options provided). For "other" or open-ended comments, please consult Appendix B.

3.4. Large and Medium-Sized Mammals

3.4.1. Characteristics of the Respondents

The vast majority of the respondents had actual personal knowledge or experience with the design, implementation or evaluation of wildlife fencing or associated measures for large or medium-sized mammals (Figure 6).

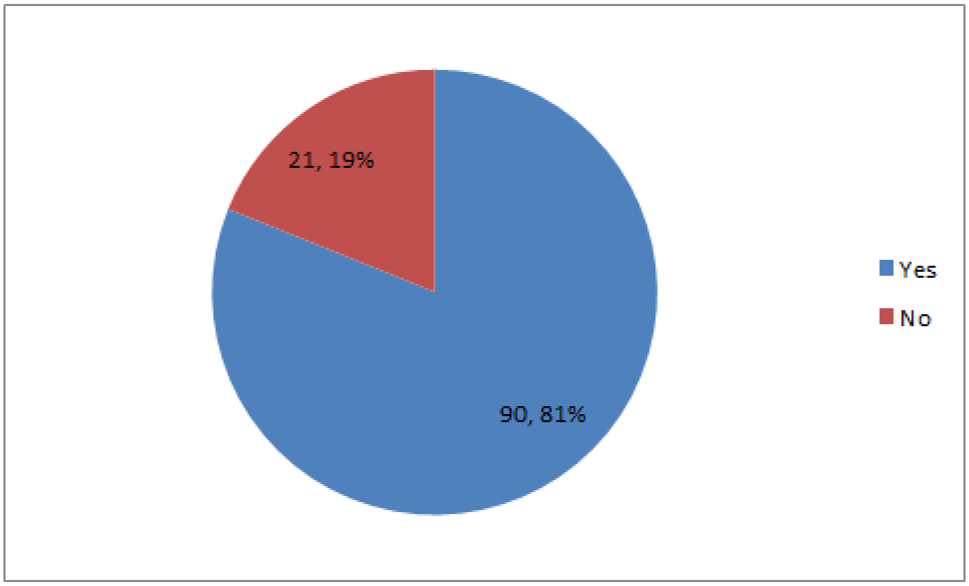

Figure 6: Number and percent of respondents with knowledge of large and medium mammal fencing and associated measures (n = 111).

3.4.2. Measures to Keep Large and Medium-Sized Mammals Off the Road

Woven wire mesh fences – either with consistent mesh size throughout or smaller mesh sizes towards the bottom - are the most frequently used type of fence for ungulates (Figure 7 and 8). Chain-link and electric fences are used less frequently. For carnivores chain-link fences are used most often (Figure 7 and 8).

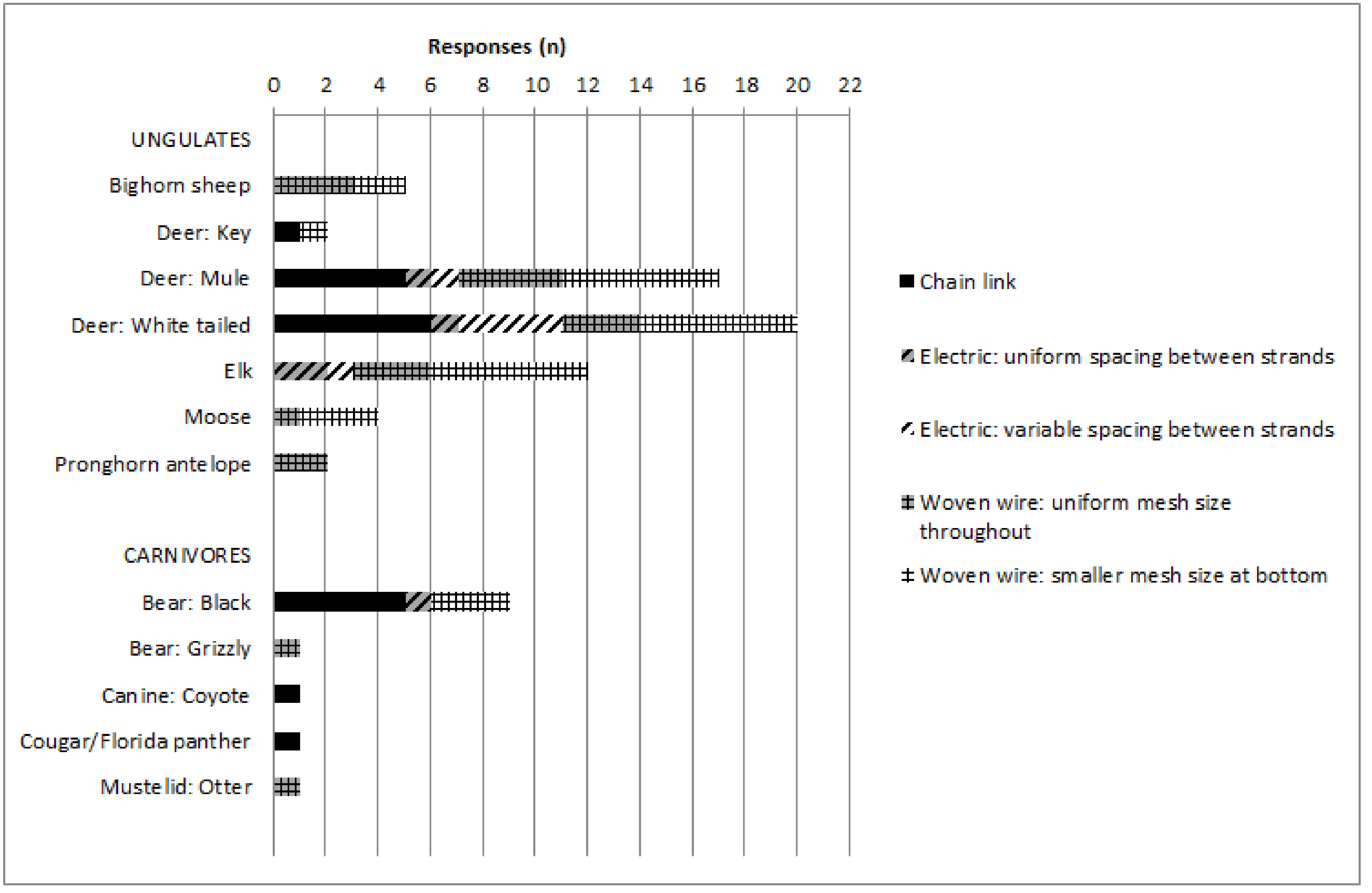

Figure 7: Number of responses indicating an exclusionary fence design has or will be implemented for a target mammal species (n). Note: 40 respondents answered this question but each respondent could enter multiple responses.

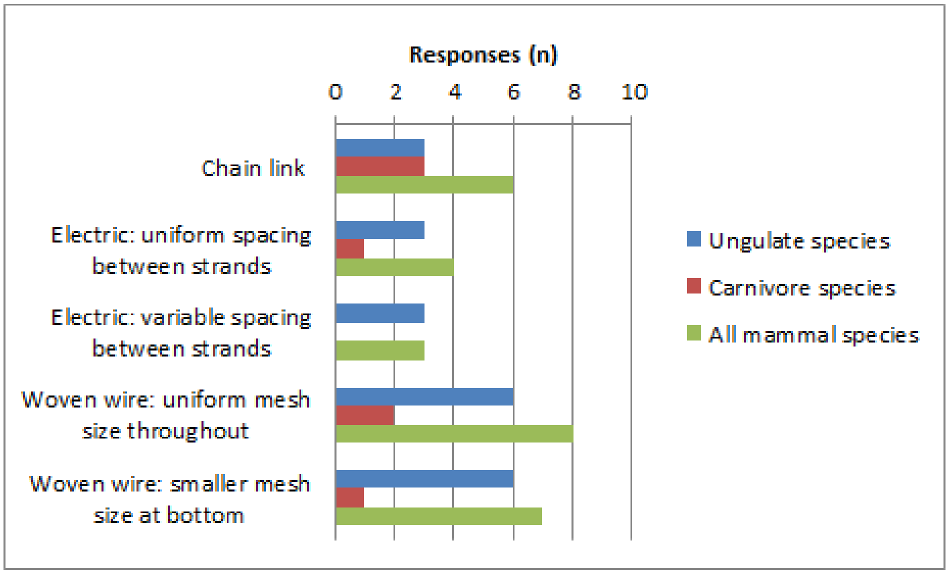

Figure 8: Number of responses indicating an exclusionary fence design has or will be implemented for a mammal group (n). Note: 40 respondents answered this question but each respondent could enter multiple responses.

Posts used for woven wire mesh fencing are typically wood or steel posts whereas chain-link fences typically have steel posts (Table 4). Electric fences use fiberglass or steel posts.

Table 4: Post/fence material combinations (blackened areas) reported for excluding mammals.

	FENCE MATERIAL				
POST MATERIAL	Chain link	Electric: uniform spacing between strands	Electric: variable spacing between strands	Woven wire: uniform mesh size throughout	Woven wire: smaller mesh size at bottom
Fiberglass		■	■		
Galvanized Steel	■		■	■	■
Metal: C-post	■			■	■
Metal: T-post	■	■	■	■	■
Plastic lumber				■	
Wood: not pressure treated				■	■
Wood: pressure treated	■			■	■

Fence height is influenced by the jumping and climbing abilities of the target species (Figure 9). For ungulates the most common fence height is 2.4 m (8 ft) and this is typically at least 80% effective in reducing deer-vehicle collisions. For large carnivores with good climbing ability effective fencing is typically higher: 3.0 m (10 ft).

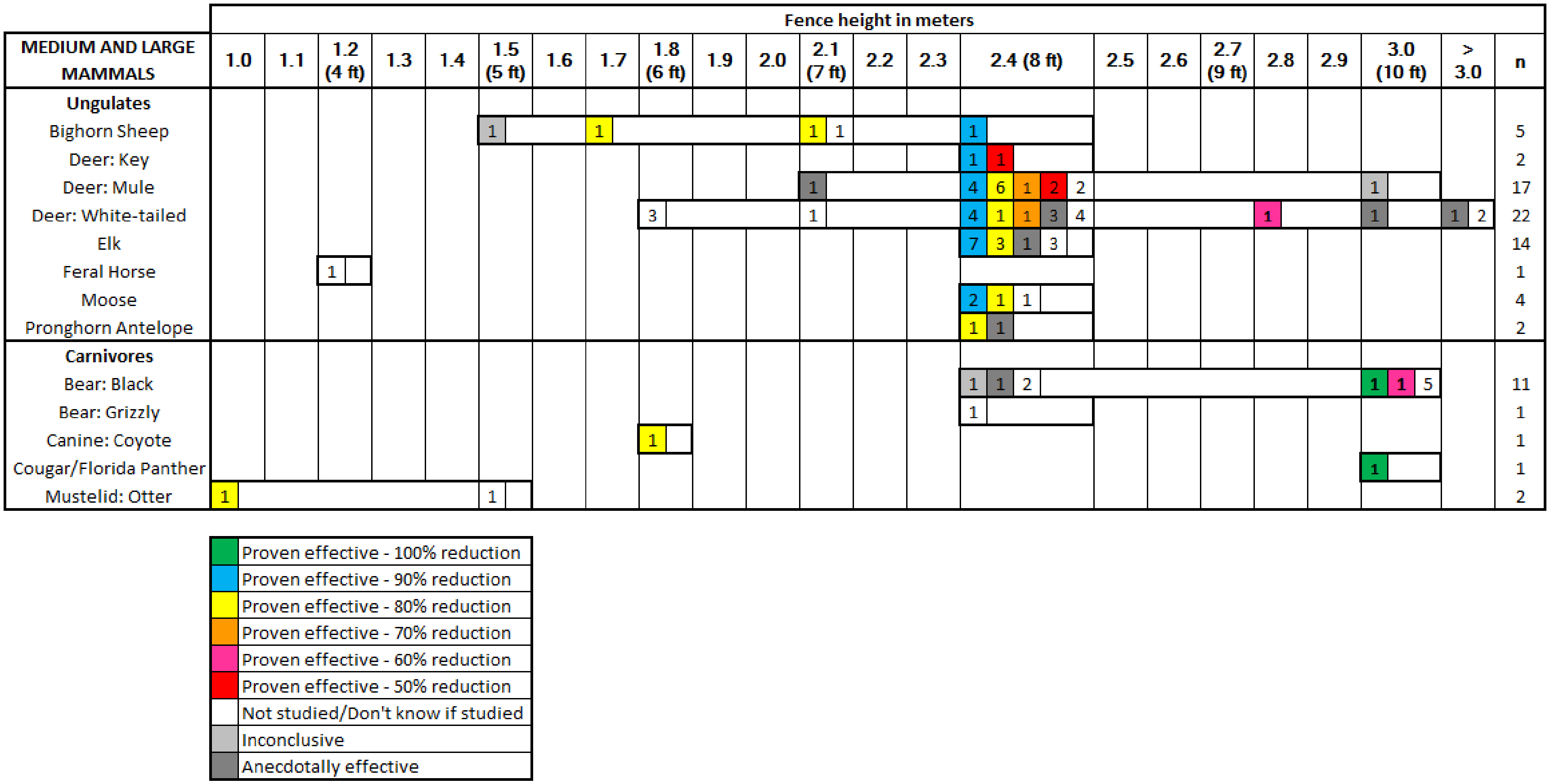

Figure 9: Number of responses indicating a particular height has or will be implemented and associated level of effectiveness for a target mammal species (n). Note: 40 respondents answered this question but each respondent could enter multiple responses.

Costs for wildlife fencing vary widely, partly depending on dig barriers or outriggers to deter animals from digging under or climbing over the fence (Figure 10). However, ungulate fencing typically costs between $21-$80 per m (3.3 ft) (Figure 10).

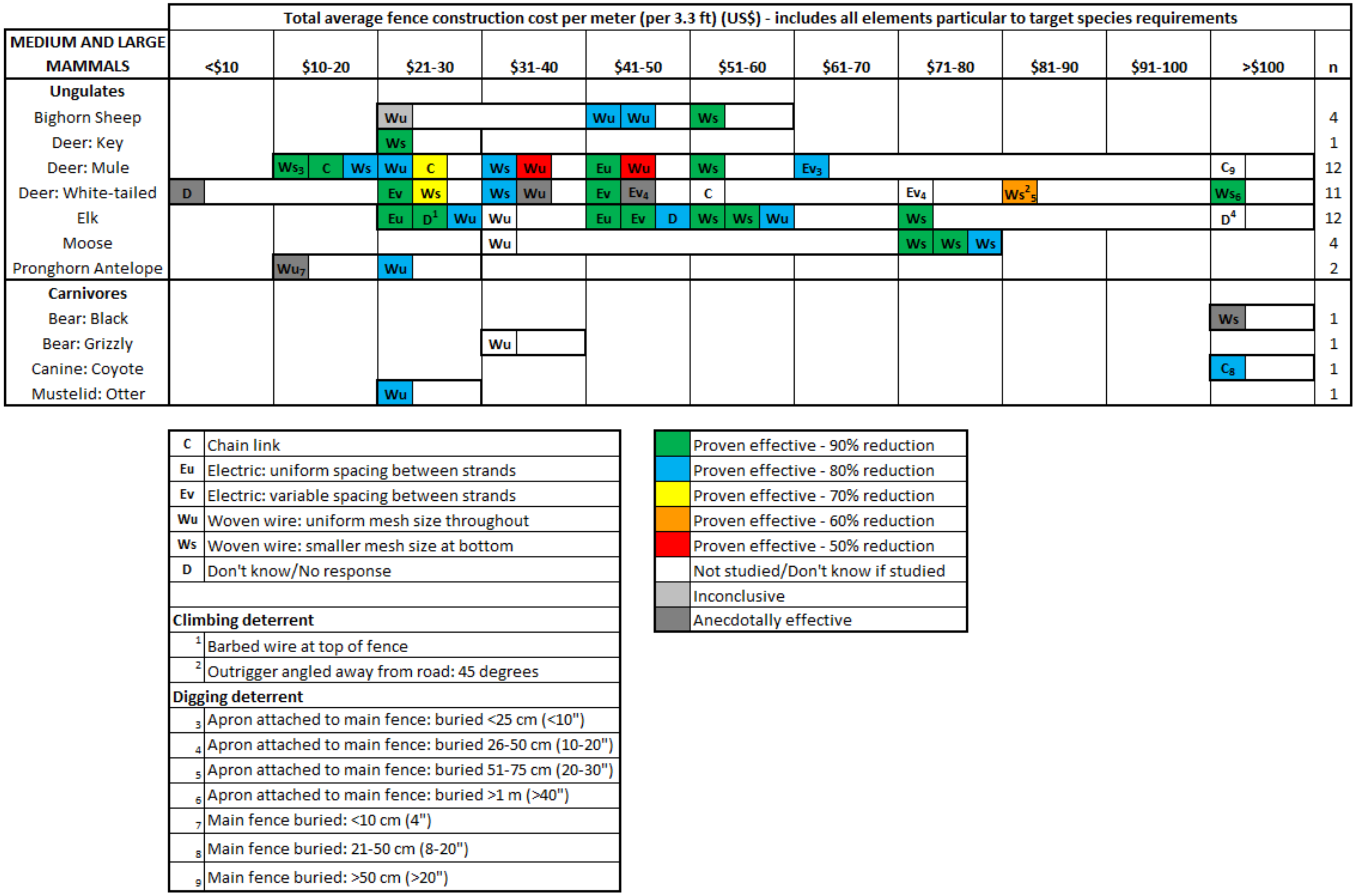

Figure 10: Range of cost and level of effectiveness in reducing wildlife-vehicle collisions or roadkill per fence design and target mammal species. Note: 40 respondents answered this question but each respondent could enter multiple responses. Only those entries with cost information are included. Refer to Appendix C-1 for more information on proven effective designs.

Climbing deterrents are mostly used for species with good climbing ability such as black bear and mountain lions (Figure 11 and 12). Outriggers angling away from the road are used most frequently (Figure 12).

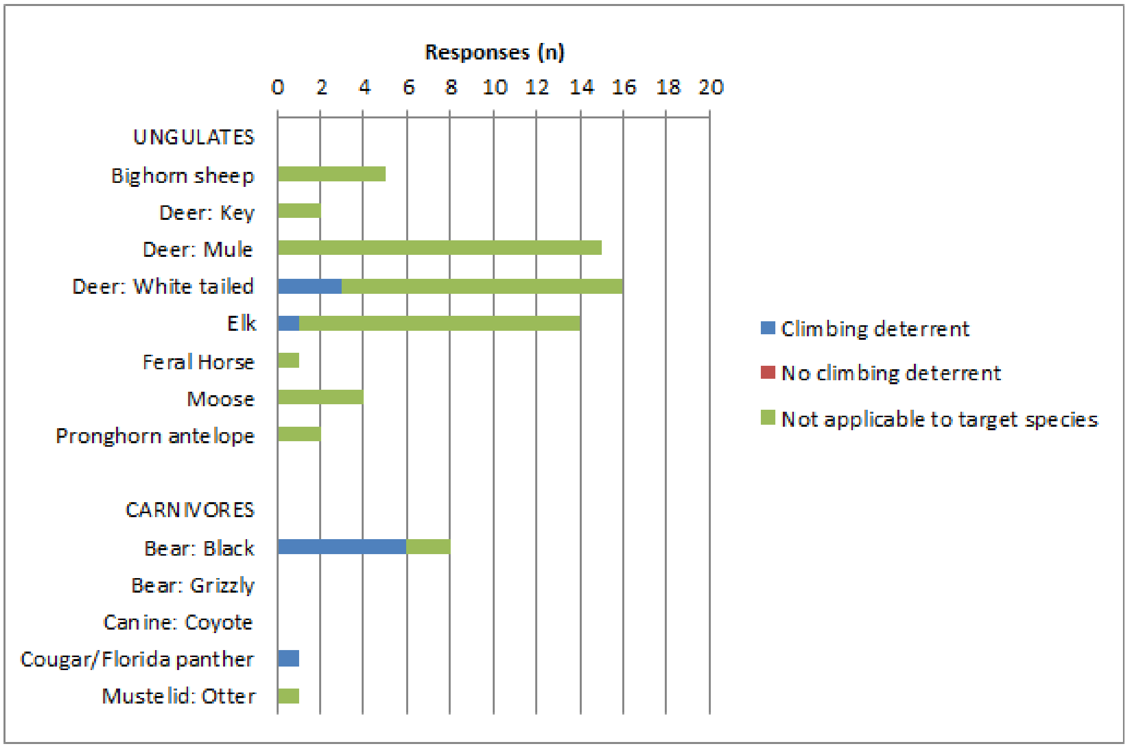

Figure 11: Number of responses indicating whether a climbing deterrent has or will be implemented as part of an exclusionary fence design for a target mammal species. Note: 38 respondents answered this part of the question but each respondent could enter multiple responses.

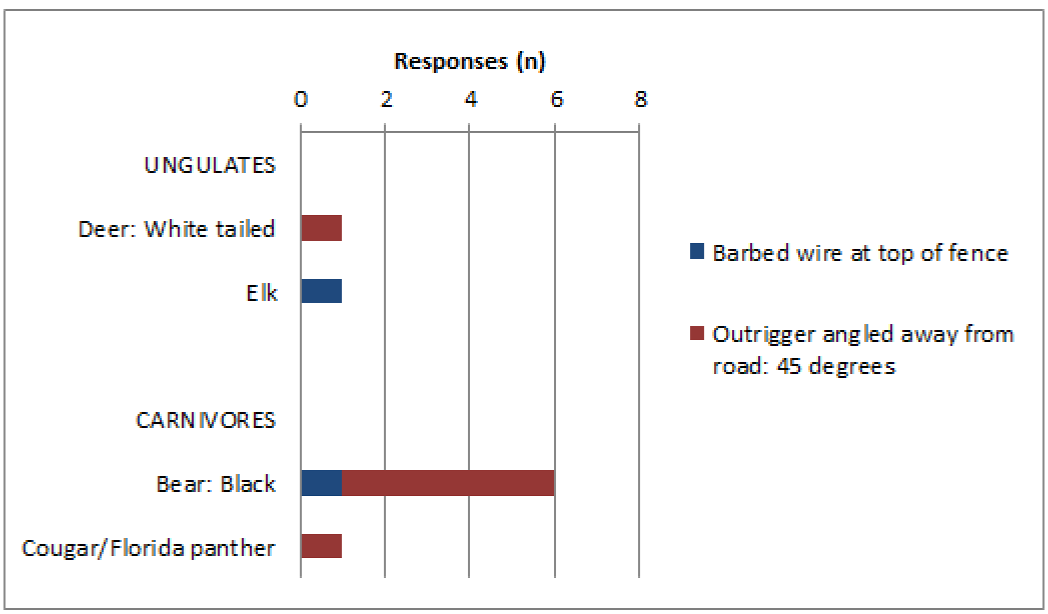

Figure 12: Number of responses indicating what type of climbing deterrent has or will be implemented for a target mammal species (n).

Digging deterrents ("aprons") are both implemented at fences primarily designed for ungulates as carnivores (Figure 13). This is probably an indicator that while fences may be designed with a specific target species in mind the actual design is based on a wider range of species so that a fence generates maximum benefit. Interestingly fences that are primarily designed for carnivores have the fence itself buried rather than an "apron" that is attached to the main fence (Figure 14).

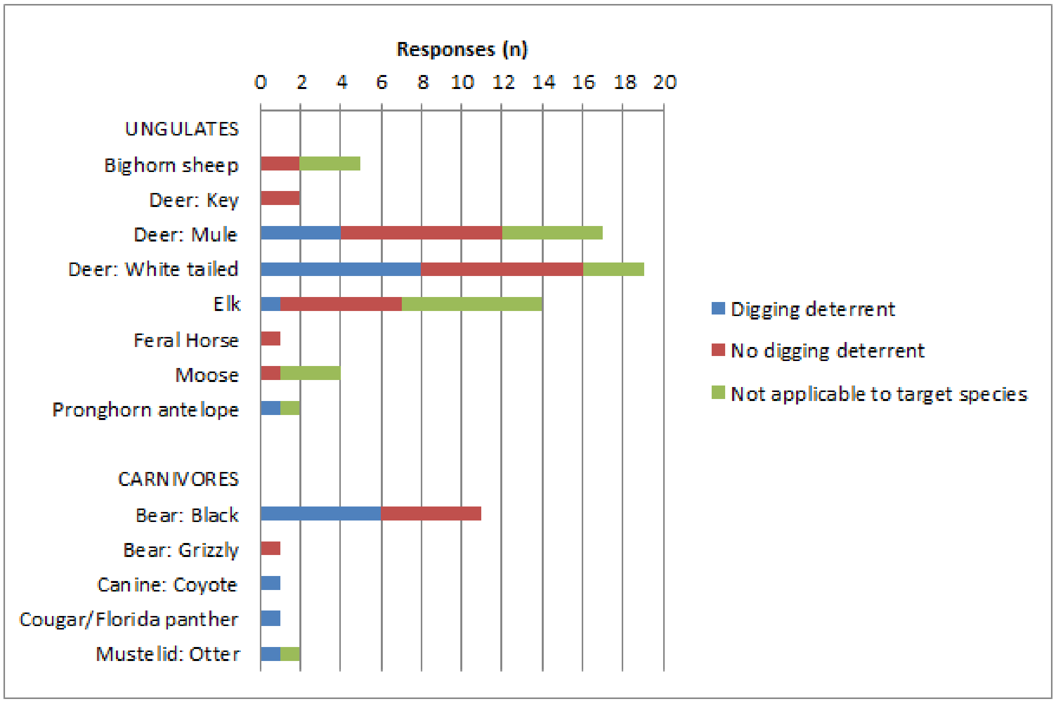

Figure 13: Number of responses indicating whether a digging deterrent has or will be implemented as part of an exclusionary fence design for a target mammal species. Note: 38 respondents answered this part of the question but each respondent could enter multiple responses.

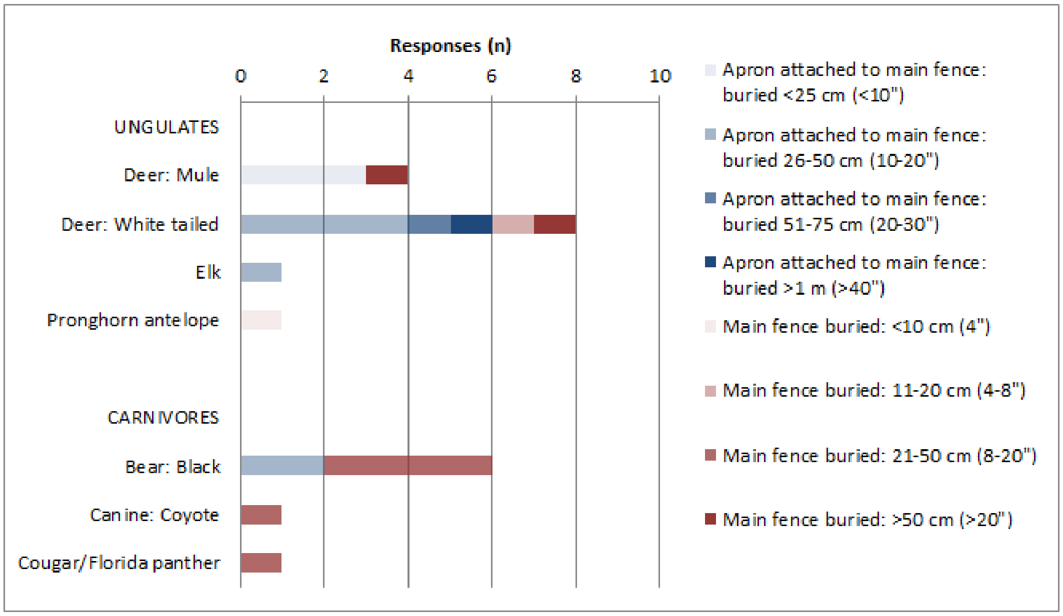

Figure 14: Number of responses indicating what type of digging deterrent has or will be implemented for a target mammal species (n).

Falling trees, people making holes in the fence and erosion require the most maintenance (Figure 15).

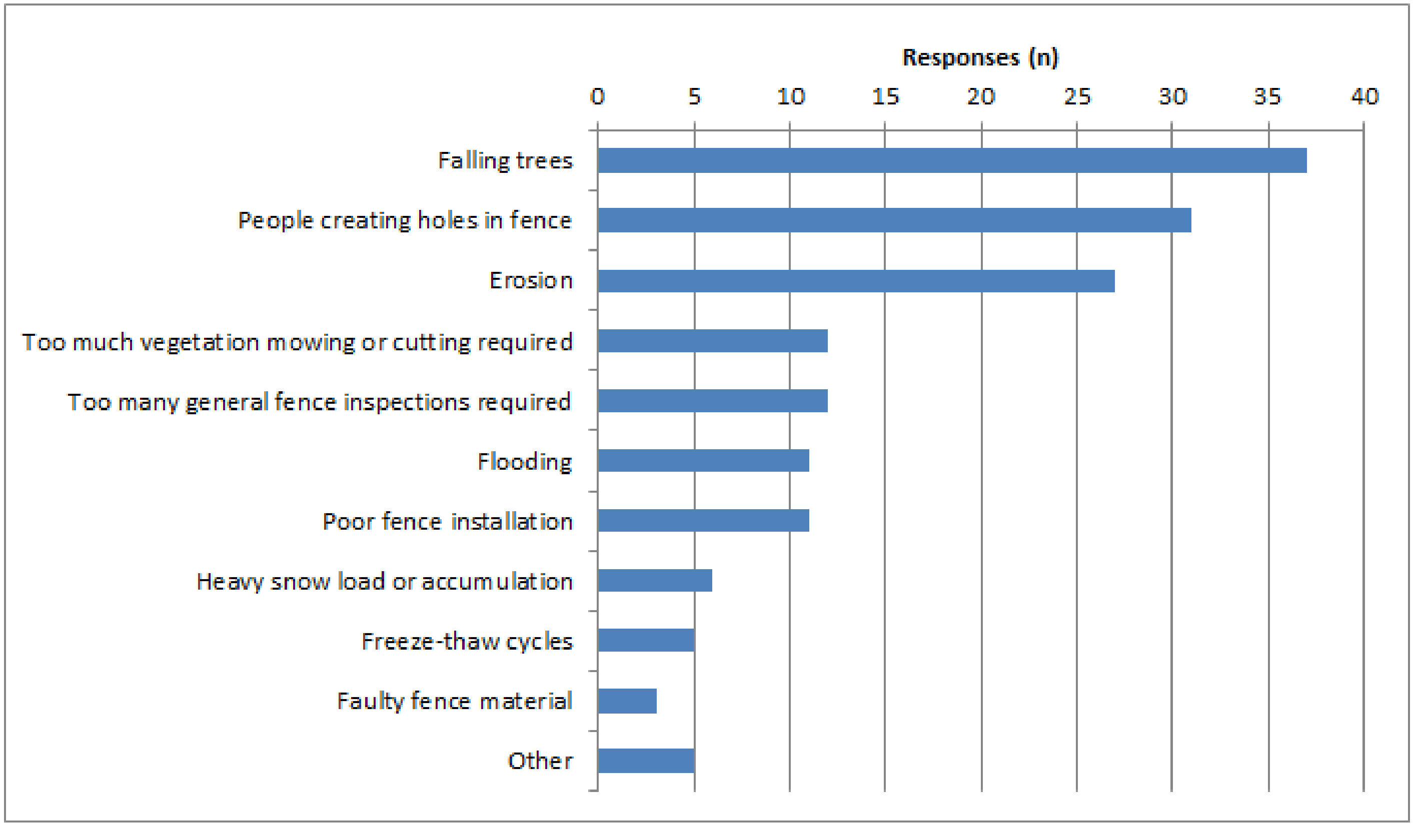

Figure 15: Number of responses indicating experience with maintenance issues with a particular large or medium mammal fence design (n). Note: 32 respondents answered this question but each respondent could enter multiple responses. See Appendix B Question 6 for "other" responses.

The most common unintended negative side effects of fences include the fences being a barrier for non-target species for which no safe crossing opportunities have been provided, entanglement in the fence of non-target species, decrease in human access, and unacceptable effects on landscape aesthetics (Figure 16).

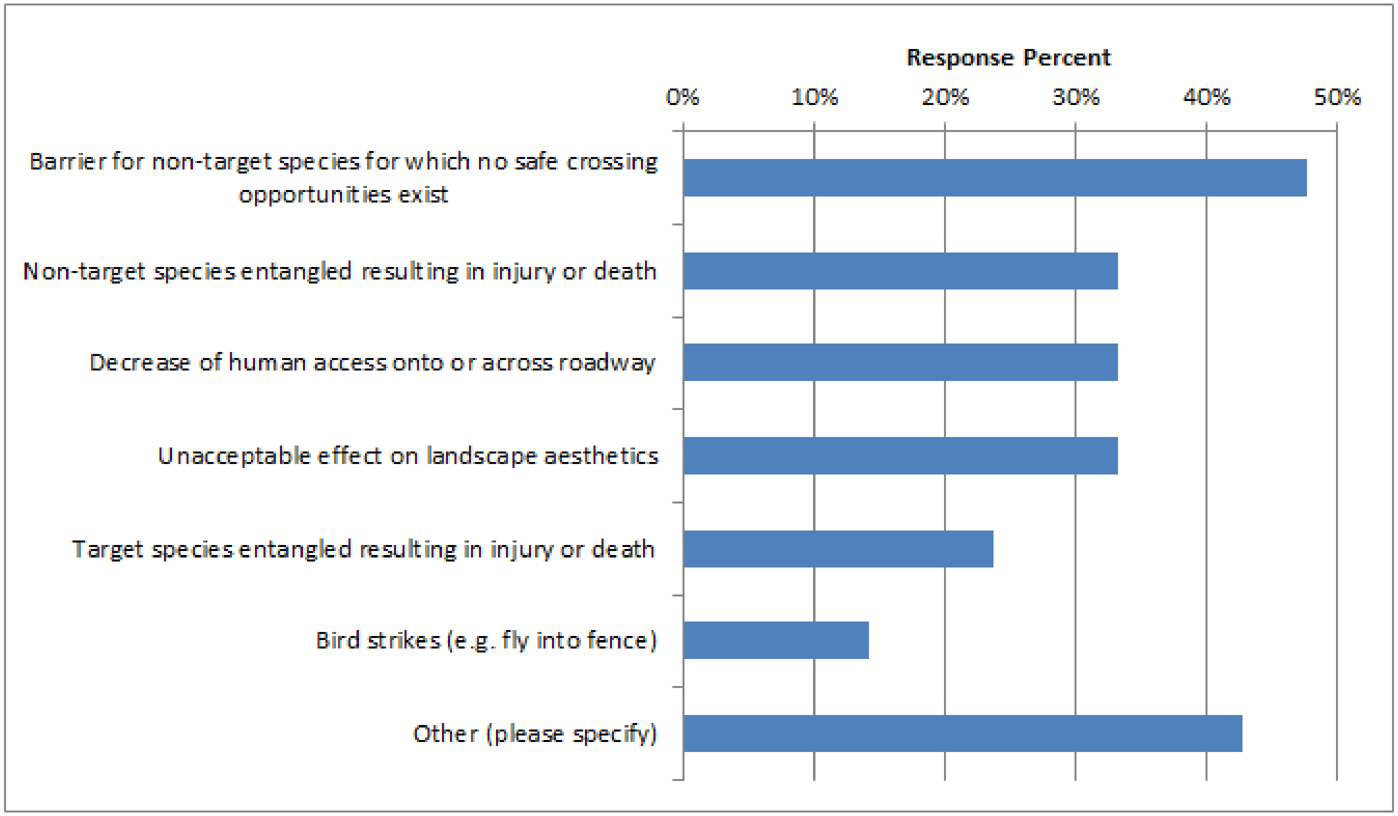

Figure 16: Response percent agreement indicating direct experience with negative, unintended effects with large or medium mammal fencing projects (n = 21). See Appendix B Question 16 for "other" responses.

3.4.3. Allow Wildlife to Escape the Fenced Road Corridor

Jump-outs and one-way gates are the most commonly used measures that allow wildlife to escape the fenced road corridor (Figure 17 and 18). Most of them have not been evaluated for their effectiveness in allowing animals to escape the fenced road corridor, and the costs vary widely. Effective jump-outs varied in costs between under $2,000 and under $13,000 per jump-out whereas. One-way gates were generally not evaluated or found to be only marginally effective in allowing animals to escape from the fenced road corridor. One-way gates have only been reported for deer, elk, and moose.

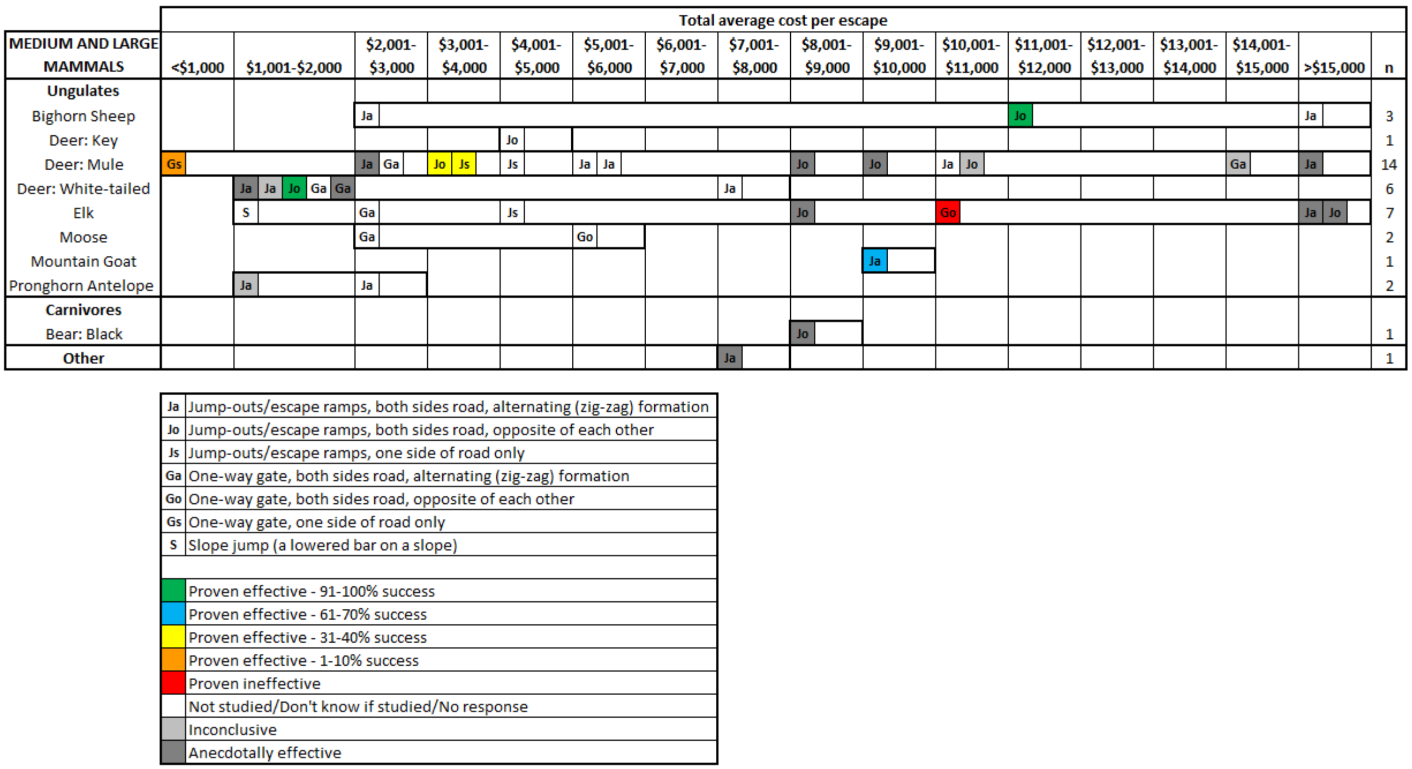

Figure 17: Range of cost and level of effectiveness to allow wildlife to jump "down" from the fenced corridor to the safe side of the fence per escape design and target mammal species. Note: 30 respondents answered this question but each respondent could enter multiple responses. Only those entries with cost information are included. Refer to Appendix C-2 for more information on proven effective designs.

Interestingly jump-outs are considered quite effective in keeping animals out of the fenced road corridor while information for one-way gates is typically lacking.

MEDIUM AND LARGE MAMMALS	Total average cost per escape																
	<$1,000	$1,001-$2,000	$2,001-$3,000	$3,001-$4,000	$4,001-$5,000	$5,001-$6,000	$6,001-$7,000	$7,001-$8,000	$8,001-$9,000	$9,001-$10,000	$10,001-$11,000	$11,001-$12,000	$12,001-$13,000	$13,001-$14,000	$14,001-$15,000	>$15,000	n
Ungulates																	
Bighorn Sheep			Ja									Jo				Ja	3
Deer: Key					Jo												1
Deer: Mule	Gs		Ja Ga	Jo Js	Js	Ja Ja			Jo	Jo	Ja Jo				Ga	Ja	14
Deer: White-tailed		Ja Ja Jo Ga Ga						Ja									6
Elk		S	Ga		Js				Jo		Go					Ja Jo	7
Moose			Ga			Go											2
Mountain Goat										Ja							1
Pronghorn Antelope		Ja	Ja														2
Carnivores																	
Bear: Black									Jo								1
Other								Ja									1

Ja	Jump-outs/escape ramps, both sides road, alternating (zig-zag) formation
Jo	Jump-outs/escape ramps, both sides road, opposite of each other
Js	Jump-outs/escape ramps, one side of road only
Ga	One-way gate, both sides road, alternating (zig-zag) formation
Go	One-way gate, both sides road, opposite of each other
Gs	One-way gate, one side of road only
S	Slope jump (a lowered bar on a slope)
	Proven effective - 91-100% success
	Proven effective - 1-10% success
	Not studied/Don't know if studied/No response
	Inconclusive
	Anecdotally effective

Figure 18: Range of cost and level of effectiveness to keep wildlife from jumping "up" to the fenced corridor from the safe side of the fence per escape design and target mammal species. Note: 30 respondents answered this question but each respondent could enter multiple responses. Only those entries with cost information are included. Refer to Appendix C-3 for more information on proven effective or proven ineffective designs.

Jump-out height varies between 1.5-3.0 m (5-10 ft) (Figure 18). Effective or somewhat effective jump-outs that allow wildlife to escape the fenced road corridor have a height between 1.7-2.0 m (<6-<7 ft) (Figure 19). Information on appropriate heights to keep animals from jumping into the fenced road corridor was mostly lacking (Figure 20).

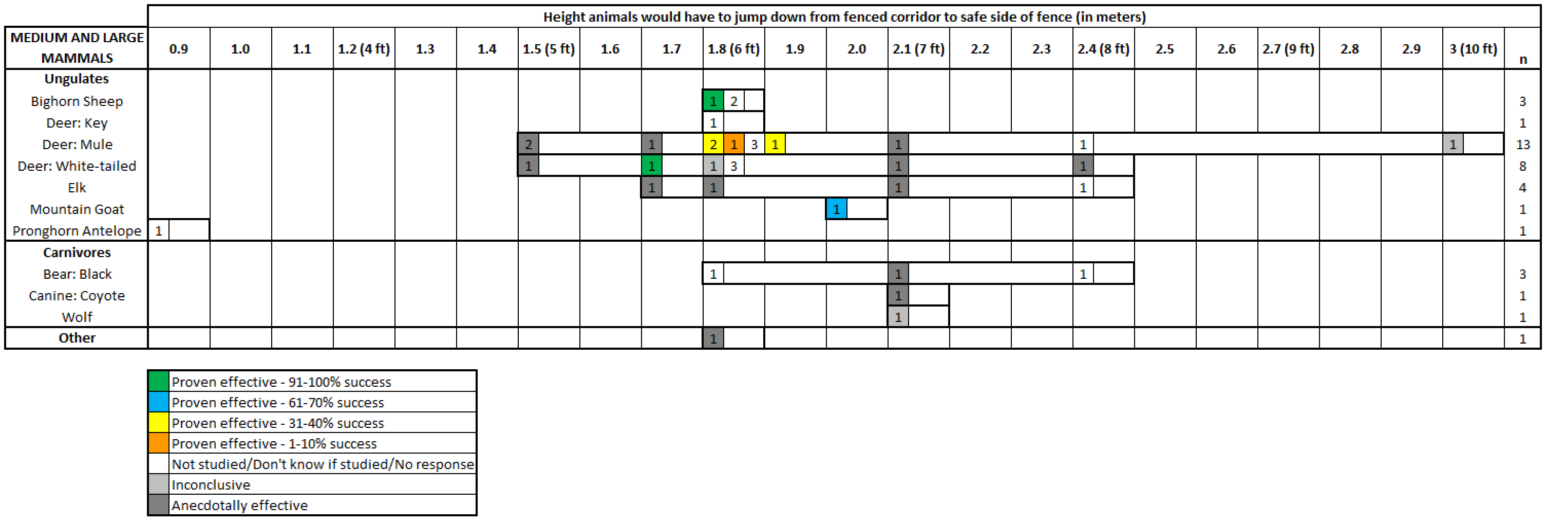

Figure 19: Level of effectiveness and range of jumping "down" heights from fenced corridor to safe side of fence per target mammal species.

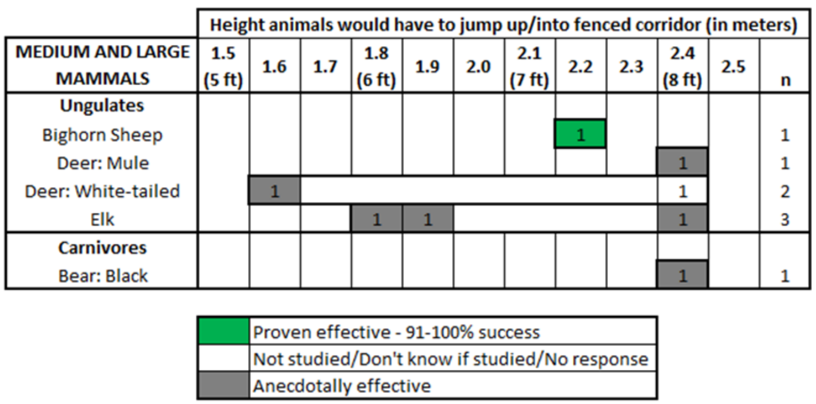

Figure 20: Range of jumping "up" heights from safe side of fence to fenced corridor per target mammal species. Note: Only those that reported the presence of a bar that increased the height required to jump up into the fenced corridor (versus jumping down from the fenced corridor) are included.

Distances between escape opportunities on one side of the road varies enormously (Figure 21). Escape opportunities are installed on opposite sides of the road as well as in a zig-zag pattern.

		Distance between escapes on one side of road (in meters along road length)																			
ESCAPE DESIGN	MEDIUM AND LARGE MAMMALS	51-100 (164-328 ft)	101-150 (328-492 ft)	151-200 (492-656 ft)	201-250 (656-820 ft)	251-300 (820-984 ft)	301-350 (984-1,148 ft)	351-400 (1,148-1,312 ft)	401-450 (1,312-1,476 ft)	451-500 (1,476-1,640 ft)	501-550 (1,640-1,804 ft)	551-600 (1,804-1,969 ft)	601-650 (1,969-2,133 ft)	651-700 (2,133-2,297 ft)	701-750 (2,297-2,461 ft)	751-800 (2,461-2,625 ft)	801-850 (2,625-2,789 ft)	901-950 (2,953-3,117 ft)	951-1000 (3,117-3,281 ft)	>1000 (>3,281 ft)	n
Jump-out/escape ramp: both sides of road, alternating (zig-zag) formation	**Ungulates**																				
	Bighorn Sheep														1		1				2
	Deer: Mule														1	2	1			1	5
	Deer: White-tailed		1				2				2		1								6
	Elk															1					1
	Mountain Goat										1										1
	Pronghorn Antelope	1															1				2
	Other															1					1
Jump-out/escape ramp: both sides of road, opposite of each other	**Ungulates**																				
	Bighorn Sheep																1				1
	Deer: Key									1											1
	Deer: Mule						1		1							1				1	4
	Deer: White-tailed	1							1												2
	Elk															1	1				2
	Carnivores																				
	Bear: Black	1								1						1					3
	Canine: Coyote																		1		1
	Wolf																		1		1
Jump-out/escape ramp: one side of road only	**Ungulates**																				
	Deer: Mule						1			1											2
	Elk									1											1
One-way gate: both sides of road, alternating (zig-zag) formation	**Ungulates**																				
	Deer: Mule									1										1	2
	Deer: White-tailed			1							1										2
	Elk						1			1							1				3
	Moose									1											1
One-way gate: both sides of road, opposite of each other	**Ungulates**																				
	Elk								1												1
	Moose																		1		1
Slope jump (a lowered bar on a slope)	**Ungulates**																				
	Elk															1					1

Figure 21: Distance and configuration of escape opportunities.

3.4.4. Keep Wildlife Out of Fenced Road Corridor at Fence Gaps and Fence Ends

For this report the researchers distinguished between the following locations for measures at fence ends (Figure 22):

1. On the travel lanes
2. Between the edge of the pavement and the fence line.

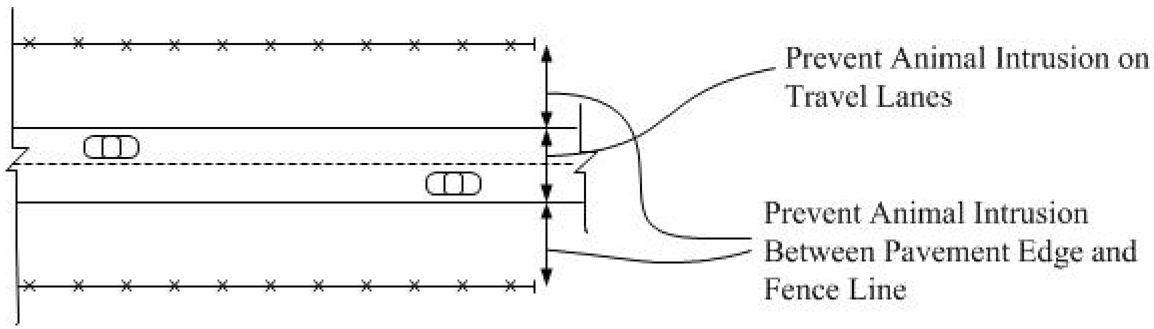

Figure 22: Range of cost and level of effectiveness in excluding target species per gap treatment and target mammal species. Note: 30 respondents answered this question but each respondent could enter multiple responses. Only those entries with cost information are included. Refer to Appendix C-4 for more information on proven effective or proven ineffective designs.

Wildlife guards with metal bars are the most frequently installed measure for ungulates to keep them from accessing the fenced road corridor at fence gaps or fence ends (Figure 23). Both wildlife guards and electric mats or electric concrete embedded in the roadway have proven to be effective in excluding wildlife from the fenced right-of-way. Animal detection systems have also been found effective (in reducing collisions) (Figure 23) but while they are much more costly than wildlife guards, electric mats or electric concrete they do allow wildlife to cross the highway.

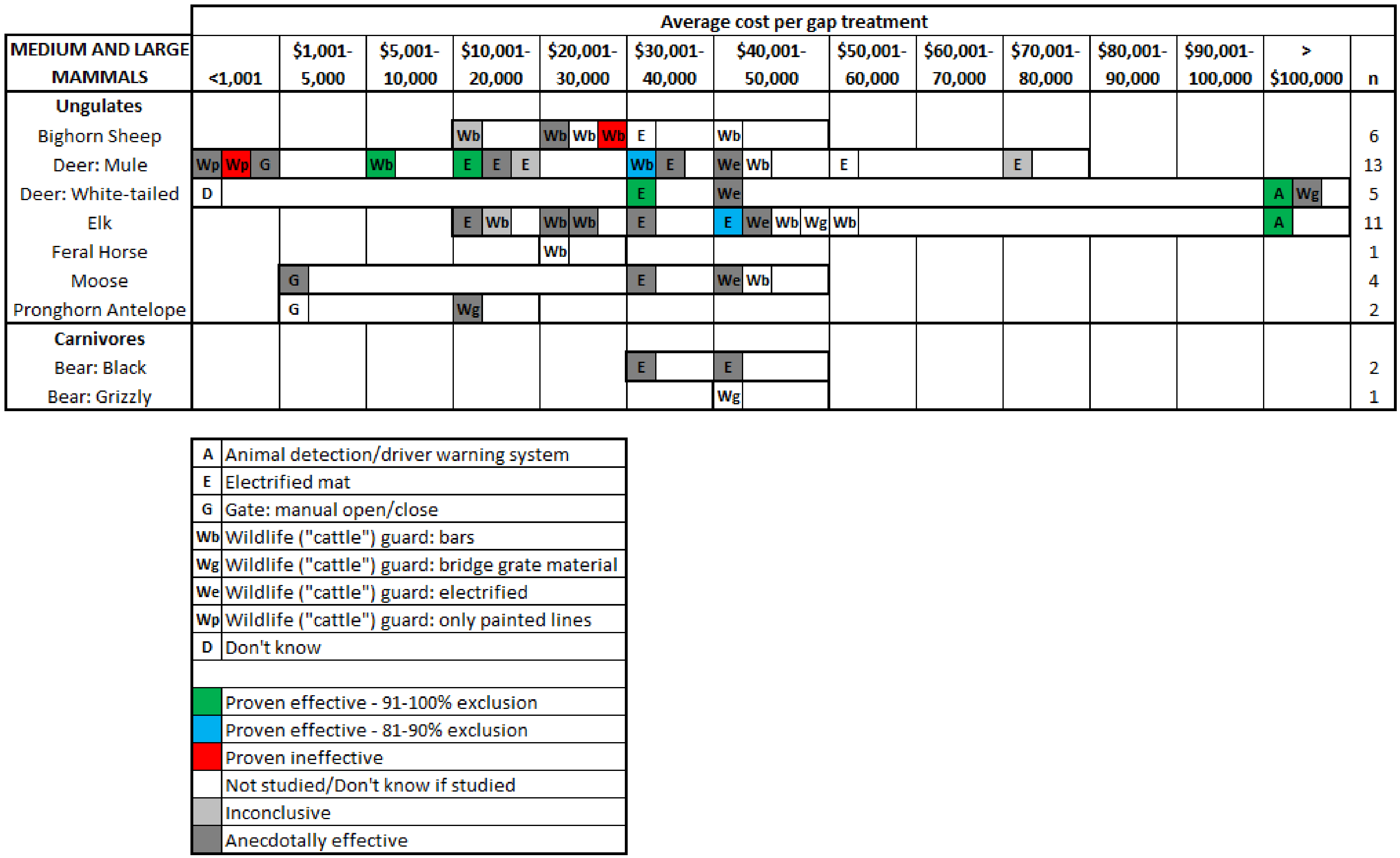

Figure 23: Range of cost and level of effectiveness in excluding target species per gap treatment and target mammal species. Note: 30 respondents answered this question but each respondent could enter multiple responses. Only those entries with cost information are included. Refer to Appendix C-4 for more information on proven effective or proven ineffective designs.

Effective wildlife guards are often between <3.0-<5.5 m (<10-<16 ft) wide (Figure 24). Effective electric mats are typically less wide: <1.5-<3.0 m (<5-<10 ft).

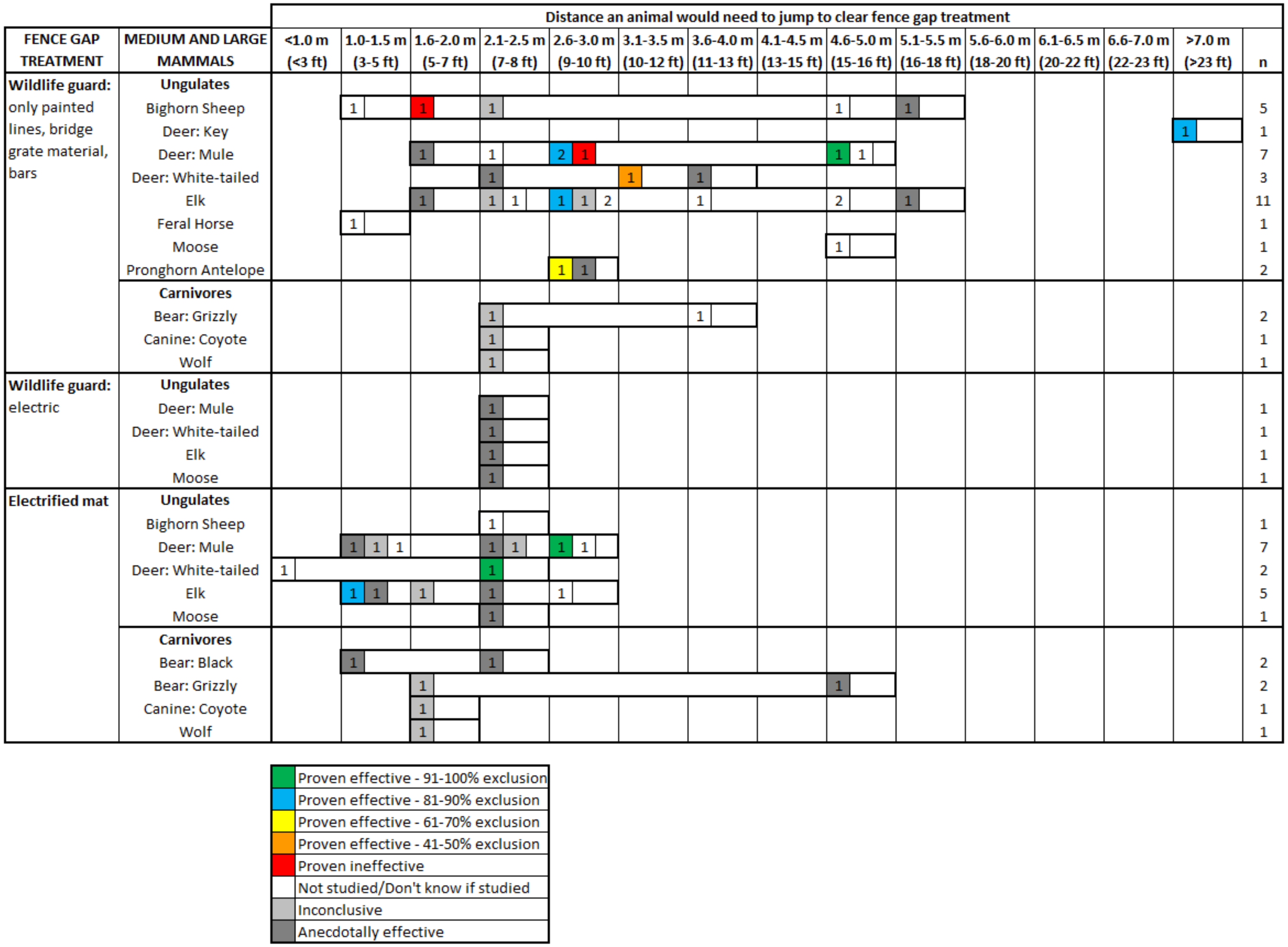

Figure 24: Level of effectiveness and range of jumping distances to clear fence gap treatments designed for target mammal species.

Respondents indicated that appropriate places for a fence to end include drainage structures and road cuts (Figure 25).

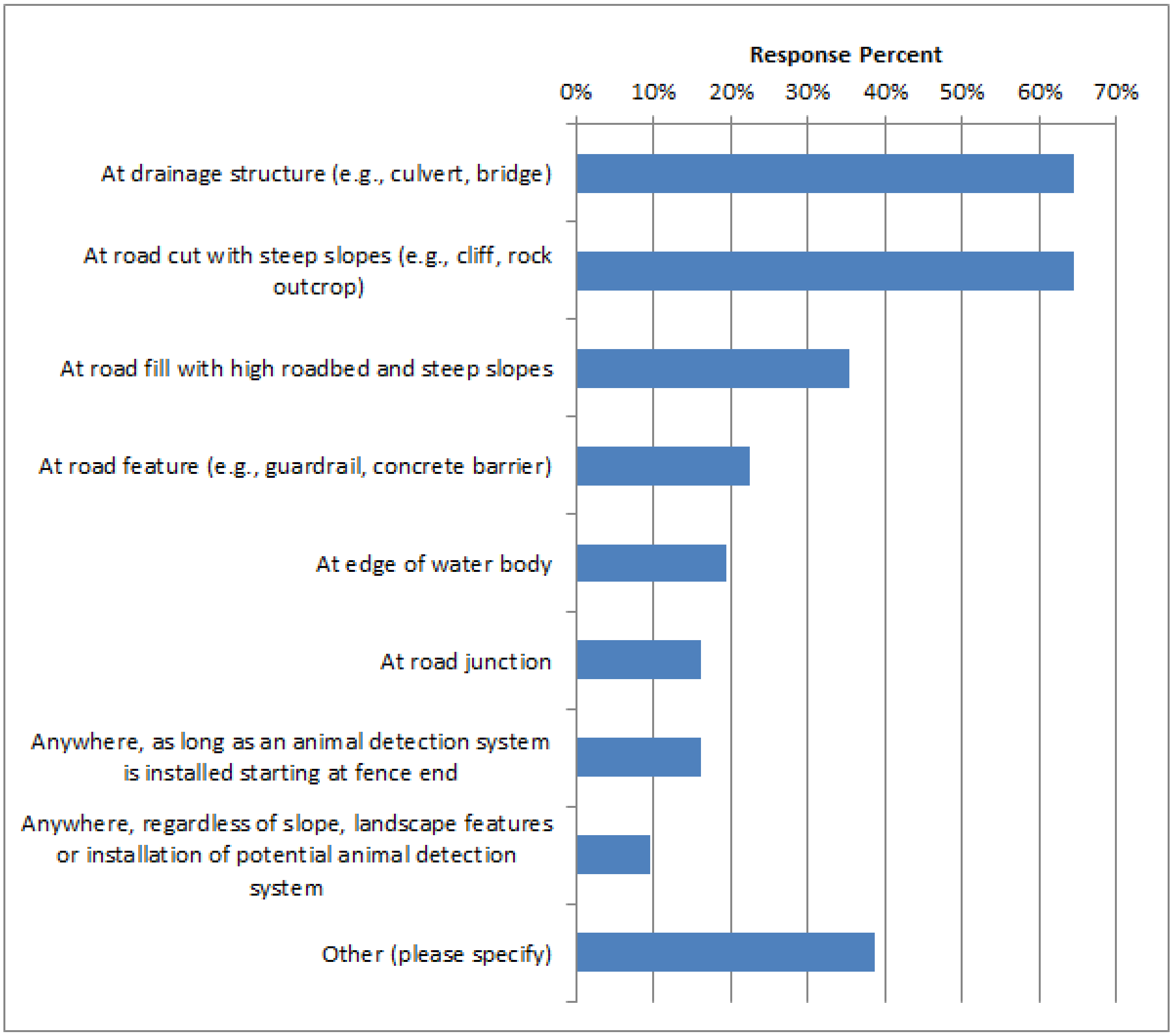

Figure 25: Response percent agreement regarding good practice for where to end a fence to reduce a large number of large or medium mammal crossings at grade. (n = 31). See Appendix B Question 9 for "other" responses.

3.4.5. Allow Humans to Get In and Out of the Fenced Road Corridor

Gates (various types) were generally considered the most appropriate measure to allow for human access in and out of the fenced road corridor (Figure 26). Wildlife guards with bars and upward facing edges, locked gates and electrified wildlife guards were considered least suitable.

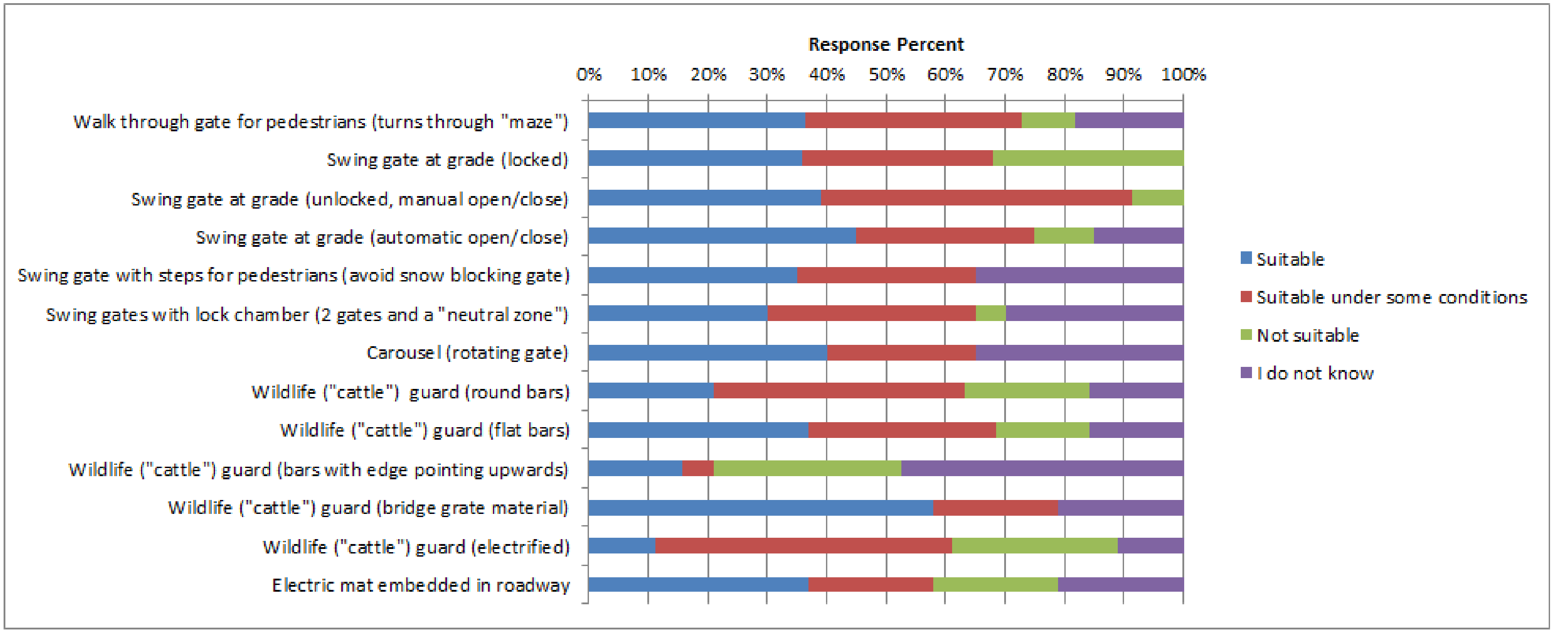

Figure 26: Response percent indicating suitability of access facilities in mammal fencing for pedestrians. Note: n = 27 but not every respondent provided an answer for each access option.

Wildlife guards with bridge grate material and electric mats embedded in the roadway were considered the most suitable access measures for bicyclists (Figure 27). Locked swing gates and swing gates with steps were considered least suitable.

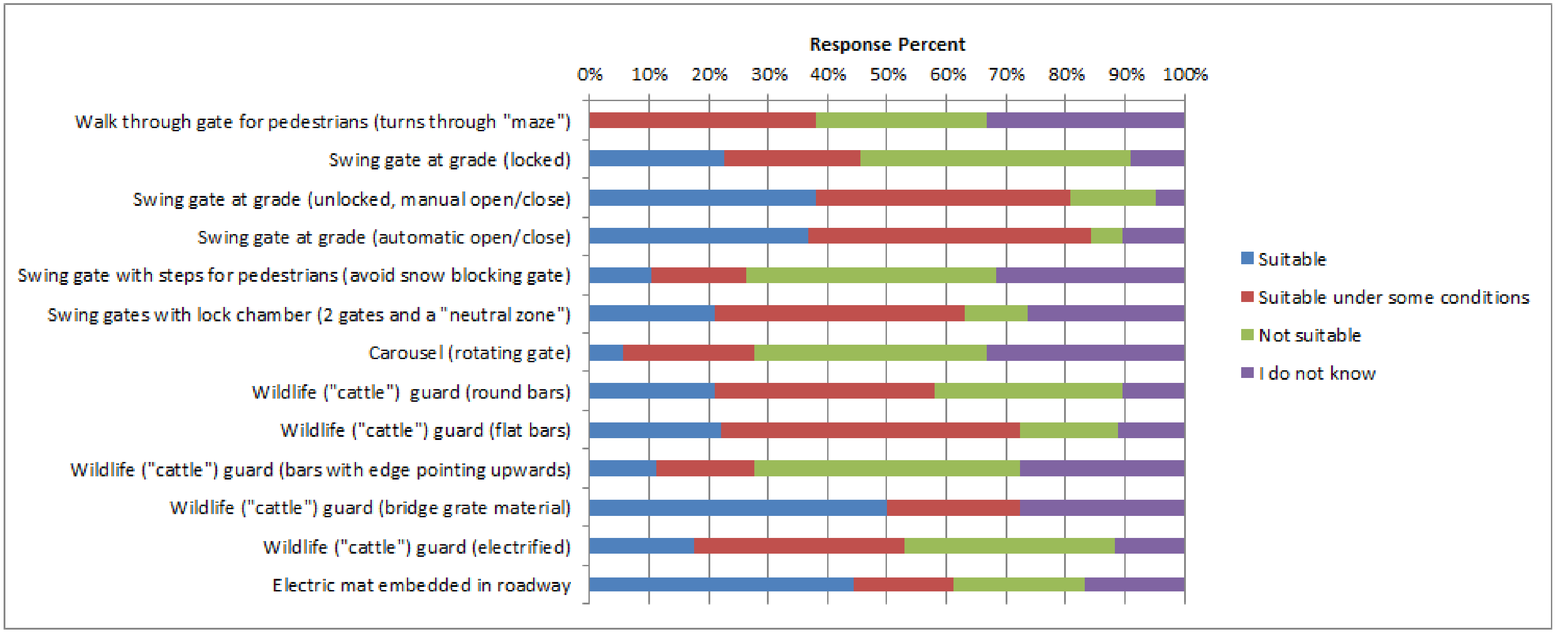

Figure 27: Response percent indicating suitability of access facilities in mammal fencing for bicyclists. Note: n = 27 but not every respondent provided an answer for each access option.

Suitable access measures for horses are relatively challenging (Figure 28). However, automatic and manual swing gates were considered most suitable whereas wildlife guards of various types and electric mats were considered least suitable.

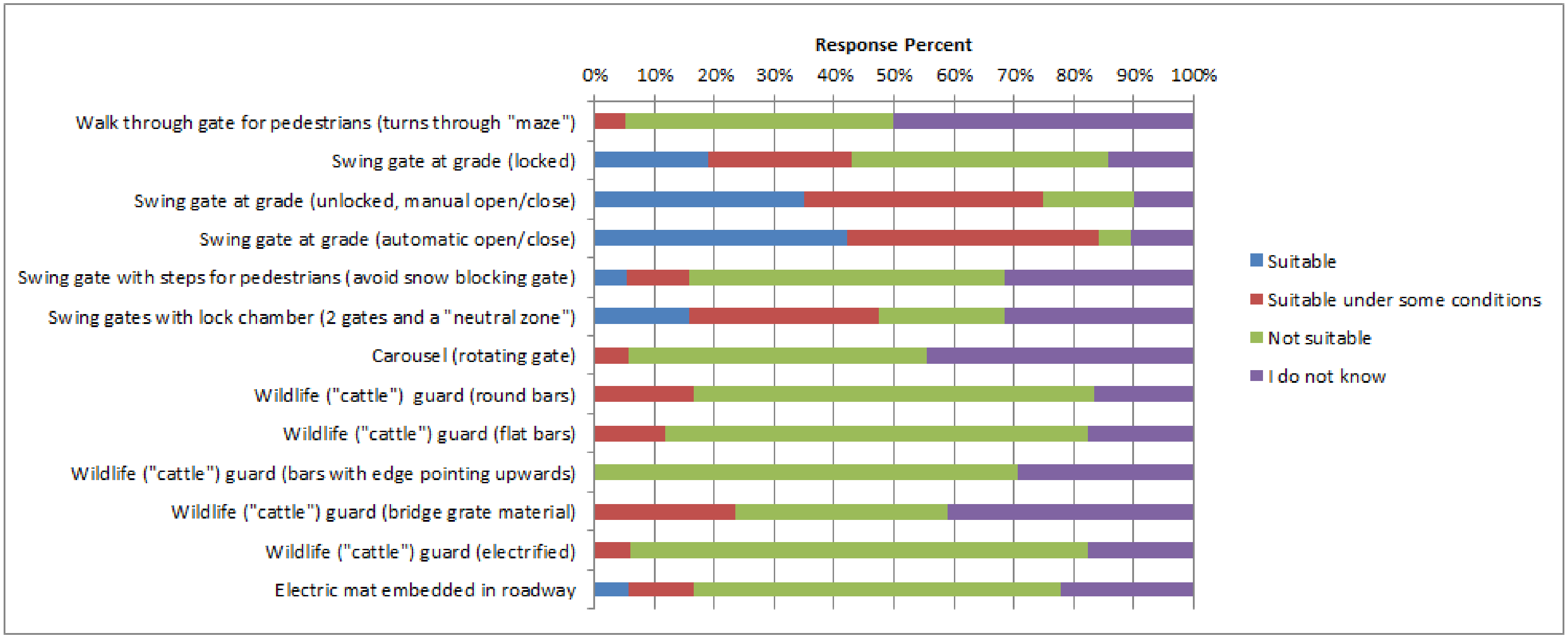

Figure 28: Response percent indicating suitability of access facilities in mammal fencing for equestrian use. Note: n = 27 but not every respondent provided an answer for each access option.

Access for motorized vehicles appeared least problematic with various types of wildlife guards and electric mats being considered as most suitable and walk-through gates, carousels and swing gates with steps being categorized as least suitable (Figure 29).

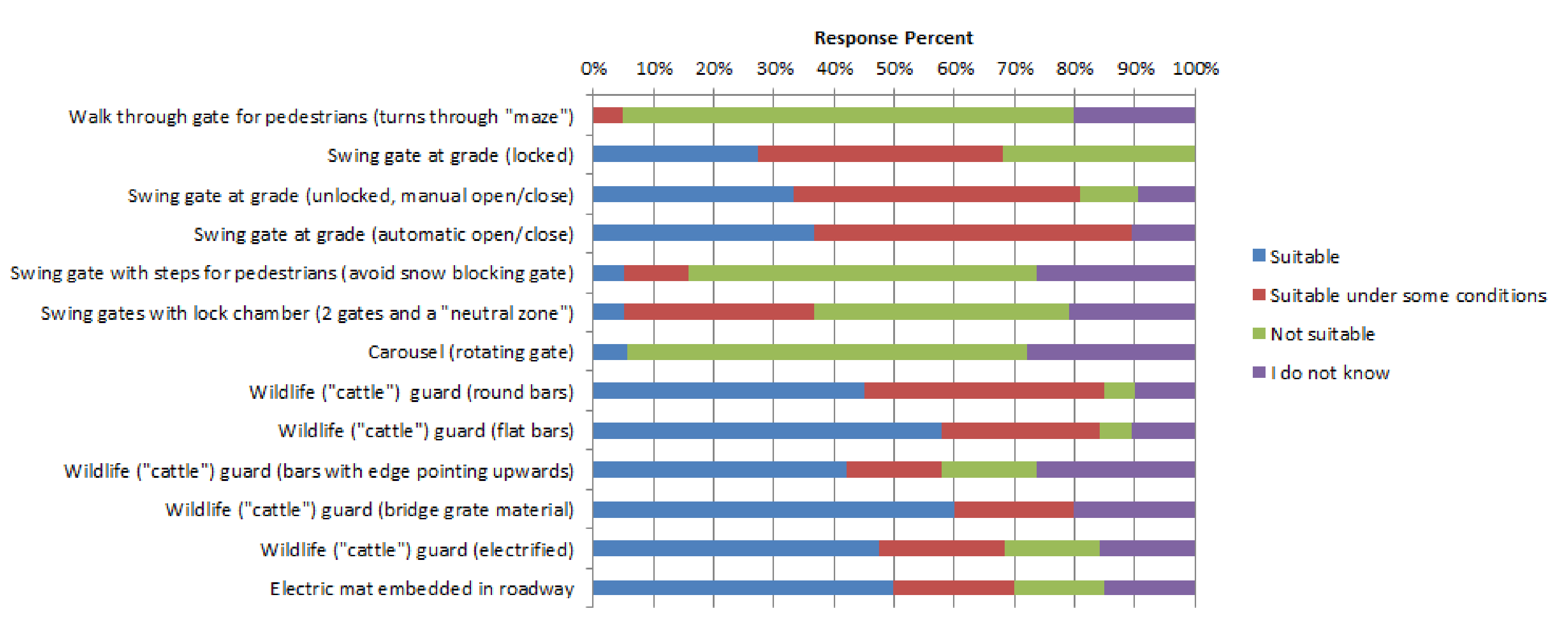

Figure 29: Response percent indicating suitability of access facilities in mammal fencing for motorized use. Note: n = 27 but not every respondent provided an answer for each access option.

Agency personnel and contractors mostly use use assess points through fencing only sometimes (Figure 30). However, that does not mean that access is not important.

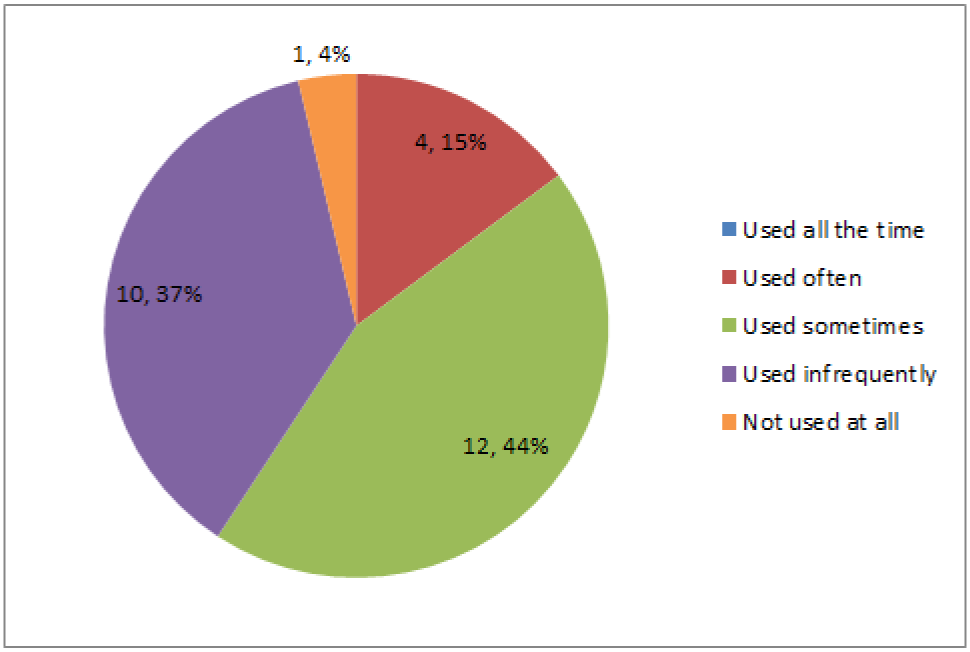

Figure 30: Number and percent of respondents indicating whether access points in mammal fencing designed for agency personnel or contractors are actually being used by agency personnel and contractors (n = 27).

3.4.6. At Grade Crossing Opportunities for Wildlife at Gaps or Fence Ends

Most respondents would not consider at grade crossing opportunities for wildlife (Figure 31).

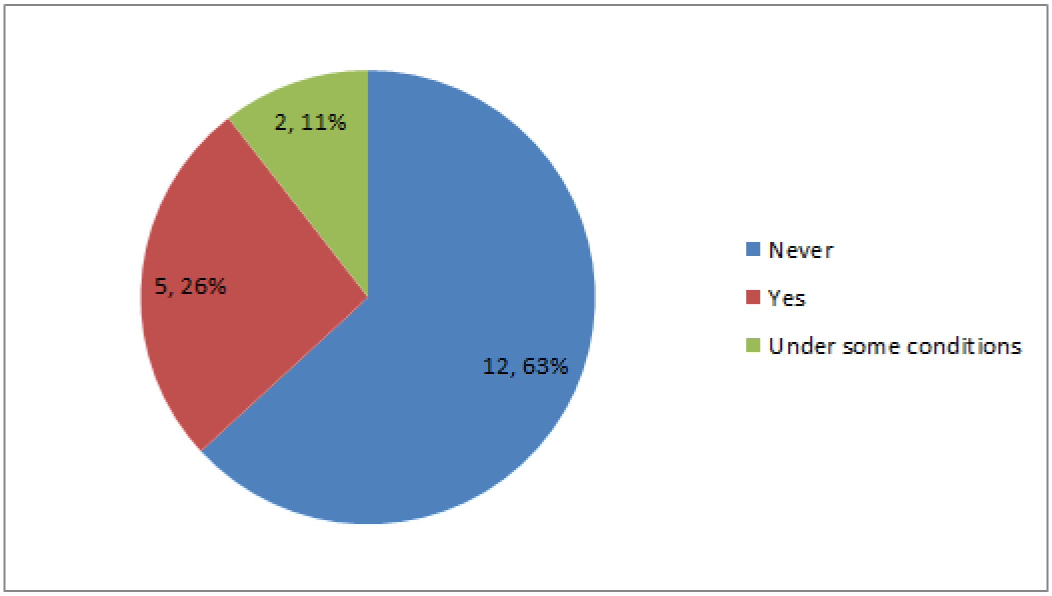

Figure 31: Number and percent of responses indicating whether an at grade wildlife crossing for mammals is allowed in fenced road corridor at a fence gap. Note: 16 respondents answered this question but each respondent could enter multiple responses.

Wildlife guards (bars and electrified), electrified mats, and fence ends close to the edge of the pavement are used most frequently to keep wildlife from entering the fenced right-of-way between the edge of the pavement and the fence line (Figure 32). Costs per treatment are typically <$5,000-<30,000. Interestingly boulder fields have been proven marginally effective or ineffective.

MEDIUM AND LARGE MAMMALS	Average cost per fence end/gap treatment between pavement edge and fence line															
	<$100	$101-500	$501-1,000	$1,001-5,000	$5,001-10,000	$10,001-20,000	$20,001-30,000	$30,001-40,000	$40,001-50,000	$50,001-60,000	$60,001-70,000	$70,001-80,000	$80,001-90,000	$90,001-100,000	> $100,00	n
Ungulates																
Bighorn Sheep						We[1]										1
Deer: Mule	Wb			Fb[1] B	E[1]	Wb Fc[1]	E				E[1]					8
Deer: White-tailed	Fa Fc[3]		B[1]	Fa B	E[1]	We[1]			B[3]							8
Elk	Fa[1]			Fa Fc[1]	E[1] B[3]	E We[1]	E[1]								B[2]	9
Moose			Fb		E[1]	We[1]										3
Pronghorn Antelope				Fb[1]												1
Carnivores																
Bear: Black					E[1]											1

B	Boulder field
E	Electrified mat
Fa	Fence angled away from paved surface
Fc	Fence brought close to paved surface
Fb	Fence both angled away and brought close to paved surface
Wb	Wildlife ("cattle") guard: bars
We	Wildlife ("cattle") guard: electrified
Measure to reduce impact of vehicle crash with fence end treatment	
1	Break away fence poles
2	Guardrail (incl. cables) between pavement and fence end treatment
3	Jersey barrier between pavement and fence end treatment

Green	Proven effective - 91-100% exclusion
Blue	Proven effective - 81-90% exclusion
Yellow	Proven effective - 61-70% exclusion
Red	Proven ineffective
White	Not studied/Don't know if studied
Light grey	Inconclusive
Dark grey	Anecdotally effective

Figure 32: Range of cost and level of effectiveness of fence end/gap treatment in excluding target species from entering the space between pavement edge and fence line at at-grade crossing opportunities per target mammal species. Note: 22 respondents answered this question but each respondent could enter multiple responses. Only those entries with cost information are included. Refer to Appendix C-5 for more information on proven effective or proven ineffective designs.

The width for wildlife guards or electrified mats on the side of the road varies between <1.5-<5.0 m (<5-<16 ft) (Figure 33).

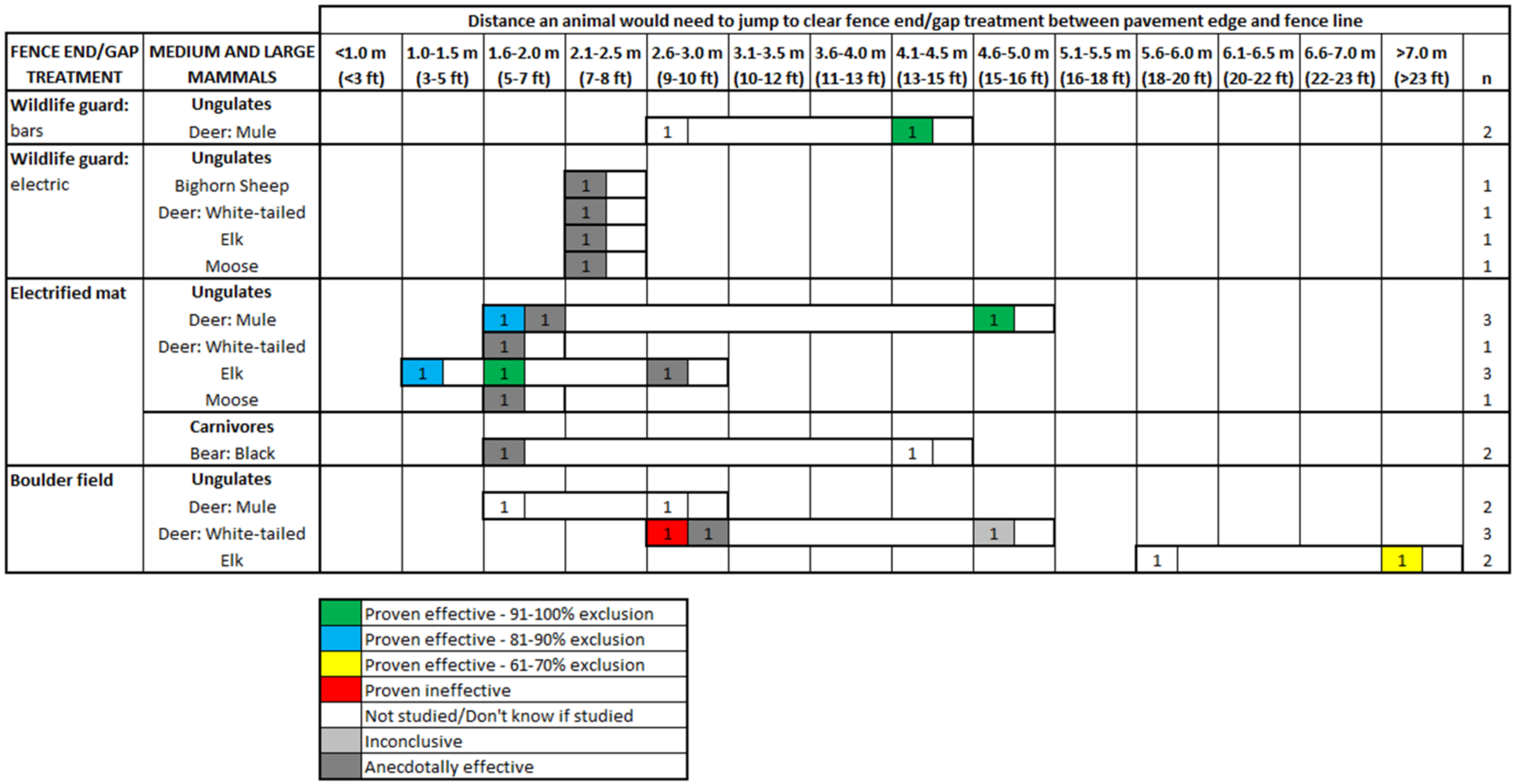

Figure 33: Level of effectiveness and range of jumping distances to clear fence end/gap treatments (between pavement edge and fence line) designed for target mammal species.

The costs for fence end or fence gap treatments varied widely, but effective treatments typically cost between $30,000-$60,000 (Figure 34).

MEDIUM AND LARGE MAMMALS	Average cost per fence end/gap treatment on travel lanes															
	<$100	$101-500	$501-1,000	$1,001-5,000	$5,001-10,000	$10,001-20,000	$20,001-30,000	$30,001-40,000	$40,001-50,000	$50,001-60,000	$60,001-70,000	$70,001-80,000	$80,001-90,000	$90,001-100,000	> $100,00	n
Ungulates																
Bighorn Sheep								Wb [dark grey]	Wb	E [orange]						3
Deer: Mule		Wp [red] Wp [dark grey]					Wb	E [dark grey]	Wb							5
Deer: White-tailed					E			E [green]							Wg [dark grey]	3
Elk		Wp [light grey]				E [dark grey]		E [green]	Wb	E [blue] Wb						6
Moose									Wb							1
Carnivores																
Bear: Black								E [dark grey]	E [dark grey]							2

E	Electrified mat
Wb	Wildlife ("cattle") guard: bars
Wg	Wildlife ("cattle") guard: bridge grate material
Wp	Wildlife ("cattle") guard: only painted lines
[green]	Proven effective - 91-100% exclusion
[blue]	Proven effective - 81-90% exclusion
[orange]	Proven effective - 51-60% exclusion
[red]	Proven ineffective
[white]	Not studied/Don't know if studied
[light grey]	Inconclusive
[dark grey]	Anecdotally effective

Figure 34: Range of cost and level of effectiveness of fence end/gap treatment in excluding target species from entering the travel lanes per target mammal species. Note: 15 respondents answered this question but each respondent could enter multiple responses. Only those entries with cost information are included. Refer to Appendix C-5 for more information on proven effective or proven ineffective designs.

The width for wildlife guards or electrified mats on the pavement varies between <1.5-<5.0 m (<5-<16 ft) (Figure 35). Electric mats have been found most effective.

		Distance an animal would need to jump to clear fence end/gap treatment on travel lanes														
FENCE END TREATMENT	MEDIUM AND LARGE MAMMALS	<1.0 m (<3 ft)	1.0-1.5 m (3-5 ft)	1.6-2.0 m (5-7 ft)	2.1-2.5 m (7-8 ft)	2.6-3.0 m (9-10 ft)	3.1-3.5 m (10-12 ft)	3.6-4.0 m (11-13 ft)	4.1-4.5 m (13-15 ft)	4.6-5.0 m (15-16 ft)	5.1-5.5 m (16-18 ft)	5.6-6.0 m (18-20 ft)	6.1-6.5 m (20-22 ft)	6.6-7.0 m (22-23 ft)	>7.0 m (>23 ft)	n
Wildlife guard: only painted lines, bridge grate material, bars	**Ungulates**															
	Bighorn Sheep					1				1						2
	Deer: Mule			1, 1						1						3
	Deer: White-tailed							1								1
	Elk				1			1	1	1						4
	Moose									1						1
Electrified mat	**Ungulates**															
	Bighorn Sheep		1													1
	Deer: Mule			1	1											2
	Deer: White-tailed		1		1											2
	Elk		1, 1		1											3
	Carnivores															
	Bear: Black			1	1											2

- Proven effective - 91-100% exclusion
- Proven effective - 81-90% exclusion
- Proven effective - 51-60% exclusion
- Proven ineffective
- Not studied/Don't know if studied
- Inconclusive
- Anecdotally effective

Figure 35: Level of effectiveness and range of jumping distances to clear fence end/gap treatments (on travel lanes) designed for target mammal species.

At grade crossing opportunities were typically installed at highways with a traffic volume between 7,000-14,000 vehicles per day (Table 5). Some of the at grade crossing opportunities had warning signs (standard, enhanced or animal detection systems), sometimes with advisory speed limit reduction. The width of the gap varied between <10-100 m (34-329 ft) (Table 5), but the width was most frequently between <10-40 m (<34-132 ft) (Figure 36).

Table 5: Characteristics of at-grade crossing opportunities at fence gaps per target mammal species.

Primary target LARGE MAMMAL species	Fence gap width (meters)	Crossing zone width on road surface (meters)	Maximum traffic volume for at grade crossing (vehicles/day)	Maximum number of lanes (total for 2 travel directions)	Warning signs	Traffic calming	Speed reduction
Deer: Mule	1-10 (3-34 ft)	1-10 (3-34 ft)	9001-10000	4	Standard warning signs	No	No
	21-30 (68-100 ft)	11-20 (35-67 ft)	10001-11000	4	Animal detection system	Unknown	Yes, advisory speed limit reduction
	21-30 (68-100 ft)	91-100 (297-329 ft)*	9001-10000	4	Enhanced warning signs (special text and permanent lights/flags)	Unknown	Unknown
Deer: White tailed	31-40 (101-132 ft)	31-40 (101-132 ft)	7001-8000	2	Animal detection system	No	No
Elk	21-30 (68-100 ft)	11-20 (35-67 ft)	10001-11000	4	Animal detection system	Unknown	Yes, advisory speed limit reduction
	31-40 (101-132 ft)	31-40 (101-132 ft)	7001-8000	2	Animal detection system	No	No
	61-70 (199-231 ft)	31-40 (101-132 ft)	13001-14000	2	Animal detection system	No	Yes, advisory speed limit reduction
Moose	1-10 (3-34 ft)	1-10 (3-34 ft)	8001-9000	2	No	No	No

* Crossing zone width indicated to be wider than fence gap width

At grade crossings designed for ungulates	Width in meters										
	1-10 (3-34 ft)	11-20 (35-67 ft)	21-30 (68-100 ft)	31-40 (101-132 ft)	41-50 (133-165 ft)	51-60 (166-198 ft)	61-70 (199-231 ft)	71-80 (232-264 ft)	81-90 (265-296 ft)	91-100 (297-329 ft)	n
Fence gap	2		3	2			1				8
Crossing zone on road surface	2	2		3						1*	8

* Crossing zone width indicated to be wider than fence gap width

Figure 36: Typical width for at-grade crossing opportunities at fence gaps designed for ungulates. Note: Six respondents answered this part of the question but each respondent could enter multiple responses.

The vast majority of the respondents indicated that it is good practice, in principle, to always accompany wildlife fencing along highways with safe crossing opportunities (Figure 37).

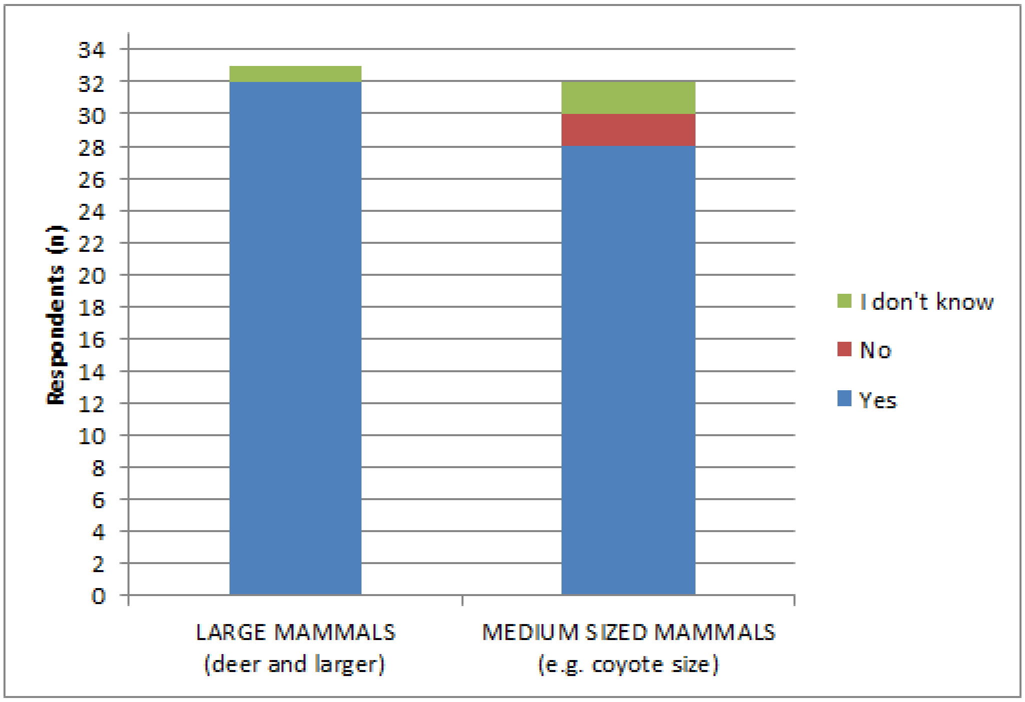

Figure 37: Number of respondents indicating whether it is good practice to, in principle, always accompany wildlife fencing along highways in combination with safe crossing opportunities (e.g., overpass, underpass) for large and medium mammals (n=33).

3.5. Amphibians and Reptiles

3.5.1. Characteristics of the Respondents

The vast majority of the respondents had actual personal knowledge or experience with the design, implementation or evaluation of wildlife fencing or associated measures for reptiles of amphibians (Figure 38).

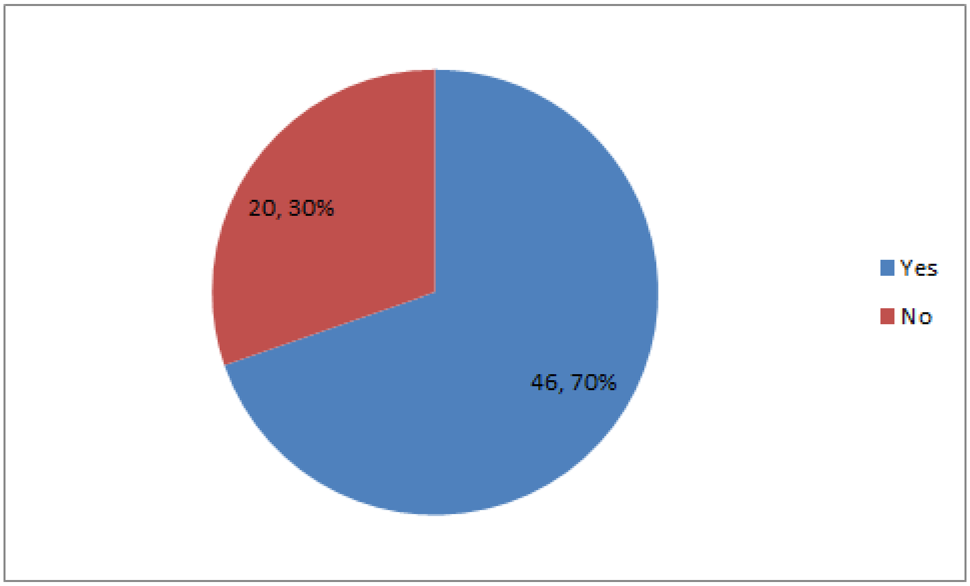

Figure 38: Number and percent of respondents with knowledge of amphibian and reptile fencing and associated measures (n = 66).

3.5.2. Measures to Keep Amphibians and Reptiles Off the Road

Fences are most frequently implemented for frogs (excluding tree frogs) and salamanders and aquatic and terrestrial turtles (Figure 39). Vinyl drift fencing (plastic sheets) and woven wire fencing were used most often for amphibians, whereas chain-link and woven wire fencing were used most frequently for turtles.

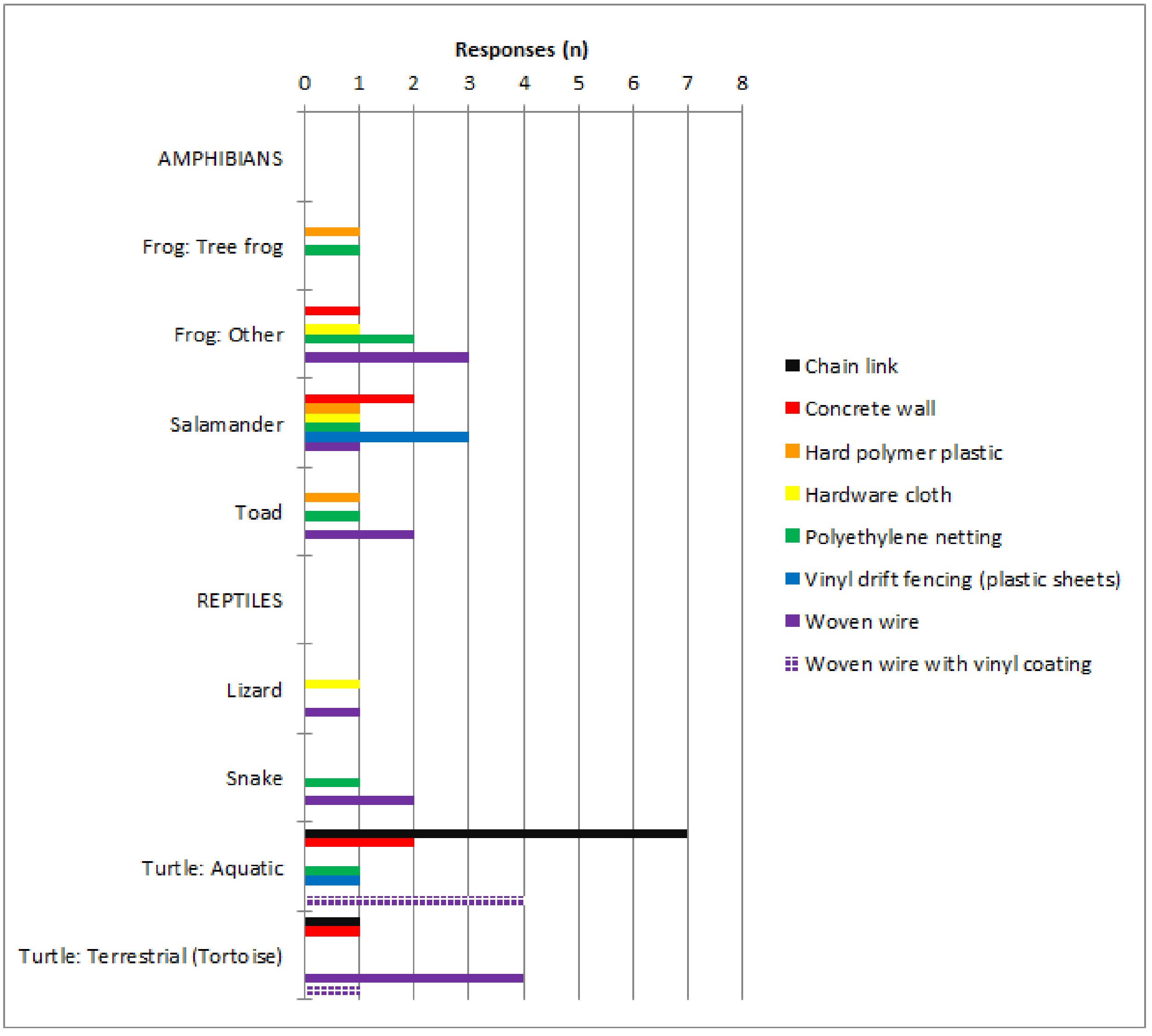

Figure 39: Number of responses indicating an exclusionary fence design has or will be implemented for a target amphibian/reptile species (n = 28).

The material for the posts for amphibian and reptile fencing and barriers varies substantially (Figure 40). Concrete walls do not necessarily need posts. Fiberglass, and various types of steel posts are typically used for woven wire fencing.

	FENCE MATERIAL										
POST MATERIAL	Chain link	Concrete Wall	Hard polymer plastic	Hardware Cloth	Polyethylene netting	Vinyl drift fencing (plastic sheets)	Woven wire: mesh < 1 cm (<0.5")	Woven wire: mesh 1.1-2 cm (0.5-1.0")	Woven wire: mesh > 2 cm (>1.0")	Woven wire with vinyl coating: mesh 1.1-2 cm (0.5-1.0")	Woven wire with vinyl coating: mesh > 2 cm (>1.0")
Concrete		■									
Fiberglass							■	■			
Galvanized steel	■			■	■		■		■	■	
Metal: C-post	■										
Metal: T-post	■			■	■		■	■	■	■	■
Plastic lumber			■								
Rebar					■						
Wood: not pressure treated						■	■				
Wood: pressure treated	■						■				

Figure 40: Post/fence material combinations (blackened areas) reported for excluding amphibians/reptiles.

For amphibians the most frequently used height for effective fencing or barriers is 31-60 cm (Figure 41). The range is somewhat similar for reptiles, but most fencing or barriers for reptiles tends to be around 76-105 cm.

AMPHIBIAN OR REPTILE SPECIES	Fence height in meters										n
	0.10 - 0.15 (4 - 6 in)	0.16 - 0.30 (6 - 12 in)	0.31 - 0.45 (12 - 18 in)	0.46 - 0.60 (18 - 24 in)	0.61 - 0.75 (24 - 30 in)	0.76 - 0.90 (30 - 35 in)	0.91 - 1.05 (35 - 41 in)	1.06 - 1.20 (41 - 47 in)	1.21 -1.35 (47 - 53 in)	1.36 - 1.50 (53 - 59 in)	
Amphibians											
Frog: Tree frog			1 (orange)			1					2
Frog: Other				1 (yellow) 1 (pink) 1		1 (red) 1	1	1 (yellow)			7
Salamander			1 (green) 1	1 (grey) 2		1 (red)	1 (light grey) 2				9
Toad			1 (blue)	2 (yellow)		1 (red)					4
Reptiles											
Lizard					1 (grey)	1					2
Snake			1			1 (red)	1 (grey)		1 (grey)		4
Turtle: Aquatic	1			1 (pink) 1 (light grey) 2 (grey) 1	1 (grey)	1 (blue) 1 (yellow) 1 (red) 1 (grey)	1 (yellow)		1 (blue) 1 (grey)	1	15
Turtle: Terrestrial (Tortoise)			1 (green) 2 (grey)	1 (grey) 1		1 (grey)	1				7

green	Proven effective - 100% reduction
blue	Proven effective - 90% reduction
yellow	Proven effective - 80% reduction
orange	Proven effective - 70% reduction
pink	Proven effective - 20% reduction
red	Proven ineffective
white	Not studied/Don't know if studied
light grey	Inconclusive
grey	Anecdotally effective

Figure 41: Number of responses indicating a particular height has or will be implemented and associated level of effectiveness for a target amphibian/reptile species (n). Note: 28 respondents answered this question but each respondent could enter multiple responses.

Construction costs for effective fencing for amphibians varies between $10-50 per m (Figure 42). Effective reptile fencing varied between $10-40 per m.

AMPHIBIAN OR REPTILE SPECIES	Total average fence construction cost per meter (per 3.3 ft) (US$) - includes all elements particular to target species requirements						
	<$10	$10-20	$21-30	$31-40	$41-50	>$100	n
Amphibians							
Frog: Tree frog				P_8	Hp^4		2
Frog: Other		$W<^4_8$ $W<^2_7$		P_8			3
Salamander	$W<^2_8$			P_8	Hp^4	Co^3	4
Toad		$W<^4_8$ $W<^4_7$		P_8	Hp^4		4
Reptiles							
Lizard			H_8 $W>_9$				2
Snake	W^1_9			P_8			2
Turtle: Aquatic	C^1_8 Co^2_8 V_8 C^4_8	$Wv>^1_9$ Wv^2_7	Wv^4_7 C_6	P_8 C_8			10
Turtle: Terrestrial (Tortoise)	$W>_8$	$W>_9$ Co_9		C_8			4
Other		$W<_5$					1

C	Chain link
Co	Concrete wall
H	Hardware cloth
Hp	Hard polymer plastic
P	Polyethylene netting
V	Vinyl drift fencing (plastic sheets)
W<	Woven wire: mesh < 1 cm (<0.5")
W	Woven wire: mesh 1.1-2 cm (0.5-1.0")
W>	Woven wire: mesh > 2 cm (>1.0")
Wv	Woven wire with vinyl coating: mesh 1.1-2 cm (0.5-1.0")
Wv>	Woven wire with vinyl coating: mesh > 2 cm (>1.0")
Climbing Deterrent	
1	Flashing mounted on fence
2	Outrigger angled away from road: 45 degrees
3	Outrigger angled away from road: 90 degrees
4	Other overhang
Digging Deterrent	
5	Apron attached to main fence: buried 26-50 cm (10-20")
6	Apron attached to main fence: buried 51-75 cm (20-30")
7	Main fence buried: <10 cm (<4")
8	Main fence buried: 11-20 cm (4-8")
9	Main fence buried: 21-50 cm (8-20")

	Proven effective - 100% reduction
	Proven effective - 90% reduction
	Proven effective - 80% reduction
	Proven effective - 70% reduction
	Proven effective - 20% reduction
	Proven ineffective
	Not studied/Don't know if studied
	Inconclusive
	Anecdotally effective

Figure 42: Range of cost and level of effectiveness in reducing wildlife-vehicle collisions or roadkill per fence design and target amphibian/reptile species. Note: 28 respondents answered this question but each respondent could enter multiple responses. Only those entries with cost information are included. Refer to Appendix C-7 for more information on proven effective designs.

Climbing and digging deterrents were typical for most amphibian and reptile fencing and barriers (Figures 43-46).

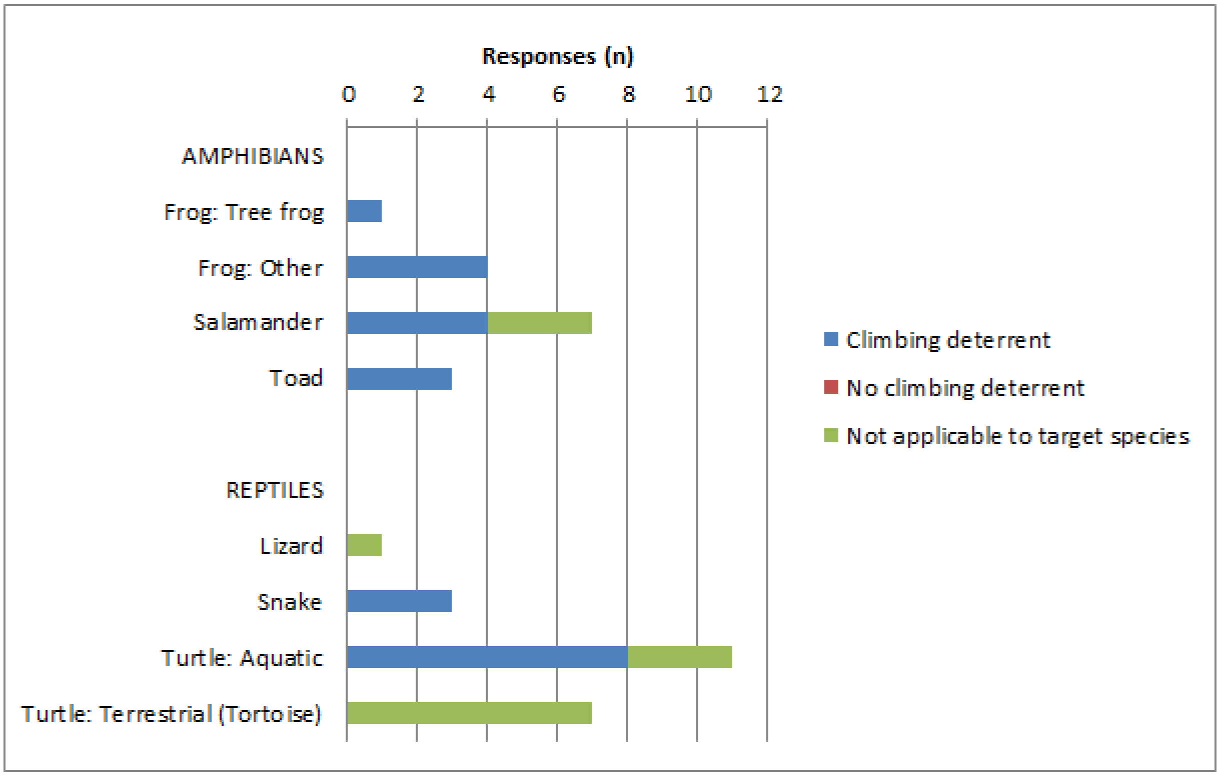

Figure 43: Number of responses indicating whether a climbing deterrent has or will be implemented as part of an exclusionary fence design for a target amphibian/reptile species. Note: 25 respondents answered this part of the question but each respondent could enter multiple responses.

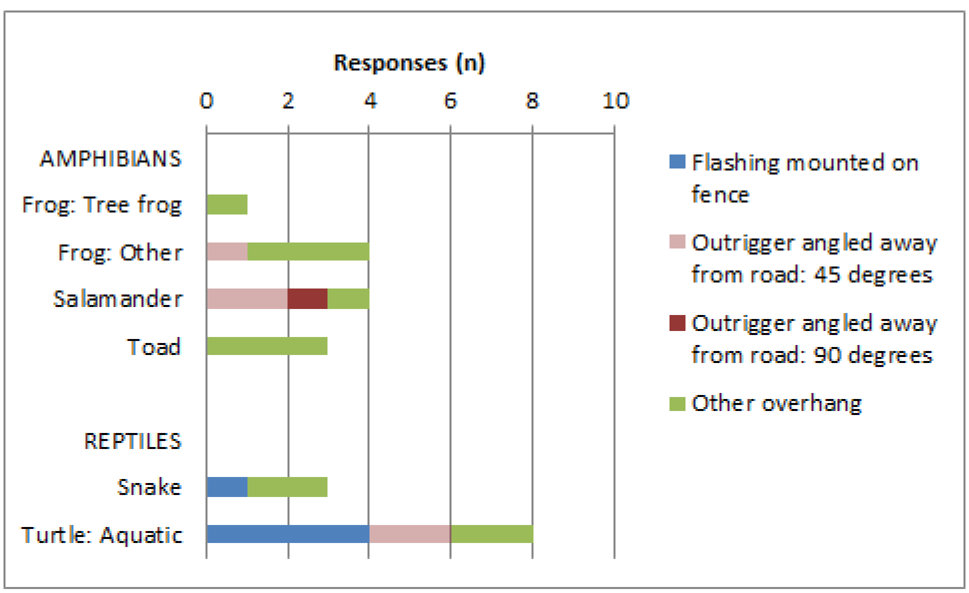

Figure 44: Number of responses indicating what type of climbing deterrent has or will be implemented for a target amphibian/reptile species (n).

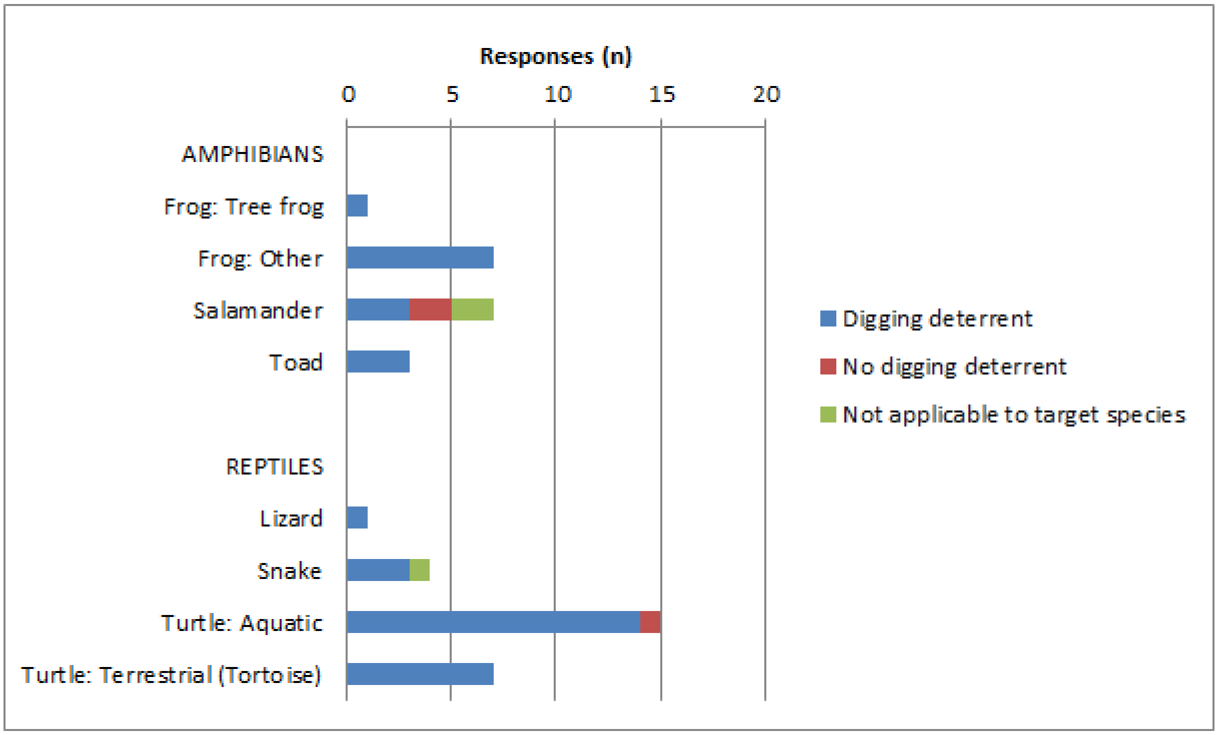

Figure 45: Number of responses indicating whether a digging deterrent has or will be implemented as part of an exclusionary fence design for a target amphibian/reptile species. Note: 26 respondents answered this part of the question but each respondent could enter multiple responses.

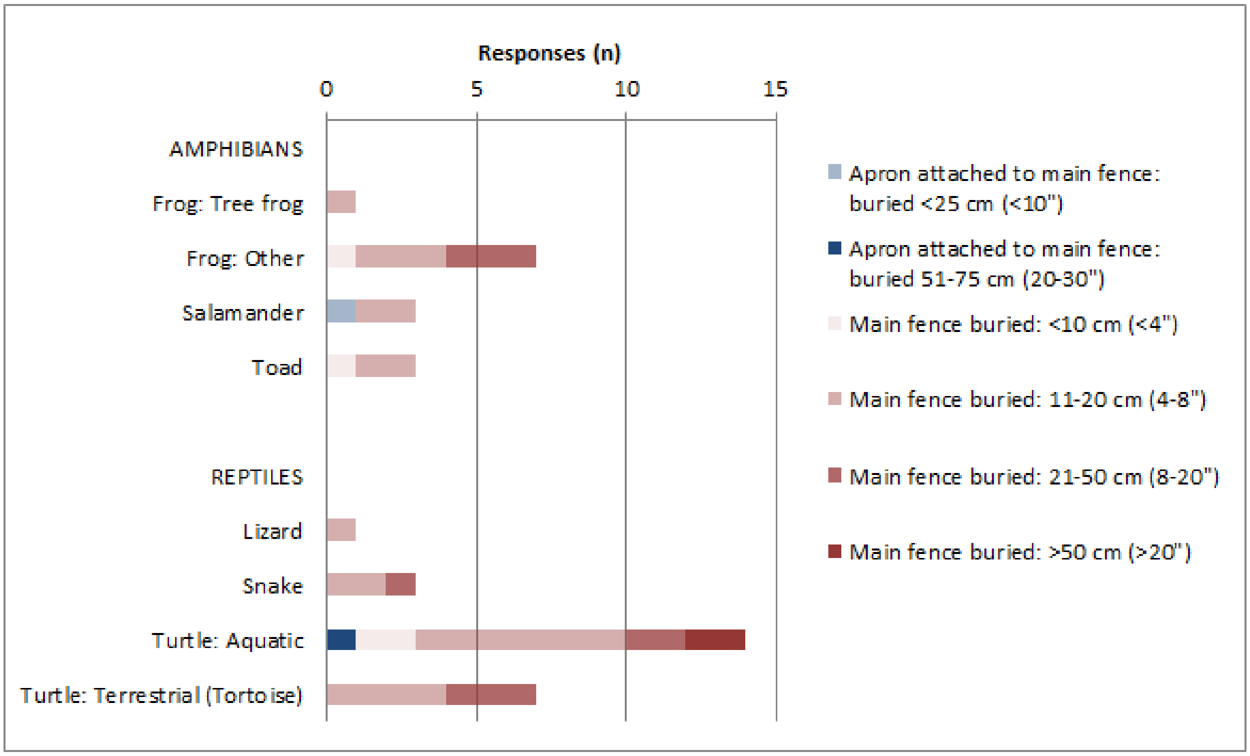

Figure 46: Number of responses indicating what type of digging deterrent has or will be implemented for a target amphibian/reptile species (n).

Erosion, frequent vegetation mowing or cutting, poor fence installation and frequent inspections were the most common maintenance problems (Figure 47).

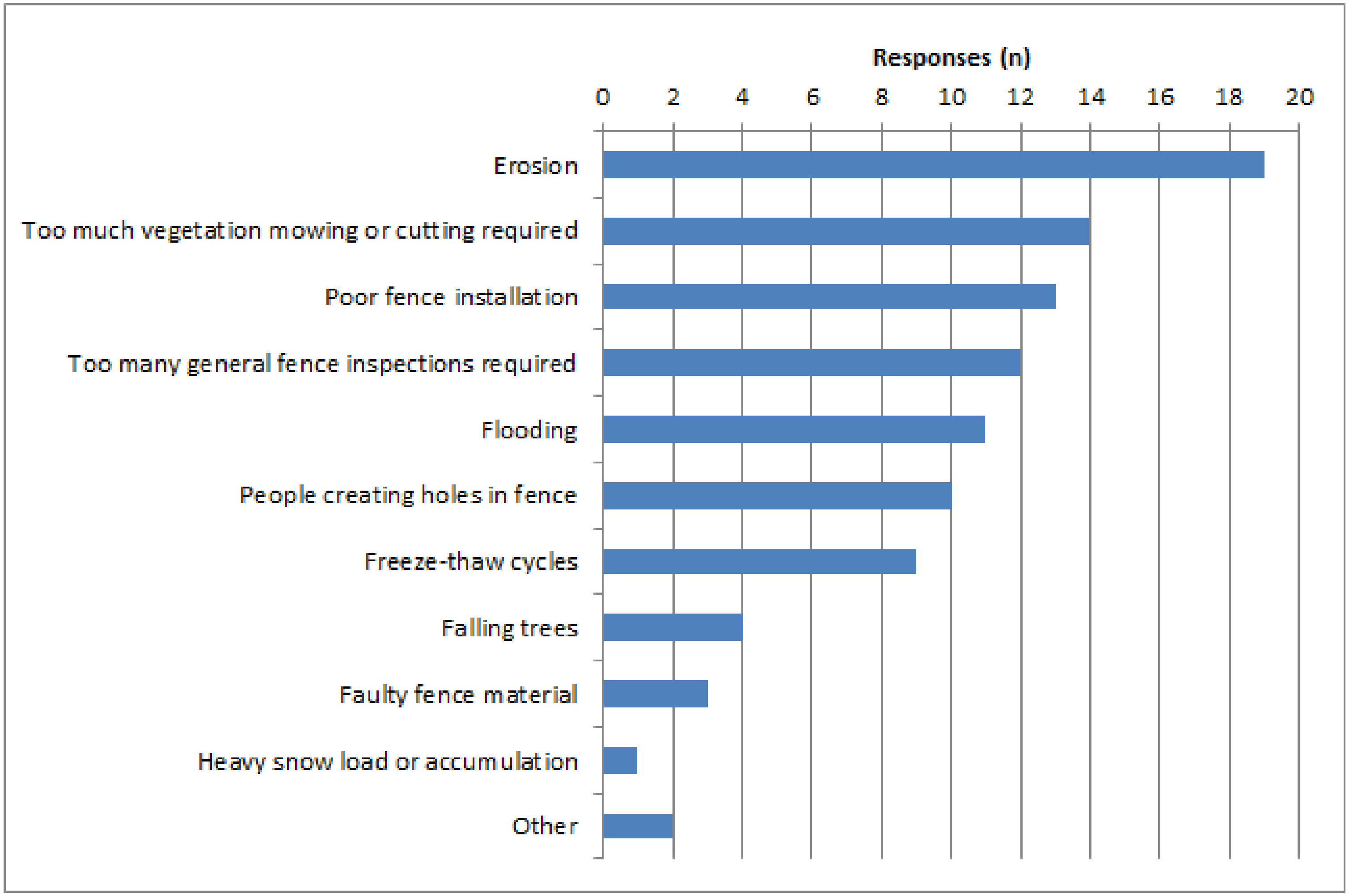

Figure 47: Number of responses indicating experience with maintenance issues with a particular amphibian/reptile fence design (n). Note: 18 respondents answered this question but each respondent could enter multiple responses. See Appendix B Question 20 for "other" responses.

Amphibian and reptile fencing or barriers can be a barrier for other species groups (Figure 48). Other negative or unintended effects of amphibian or reptile fencing include entanglement on non-target species.

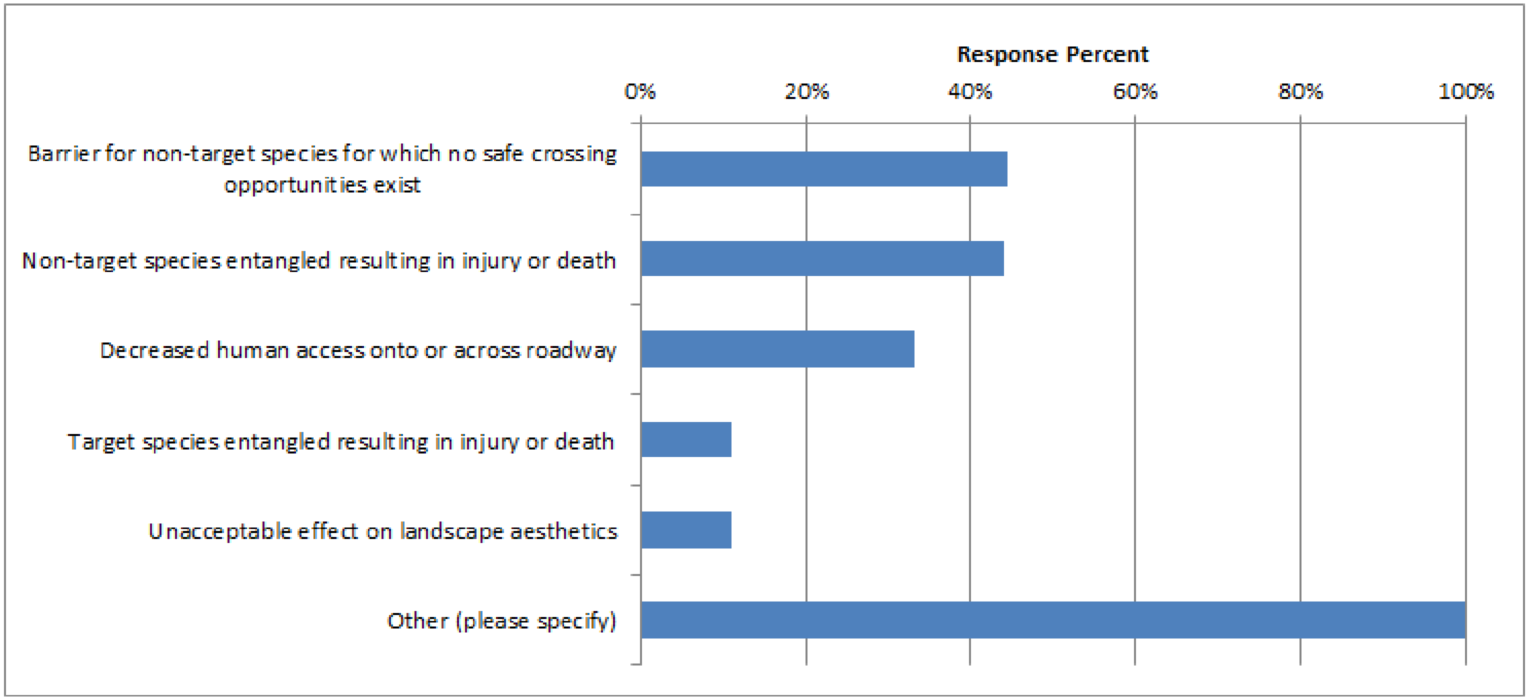

Figure 48: Response percent agreement indicating direct experience with negative, unintended effects with amphibian/reptile fencing projects (n = 9). See Appendix B Question 28 for "other" responses.

3.5.3. Allow Wildlife to Escape the Fenced Road Corridor

Escape opportunities for amphibians or reptiles from the fenced road corridor are typically anywhere or at most 100 m apart (Table 6). The heights of the escape opportunities are similar to the heights of the fencing or barrier.

Table 6: Responses pertaining to escape design, placement, height, effectiveness and cost per amphibian/reptile species. Note: 15 respondents answered this question but each respondent could enter multiple responses. Only those entries with information are included. Refer to Appendix B-Question 25 for "other" escape designs or rationale for why no escape design is implemented.

AMPHIBIAN OR REPTILE SPECIES	Escape design	Distance between escapes on one side of road (in meters along road length)	If Jump-outs/escape ramps, height animals would have to jump down from fenced corridor to safe side fence (in meters)	If Jump-outs/escape ramps with bar/plank, height animals would have to jump up/into fenced corridor (in centimeters)	Effectiveness: % of animals on top that jump down	Effectiveness: % of animals at bottom that DO NOT jump up	Known potential for animal entanglement in escape itself	Total average cost per escape
Amphibians								
Frog: Other	Other (please specify in comments)	<50 (<164 ft)	NA	NA				
	Other (please specify in comments)	<50 (<164 ft)	0.9 (3 ft)	NA				
Toad	Jump-outs/escape ramps, both sides road, opposite of each other	51-100 (164-328 ft)	0.4	NA	Don't know if design has been evaluated	Don't know if design has been evaluated	No	Less than $1,000
Reptiles								
Snake	Jump-outs/escape ramps, both sides road, opposite of each other	51-100 (164-328 ft)	1	NA	Anecdotally effective	Proven effective - 91-100% exclusion	Don't know	
Turtle: Aquatic	Jump-outs/escape ramps, both sides road, opposite of each other	51-100 (164-328 ft)	0.6 (2 ft)	NA	Anecdotally effective	Anecdotally effective	Don't know	
	Jump-outs/escape ramps, both sides road, opposite of each other	51-100 (164-328 ft)	1	NA	Anecdotally effective	Proven effective - 91-100% exclusion	Don't know	
	One-way gate, both sides road, alternating (zig-zag) formation	51-100 (164-328 ft)	0.6 (2 ft)	0.6 (2 ft)	Don't know if design has been evaluated	Don't know if design has been evaluated	Don't know	
	None, but if barrier wall, animals can jump/fall to safe side fence anywhere	<50 (<164 ft)	0.3 (1 ft)	NA	Don't know if design has been evaluated	Don't know if design has been evaluated	Don't know	

The distance between escape oppotunities on one side of the road is less than 100 m (328 ft) (Figure 49).

ESCAPE DESIGN	AMPHIBIAN OR REPTILE SPECIES	Distance between escapes on one side of road (in meters along road length) <50 (<164 ft)	51-100 (164-328 ft)	101-150 (328-492 ft)	n
Jump-out/escape ramp: both sides of road, opposite of each other	**Amphibians**				
	Toad		1		1
	Reptiles				
	Snake		1		1
	Turtle: Aquatic		2		2
Jump-out/escape ramp*	**Amphibians**				
	Frog: Other	1			1
One-way gate: both sides of road, alternating (zig-zag) formation	**Reptiles**				
	Turtle: Aquatic		1		1
One-way gate*	**Amphibians**				
	Frog: Other	1			1
None: animals can jump/fall to safe side fence anywhere	**Reptiles**				
	Turtle: Aquatic	1			1

*Configuration of escapes along road not reported.

Figure 49: Distance between escape opportunities on one side of the road.

3.5.4. Keep Wildlife Out Off Fenced Road Corridor at Fence Gaps and Fence Ends

Gates and wildlife guards are the most frequently used treatments for reptiles and amphibians at fence gaps and fence ends (Figure 50). They typically cost between $500-$10,000 per treatment.

	Average cost per gap treatment					
AMPHIBIAN OR REPTILE SPECIES	**<$100**	**$101-500**	**$501-1000**	**$1,001-5,000**	**$5,001-10,000**	**n**
Reptiles						
Lizard					Gm[3]	1
Snake	N					1
Turtle: Aquatic	N					1
Turtle: Terrestrial (Tortoise)			Gm[2]		Wb	2
Other				Ga[1] Gm[1]		2

Ga	Gate: automatic open/close
Gm	Gate: manual open/close
Wb	Wildlife ("cattle") guard: bars
N	Not reported
Provision to keep animal from crawling under gate	
1	Flap attached to gate
2	Tight fitting gate
3	Flap, doorstep and tight fitting gate
(shaded)	Anecdotally effective

Figure 50: Range of cost and level of effectiveness in excluding target species per gap treatment and target amphibian/reptile species. Note: 15 respondents answered this question but each respondent could enter multiple responses. Only those entries with cost information are included.

Most respondents agree that it is considered good practise to end a fence at a drainage structure, road cut or at the edge of a water body (Figure 51).

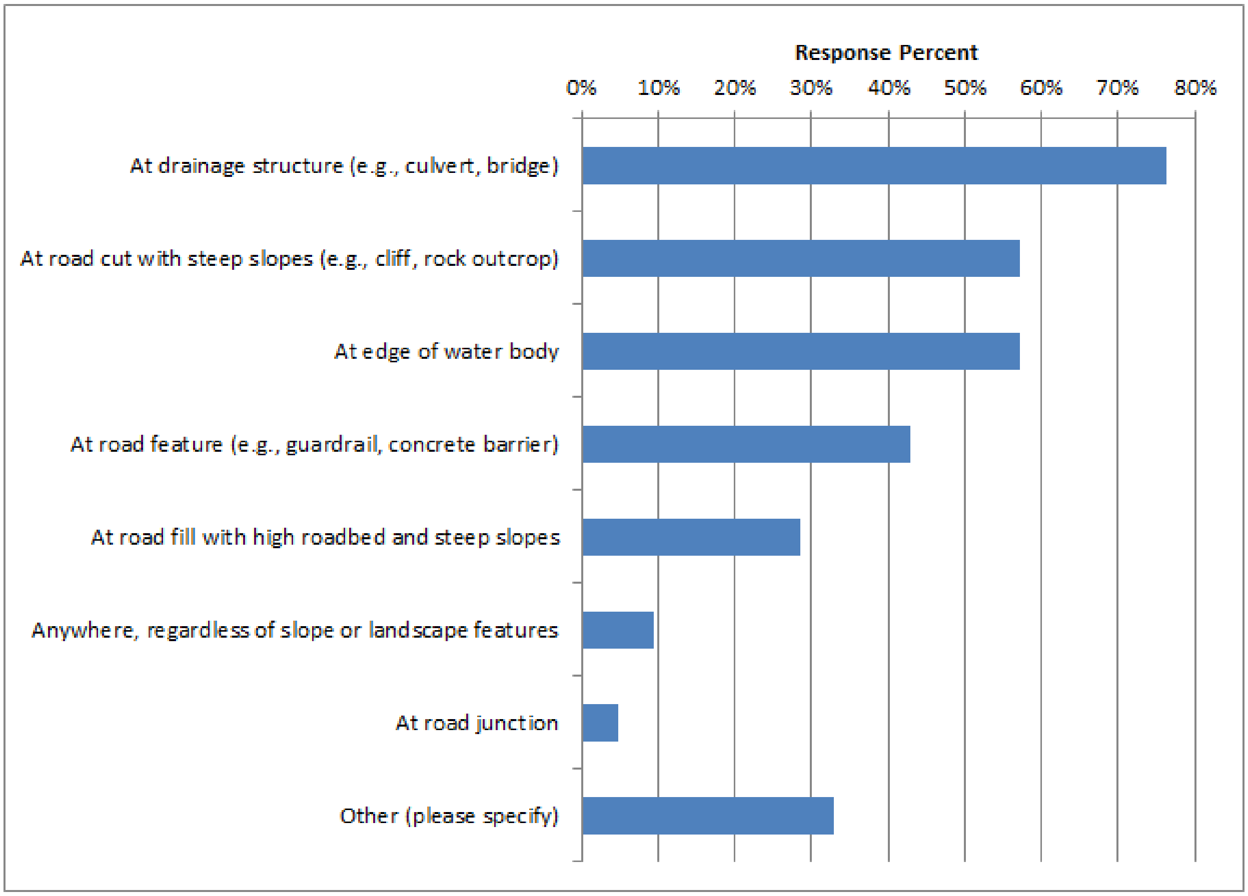

Figure 51: Response percent agreement regarding good practice for where to end a fence to reduce a large number of amphibian/reptile crossings at grade (n = 21). See Appendix B Question 22 for "other" responses.

3.5.5. Allow Humans to Get In and Out of the Fenced Road Corridor

Various types of gates were considered most suitable for pedestrians to cross amphibian fences or barriers (Figure 52). Wildlife guards and electric mats were considered least suitable.

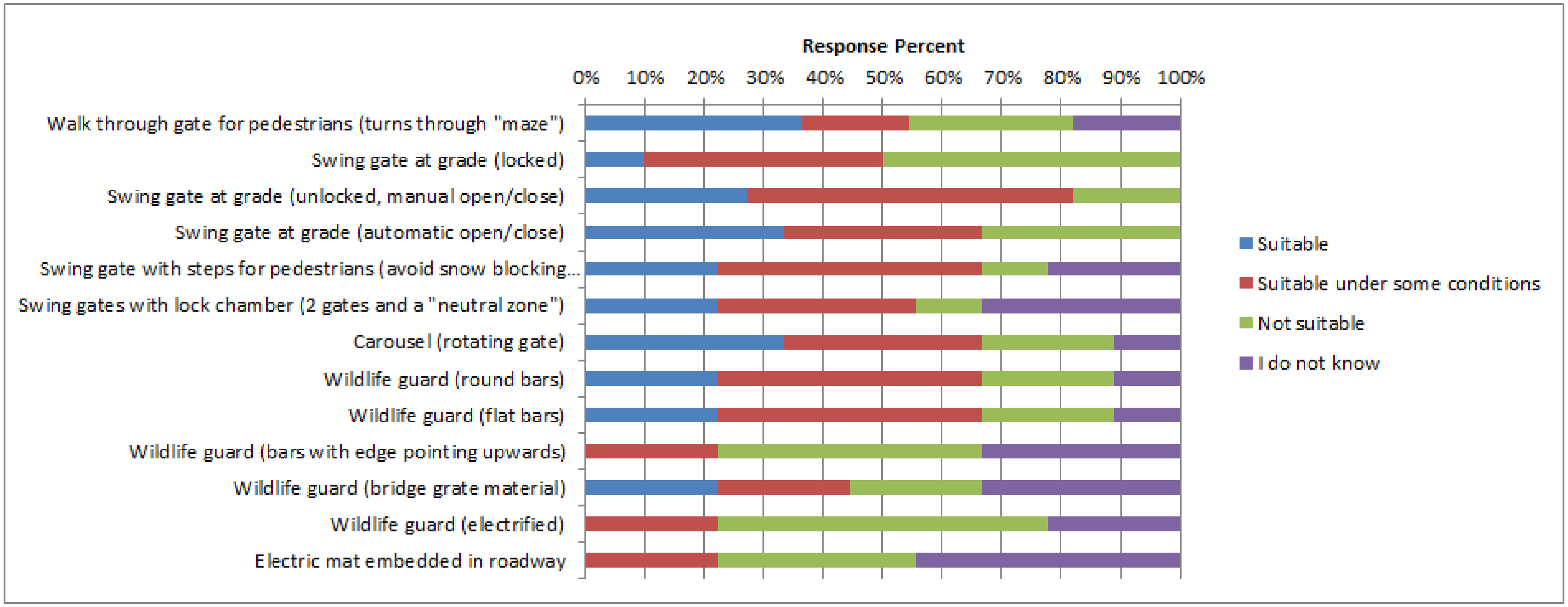

Figure 52: Response percent indicating suitability of access facilities in amphibian/reptile fencing for pedestrians. Note: n = 12 but not every respondent provided an answer for each access option.

Gates and wildlife guards were considered the mostr suitable access facilities to enter and leave the fenced road corridor for cyclists (Figure 53). Locked gates, gates that require turning and wildlife guards with the edge of the bars pointing upwards were considered least suitable.

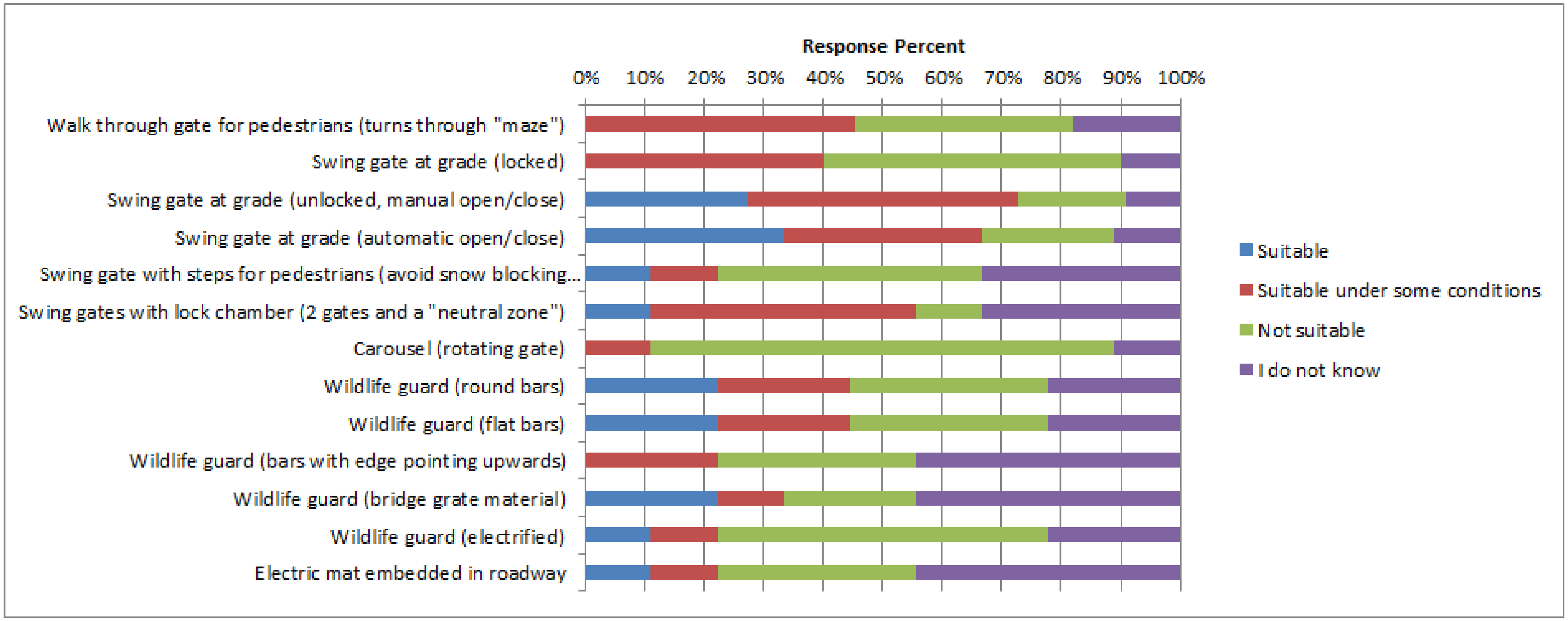

Figure 53: Response percent indicating suitability of access facilities in amphibian/reptile fencing for bicyclists. Note: n = 12 but not every respondent provided an answer for each access option.

Gates were considered most suitable for horses and their riders to enter and leave the fenced road corridor (Figure 54). Gates that require turning and wildlife guards were considered least suitable.

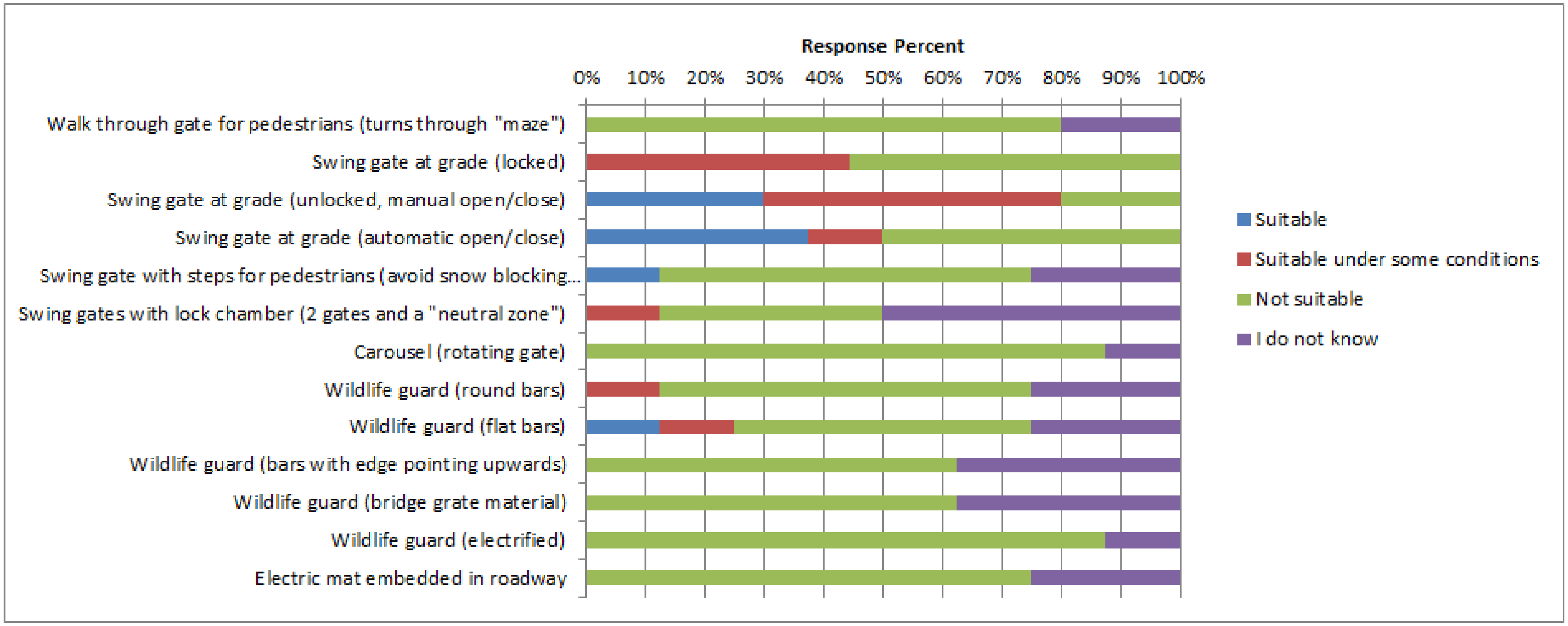

Figure 54: Response percent indicating suitability of access facilities in amphibian/reptile fencing for equestrian use. Note: n = 12 but not every respondent provided an answer for each access option.

Wildlife guards, certain types of gates and electric mats were considered suitable for motorized vehicles to enter and leave the fenced road corridor (Figure 55).

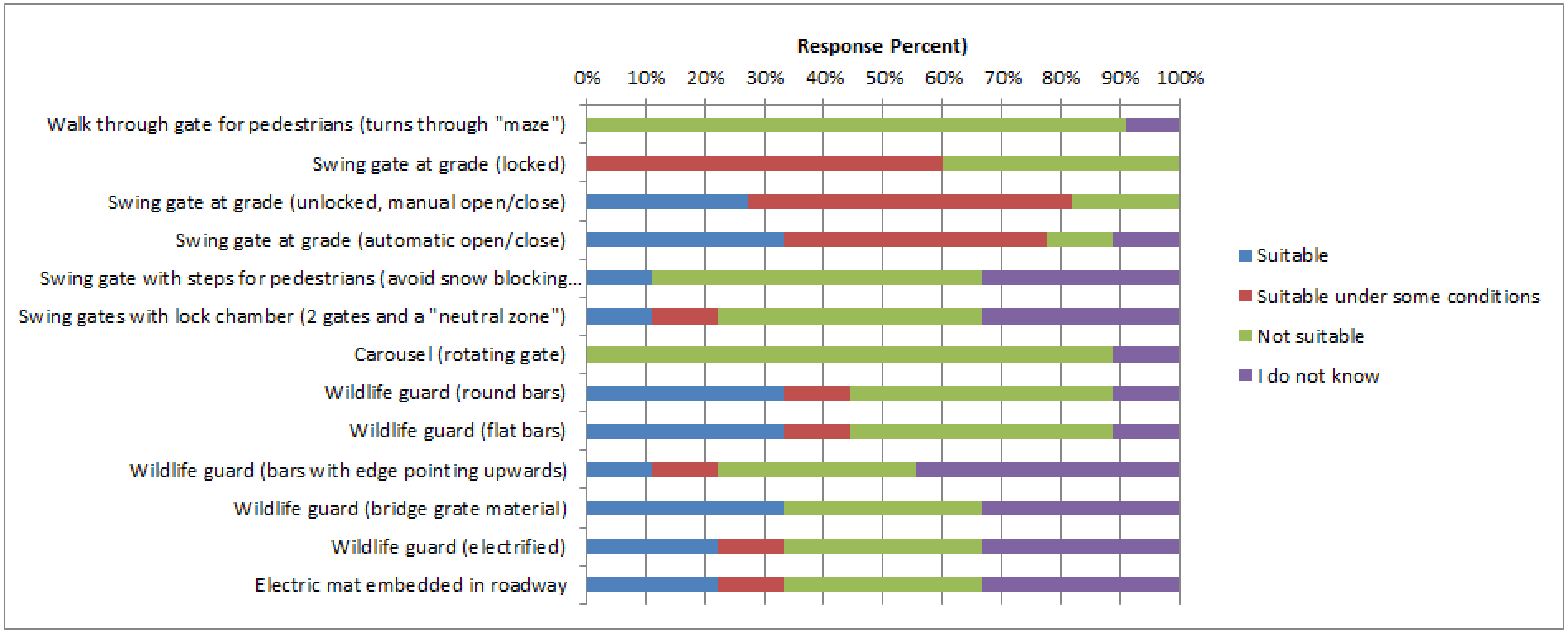

Figure 55: Response percent indicating suitability of access facilities in amphibian/reptile fencing for motorized use. Note: n = 12 but not every respondent provided an answer for each access option.

3.5.6. At Grade Crossing Opportunities for Wildlife at Gaps or Fence Ends

At fence ends or gaps in the fence the fence end typically angles away from the road (Figure 56). These treatments are relatively inexpensive (<$100).

	Average cost per fence end/gap treatment between pavement edge and fence line				
AMPHIBIAN OR REPTILE SPECIES	<$100	$101-500	$501-1,000	$1,001-5,000	n
Amphibians					
Frog: Other	Fa, Fa				2
Toad	Fa, Fa				2
Reptiles					
Snake	Fa				1
Turtle: Aquatic	Fa, Fa[1]	Fa			3
Turtle: Terrestrial (Tortoise)		Fa		B, Wb	3

B	Boulder field
Fa	Fence angled away from paved surface
Wb	Wildlife ("cattle") guard: bars
Measure to reduce impact of vehicle crash with fence end treatment	
1	Break away fence poles
(blue)	Proven effective - 81-90% exclusion
(yellow)	Proven effective - 71-80% exclusion
(white)	Not studied/Don't know if studied
(light grey)	Inconclusive
(dark grey)	Anecdotally effective

Figure 56: Range of cost and level of effectiveness of fence end/gap treatment in excluding target species from entering the space between pavement edge and fence line at at-grade crossing opportunities per target amphibian/reptile species. Note: 16 respondents answered this question but each respondent could enter multiple responses. Only those entries with cost information are included.

The width of barriers at a fence gap or fence end, on the pavement or on the side of the road, is typically <1.5 m (<5 ft) (Figure 57, Table 7).

		Distance an animal would need to jump to clear fence end/gap treatment between pavement edge and fence line														
FENCE END/GAP TREATMENT	AMPHIBIAN OR REPTILE SPECIES	<1.0 m (<3 ft)	1.0-1.5 m (3-5 ft)	1.6-2.0 m (5-7 ft)	2.1-2.5 m (7-8 ft)	2.6-3.0 m (9-10 ft)	3.1-3.5 m (10-12 ft)	3.6-4.0 m (11-13 ft)	4.1-4.5 m (13-15 ft)	4.6-5.0 m (15-16 ft)	5.1-5.5 m (16-18 ft)	5.6-6.0 m (18-20 ft)	6.1-6.5 m (20-22 ft)	6.6-7.0 m (22-23 ft)	>7.0 m (>23 ft)	n
Wildlife guard:	**Reptiles**															
bars	Turtle: Terrestrial (Tortoise)	1														1
Electrified mat	**Reptiles**															
	Snake		1													1
Boulder field	**Reptiles**															
	Turtle: Terrestrial (Tortoise)					1									1	2

Figure 57: Range of jumping distances to clear fence end/gap treatments (between pavement edge and fence line) designed for target amphibian/reptile species. All responses are "not studied/don't know if they were studied."

Table 7: Responses pertaining to fence end/gap treatments (on travel lanes), clearance distance, effectiveness and cost per amphibian/reptile species. Note: There were only two responses for this topic.

AMPHIBIAN OR REPTILE SPECIES	Fence end treatment	Distance animal would have to cross to clear barrier (wildlife guard, electric mat)	Effectiveness in excluding target species	Average cost per fence end treatment
Reptiles				
Snake	Electrified mat	1.0-1.5 m (3-5 ft)	Don't know if design has been evaluated	
Turtle: Terrestrial (Tortoise)	Wildlife guard: bars	Less than 1.0 m (<3 ft)	Don't know if design has been evaluated	$1,001-$5,000

Most respondents consider it good practise to, in principle, always accompany fencing or barriers for amphibians and reptiles with safe crossing opportunities for the species groups concerned (Figure 58).

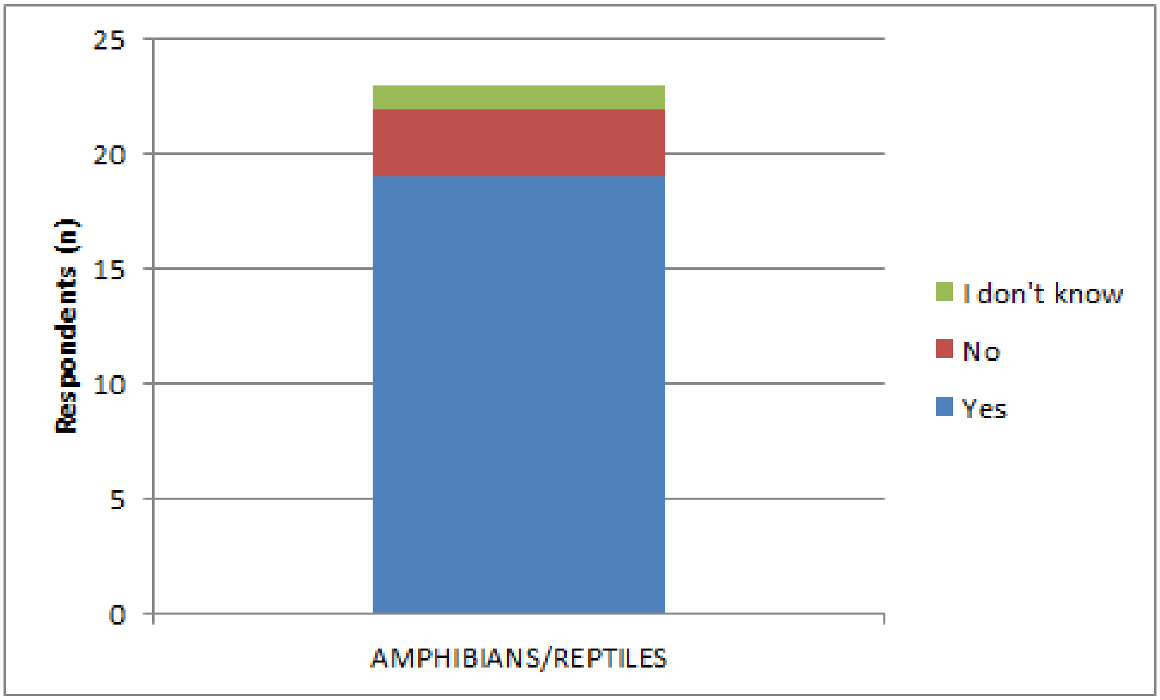

Figure 58: Number of respondents indicating whether it is good practice to, in principle, always accompany wildlife fencing along highways in combination with safe crossing opportunities (e.g., overpass, underpass) for amphibians/reptiles (n = 23).

3.6. Design Plans and Specifications

3.6.1. Introduction

For a given highway project, plans and specifications are developed by the designer to guide the construction effort. Plans include drawings specific to the project in addition to referencing standard drawings that are developed and maintained by the state DOT. Similar to drawings, specifications (text) included with plans can be specific to a project or copied/referenced from the state DOT's a set of standards specifications. The purpose of this chapter is to summarize the design plans and specifications for wildlife fencing and associated measures that the respondents made available to the authors of this report.

A number of plans and specifications (or specs) were collected during this project as summarized in Table 8. Most were project specific, but some states are starting to incorporate wildlife fencing into their standard drawings and standard specifications. Species identified in Table 8 are included if specifically mentioned in the plans/specs or known by the author. The species listed may be the target or predominant species, but most installations address multiple small and large animal species together. Plans and specifications reviewed were based mostly on those submitted by survey respondents. This is not intended as an all-inclusive list of plans/specs for the US or even the states listed.

Table 8: Summary of plans reviewed.

State	Project	Species	Elements
WY	US 191 Trappers Point	Deer, pronghorn	Fence, escape ramp, veh. gate, wildlife guard
NE	I-80 Platte River, Standard	Deer	Fence, escape ramp
NE	I-80 Platte River	Deer	Electric fence, escape ramp
UT	Standard	Deer	Fence, escape ramp
CA	Union Valley Parkway, City of Santa Maria	California tiger salamander, red legged frog	Barrier, culvert
RI	RTE 114	Terrapin	Barrier
IA	Standard	Deer	Fence, one-way gate
IA	Standard	Sm. mammal, reptile, amphibian	Fence, veh. gate
Can. Natl. Parks	Standard	Large animal	Fence, veh. gate
NV	US 93	Deer	Fence, escape ramp
NV	Standard	Tortoise	Fence
Ontario	Hwy 11	Ungulate	Fence, one-way gates, escape ramps, ped. gate
WA	I-90 Snoqualmie, US 97A N of Wenatchee	Ungulate	Fence, wildlife guard, ped. gate, veh. gate, escape ramp
FL	SR 429, SR 9	Panther	Fence
AZ	SR 260, US 93, Standard	Deer, big horn sheep, elk	Fence, escape ramp, one-way gate, electric mat guard, wildlife guard
AZ	SR 86, Standard	Tortoise	Fence
AZ	Unspecified project	Flat-tailed horned lizard	Fence

This chapter summarizes some of the details of these plans and specifications. Large animal wire mesh fencing is detailed first with details on different design elements such as escape ramps, wildlife guards and gates. Small animal fencing (or barrier wall) is summarized next. Although crossing structures are often considered necessary element to include along with fencing they are not discussed here as those plans were not collected and the focus of this project is on the fencing.

Although material types and sizes are discussed, often more important to the success of a fencing project are the more subtle details of how the fence is constructed. For example, the plans and specs could specify the maximum gap below the wire mesh fence and the natural ground, but not specify this requirement for vehicle access gates. Figure 59, shows a vehicle gate installed on uneven ground that has a large gap on one side. The gap may allow animals to enter the fenced road corridor which threatens the effectiveness of the entire set of mitigation measures.

Figure 59: Example of how not specifying gate installation details could lead to large gaps in fence gate. (source: Pat McGowen).

This summary is intended to help designers (when developing project specific plans and specs) and State DOTs (with developing standard drawings and specifications). Not only does it provide a range of the types of materials currently in use, but subtle details of fencing installation may improve the success of wildlife fencing installations.

3.6.2. Wire Mesh Fencing for Large Animals

Often drawings and specifications call out “deer fence.” White-tailed deer might be the target species, but more typically the fence is designed for a number of large animals which could include grizzly bear, black bear, pronghorn, white-tailed deer, black-tailed deer, elk, moose, big horn sheep, and Florida panthers. Although this section focusses on large animals, it often includes small animals in the design details (for example, see the section on the buried apron design element).

Location

Generally the wildlife fence is located on the edge of the right-of-way running parallel with the roadway. In this case the wildlife fencing replaces the existing right-of-way fence. Some projects specify placing the fence closer to the roadway, 12 feet (3.7 m) for example, presumably to allow maintenance vehicles on both sides of the fence or minimize potential damage from falling trees that may be cut within the right of way.

Often, a jog in the fence was included at culvert inlet/outlet locations so that the fence would be on the roadway side of the culvert. When this is done, fencing should continue behind the culvert or tie directly into the wing-wall/head-wall of the culvert structure (Figure 60). This jog could be a right angle, but more often (particularly for larger crossing structures, the fence runs at 45 degree angles to the roadway.

For one set of plans, the fence line was occasionally taken behind private property (Figure 61). This can eliminate the need for gates or cattle guards on the property driveways, but does require the additional cost of an easement for the fence (in this case 15-30 ft wide).

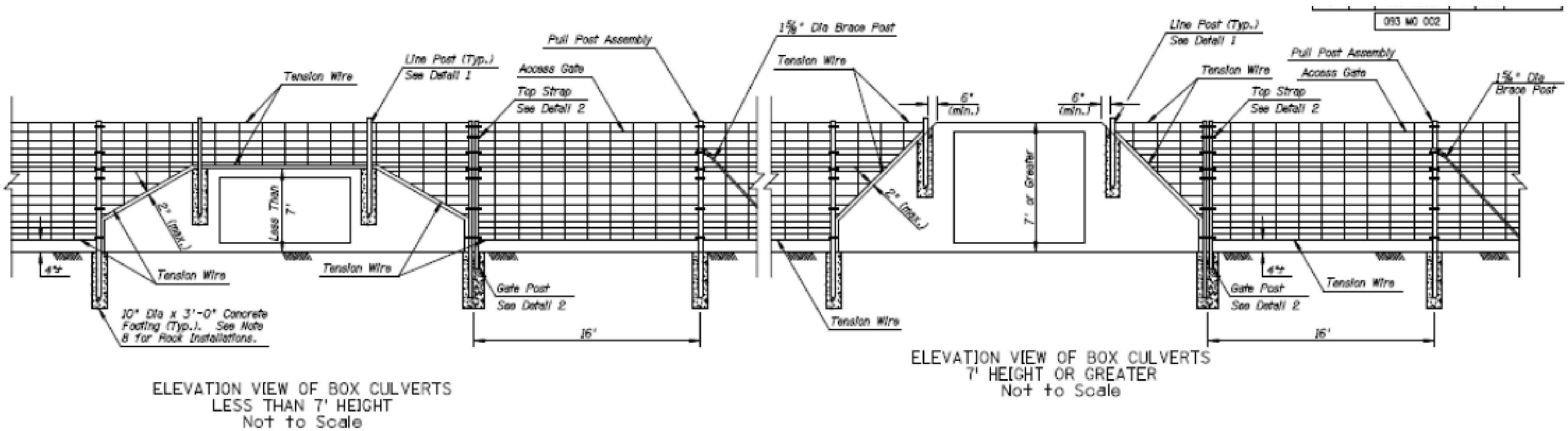

Figure 60: Example of how fence is tied into culvert structures with posts behind the wing wall next to the culvert box (AZDOT, 2005a).

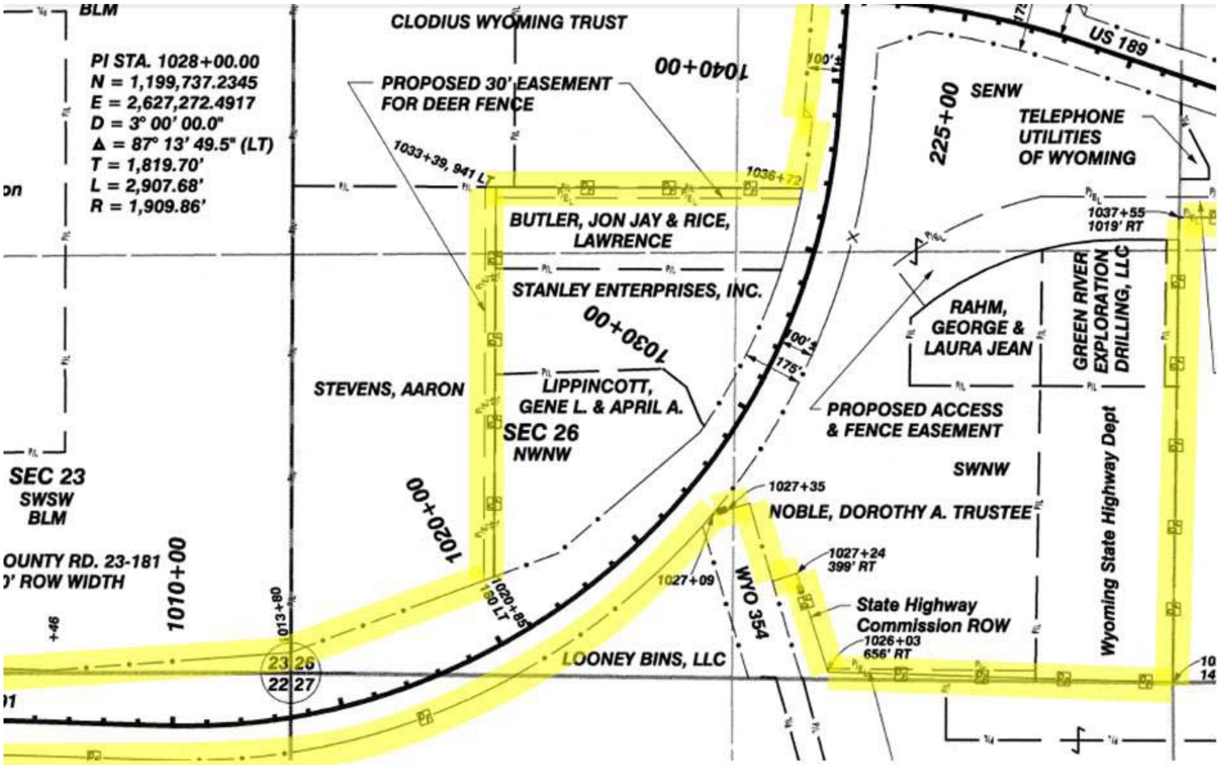

Figure 61: Fence line is taken behind private property instead of following the edge of the highway right of way. Location of wildlife fence is highlighted in yellow. (WYDOT, 2009).

Fence Post Type and Spacing

In some cases the same type of fence post is used throughout, but in most cases smaller posts are used along the fence line with stronger posts placed intermittently and at key bracing points such as corners and ends. For consistency, the following terminology is defined:

- Line posts are the weakest and most frequent posts used along the straight runs of fencing.
- Intermediate posts are single posts that are stronger than line posts and used intermittently along straight runs of fencing to add strength.
- Brace posts (sometimes called pull posts) are used in the middle of long straight runs to add strength. They are typically a set of two or three posts with extra bracing between each pair which could include:
  - A horizontal brace, of material similar to the post, near the top (and sometimes the bottom) of the posts
  - A diagonal wire between two posts and/or
  - A diagonal post attached to post that has a footing in the ground.
- End or corner posts are similar to brace posts and are used at fence ends, gates, or where fence changes direction including major changes in grade.

The sizes of these need to be considered collectively because some designs allow for very low cost line posts, but require stronger intermediate and/or bracing points. Table 9 provides details of different installations. For the footings, posts could be driven into the ground a specified depth, or a hole of specified size is dug and backfilled with soil or concrete.

Table 9: Fence post type and spacing.

State	Line Post	Line post spacing (max)	Line post footing	Intermediate post	Inter-mediate spacing (max)	Intermediate post footing	Bracing post and footing	Bracing Spacing
WY	Alternating 5" diam. 12' long treated wood post 2" diam. wood stays	8'3"	3' 10" bury (None for stays)	10' metal	500'	2' driven	7" diam post, two 5" diam horizontal braces with diagonal brace wire	600'
NE	2.5"diam 11.5' long schedule 40 steel	12'	1' diam 3.5' deep concrete	none	none	none	Same as line, but additional diagonal post	330'
IA	T-posts 12' long	16'	Driven 3'8"	6" diam wood 12' long	48'	Buried 3'8"	Same as line, but metal horizontal brace and diagonal wire	160' or 960' with stronger end post
Canada National Parks	15-20cm diam wood 3.7m long	6m	n/a	20cm diam wood 4.2m long	As required	n/a	n/a	100m
NV	Steel t-posts 10' long grade 133	12'	Driven 2'	2 3/8" diam recycled oilfield drill pipe 12' long	48'	4' buried w/ concrete or pea gravel backfill	2 7/8" diam recycled oilfield drill pipe 12' long w/ similar horizontal brace and diagonal wire	1320'
Ontario	88.9mm (3.5") outside diam X 5.74mm (0.226") WT schedule 40 steel	5m (16.4')	350mm (13.78") diam concrete				Same as line with 42.9mm (1.69") OD steel horizontal and diagonal post brace	200m (656')
WA	T-posts 133 lbs/ft	16'	Driven 2', for rock 2" diam hole w/ grout	steel post (diam not specified) w/ two diagonal brace posts 1 5/8" diam	330'	10" diam, 3' concrete and 18" cube concrete for diagonal brace		
AZ	T-posts 1.5 lb/ft 10' long	20'	Driven 2', for rock 2" diam grout	2 3/8" diam steel 14'long	120'	1.5' diam 4.75' deep concrete	2 7/8" steel 14' long and two additional diagonal steel all in footings	1320'
FL	1.9" outside diam 2.28 lbs/ft schedule 40 steel 14' long	10'	Driven 5'				Same as line w/ 4" wood horizontal brace and diag wire	

' = foot (0.304 m), " = inch (2.54 cm), diam = diameter, n/a = info not available

Wire Mesh

For the primary fence material, 12.5 gauge wire mesh is almost universal for the plans/specs reviewed (material and mesh size for buried aprons are discussed separately). Mesh size can be constant, but occasionally the spacing between horizontal strands is graduated. Sometimes the standard specifies placing the smaller mesh gaps at the bottom, presumably for restricting entry of smaller animals. However, the smaller gaps are typically intended by the manufacturer to increase the tensile strength of the mesh at the top or center of the pole. Most manufacturers specify smaller gaps at the top for strength/durability reasons.

Mesh size between vertical wires was as small as 2 inches for Florida, presumably to make it difficult for panthers to climb the fence. The rest of the plans ranged from 6-12 inch spacing between vertical wires. For constant mesh size, the smallest spacing between horizontal wires was Florida with 4 inch spacing. For graduated mesh, the spacing typically started at 3-4 inches and increased to 7-8 inches.

Welded wire mesh was never specified, only woven or knotted. Knotted is typically stronger than woven and more expensive. Note that some of the standards above regarding knotted and mesh sizes may be based on domestic materials rather than what is available elsewhere in the world.

Specifications varied as to using the number of rolls of wire mesh to be use from one (eight foot roll), two (four foot rolls) or three (32 inch rolls). Wire mesh, metal poles and associated hardware (e.g., staples, bolts) are typically specified to be galvanized.

Bottom Gaps

If a buried apron (discussed next) is not used, the maximum gap between the bottom of the wire mesh and the fence is typically specified. The maximum allowable gap between the ground and the bottom of the wire mesh ranged from 2 to 6 inches. An additional strand of barbed wire below the wire mesh is sometimes specified. For example, a 2.5 inch maximum gap is allowed between the mesh and the ground, but an additional strand of barbed wire had to be within 1.5 inches from the ground. Major dips, drainages, and gates are typically dealt with separately.

Major Dips and Drainages

Many plans specified how to deal with the bottom gap at major dips, particularly drainages where wire mesh cannot be kept close to natural ground. Additional wires (typically 12.5 gauge barbed wire) are strung between the posts with a dead-man or additional post (Figure 62).

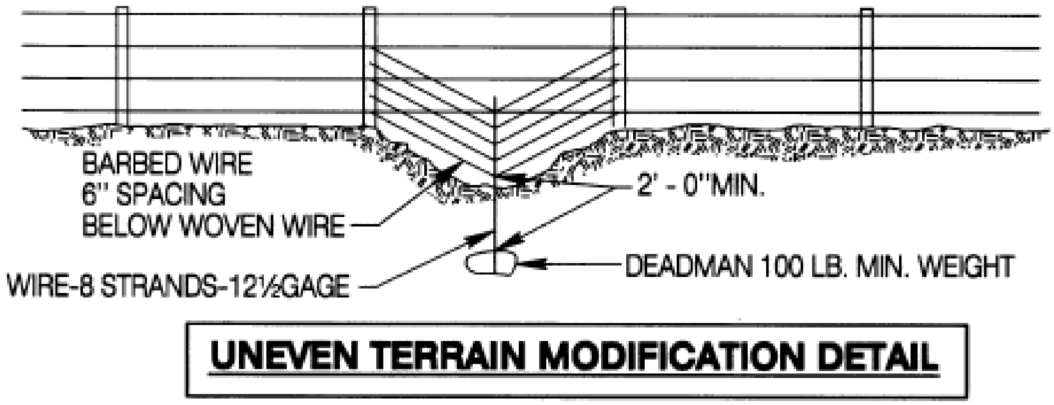

Figure 62: Example of Drainage (WDOT, 2009).

Of course the gaps between these additional wires should be specified. The specifications found were 6 to 9 inches. For an active drainage, the setup above could get clogged. One specification called for placing T-posts 10 inches apart in the channel downstream of the fence. Another approach for dealing with active drainages is shown in Figure 63).

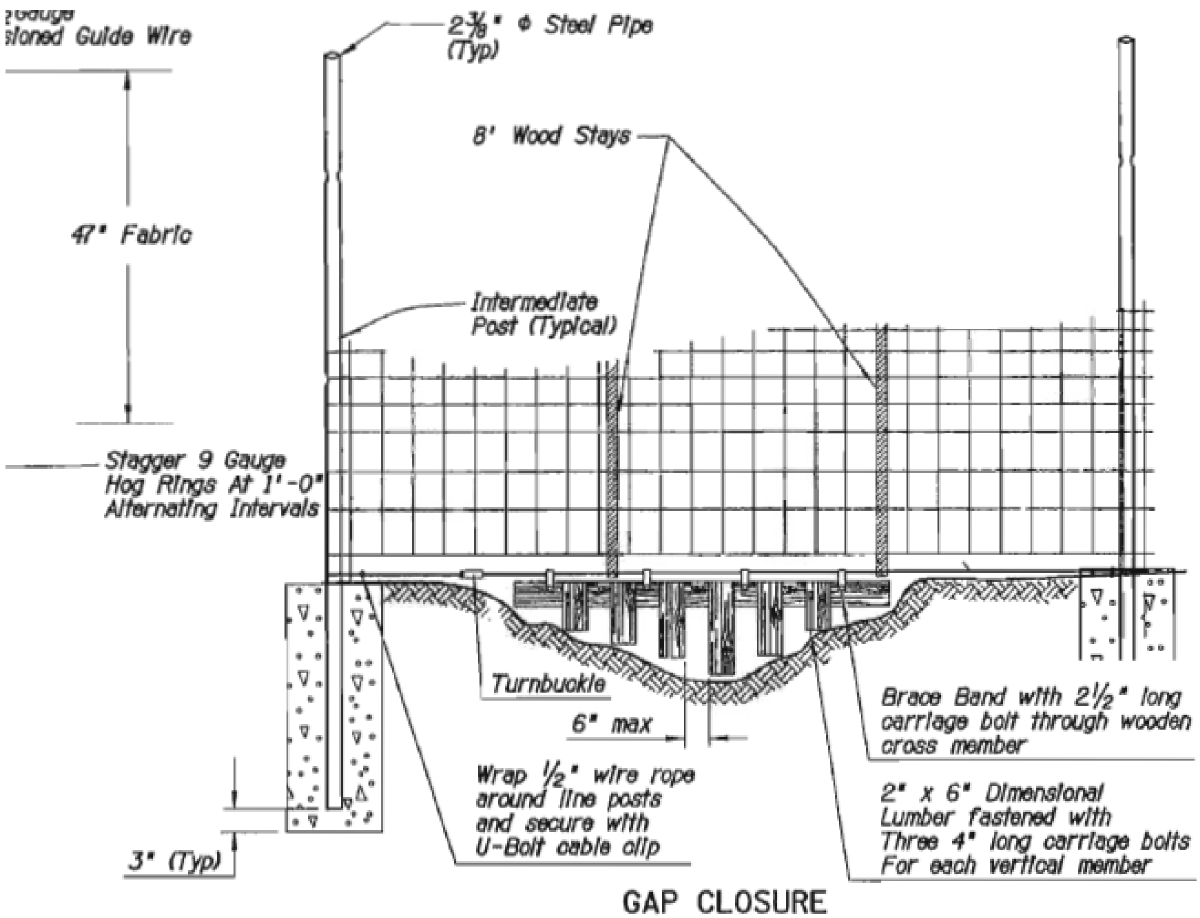

Figure 63: To maintain integrity of the fence, timbers are hung which allow water and some debris to flow through, but maintain the barrier (AZDOT, 2005b).

Vehicle and Pedestrian Access Gates

Gates are needed to provide vehicle and/or pedestrian access while maintaining the barrier created by the fence. Specifications should include how to deal with gaps under and around gates.

Gate clearances below gates are occasionally the same as specified for the wire mesh, but if a buried apron is applied, a maximum clearance should be specified (typically 2-4”). Additionally gates need to be either the same height as the fence, or have a header over the top of the gate of wire mesh or barbed wire. Refer to the section on small animals to see how Iowa uses rubber belting to eliminate gaps at gates.

Buried Apron

To eliminate the gap at the bottom of the fence, wire mesh is buried. This could be either the main fencing mesh or an additional roll of wire mesh tied to the bottom of the fence mesh. A mesh, separate from the main fencing mesh, to be buried may be helpful for excluding smaller animals as smaller mesh size could be specified for closer to the ground.

The material used for the buried apron is chain link or wire fabric. In some cases a smaller gauge is specified (e.g., 9 gauge). Because the 12.5 gauge fence provides the needed structural support, a lower gauge on the apron could reduce costs. Some specify zinc or other corrosive resistant material. Either a trench is dug and backfilled over the apron, or soil is placed on top of apron (particularly as an option for rock areas). Bury depth ranges from 7 inches to 3 feet. Mesh is buried either vertically, angled away from fence, or bent as shown in Figure 64.

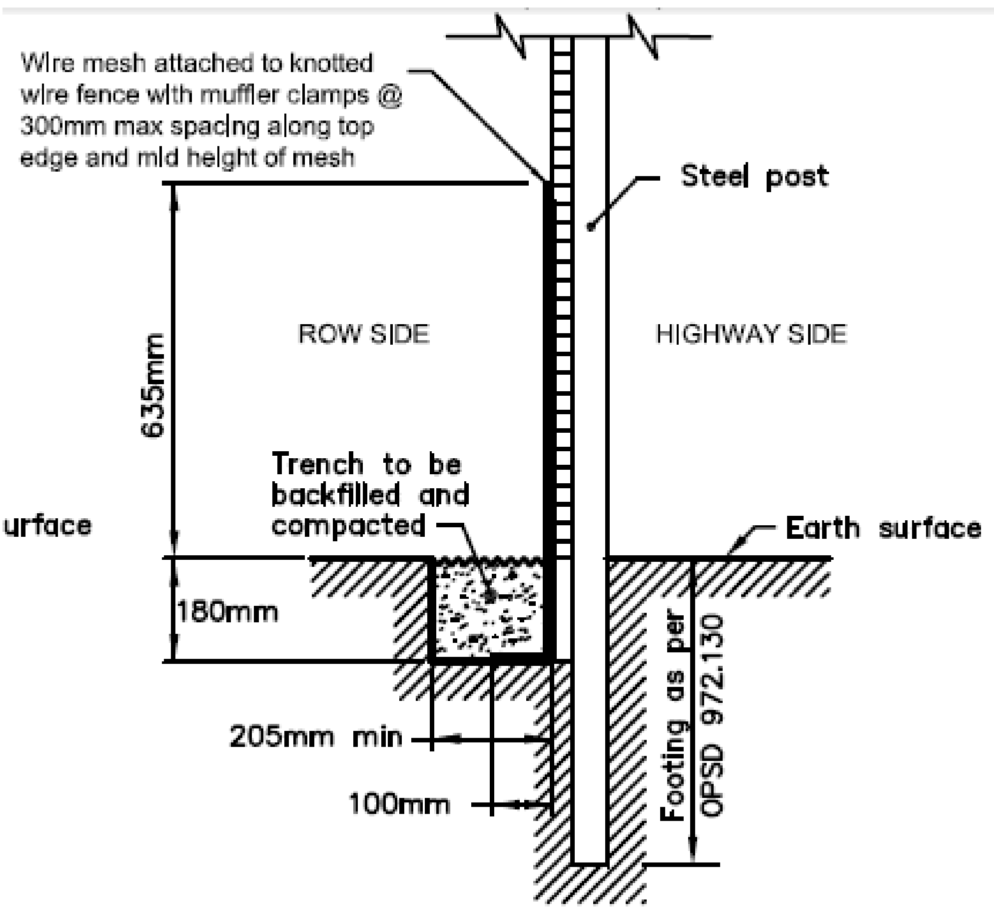

Figure 64: Wire mesh apron attached to wire mesh fence and buried (Ontario Ministry of Transportation, 2012).

Terminals

It is not ideal to just end the wildlife fence with no method to guide animals to the non-roadway side of the fence terminus. There were several options identified in the plans and specs. The fence could be attached to right-of-way fence that continues indefinitely. The fence could also be flared toward the roadway at least partially up a fill slope, or the fence could end at a culvert or crossing structure.

Arizona specifies flaring fence toward road and onto embankment for a fill slope (road is higher than natural ground) or for cut slopes (road is lower than natural ground) angling fence toward roadway and creating a boulder field. See Figure 65 for layout.

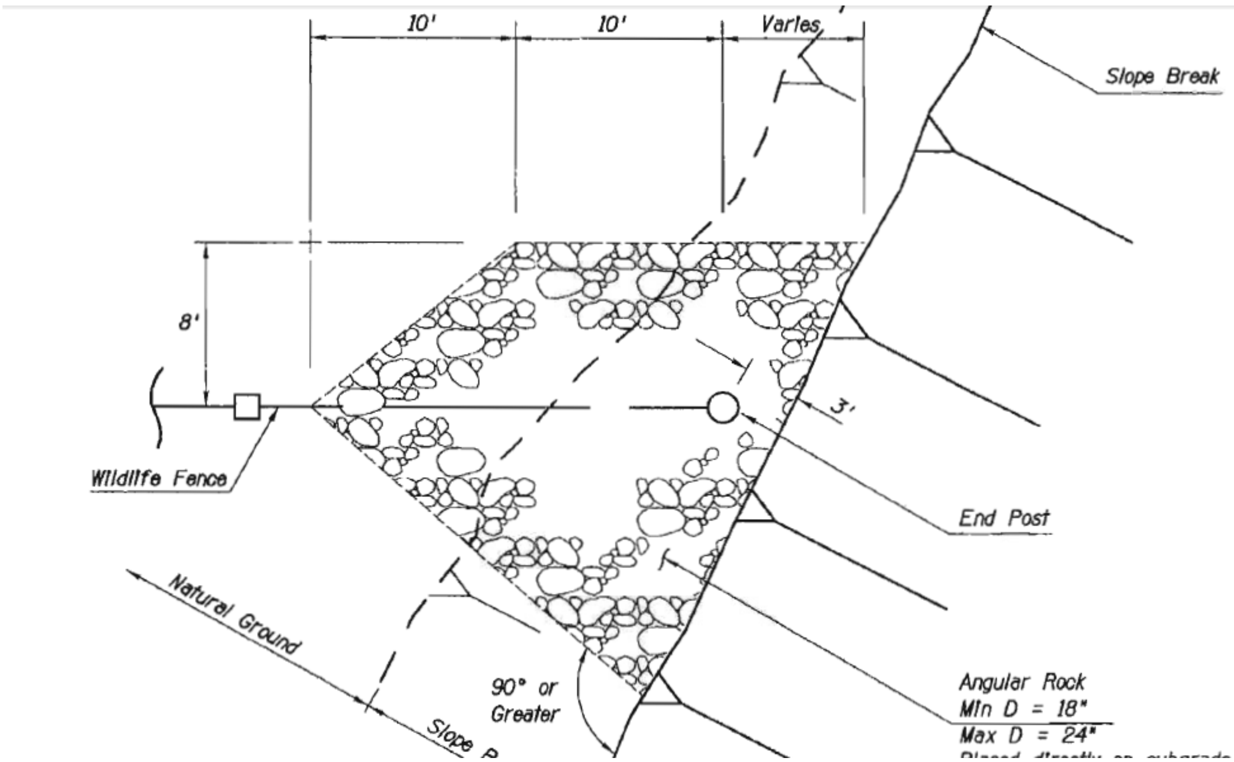

Figure 65: Road is not shown but is positioned running northeast in above figure. Fence is angled toward road and rip rap (boulders) are placed in the roadside ditch (AZDOT, 2001).

Wildlife Guards

Wildlife guards are typically double sized cattle guards placed on approach roads in order to maintain the barrier created by the wildlife fence across the approach road. Guards could be placed toward the road to create a straighter barrier line on the wildlife side of the fence (Figure 66).

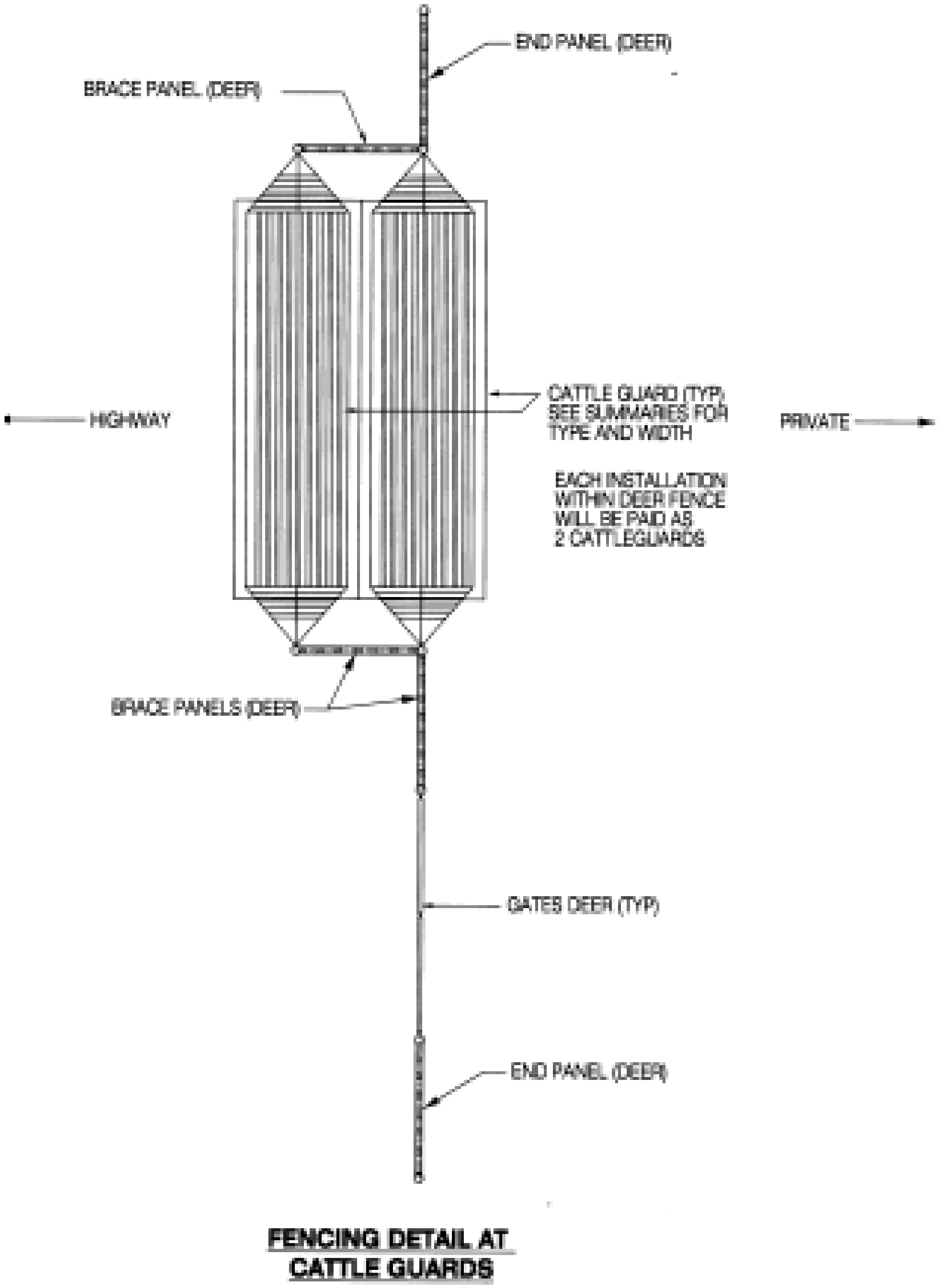

Figure 66: Guard protrudes into roadway side of fence to maintain straighter barrier line (WYDOT, 2009).

Wire mesh of similar needs to be placed under wings of the typical cattle guard and any ledges (even narrow ones) should be blocked. The fence could be continued into the guard with T-posts as shown in Figure 67. Gaps in the guard ranged from 3 to 9 inches. A pedestrian gate may be installed near the guard to allow a safe crossing.

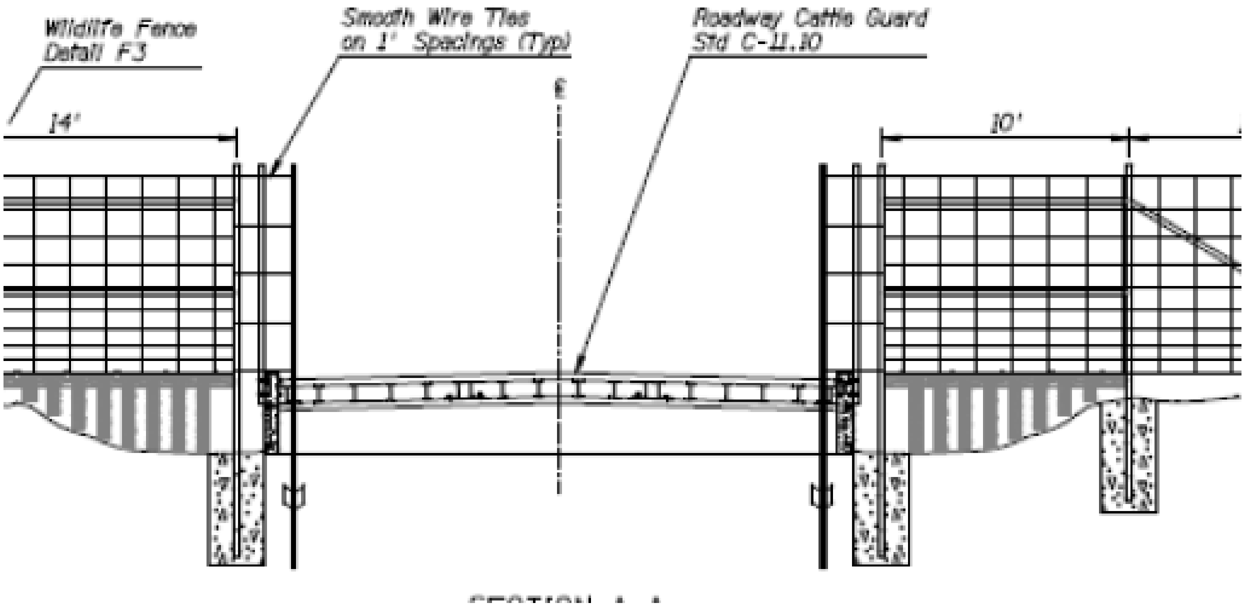

Figure 67: T-Posts are used to continue fencing onto the guard so as to eliminate any ledges that could be used by wildlife to cross over guard (AZDOT 2005a).

Electric Guard

The Electromat brand devices can replace a wildlife guard on approach roadways. This device is composed of panels put on the road that give an electric shock when stepped on. Two widths of 46” an 60” were specified. A deicing system in the gravel bed under the Electromat and a pedestrian deactivation switch and timer were options specified.

Escape Ramps

Escape ramps (or jump-outs) are placed to allow animals trapped on the roadway side of the fence to escape to the other side of the fence. A retaining wall and mound of earth create a drop that an ungulate may be willing to jump down, but not up.

These are placed most often at crossing structure locations or intermittently (e.g., every half mile) along the fence. In fact, the bridge abutment of a wildlife underpass can be used as a kind of free escape ramp. A planned jog in the fence can be used as a potential funnel for wildlife, or the escape ramp can be placed in-line with the fence with a small section of perpendicular fencing. Fencing may be angled as opposed to perpendicular to create more of a funnel. Utah has a unique plan for multiple escape ramps working together to funnel wildlife to the escape (Figure 68).

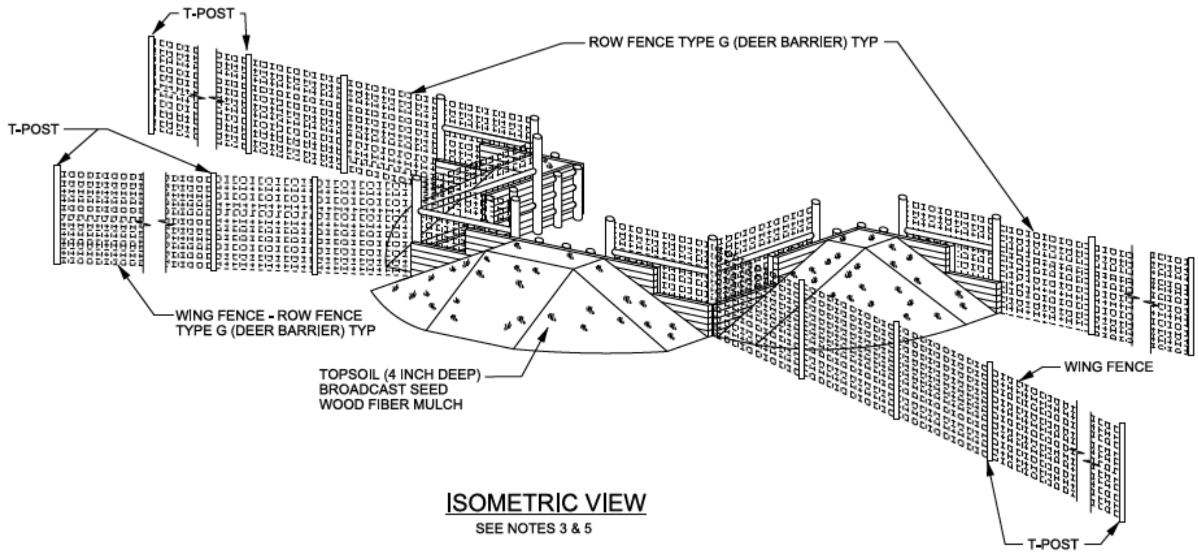

Figure 68: Multiple escape ramps used to allow a fencing funnel to the ramps (UDOT, 2014).

Material for the retaining wall is most commonly wood planks with wood or metal posts (sometimes the same type of post as the fence posts). Other material includes gabion and concrete wall. The height of the retaining wall ranged from 5 to 6 feet. In one example of a concrete retaining wall that was 6 feet high an additional horizontal bar was placed 2 feet above the top of the retaining wall.

The slope of the ramp ranged from as steep as 2:1 (i.e., 2 feet horizontal to one foot vertical) to 4:1. One option is to have a steep slope perpendicular to the roadway and fence (2:1) and a softer slope along the fence up to the top of the retaining wall (4:1).

Typically a flat landing area is provided on top; either square, rectangle, quarter-circle or semi-circle. Example sizes are 4 feet square 4 by 8 feet rectangle and 6 feet diameter. One plan provided an additional downslope leading to the flat landing area. The opening in the fence at the top of the retaining wall ranged from 4 to 24 foot opening.

One set of plans did run the fence up the slope along the retaining wall to maintain 8 foot high fence even on the top of the escape ramp. Most others maintained a level fence top so that the fence was only a few feet high on the top of the retaining wall, but the total height of the retaining wall and fence above was 8 feet. The fence should be attached directly to the face of the retaining wall or be close to the back of the retaining wall to minimize any gaps. Other specifications of note included compacting soil to 90 percent and creating a clearing below the retaining wall of 5 m radius to provide visibility for wildlife.

One-Way Gates

A few plans specified one-way gates. These are openings with tines that are curved away from the roadway side of the fence and on a spring loaded hinge so they can be pushed open in only one direction (Figure 69).

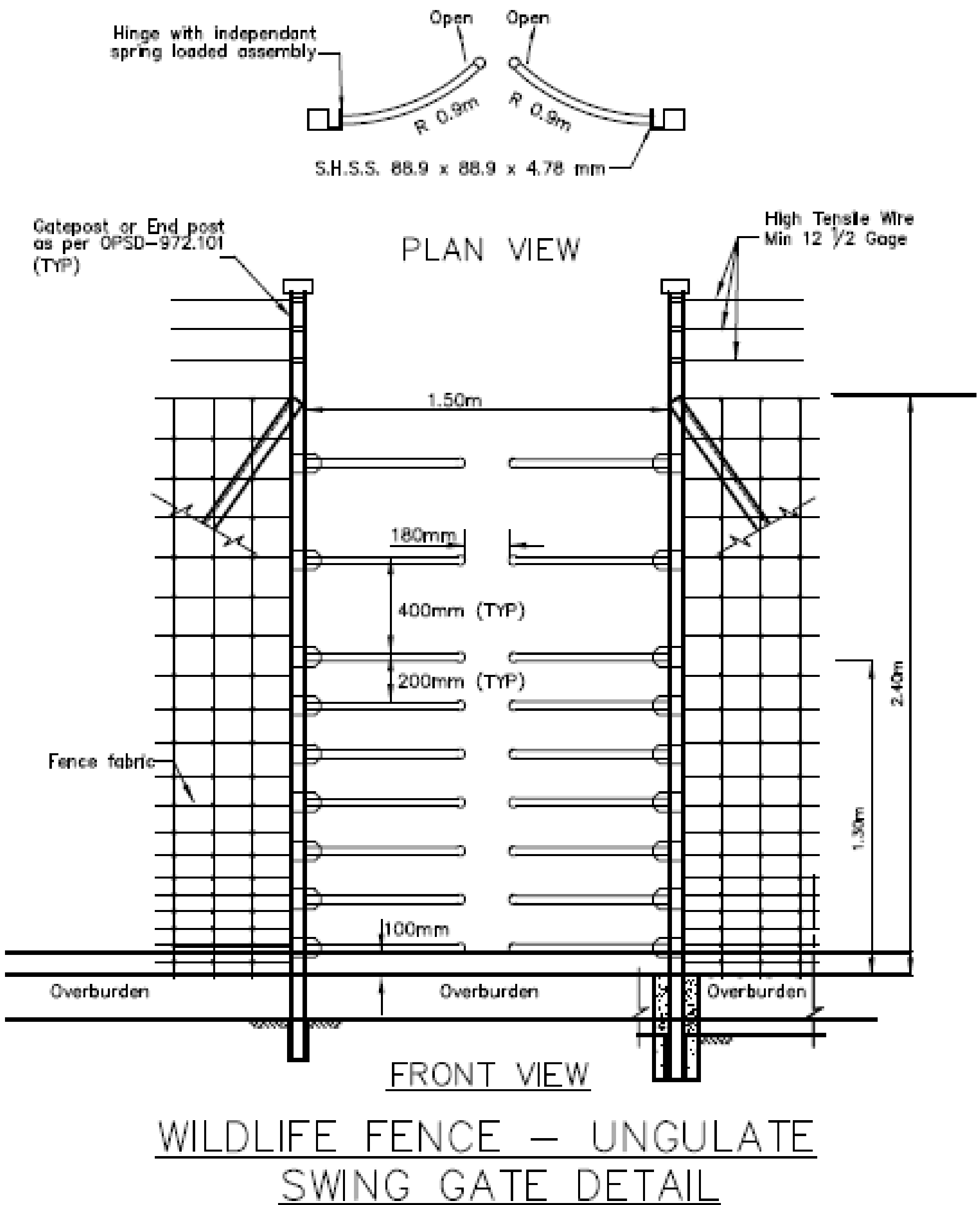

Figure 69: Example of one-way gate (Ontario Ministry of Transportation, 2012.

All three examples of one way gates were approximately a 5 foot wide opening with spring loaded hinges. One had all tines on a plate with two hinges so they swung together, while the other two plans had a separate spring loaded hinge on each tine hinges require minimum pressure to open. The arc of the tines ranged from a radius of 26 to 35 inches. The vertical spacing of the tines varied somewhat:

- 8 tines space 6 inches apart,
- 9 tines, top two gaps are 16 inches and rest are 8 inches, or
- 7 tines with three 10 inch gaps and three 6 inch gaps.

3.6.3. Other Details

Typically wire mesh is attached on the wildlife (non-highway) side of posts. However, for fencing on the inside of curves, it should be placed on roadway side of the posts to minimize tension on the staples or attachments to the post (if a buried apron is used, this is not an option). If a fence is near an electric transmission line there must be a grounding wire on posts nearby (e.g., if within 200 feet of transmission line, grounding every quarter mile). Outriggers with three strands of barbed wire were used in Florida to discourage climbers.

Summary of Specifications

Assuming the designer will determine the best post and fence materials considering cost, durability etc., the following are additional specifications that could be considered. Specific numbers provided below are just for example and should be adjusted for target species and local needs. This list is intended to help the designer think of details that may be overlooked. If not clear the reason for the specification is included in parentheses.

- Fence mesh to be a minimum of 7.5 feet above ground at its lowest point.
- Except where specified, fence to be located 12 feet from edge of right of way (maintenance).
- Fence wire to be placed on field side (non-roadway side) of fence.
- All wire ties, brace wires, staples and other accessories shall be galvanized in accordance with AASHTO M 232.
- Where fence crosses electric transmission lines, contractor shall furnish and install a grounding conforming to appropriate codes and standards.
- For fencing with no buried wire mesh, the maximum gap allowed between the bottom of the fence and the ground is 3 inches. For uneven terrain where gaps are greater than 3 inches refer to uneven terrain detail (a detail of how best to use dead-men or additional posts needs to be included).
- 3 inch maximum gate ground clearance.
- At gates wire mesh should extend significantly beyond the frame to cover any gaps between the gate and the frame.
- A high tensile line wire shall be attached to posts above wire mesh (tree falls).

- Fencing line shall be adjusted to be on the roadway side of culverts. If fence posts can be placed within 5 inches of wing walls, the fence height behind the culvert can be reduced as long as the total height of fencing and culvert at the headwall is more than 8 feet.
- At fence terminals… wing fence, boulder field, angle toward road into fill slope.
- Depending on wire mesh roll length, post spacing shall be shortened or an additional post added so the junction between rolls is at a post location.
- Experienced biological monitor shall oversee the installation.
- Fencing posts shall be installed plumb except 3 degrees from vertical angled away from the roadway.

  For escape ramps
- Soil shall be natural surrounding soil compacted to 90 percent.
- Posts shall be tied to retaining wall so gaps do not exceed 3 inches.
- Ramp to be a maximum of 3:1 slope with rounded corners.
- Seed and re-vegetate ramp and surrounding area.
- An area of 5 feet diameter at the ground below retaining wall is to be cleared of vegetation (visibility by wildlife).

3.6.4. Small Animals

Only a few plans and specs were collected for small animal fencing/barriers. They are described individually below.

A terrapin barrier in Rhode Island specified attaching wire mesh to the back of existing guardrail where the roadway boarders a river. Fencing material is 14 gauge welded wire mesh ½ inch (horizontal) by 1 inch (vertical) galvanized and PVC coated. The mesh is 2 feet wide and to be buried 3 inches. Mesh sections should overlap at least 6 inches. Work is not permitted May to Sept and during construction, inspection is required prior to and weekly by DOT environmental scientist to identify and relocate terrapins and eggs. The contractor must provide extra fencing material along with construction (for future repairs).

Iowa small mammal, reptile and amphibian fence is specified as 14 gauge chain link fence fabric, ¼ inch mesh size, 48 inches wide, buried 12 inches. This is attached to field fence (or deer fence). Seams are overlapped 6 inches. For gates on access roads, a 4 foot wide (or 4 foot length of approach road) concrete pad is specified for a nice flat surface with no ruts below the gate. Fabric reinforced rubber belting (1/4 inch thick and 12 inch wide) is attached to the bottom of gate and between posts and gate. Bottom of belting must be within ½" of concrete. If a double gate is use the belting is overlapped at the center where gates meet.

For tortoise in Arizona, 1 by 2 inch wire mesh 36 inches wide, is to be buried 12 inches. The height above ground is average 24 inches, but a minimum 18 inches and minimum buried depth of 6 inches is required. If burying is not possible due to rock, bend the mesh at the ground and add 4 inches of soil to bury mesh. Mesh is 16 gauge or heavier. The mesh can be attached to existing fence, but add t-posts where spans exceed 10 feet. If constructing new fence, use 5-6 foot T-posts. Attach mesh to fence gates to close gaps and make sure ground clearance under gate is zero. Attach fence to all culverts to allow tortoise to use as a crossing opportunity. Monitor and repair fencing particularly at washes.

Nevada specifies the same wire mesh material for tortoise as Arizona. The specifications for burying are a little different. It is bent 90 degrees with 14 inches of mesh perpendicular at the bottom of a 4 inch deep trench.

The standard for flat tailed horned lizard in Arizona allows for new fence, or adjustment of existing right-of-way fencing. Wire mesh with ¼ inch mesh size 36 inches wide is to be attached to new fence posts or existing fencing and buried 6 inches. For new fencing, wire strands above the mesh are added to appropriate height for right-of-way fence. Surveys are to be conducted before and after construction to relocate animals that could be disturbed or trapped on the roadway side of fence.

For California tiger salamander and red legged frog, the barrier specified is two feet above ground, and three feet buried concrete wall. The bury depth is to prevent other animals from digging holes that could be used by the target species. The top edge has a 6 inch overhang. Soft bottomed culverts for crossing opportunities are specified every 100 feet. The concrete barrier is to be flush with the opening of the culvert so there are no gaps.

4. COST-BENEFIT ANALYSES

4.1. Introduction

The costs for wildlife fencing, associated mitigation measures, and safe crossing opportunities for wildlife can be substantial (Huijser et al., 2009a; Chapter 3 in this report). However, wildlife fencing, in combination with safe crossing opportunities for wildlife, can also reduce collisions with large ungulates by 80-100% (see review in Huijser et al., 2009a). When mitigation measures reduce collisions with large wild mammals they generate economic benefits. Huijser et al. (2009a) conducted cost-benefit analyses for a range of different types and combinations of mitigation measures and calculated how many deer, elk, or moose need to be hit (based on historic data before the implementation of mitigation measures), in order for the mitigation measures to "break-even" or generate benefits in excess of costs. These cost-benefit analyses are largely based on human safety parameters and do not include other potential parameters (e.g. parameters related to biological conservation). However, Huijser et al. (2009a) showed that it can make economic sense based on human safety parameters alone to implement mitigation measures that reduce wildlife-vehicle collisions and that also allow wildlife to safely cross the highway. While the outcomes of these cost-benefit models are likely very useful, decisions on potential implementation of measures should not solely be based on the outcome of this cost-benefit model as the model is limited to the costs associated with human safety parameters.

The cost-benefit analyses by Huijser et al. (2009) were based on cost estimates for 2007. In this chapter we use new and updated cost information for the construction of wildlife fencing and associated measures obtained through the survey (Chapter 3). However, the costs for other mitigation measures (e.g. wildlife crossing structures) and the costs associated with ungulate-vehicle collisions were not updated.

4.2. Methods

The costs (see Chapter 3) for effective fencing for wild ungulates is summarized in Table 10. For the purpose of this report, "effective" fencing was defined as "interviewees need to have reported that the fencing is at least 80% effective in reducing collisions with large mammals" (see Chapter 3). Furthermore, the researchers distinguished between two types of wildlife fencing: woven wire and electric (Table 10). In addition the researchers summarized the costs for jump-outs and barriers at fence ends (wildlife guard, electric mat) that aim to reduce the likelihood that large ungulates enter the fenced road corridor (Table 10). Similar to fencing, the jump-outs had to be considered at least 80% effective in allowing large mammals to escape the fenced road corridor and keeping large mammals from entering the fenced road corridor, and the barriers at the fence ends had to be considered at least 80% effective in keeping large mammals from entering the fenced road corridor. Measures that are barriers at gaps in a fence (e.g. wildlife guards, electric mats or animal detection systems) also had to be at least 80% effective in reducing collisions with large mammals to be included. Only measures that had at least two cost-estimates were included in the analyses.

Table 10: Costs associated with various mitigation measures based on the survey (this) report) and an earlier publication (Huijser et al., 2009a).

Measure	Type (unit)	Costs based on Huijser et al., 2009a ($)	Data from the survey (this report)				
			Average costs ($/m)	SD ($)	Max ($)	Min ($)	N
Fence	Woven wire (/m)	48	49	24	100	15	19
	Electric (/m)	N/A	42	14	65	25	7
Jump-outs	(/structure)	9,813	5,900	4,336	11,500	1,500	3
Fence gap treatment	Wildlife guard, metal bars (/gap)	n/a	21,250	19,445	35,000	7,500	3
	Electric mat (/gap)	n/a	31,667	15,275	45,000	15,000	3
	Animal detection system (/gap)	n/a	100,000	-	100,000	100,000	3
Fence end treatment	Electric mat (/fence end)	n/a	41,667	11,547	55,000	35,000	3

The costs for woven wire wildlife fencing as reported by the respondents ($49/m, see Chapter 3) was very similar to what Huijser et al. (2009) used for their earlier cost-benefit analyses ($48/m). The costs for wildlife jump-outs, as reported by the respondents, were, on average, substantially lower than the value used by Huijser et al. (2009). Other parameters and values were either new (e.g. for electric mats) (Table 10) or they remained the same as in Huijser et al. (2009) (Table 11). The analyses were conducted for a 75 year long time period and for a discount rate of 3% (see Huijser et al. (2009) for further details on the methodology).

Table 11: Standardized costs for wildlife fencing, fence end treatment, underpass and wildlife jump-pouts used for the analyses in this report.

	Costs (/km) Wildlife fencing (woven wire)	Costs (/km) Wildlife fencing (electric)	Costs (/underpass) (7 m wide, 4-5 m high) Large mammal underpass	Costs (/structure) Jump-out	Costs (/fence end) Electric mat at fence end
Planning	$0	$0	$50,000	$0	$0
Construction	$98,000	$84,000	$500,000	$5,900	$31,667
Structures (n/km)	n/a	n/a	0.5	7	n/a
Maintenance (/yr)	$500	$500	$1,000	$0	$500
Life span (yrs)	25	25	75	75	10
Removal costs	$10,000	10,000	30,000	$0	$500

For the current report cost-benefit analyses were conducted for four different types and combinations of mitigation measures (Table 12).

Table 12: Mitigation packages included in the cost-benefit analyses and the functions included in the individual packages.

	Keep wildlife from entering road	Allow wildlife to escape the fenced road corridor	Warn drivers and traffic calming in fenced road corridor	Allow humans to get in and out of the fenced road corridor	Provides safe crossing opportunities for wildlife
Wildlife fencing (woven wire) only	Yes	No	No	No	No
Wildlife fencing (electric) only	Yes	No	No	No	No
Wildlife fencing (woven wire) in combination with one large mammal underpass (about 7 m wide, 4-5 m high) every 2 km	Yes	No	No	No	Yes
Wildlife fencing (woven wire) in combination with one large mammal underpass (about 7 m wide, 4-5 m high) every 2 km, and 7 wildlife jump-outs per km road length (see Huijser et al. (2009) for spatial arrangement of the number of jump-outs)	Yes	Yes	No	No	Yes

Huijser et al. (2009) did not include fence gap or fence end treatments in their analyses. The number of fence gaps is of course dependent on the number of access roads which in turn is highly variable given the specific road section that may be of interest. However, it is best to minimize access roads as mitigation measures at access roads may still be a "weak spot" in the fenced road corridor, and since the fence gap treatments are more expensive than wildlife fencing it would also increase the costs associated with the implementation of the mitigation package. Because of the variable nature for the number of fence gap treatments that may be required, fence gap treatments at access roads were not included in the cost-benefit analyses for this report. Fence end treatments were included as an "add-on analysis" as the number of fence end treatments required is always the same; one for each fence end. The complication is that the relative costs (costs per km per year) for fence end treatments depend on the road length fenced; the longer the fenced road section, the lower the costs per kilometer per year. Therefore an analysis was conducted to investigate the effect of road length on the costs per kilometer of the mitigation measures. This analysis was only conducted for the 4th mitigation package listed above: "Wildlife fencing (woven wire) in combination with one large mammal underpass (about 7 m wide, 4-5 m high) every 2 km, and 7 wildlife jump-outs per km road length (see Huijser et al. (2009) for spatial arrangement of the number of jump-outs)." The type of fence end treatment was an electrified mat embedded into the pavement (Table 11). The "add-on" analyses for fence ends was conducted for the following road lengths: 1, 2, 3, 4, 5, and 10 km. These road sections were projected to have the following number of wildlife underpasses: 1 (for 1 km), 1 (for 2 km), 2 (for 3 km), 2 (for 4 km), 3 (for 5 km), and 5 (for 10 km).

The output of the cost-benefit analyses are "threshold values." Threshold values are the minimum amount of "benefits" (e.g. expressed in US$) that need to be generated (e.g. through reducing collisions with large ungulates) in order for a mitigation measure package to pay for itself. The benefits were also expressed as the number of wild ungulates-vehicle collisions that need to occur on an "unmitigated" road section in order for the different mitigation measure packages to pay for themselves through a reduction in wildlife-vehicle collisions (assuming 86% effectiveness in reducing collisions with large mammals). Because the costs associated with a collision with larger species are higher than for smaller species (see Huijser et al., 2009a), the threshold values (expressed as the number of wild ungulates-vehicle collisions) are higher for deer than for elk or moose. This essentially means that more deer-vehicle collisions than elk- or moose-vehicle collisions need to be prevented through the implementation of the mitigation measures in order for the mitigation measures to pay for themselves.

While two of the four mitigation measure packages include wildlife fencing only, the researchers consider the implementation of wildlife fencing as a stand-alone mitigation measure bad practice. It is considered good practice to not increase the barrier effect of roads and traffic without also providing for effective and safe crossing opportunities. The "wildlife fence only" packages are for illustrative purposes only.

4.3. Results

The "threshold values" for the four different mitigation packages (see Table 12; for input values see Table 11) are summarized in Table 13.

Table 13: Threshold values for four different types and combinations of mitigation measures (each of these is estimated to reduce collisions with large ungulates by 86% (see review in Huijser et al., 2009a).

	Wildlife fence (woven wire)	Wildlife fence (electric)	Wildlife fence and underpass	Wildlife fence, underpass, and jump-outs
US$ ($)	$6,419	$5,615	$16,766	$18,157
Deer (n)	1.13	0.99	2.95	3.19
Elk (n)	0.43	0.37	1.12	1.21
Moose (n)	0.24	0.21	0.63	0.69

The average electric wildlife fence was less expensive than the average woven wire wildlife fence, resulting in lower threshold values. Adding large mammal underpasses substantially increases the thresholds, but subsequently adding wildlife-jump-outs resulted in a relatively small increase of the thresholds.

Adding an electrified mat to the fence end to woven wire wildlife fencing, large mammal underpasses, and wildlife jump-outs was relatively expensive for short road sections (Figure 70). If the mitigation measures are implemented over longer distances (e.g. at least 3-5 km in road length), then the costs for the mitigation measures per kilometer are reduced. When the threshold measured in US$ is translated into the number of deer, elk or moose-vehicle collisions that need to occur on an unmitigated road for the mitigation package to break even, the cost reductions (per kilometer mitigated road) are most noticeable for the smallest large wild ungulate included in the analysis; deer.

The jagged nature of the lines in Figure 70 is because the analyses were conducted based on real world configurations for the mitigation measures, specifically the underpasses. The analyses included one overpass per 2 km, but both a 3 and a 4 km long road section required 2 underpasses (the 3 km long section did not require 3.5 underpasses). This meant that the costs per kilometer for uneven road lengths (e.g. 1, 3, 5 km) were always relatively high compared to even road lengths (e.g. 2, 4, 10 km).

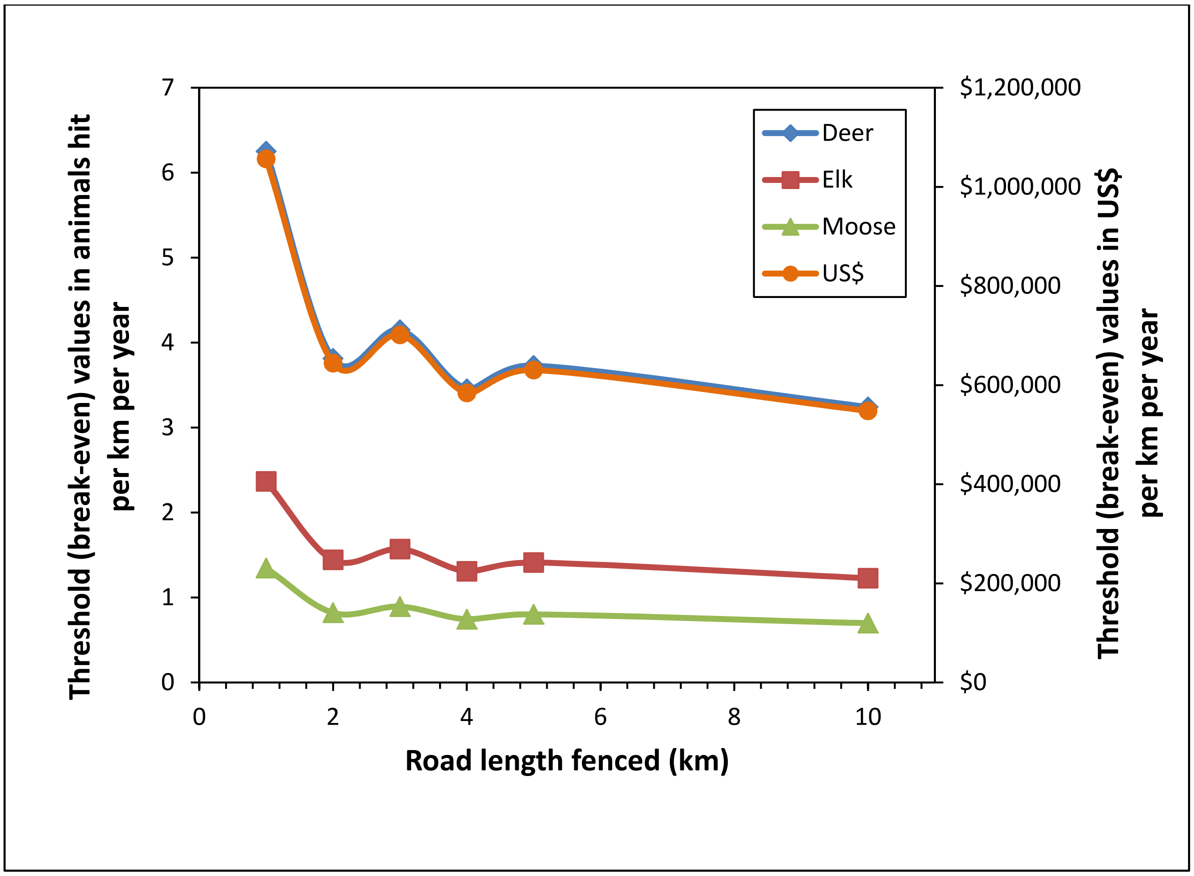

Figure 70: The thresholds expressed in US$ (right vertical axis) and in animals hit per kilometer per year (left vertical axis) for a wildlife fences (woven wire) in combination with a large mammal underpasses (once every 2 km), wildlife-jump-outs (7 per kilometer) and electric mats at the two fence ends in relation to the length of the road length fenced.

4.4. Discussion and Conclusions

4.4.1. Cost Estimates for the Mitigation Measures

Electric wildlife fencing is, on average, a little less expensive than woven wire wildlife fencing. However, most woven wire fences are not only a barrier to large mammals, but also to medium sized mammals, whereas typical electric fences contains of strands that allow medium sized mammals to still crawl under the fence. However, there are electric fence designs specifically for medium sized mammals available. Since the fence costs for mesh wire fencing based on the survey (see Chapter 3) were very similar to earlier estimates from Huijser et al. (2009), the threshold values for wildlife fencing are very similar to those presented by Huijser et al. (2009). However, the respondents reported that average cost for a wildlife jump-outs was considerably lower than estimated by Huijser et al. (2009), and new estimates were available for fence end and fence gap treatments.

4.4.2. Mitigation Packages Considered

While the cost-benefit analyses conducted for this report included two mitigations measure packages with wildlife fencing only (excluding safe crossing opportunities for wildlife), the associated analyses were for illustrative purposes only. Wildlife fencing without safe crossing opportunities for wildlife can substantially reduce wildlife-vehicle collisions and can improve human safety. However, well designed wildlife fencing also increases the barrier effect of roads and traffic to wildlife, perhaps to a level where the transportation corridor is an almost impermeable and absolute barrier. Small and isolated wildlife populations are at greater risk of extinction or extirpation than large and well connected wildlife populations. Therefore the researchers consider it good practice to never increase the barrier effect of roads and traffic without also providing for safe and effective wildlife crossing opportunities.

The other two mitigation packages did include safe crossing opportunities for wildlife. Only large mammal underpasses were considered (one every 2 km) for the analyses. However, depending on the requirement of the target species, other types, dimensions and spacing of crossing structures may need to be considered. One of the mitigation packages also included jump-outs that are designed to allow wildlife that is caught in the fenced road corridor to jump to the safe side of the fence. The authors of this report consider the latter mitigation package most appropriate. However,

4.4.3. Relative Costs per Kilometer Road Length Mitigated

Fence end treatments, specifically electric mats embedded in the pavement, are likely to reduce intrusions of wildlife (e.g. large ungulates) into the fenced road corridor and increase the effectiveness of the mitigation measures in reducing wildlife-vehicle collisions. However, the costs associated with fence end treatments are relatively high for short fenced road sections. The costs for the mitigation measures, expressed as costs per kilometer mitigated road, are lower if the fenced road sections are at least 3-5 km in length. The authors of this report do recommend including fence end treatments in potential mitigation efforts, especially if the road section that is mitigated is relatively short in relation to the length of a mortality hotspot and recommended buffer zones.

5. RECOMMENDATIONS

5.1. Recommendations vs. Best Management Practices

A best practice can be defined as "a method or technique that has consistently shown results superior to those achieved with other means, and that is used as a benchmark." In addition, a "best" practice can "evolve to become better as improvements are discovered." While some research has been conducted and published with regard to the design, implementation and maintenance of wildlife fencing as well as the effectiveness of wildlife fencing in reducing wildlife-vehicle collisions (see literature review), there is insufficient data based on comparative tests for the different fence designs and associated mitigation measures to describe certain designs as "best practice." In addition, the survey mainly describes what practitioners have implemented rather than what has been investigated and proven to be effective. However, the authors of this report are comfortable providing "recommendations" based on the limited amount of information that is currently available.

5.2. Design Recommendations

5.2.1. Always Combine Wildlife Fences with Safe Crossing Opportunities

Wildlife fencing has two functions:

1. Reduce access of wildlife to the highway, thereby reducing the probability of wildlife-vehicle collisions (see e.g. Huijser et al., 2008a; Clevenger & Huijser, 2011).
2. Help guide wildlife to safe crossing opportunities (e.g. wildlife overpasses or underpasses) (see e.g. Dodd et al., 2007a; Gagnon et al., 2010), thereby increasing wildlife use of the safe crossing opportunities.

If wildlife fencing is designed, implemented and maintained correctly, the highway corridor becomes an almost absolute barrier to wildlife. This is especially problematic for species that have home ranges that are larger than the areas within the meshes of the road network, or for species that need to be able to migrate between habitat patches on both sides of a highway in order to have a viable population in the region. Therefore it is considered good practice to always combine wildlife fencing with safe crossing opportunities for wildlife. It is considered bad practice to only implement wildlife fencing without safe crossing opportunities for wildlife as fencing alone (without safe crossing opportunities for wildlife) is likely to negatively affect at least some species (including species that may not have been identified as a "target species" by the project) at the population level (Jaeger & Fahrig, 2004).

Similar to wildlife fencing, safe crossing opportunities for wildlife have two functions as well:

1. Provide safe and effective crossing opportunities to the other side of the highway for wildlife, thereby providing habitat connectivity for wildlife (see e.g. Clevenger & Huijser, 2011).

2. Help reduce wildlife intrusions into the right-of-way, thereby further reducing the probability of wildlife-vehicle collisions.

While wildlife crossing structures (i.e. underpasses and overpass) are not part of the current report, it is important that such crossing opportunities:

1. Are designed for the target species. Different animal species have higher or lower use rates for different types and dimensions of crossing structures (see e.g. Clevenger & Huijser, 2011). The structures should meet the requirements of the target species.
3. Are located at the correct locations. The structures need to be constructed where the target species are or are most likely to approach and cross the highway.
4. Are provided in sufficient numbers, avoiding long road sections with wildlife fencing without safe crossing opportunities for wildlife (e.g. Bissonette & Adair, 2008).

The basic requirements for safe wildlife crossing opportunities listed above imply that existing structure that were constructed for other purposes (e.g. stream or river crossing, low volume road, livestock) are not necessarily of the correct type or dimensions for the target species. In addition, existing structures may not be located where the target species approach and cross the road, and existing structures may also be too far apart given the home range size of the target species or their willingness to walk long distances parallel to the wildlife fencing looking for a suitable crossing opportunity.

No matter how well a wildlife fence is designed, installed and maintained, there will always be some situations where animals may end up in the fenced road corridor through jumping, climbing, digging, or pushing over, under or through the wildlife fencing. If attractive safe crossing opportunities are provided with a design (type, dimensions) that matches the requirements of the target species, if the crossing structures are built at the correct locations, and in sufficient numbers, the target species may use these safe crossing opportunities instead of breaching the fence. Therefore, the effectiveness of wildlife fencing in reducing wildlife-vehicle collisions can be (somewhat) increased by providing safe crossing opportunities for wildlife.

At grade crossing opportunities are part of the current report. Between the literature review and the survey at grade crossing opportunities are implemented on roads that have relatively low traffic volume: a few thousand up to perhaps 14,000 vehicles per day at a maximum. For high volume roads (certainly for highways with more than 15,000 vehicles per day), a physical separation of traffic and wildlife (i.e. underpasses and overpasses) is highly preferable. The gap width varied between about 10-300 m, but it appears that a gap width of several tens of meters (e.g. 30 m up to perhaps 100 m) strikes a good balance between providing a large enough opening that may encourage wildlife to approach the road while also encouraging wildlife to cross the road rather than spend time on or along the road. In addition, drivers may still experience this distance as a “spot” rather than as a road section and they may therefore be more alert or more likely to reduce the speed of their vehicle. Mandatory or advisory speed limit reduction in combination with traffic calming measures (e.g. speed bumps and/or bulb-outs) may be considered, especially at low volume roads that may have a low design speed already. Adding an animal detection system to the gap is likely to further reduce the likelihood of wildlife-vehicle collisions at a gap. Warning signs associated with an animal detection system should preferably include advisory or mandatory speed limit reduction when activated.

5.2.2. Define the Problem and Select the Mitigation Measures Accordingly

While it may be obvious and clear in some cases, it is important to explicitly define the problem and the species involved (target species). For example, possible "problems" that may lead to the consideration of wildlife fencing and associated measures are:

1. Human safety: A relatively high number of collisions with large common mammals along a highway section (e.g. Huijser et al., 2007; Cramer et al., 2014). The species are generally large mammals as they must be large enough to cause substantial vehicle damage and to be a substantial threat to human safety. The species are also typically common as they must be abundant enough for the collisions to occur in relatively high numbers.
2. Biological conservation:
    a. Current or possible future direct road mortality of selected wildlife species as a result of a collision with a vehicle. This typically relates to rare or threatened species that are a conservation concern and for which unnatural sources of mortality should be minimized. The species can be from any taxonomic group (e.g. mammals, birds, reptiles, amphibians), and their body size does not matter. The species concerned may only be present in low numbers in crash or carcass data. Rare and threatened species can even be absent from crash and carcass data because they are rare, because crash and carcass data do not include every crash or carcass that has occurred, and because rare and threatened species may be (legally or illegally) removed before the crash or carcass can be recorded by law enforcement or transportation organization personnel.
    b. Current or potential future movements across the landscape (and the highway) of selected wildlife species that may have low or lower population viability in the region if they would be isolated within the meshes of the road network. This typically relates to rare or threatened species that are a conservation concern and for which unnatural sources of mortality should be minimized. The species can be from any taxonomic group (e.g. mammals, birds, reptiles, amphibians), and their body size does not matter. The type of information required can include crash and carcass data, but it most often also includes data on wildlife movements and/or establish or projected areas designated as core areas and corridors.
3. Economics: The costs associated with large mammal-vehicle collisions are considered "too great of a financial burden to society" (e.g. vehicle repair costs, costs associated with human injuries and fatalities).

Each type of problem is likely to have its own specific objective, data type, analyses, and "success parameter." Note that the road sections that may be identified and prioritized based on human safety concerns are not necessarily the same road sections that would be identified and prioritized based on biological conservation parameters. However, wildlife fencing and associated measures (including safe crossing opportunities for wildlife) can play a role in addressing all of the different types of problems described above.

5.2.3. The Context of the Landscape

Mitigation measures in protected areas.
Wildlife fencing and associated measures can affect landscape aesthetics in any landscape type. National Parks or other protected areas typically have scenic landscapes and many people do not want to have an obstructed view. However, the severity of the impact of wildlife fences and associated impacts on landscape aesthetics must be weighed against the impact of the road and the traffic on the environment (specifically wildlife) and the risks for human safety. It appears wildlife fencing and associated measures are almost always appropriate with high traffic volumes and a high design speed, indicative of the purpose of the highway; a through-highway that just happens to go through a protected area. The main interest of the people traveling on these highways is, in general, not with the scenic landscape or the wildlife; it is to travel from one point to another in a safe and efficient way, and the area surrounding the highway is of secondary importance. On the other hand, relatively low volume roads with a relatively low design speed may provide access to different places within the protected area. The purpose of these roads may predominantly be to enable people to enjoy the scenery and wildlife, including what they may encounter between different scheduled stops. Wildlife fencing and associated measures are generally not appropriate or less appropriate for roads if the people that travel on these roads are primarily there to enjoy the scenery. Wildlife fencing and associated measures would not only obstruct the view, but they also increase the “distance” to nature and the physical separation from nature. This is the opposite of what most managers of protected areas have in mind; they would like to see people that visit the areas connect with nature rather than disconnect from nature.

Mitigation measures in multi-functional landscapes.
Most roads and highways in multifunctional landscapes are there to enable people to travel to and from places; the roads and highways are – in general – not built for people to enjoy the landscape. In addition, given the multiple uses of a multifunctional landscape (e.g. agriculture, villages, and cities) the native vegetation may not exist anymore. This suggests that landscape aesthetics may not be as an important of an issue if a road section needs to be mitigated. However, in reality there can be opposition against wildlife fencing and associated measures. People that live in the “country” may not appreciate a tall wildlife fence adjacent to or near their property as the view from their home or property is obstructed or because they do not want to feel “fenced in.” In addition, access roads in a fenced road section require measures such as gates, wildlife guards or electric mats or electric concrete. Local landowners may experience such structures as time consuming, uncomfortable or dangerous. Minimizing the number of access points likely improves the effectiveness of the mitigation measures in reducing wildlife-vehicle collisions, but that may result in frontage roads that combine multiple driveways or side roads which can somewhat increase travel distance for the people that use these roads. While all of these concerns can be valid, they must be weighed against the problem at hand (e.g. wildlife-vehicle collisions with potentially serious implications for human safety and biological conservation). Regardless, because of public pressure transportation agencies may be tempted to provide safe crossing opportunities without wildlife fencing or very limited wildlife fencing. While this may sound like a workable compromise short mitigated road sections are likely to have fence end effects that jeopardize the overall effectiveness of the mitigation measures that are implemented (see next paragraph). In other words, the investments in wildlife fencing and associated mitigation measures do not generate as many benefits as they could if the road

sections that are mitigated are short in length. The authors of this report suggest implementing wildlife fencing and associated measures for large mammals over at least several kilometers (see later), and not shorter.

5.3. Decide on the Spatial Configuration of the Mitigation Measures

5.3.1. Fence Length

Cover the entire hotspot as well as additional buffer zones on each end.
Wildlife fences for large mammals are typically installed at locations where concentrations ("hotspots") of large mammal-vehicle collisions occur. To be effective in reducing wildlife-vehicle collisions, the fences need to cover the entire road length of the hotspot. However, the fencing needs to extend further than the actual hotspot to prevent animals that approach the road at the hotspot from simply walking to the fence end and crossing at grade ("fence end run") (e.g. Bissonette & Rosa, 2011). The radius or diameter of the home range for the target species in combination with the length of the "hotspot" can be used to decide on the appropriate length of the fence (Bissonette & Adair, 2008; Huijser et al., 2008b). Thus, the road length fenced should cover the entire length of a mortality hotspot as well as a buffer zone extending from each end of a hotspot. The authors of this report suggest that the length of the buffer zone (extending from the edge of a hotspot) for deer (Odocoileus spp.) is about 1000 m (3,280 ft).

Do not block successful wildlife crossings.
Wildlife fencing should always be combined with safe and effective crossing opportunities for wildlife. Wildlife fencing should not be installed at road sections where wildlife may currently cross the road successfully, at least not without also providing for safe and effective wildlife crossing opportunities. In other words, the location of safe crossing opportunities should not only be based on observations of dead animals (unsuccessful crossing attempts), but also on observations of wildlife that is alive on or near the road (successful crossing attempts). Wildlife fencing should not inadvertently block animals from crossing the road simply because no or few animal were hit before the fencing was implemented.

Wildlife fencing is likely more effective if implemented over long distances.
Regardless of the length of a wildlife fence, there are is always a start and an end point. These start and end points can be "messy" because of a "fence end run" or because animals may enter the fenced road corridor at a fence end. Extending the fence to include a buffer zone in addition to a "hotspot" (see earlier), and installing "fence end treatments" (e.g. wildlife guards, electric mats or electric concrete) can reduce the likelihood of a concentration of wildlife-vehicle collisions at or near a fence end. However, there may still be a certain "fence end effect." The area affected by the fence end effect is - at least theoretically - constant. This implies that shorter sections of fence are more likely to experience an influence of the fence end effect than longer sections of fence, and that road sections that are fenced over a greater distance are more likely to have a substantial reduction in wildlife-vehicle collisions than road sections that are fenced over a relatively short distance. In addition, the location of wildlife-vehicle collisions or wildlife

carcasses has a certain level of accuracy (or inaccuracy). If the crash or carcass data are collected to within 0.1 km (or 0.1 mi) accuracy, then the effectiveness of road sections with "only" 0.2 km (or 0.2 mi) of wildlife fencing may be entirely affected by the inaccuracy of the crash or carcass data. In contrast, a road section that is fenced over 5 km only has a small influence of potential data inaccuracies (assuming the spatial accuracies of crash and carcass data are 0.1 km or 0.1 mi). Fence end effects and inaccuracies in the crash or carcass data suggest that relatively long road sections with wildlife fencing are more likely to reduce wildlife-vehicle collisions or more likely to demonstrate such a reduction than shorter road sections. This suggests that it is preferable to implement wildlife fencing over long road sections than short road sections.

Fence at least 3-5 km of road to reduce the relative costs per km.
The relative costs of wildlife fencing and associated measures per kilometer (or mile) decreases with increasing fence length (see Chapter 4, cost-benefit analyses). This is because the costs for fence end treatments (e.g. wildlife guard, electric mat or electric concrete) are "diluted" if the road length fenced is increased. Based on the cost-benefit analyses it appears that the relative costs of the mitigation measures (fencing and associated measures including fence end treatments) are relatively high for road lengths shorter than 3-5 km and relatively low for road sections longer than 3-5 km. Combined with the possible fence end effects (see earlier) and possible inaccuracies in crash and carcass data (see earlier), it appears that the most effective wildlife fencing is at least 3-5 km long in road length, both in terms of actual or demonstrable crash reduction and relative costs per km (or mi).

5.3.2. Fence Configurations and Fence End Locations

Implement wildlife fencing on both sides of the highway and do not stagger the fence.
Wildlife fencing should typically be implemented on both sides of a road with the fence ends ending opposite of each other. If a fence is present on one roadside only, animals that approach from the other side still get on the road, and they may spend more time on the road because a fence on the other side of the road does not allow them to leave the road corridor. Fence ends that do not end on opposite sides of the road (i.e. "staggered") can lead to similar problems, and they may result in an increased probability that animals wander off into the fenced road corridor rather than cross at grade at a fence end.

Consider positioning the fence a little in from the right-of-way boundary.
Wildlife fencing should typically be positioned outside of the clear zone. In most cases wildlife fencing is positioned on the right-of-way boundary where it replaces the right-of-way fence. However, it may be more practical to place the wildlife fence a little closer to the highway to allow for legal access and/or easy physical access for mowing or cutting of vegetation and maintenance of the wildlife fence.

End a fence at a wildlife crossing structure or at suitable landscape features if possible.
A wildlife crossing structure at a fence end may reduce "fence end runs" (Allen et al., 2013). However, if the road length fenced includes the entire length of a hotspot and adjacent buffer zones, a wildlife crossing structure at a fence end may not be used very much. Therefore - at a micro scale – consider having the location of fence ends coincide with topography or other

landscape features to reduce the probability of fence end runs. Steep slopes (road cut or fill), river crossings, or areas with relatively high levels of human presence and disturbance are good examples of where one may choose to have a fence end.

Consider ending the fence at a straight road section with good visibility for drivers.
When large mammals are among the target species and human safety is a concern, consider ending the fence at a straight road section with good visibility for drivers.

Consider a warning sign at the end of a fenced road section.
A warning sign at the end of a fenced road section would alert drivers that the upcoming road section is not equipped with mitigation measures aimed at keeping large mammals off the highway.

Consider bringing the fence ends close to the pavement.
Bringing the fence ends close to the pavement is likely to reduce the probability of wildlife entering the fenced right-of-way by walking in the right-of-way. This typically brings the wildlife fence, including the end post in the clear zone. This can be mitigated by constructing a guard rail or a Jersey barrier so that vehicles cannot crash directly into the fence or fence post.

Consider placing a wildlife guard (bridge grate material) or electric mat or electric concrete on highway at fence ends.
In combination with bringing the fence end close to the pavement (see previous point), a wildlife guard (bridge grate material) or an electric mat or electric concrete are likely to substantially reduce intrusions into the fenced road corridor at a fence end.

5.3.3. Target Species and Design of the Fencing

The design of the mitigation measures, including wildlife fencing, should be based on the biological characteristics and requirements of the target species. For example, a mountain lion (*Puma concolor*) is a very capable climber and jumper, and canids are capable to dig under a fence. Thus, for each of the target species their ability to jump, climb, dig, or push over, under or through the wildlife fencing or associated measures should be carefully assessed based on the knowledge and expertise of experts. The wildlife fencing and associated measures should then be designed accordingly (see Table 14 through 17 for suggestions). While large mammals, particularly large ungulates, tend to receive most attention when implementing wildlife fencing and associated measures, amphibian and reptile species may suffer more from direct mortality with severe consequences for their population survival probability in an area or even within the United States as a whole (Huijser et al., 2008a).

Table 14: Wildlife fence design recommendations for fence design for ungulates (Partially based on Kruidering et al., 2005; Clevenger & Huijser, 2011).

Target species (group)	Fence height (m)	Fence material	Dig barrier required	Overhang required	Post type
Deer (*Odocoileus* spp.)	2.4	Woven wire, (12.5 gauge, mesh size 15-18 cm (6-7 inches)) or electric (potentially only 1.8 m high)	No	No	Wood (diameter 13 cm (5 inches) for line posts and at least 16 cm (6.5 inches) for corner posts), metal or fiberglass (wood posts typically 4.2-5.4 m (10-18 ft) apart and 0.9-1.2 m (3-4 ft) deep
Elk (*Cervus canadensis*)	2.4	Woven wire, (12.5 gauge, mesh size 15-18 cm (6-7 inches)), or electric	No	No	Wood (diameter 13 cm (5 inches) for line posts and at least 16 cm (6.5 inches) for corner posts), metal or fiberglass (wood posts typically 4.2-5.4 m (10-18 ft) apart and 0.9-1.2 m (3-4 ft) deep
Moose (*Alces alces*)	2.4	Woven wire, (12.5 gauge, mesh size 15-18 cm (6-7 inches)) or electric* *entanglement in electric fence has been observed	No	No	Wood (diameter 13 cm (5 inches) for line posts and at least 16 cm (6.5 inches) for corner posts), metal or fiberglass (wood posts typically 4.2-5.4 m (10-18 ft) apart and 0.9-1.2 m (3-4 ft) deep
Pronghorn (*Antilocapra americana*)	2.4 m is a substantial barrier, but lower fence height may also be suitable	Woven wire (12.5 gauge, mesh size 15-18 cm (6-7 inches)) or electric	No	No	Wood (diameter 13 cm (5 inches) for line posts and at least 16 cm (6.5 inches) for corner posts), metal or fiberglass (wood posts typically 4.2-5.4 m (10-18 ft) apart and 0.9-1.2 m (3-4 ft) deep
Bighorn sheep (*Ovis canadensis*)	3.0	Woven wire (12.5 gauge, mesh size 15-18 cm (6-7 inches)) or electric	No	No	Wood (diameter 13 cm (5 inches) for line posts and at least 16 cm (6.5 inches) for corner posts), metal or fiberglass (wood posts typically 4.2-5.4 m (10-18 ft) apart and 0.9-1.2 m (3-4 ft) deep

Table 15: Wildlife fence design recommendations for fence design for carnivores (Partially based on Kruidering et al., 2005; Clevenger & Huijser, 2011).

Carnivores					
Red fox (*Vulpes vulpes*)	1.8	Woven wire (12.5 gauge, mesh size 8 cm (3 inches)) or chain-link	Yes	No	Wood or metal
Coyote (*Canis latrans*)	1.8	Woven wire (12.5 gauge, mesh size 8 cm (3 inches)) or chain-link	Yes	No	Wood or metal
Wolf (*Canis lupus*)	2.4	Woven wire (12.5 gauge, mesh size 8 cm (3 inches)) or chain-link	Yes	No	Wood or metal
Mountain lion (*Puma concolor*)	3.0	Chain-link	Yes	Yes	Metal
Black bear (*Ursus americanus*)	3.0	Chain-link	Yes	Yes	Metal
Grizzly bear (*Ursus arctos*)	2.4	Woven wire (12.5 gauge) or chain-link	Yes	No	Wood or metal

Table 16: Wildlife fence design recommendations for fence design for amphibians and reptiles (Partially based on Kruidering et al., 2005; Clevenger & Huijser, 2011).

Amphibians (toads, frogs (excl. tree frogs), salamanders	0.4-0.6	Smooth plastic sheets (high-density polyethylene (HDPE) or barrier wall (e.g. plastic, composite or concrete)	Yes (0.1 m in ground	(Yes)	Wood or metal
Snakes, lizards	0.6-1.1	Smooth plastic sheets (high-density polyethylene (HDPE) or barrier wall (e.g. concrete)	Yes (0.1 m in ground	(Yes)	Wood or metal
Turtles and tortoises	0.3-0.6	Chain-link, barrier wall (e.g. concrete), or mesh wire fencing (e.g. 1x1 cm (0.4x0.4 inches) or 1.3x1.3 cm(0.5x0.5 inches) or 2.5x5.0 cm (1x2 inches)), sometimes with aluminum flashing (10-15 cm (4-6 inches) wide) at the top	Yes (0.05-0.20 m in ground)	(Yes)	Wood or metal
Alligators, crocodiles	1.1	Chain-link or concrete barrier wall		Yes (0.15 m)	

Table 17: Fence end and access point recommendations for different species and species groups.

Location and Purpose of Measures	**Main measure**			**Additional or supportive measures**
	Type	**Width**	**Features**	
Fence end	For ungulates: Electric mat/concrete or wildlife guard (modified bridge grate). Note: wildlife guards with bars are not suitable for high speed and high volume traffic. For non-ungulates (e.g. canids, felids, bears) use electric mat/concrete or electrified wildlife guard.	Electric mat/concrete: 1.8 m. Wildlife guards: at least 3 m, preferably about 6 m.	Electric mat or concrete can be heated to melt off snow and ice. Electric mat or concrete can be accompanied by a safety button that temporarily cuts off the electricity (e.g. for pedestrians or horseback riders).	Bring fence end close to pavement, protected with guard rail. Extend wildlife fence alongside the mat or guard. For wildlife guards: make the concrete ledge of the pit across its entire length inaccessible to wildlife. For wildlife guards: provide escape ramps for small animals that may fall into the pit under wildlife guard. Alternatively, allow for escape opportunities on the side of the pit.
Access road for motorized vehicles	Electric mat/concrete or wildlife guard. Note: if a wildlife guard is used on a an access road with high traffic volume, then use modified bridge grate rather than bars	See row above	See row above	See last 3 points row above
Trail for hikers or fishing access	Swing gate	Variable, dependent on type of use	Consider positioning gate at an angle so that gravity automatically closes the gate.	Consider a concrete base for a close fit and to keep wildlife from digging and crawling under gate.
Trail for bicyclists	Wildlife guard (modified bridge grate is most suitable, safe and comfortable)	Variable, dependent on type of use		See last 3 points in first row.
Trail for horseback riders	Carousel	Variable, dependent on type of use	Consider positioning central post at an angle so that gravity automatically closes the gate.	Consider a concrete base for a close fit and to keep wildlife from digging and crawling under carousel.

Table 18: Escape opportunities for wildlife from the right-of-way.

Species or species group	Height (m)	Additional or supportive measures
Deer (*Odocoileus* spp.), elk (*Cervus*	1.5-1.8	Consider placing a bar or plank about 40 cm above the top

canadensis)		of the jump-out to make it harder for wildlife to jump up (while not making it harder to jump down) Place flat landing pad (e.g. sand) starting about 1.5-1.8 m from the base Consider placing a short fence perpendicular to the main wildlife fence on top of the wildlife jump-out For climbers (e.g. bears), consider attaching a smooth metal plate to the wall of the jump-out.
Bighorn sheep (*Ovis canadensis*)	1.8-2.1	See points in previous row.

Despite specifies-specific recommendations (Table 14 through 16), there are typically multiple target species present in an area. In those situations design the fence based on the highest requirements. For example, the jumping capabilities of one species may dictate fence height (e.g. Foster & Humphrey, 1995) while the digging capabilities of another target species may dictate the need for a dig barrier. However, target species represent a selection of the species that are present in an area, and non-target species may also threaten the integrity of the wildlife fence. Therefore it is advisable to also evaluate the potential effect of non-target species on the integrity of the fence. For example, if deer (*Odocoileus* spp.) is the target species, no dig barrier may be required. However, if coyotes are abundant in the area, coyotes may frequently dig under the wildlife fence. These openings under the fence may then also be used by other wildlife species and the openings may eventually become large enough for the target species (e.g. deer) to enter the fenced road corridor. This may lead to the installation of a dig barrier even though the target species itself (e.g. deer) is not the actual species that is likely to dig under the fence.

Barrier walls that are integrated into the roadbed are very effective in keeping amphibians (excluding tree frogs) and reptiles (including snakes, turtles and tortoises) off the highway. An additional advantage of sturdy (e.g. concrete) barrier walls is that they do not require much maintenance and they stand up to activities in the right-of-way (e.g. mowing). A further advantage of barrier walls that are integrated into the roadbed is that, contrary to wildlife fencing, they do not affect landscape aesthetics. The authors of this report do not recommend geotextile or other fabric as fencing material for reptiles or amphibians as this material is highly susceptible to wear and tear and erosion and does not keep these species groups off the highway (Baxter-Gilbert, 2014).

If multiple types of fencing are required for different target species they can often be combined into one design (Kruidering et al., 2005). For example, medium sized mammals may require smaller mesh sizes (e.g. 8 cm) than large mammals (15-18 cm) the first section from the ground whereas amphibians may require plastic sheeting the first 50 cm from the ground. A buried apron (1.2-1.5 m wide), angled away from the road at a 45° angle, may be attached to the fence to discourage animals from digging under the fence. A steel cable (e.g. 3/16-inch stainless steel) on top of the fence can reduce the damage from falling trees, reduce subsequent intrusions of wildlife into the fenced road corridor and reduce maintenance costs and effort. If the fence is positioned on a slope with the highway at the downside, fence height may have to be adjusted to keep wildlife from jumping into the fenced road corridor. Measure functional fence height from about 1-2 m on the uphill side of the fence.

The authors of this report highly recommend the implementation of fence end treatments, including on the actual pavement, especially if the fenced road sections are relatively short in relation to the length of the hotspot and recommended buffer zones (see earlier), and if the fence does not end at topographic or landscape features (e.g. steep slopes or river) that are a natural barrier for the target species. The purpose of fence end treatments is to discourage wildlife (the target species) from entering the fenced road corridor at the fence ends.

For high volume access roads and access roads with many users (e.g. in contrast to one land owner) the authors of this report suggest using wildlife guards with bridge grate material, electric mats or electric concrete. For low volume access roads with one or a few landowners, consider using wildlife guards with metal bars or gates (locked or unlocked).

While standard in parts of North Western Europe, escape opportunities for small animals that may fall into the pit under a wildlife guard are typically absent in North America. The authors of this report recommend installing escape opportunities for small animals (e.g. toads, frogs, salamanders, snakes, invertebrates, small mammals) at each pit associated with a wildlife guard.

The authors of this report do not recommend painting stripes on the pavement as an alternative to real wildlife guards as they are proven to be ineffective in keeping wildlife out of the fenced road corridor.

The authors of this report do not recommend the use of one-way gates with spring-loaded tines to allow ungulates to escape from the fenced road corridor. These types of one-way gates have been found to eventually become two-way gates and wildlife may also suffer injuries or death in certain situations. One way gates with hinges have been used for medium mammal species in Europe. For those types of one-way gates it is important to have a level hard surface (e.g. concrete pad) to ensure a tight fit to the ground. In addition, regular removal of debris may be required to prevent the one-way gate from accidentally remaining open or half open.

5.3.4. Climate and Other Abiotic Processes and Design Considerations

Fence design may not only be influenced by the biological characteristics and requirements of the target species. Fence design may also be influenced by climate and other abiotic processes.

Rocky soil or bedrock.
Sandy or other relatively soft soils allow for a variety of fence posts to be installed. However, rocky soils or bedrock may require metal posts that are lowered into a drilled hole that is then filled with concrete.

Snow and ice.
Heavy snow and ice is less of a problem with high tensile wire and braided electric rope (flexible and small diameter for accumulation). Wire mesh tends to accumulate large loads, particularly with freeze thaw cycles weighing down on buried fence. If wire mesh fencing material is used I areas with heavy snowfall, attach it firmly to the fence posts.

Flooding and erosion.
Streams or rivers may have varying water levels and the stream or river may also change course. The fence posts and fence material may need to resist strong pressure from water, especially if debris is caught in the fence. Debris in a fence is less of a problem for electric wire, especially in combination with flexible posts. Automatic current limiters prevent shorting of electric fence in flooded areas.

Physical impact.
Trees may fall on a wildlife fence. High tensile wire on top of a wildlife fence may reduce the damage from falling trees and reduce maintenance effort and costs.

Corrosion and other wear and tear.
Naturally, a sturdy fence requires less maintenance than a fence that is constructed less robust. Thick and durable posts (treated wood, metal, potentially set in concrete), tick and galvanized wires (heavier galvanizing increase life span fence material) for the mesh fencing, and a solid attachment of the fencing material to the posts (especially in areas with high snow loads) are essential to reducing maintenance (Gagnon et al., 2010; Clevenger & Huijser, 2011; Giles et al., 2012).

5.3.5. Implementation Recommendations

Consider using trees and shrubs in the background to reduce impact on landscape aesthetics but beware of maintenance issues.
Shrubs and trees that are close to a fence can reduce the impact of a wildlife fence on landscape aesthetics, and they may make it more difficult for large ungulates to jump over a fence, but shrubs and trees may also result in higher levels of maintenance to fences (falling trees or branches) and animals that can climb shrubs and trees may use them to cross the fence more easily (Clevenger & Huijser, 2011). In addition, shrubs and trees that are close to the fence may hinder access for maintenance and increase maintenance costs. Removal of dead trees and shrubs before installation and at regular times after installation can help reduce damage to the fence from falling trees. If an electric fence is used, vegetation must be kept short to present leakage of electricity (Clevenger & Huijser, 2011). The vegetation alongside fences is typically kept short (regular mowing), especially if the fences are relatively short to begin with (e.g. medium mammal fences and reptile or amphibian fences) (Dodd et al., 2004).

Consider coating chain-link fencing to reduce impact on landscape aesthetics.
In some cases chain-link fencing has been coated in black plastic or spray-painted in natural colors (e.g. green) to reduce the visibility of the fence and to reduce the impact on landscape aesthetics.

Do not leave gaps between the bottom of the fence and the ground.
Take great care during the installation and avoid leaving gaps between the bottom of the fence and the ground level. If the terrain is uneven, consider burying part of the fence or attaching a dig barrier.

Position the fence away from streams and rivers that may be parallel to the highway.
Position the fence away from streams and rivers that may be parallel to the highway to avoid issues with flooding and erosion.

Ensure a tight connection between the wildlife fence and crossing structures.
It is extremely important that the wildlife fencing has a tight connection with a crossing structure. Crossing structures can include stream or river crossings, wildlife crossing structures, livestock crossings, low or high volume roads that cross over or under the fenced highway, etc. The fence height should be maintained everywhere, including where the fence connects to a structure and at the structure itself. In addition, wildlife fencing may run parallel to a wing wall of a structure for a certain distance. It is very important that the wildlife fence is positioned tight against the wing wall for the entire length of the wing wall. Do not allow for a “wedge” between the fence and the wing wall that may encourage the animals that want to exit the fenced road corridor to enter a “trap.”

Attach the fencing material to the side of the fence posts that is facing away from the road.
Some animals may try to ram or push through wildlife fencing. Therefore it is important that the fencing material is attached to the side of the fence posts that the animal is coming from (the side of the posts that is facing away from the highway). Do not attach the fencing material to the “highway side” of the posts.

Minimize the number of human access points, but do not exclude them.
Human access points in and out of the fenced road corridor are required for a wide range of uses and modes of transportation. Examples of different uses and modes of transportation include vehicles on side roads, biking, hiking or horseback riding on trails, and boating and fishing. While lateral access measures are available for a wide range of uses and transportation modes (e.g. gates, wildlife guards), such access points may be weak links in the fenced road corridor where wildlife may access the road more easily than crossing through, under or over the wildlife fence. This suggests that minimizing human access points is a good strategy. However, the need for access points should be recognized and it is important to engage with the local community about the need for and the location and design of human access points. If access is not provided at certain locations (e.g. at a location where people like to fish), people are likely to cut a hole in the fence anyway which would jeopardize the effectiveness of the mitigation measures.

Be creative when designing human access points.

Creative solutions for human access under challenging conditions or for particular uses have been developed. They include pedestrian access for high snow levels (steps up to a gate that is above the snow level), carousels for horseback riders that allow the rider to stay in the saddle, and push buttons that temporarily cut off the electricity to an electric mat or electric concrete (see Literature review).

Position wildlife jump-outs at all four corners of a wildlife crossing structure.
Wildlife-jump-outs should preferably be positioned at all four corners of a wildlife crossing structure to discourage wildlife inside the fenced road corridor from entering the roadway on a bridge or tunnel.

Consider positioning jump-outs in "bulb-outs" of the fence (away from the highway).
Animals that may parallel the fence on the highway side of the fence may experience the "setbacks" of the jump-outs away from the highway as an opening in the wildlife fence that may be worth exploring. As they explore they may decide to jump down to the safe side of the fence.

Position wildlife jump-outs in "quiet" areas.
Try to position jump-outs in "quiet" areas away from road. This may involve a greater distance to the road than where the standard fence line is. It may also involve cover (e.g. trees, shrubs) that provide a visual relief from traffic, allowing the animals to explore a jump-out without immediate panic resulting from nearby and very visible traffic.

5.3.6. Maintenance Recommendations

Put a monitoring and maintenance program in place for wildlife fencing (and associated measures).
Once wildlife fencing and associated measures have been constructed their condition should be monitored and when needed, repairs should be made quickly. Most large mammal fences are projected to have a life span of about 20-30 years. However, falling trees, erosion, vehicles that have left the roadway, and vandalism can all damage the integrity of the wildlife fence (see Chapter 3 for further details). A damaged wildlife fence may allow wildlife to enter the fenced road corridor, thereby jeopardizing the effectiveness of the mitigation measures in reducing wildlife-vehicle collisions. The authors of this report recommend implementing monitoring and maintenance programs for wildlife fencing that are aimed at quickly detecting and repairing damages to the wildlife fence or associated measures.

Vegetation management
The effectiveness of wildlife fencing may not only be jeopardized through issues with the fence itself. Vegetation growing next to, on, over, or through wildlife fencing or barrier walls can also cause problems and can make a fence more permeable to wildlife. A pro-active vegetation maintenance program can help prevent certain problems before they occur.

6. GAPS IN KNOWLEDGE

6.1. Need for Comparative Studies

If the objective is to ultimately have a selection of guidelines for "best practices", then this can only be achieved through research that compares different designs side by side under a range of different conditions (e.g. different target species, different environmental conditions). This will allow for the identification of the "best design", given the alternatives tested. This type of research is very rare however for wildlife fencing and associated measures (but see Peterson et al., 2003; Stull et al., 2011; Giles et al., 2012). Most studies into the effectiveness of wildlife fencing or associated measures evaluate only one design along a real world highway which results in a much slower accumulation of knowledge. Therefore the authors of this report suggest initiating more comparative studies for the most pertinent questions related to wildlife fencing and associated measures.

6.2. Suitability for the Target Species

Some designs for wildlife fences and associated measures appear to have been well evaluated, specifically for large common ungulates such as deer (*Odocoileus* spp.) (Stull et al., 2011). However, often there is little or no information available on what design of a mitigation measure (e.g. of a wildlife fence or wildlife guard) really is "best", or what design would be "minimally acceptable and functional" for one or more of the target species. Therefore the authors of this report recommend initiating comparative studies for different designs of mitigation measures and evaluating how well they perform for the species of interest (the target species). This type of research is especially important if the objective is to reduce collisions with large mammals, or if the objective is to reduce vehicle collisions for rare, threatened or endangered species; each collision that is not prevented can have grave consequences for either human safety, biological conservation or both. The authors of this report suggest considering using captive animals (e.g. in zoos or other facilities with captive wildlife) to test various designs of the mitigation measures (including fencing material, fence posts, dig barrier, overhang, but also wildlife guards, electric mats, electric concrete, different types of gates for human access, etc.). This type of research allows for a relatively large sample size in a relatively short amount of time. By providing food, water and shelter in different parts of the enclosure and by placing the mitigation measure (e.g. fence or wildlife guard etc.) strategically, researchers can maximize the movements of the animals and thus increase the sample size. In addition, experiments can be conducted with different levels of motivation for the animals (encouragement or discouragement) to navigate or breach the mitigation measures. Using captive animals is especially efficient if the target species include rare, threatened or endangered species as it may be next to impossible to obtain a reasonable sample size in the wild. The authors of this report recognize that there are likely differences between captive animals and individuals of the same species that live in the wild. However, implementing a design along a real world highway with grave consequences of potential mistakes, is much safer if that design is known to perform well for captive animals than if that design is essentially untested.

6.3. Minimum Fence Length and the Importance of Fence End Treatments.

Based on potential fence end runs, intrusions into the fenced right-of-way, and inaccuracies of the location for crash and carcass data short mitigated road sections are likely less effective than long mitigated road sections. At the same time there is pressure in society to only implement wildlife crossing structures (i.e. underpasses or overpasses) with no or short sections of wildlife fencing. The authors of this report suggest conducting research into the minimum recommended fence length for a variety of species, especially large mammals. Fence end treatments can reduce intrusions of wildlife into the fenced right-of-way and may make short road sections more effective in reducing wildlife-vehicle collisions, but the potential effects of fence end runs and spatial inaccuracies of the data remain. The authors of this report suggest further experiments with wildlife guards with bridge grate material and electric mats or electric concrete at fence ends (see e.g. Parker et al., 2008). Fence end treatments are particularly important it the mitigated road section is relatively short and does not cover the entire length of the crash hotspot and adjacent buffer zones.

6.4. Human Access Points.

Human access points that allow humans to leave and enter the fenced road corridor are necessary. The can relate to various modes of transportation and there are a range of mitigation measures, sometimes even quite creative ones, available. They include various types of gates, carousels, wildlife guards (bridge grate material), electric mats etc. While there is some information available on different types of wildlife guards and electric mats, electric concrete, gates and carousels have rarely been investigated for their barrier effect on wildlife or for their ease of use for humans. The authors of this report suggest interviewing people that use the areas adjacent to highways with regard to the type of use and their mode of transportation. Use this information as a starting point to identify or design access treatments that may keep the barrier effect of the fenced road corridor on wildlife intact, but that do allow for safe, efficient and comfortable access for people. If access points are not provided, people will likely make access points themselves by making gaps in the fence which threatens the effectiveness of the entire mitigation package.

6.5. Design of Wildlife Guards

Escape opportunities for wildlife from pits under wildlife guards.
While commonplace in north-western Europe, wildlife guards in North America typically lack escape opportunities for small animals that may have fallen in the pit under a wildlife guard. Species groups that may fall into these pits can include invertebrates, amphibians, reptiles, and small mammals. Research into effective escape opportunities could result in the implementation of escape opportunities and prevent a slow deaths of these animals. Escape ramps and openings on the side of a pit are among the possible types of escape opportunities.

Prevention of potential injuries and fatalities of large mammals that cross wildlife guards.
Camera monitoring of wildlife guards has shown that large mammals, including large ungulates can and do cross wildlife guards at certain times. In some cases animals have been observed

running or jumping on the wildlife guard. This may or may not result in injury or death of the animals involved. The authors of this report suggest investigating potential wildlife injuries and fatalities that may occur because of the bars or bridge grate material which may require design modifications.

6.6. Wildlife Jump-outs

Wildlife jump-outs are increasingly used as a measure to allow a wide range of medium and large mammal species to escape from the fenced right-of-way. The jump-outs should be low enough for animals to readily jump down to the safe side of the wildlife fence. On the other hand, the jump-outs should be high enough to prevent animals from jumping into the fenced right-of-way. This implies that there is an "optimum height" for jump-outs that strikes a good balance between these two objectives. There is some information of appropriate height of jump-outs for mule deer, elk and bighorn sheep. However, information for other species is typically lacking. In addition, there is often more than one target species that practitioners would like to have the jump-outs be suitable for. There are currently no guidelines that help practitioners decide on the appropriate height of jump-outs for multiple species. The authors of this report suggest initiating more studies into the optimal height of jump-outs for single target species as well as situation with multiple target species with different jumping and climbing capabilities. Experiments should include the use of planks or bars on top of the jump-out that may make it harder for animals to jump up while not making it more difficult for animals to jump down. Additional questions relate to the potential benefits of short sections of fence on top of jump-out perpendicular (or at another angle) to the main fence line. It is currently unclear whether the short fences help wildlife explore and use wildlife jump-outs.

6.7. Amphibians and Reptiles

Research on the effectiveness of wildlife fencing and associated mitigation measures for amphibians and reptiles is relatively sparse. However, it appears that the relatively small body size of many amphibians and reptiles makes it harder to keep the animals from entering the fenced road corridor. This relates to fences as well as associated measures such as wildlife guards at access roads (Ottburg & van der Grift, 2013). While plastic sheets and concrete barrier walls appear to be a substantial barrier for many amphibian and reptile species, other less effective designs continue to be implemented. Fencing with fine meshes (e.g. for toads, frogs or lizards) are susceptible to damage, e.g. from vegetation maintenance in the right-of-way. Drift fencing from geotextile fabric or other types of fabric is also not uncommon (Baxter-Gilbert, 2014), but this material is very susceptible to implementation errors and wear and tear (e.g. because of erosion and varying water levels) and should probably not be used as a long term mitigation strategy. Thus it appears that there is a need for basic comparative tests for wildlife fencing and associated mitigation measures for amphibians and reptiles. Because of the small body size of many amphibian and reptile species substantial attention is required for a proper design, implementation and maintenance. The research should probably specifically include implementation and maintenance practices to identify mitigation measures that will be effective in keeping the animals off the road for many years. A specific species group that requires a standalone research effort is tree frogs. The discs on their fingers and toes result in extreme climbing capabilities and our current designs for wildlife fencing and associated measures are not a substantial barrier for this species group. It may be that no effective physical barrier can be designed for tree frogs. Should that indeed be the case then perhaps research can identify vegetation management practices that may result in a behavioral barrier. Naturally barriers, whether physical or behavioral, should only be implemented in combination with safe crossing opportunities (perhaps arboreal crossing structures for tree frogs).

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8. APPENDIX A: SURVEY

Experiences with and opinions on wildlife fencing and associated mitigation measures

Introduction

Thank you for participating in this NCHRP survey! We value your experience and expertise.

The Western Transportation Institute at Montana State University, Dr. Patty Cramer, Venner Consulting, and ICF International are conducting a project for the National Cooperative Highway Research Program. The project aims to summarize the current state of practice and experiences in the United States and Canada with wildlife fencing and associated mitigation measures aimed at keeping wildlife off the road. While this project does not focus on wildlife underpasses and overpasses, it does include other measures that may be implemented in association with wildlife fencing such as gates, one-way gates, wildlife jump-outs or escape ramps, cattle guards or wildlife guards, boulder fields, electric mats embedded in the roadway, warning signs, and animal detection and driver warning systems. We focus on three different species groups: large mammals (i.e. deer size and larger), medium sized mammals (i.e. coyote or similar size), and reptiles and amphibians.

We invite personnel from transportation agencies, natural resource management agencies, University Transportation Centers, researchers and practitioners who have been personally involved with the design, implementation, maintenance or evaluation of these mitigation measures to participate in the project and fill out the survey. If you know of other experts who have information on these mitigation measures, please feel free to forward the link to this survey to them. We are aware of the fact that multiple people from the same organization, or multiple people from the same state may fill out this survey and that they can refer to the same projects.

We would like to receive standard specifications for wildlife fencing and associated measures including gates, one-way gates, wildlife jump-outs or escape ramps, cattle guards or wildlife guards, boulder fields, electric mats embedded in the roadway, warning signs, and animal detection and driver warning systems. You can send the standard specifications to Pat McGowen (PatM@coe.montana.edu; (406) 994-6529) or Marcel Huijser (see below). If the document is too large to send by e-mail, please contact Pat McGowen for instructions on how to upload your document to the FTP server.

This survey is voluntary. If you prefer not to answer a certain question, please skip that question and proceed to the next one. While no personally identifiable information will be published or distributed to others we may wish to contact you for clarification or additional information. If you agree to be contacted for more information, please provide your contact information.

The results will help provide guidance for future projects that include wildlife fencing and associated measures that help keep animals of the road or allow them to escape the fenced road corridor. For more information, contact Dr. Marcel Huijser, Research Ecologist, Western Transportation Institute-Montana State University (406)543-2377, mhuijser@coe.montana.edu.

Experiences with and opinions on wildlife fencing and associated mitigation measures

Basic information

1. Please check the option which best describes your affiliation:

- ◯ State or Provincial transportation agency
- ◯ State or Provincial natural resource management agency
- ◯ Federal or National transportation agency
- ◯ Federal or National natural resource management agency
- ◯ University
- ◯ Private / consulting business
- ◯ I do not wish to answer
- ◯ Other (please specify)

2. What State/Possession (USA) or Province (Canada) is/are the project(s) located in that you will provide information on?

***3. Have you been personally involved with the design, implementation, maintenance, or evaluation of wildlife exclusion fencing project(s) along roadways?**

- ◯ Yes
- ◯ No

Experiences with and opinions on wildlife fencing and associated mitigation measures

Species groups

Questions are arranged by two different species groups:

1. LARGE MAMMALS (i.e. deer size and larger) AND MEDIUM MAMMALS (i.e. coyote or similar size)

2. REPTILES and AMPHIBIANS

***4. Do you have knowledge of LARGE OR MEDIUM MAMMAL fencing and associated measures?**

- ◯ Yes
- ◯ No

Experiences with and opinions on wildlife fencing and associated mitigation measures

Keeping LARGE OR MEDIUM MAMMALS off the road

5. Please think of an exclusionary fence design that has been or will be implemented for a particular LARGE OR MEDIUM MAMMAL target species. From each of the drop down menus, please choose the option that best fits your opinion/knowledge of the best design criteria and associated information related to this target species.

You may enter information for up to ten fence designs, each pertaining to a particular LARGE OR MEDIUM MAMMAL target species. We realize that there may be more than 1 species for which the mitigation is designed. In those cases name the most important or most abundant target species.

Please note there are nine columns and you may have to widen your window or scroll sideways.

	Primary target LARGE OR MEDIUM MAMMAL species	Fencing material	Fence height (meters)	Post material	Climbing (over fence) deterrent	Digging (under fence) deterrent	Effectiveness in reducing wildlife-vehicle collisions or roadkill	Known potential for animal entanglement in fence itself	Total average fence construction cost per meter (per 3.3 ft) (US$) - includes all elements particular to target species requirements
Fence design #1									
Fence design #2									
Fence design #3									

Experiences with and opinions on wildlife fencing and associated mitigation measures

Fence design #4									
Fence design #5									
Fence design #6									
Fence design #7									
Fence design #8									
Fence design #9									
Fence design #10									

Specificy Other 1, 2,3, Comments, including potential maintenance issues or solutions, and potential sources (reports, articles)

Experiences with and opinions on wildlife fencing and associated mitigation measures

6. If you have experienced maintenance issues with the LARGE MAMMAL OR MEDIUM MAMMAL fence, what are the problems and potential solutions?

	Falling trees	Erosion	Flooding	Heavy snow load or accumulation	Freeze-thaw cycles	People creating holes in fence	Faulty fence material	Poor fence installation	Too much vegetation mowing or cutting required	Too many general fence inspections required	Other
Fence design #1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Fence design #2	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Fence design #3	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Fence design #4	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Fence design #5	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Fence design #6	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Fence design #7	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Fence design #8	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Fence design #9	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Fence design #10	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Other (please specify), comments including potential solutions, and potential sources (reports, articles)

Experiences with and opinions on wildlife fencing and associated mitigation measures

7. Please think of a fence gap (e.g., driveways, side roads) design for a particular LARGE OR MEDIUM MAMMAL target species. These gaps are not intended for at grade crossing opportunities for wildlife but they are for people in vehicles. From each of the drop down menus, please choose the option that best fits your opinion/knowledge of good design criteria for this target species.

You may enter information for up to three fence gap designs, each pertaining to a particular LARGE OR MEDIUM MAMMAL target species. We realize that there may be more than 1 species for which the mitigation is designed. In those cases name the most important or most abundant target species.

Please note there are six columns and you may have to widen your window or scroll sideways.

	Primary target LARGE OR MEDIUM MAMMAL species	Fence gap treatment	If wildlife ("cattle") guard or electric mat, what is the distance animal would need to jump to clear barrier	Effectiveness in excluding target species	Known potential for animal entanglement in fence gap treatment	Average cost per gap treatment
Fence gap design #1						
Fence gap design #2						
Fence gap design #3						
Fence gap design #4						
Fence gap design #5						
Fence gap design #6						
Fence gap design #7						
Fence gap design #8						
Fence gap design #9						
Fence gap design #10						

Experiences with and opinions on wildlife fencing and associated mitigation measures

Specifiy Other 1, 2, 3, Comments, including potential maintenance issues or solutions, and potential sources (reports, articles)

Experiences with and opinions on wildlife fencing and associated mitigation measures

8. Please think of an AT GRADE CROSSING OPPORTUNITY designed for a particular LARGE OR MEDIUM MAMMAL target species WITHIN FENCED ROAD CORRIDOR. From each of the drop down menus, please choose the option that best fits your opinion/knowledge of good design criteria for this target species.

You may enter information for up to three at grade crossing opportunity designs, each pertaining to a particular LARGE OR MEDIUM MAMMAL target species. We realize that there may be more than 1 species for which the mitigation is designed. In those cases name the most important or most abundant target species.

Please note there are six columns and you may have to widen your window or scroll sideways.

	Primary target LARGE MAMMAL species	Allow at grade wildlife crossing in fenced road corridor at a fence gap?	If you (under some conditions) allow for at grade crossing opportunity: Fence gap width (meters)	Crossing zone width on road surface (meters)	Maximum Traffic volume for at grade crossing (vehicles/day)	Maximum number of lanes (total for 2 travel directions) for at grade crossing opportunity	Warning signs at at grade crossing opportunity?	Traffic calming at at grade crossing opportunity?	Speed reduction at at grade crossing opportunity
At grade crossing design #1									
At grade crossing design #2									
At grade crossing design #3									
At grade crossing design #4									
At grade crossing design #5									
At grade crossing design #6									
At grade crossing design #7									
At grade crossing design #8									
At grade crossing design #9									
At grade crossing design #10									

Specify Other 1, 2, 3, Comments, including potential maintenance issues or solutions, and potential sources (reports, articles)

Experiences with and opinions on wildlife fencing and associated mitigation measures

9. Please choose what you think is good practice for where to end a fence to reduce a large number of LARGE OR MEDIUM MAMMAL crossings at-grade (i.e., reduce fence end run). Select all that apply.

- ☐ Anywhere, regardless of slope, landscape features or installation of potential animal detection system
- ☐ At road cut with steep slopes (e.g., cliff, rock outcrop)
- ☐ At road fill with high roadbed and steep slopes
- ☐ At edge of water body
- ☐ At drainage structure (e.g., culvert, bridge)
- ☐ At road feature (e.g., guardrail, concrete barrier)
- ☐ At road junction
- ☐ Anywhere, as long as an animal detection system is installed starting at fence end

Other (please specify)

Experiences with and opinions on wildlife fencing and associated mitigation measures

10. Please think of a fence end treatment or fence gap (designed for at grade wildlife crossing opportunity) that you consider good practice between the PAVEMENT EDGE AND FENCE LINE (SHOULDER/BERM) to discourage wildlife from entering the fenced road corridor.

You may enter information for up to three fence end designs, each pertaining to a particular LARGE OR MEDIUM MAMMAL target species. We realize that there may be more than 1 species for which the mitigation is designed. In those cases name the most important or most abundant target species.

Please note there are seven columns and you may have to widen your window or scroll sideways.

	Primary target LARGE OR MEDIUM MAMMAL species	Fence end treatment	Distance animal would have to jump to clear barrier (boulder field, wildlife ("cattle") guard, electric mat)	Measure to reduce impact of vehicle crash with fence end treatment	Effectiveness in excluding target species	Known potential for animal entanglement in fence end treatment	Average cost per fence end treatment
Fence end/gap treatment #1							
Fence end/gap treatment #2							
Fence end/gap treatment #3							
Fence end/gap treatment #4							
Fence end/gap treatment #5							
Fence end/gap treatment #6							
Fence end/gap treatment #7							
Fence end/gap treatment #8							
Fence end/gap treatment #9							
Fence end/gap treatment #10							

Specify other 1, 2, 3, Comments, including potential maintenance issues or solutions, and potential sources (reports, articles)

Experiences with and opinions on wildlife fencing and associated mitigation measures

11. Please think of a fence end treatment or fence gap (designed for at grade wildlife crossing opportunity) on the PAVED SURFACE (TRAVEL LANES) to discourage wildlife from entering the fenced road corridor.

You may enter information for up to three fence end designs, each pertaining to a particular LARGE OR MEDIUM MAMMAL target species. We realize that there may be more than 1 species for which the mitigation is designed. In those cases name the most important or most abundant target species.

Please note there are six columns and you may have to widen your window or scroll sideways.

	Primary target LARGE OR MEDIUM MAMMAL species	Fence end treatment	Distance animal would have to jump to clear barrier (wildlife ("cattle") guard, electric mat)	Effectiveness in excluding target species	Known potential for animal entanglement in fence end treatment	Average cost per fence end treatment
Fence end/gap treatment #1						
Fence end/gap treatment #2						
Fence end/gap treatment #3						
Fence end/gap treatment #4						
Fence end/gap treatment #5						
Fence end/gap treatment #6						
Fence end/gap treatment #7						
Fence end/gap treatment #8						
Fence end/gap treatment #9						
Fence end/gap treatment #10						

Specificy Other 1, 2,3, Comments, including potential maintenance issues or solutions, and potential sources (reports, articles)

Experiences with and opinions on wildlife fencing and associated mitigation measures

Escape opportunities for LARGE OR MEDIUM MAMMALS that have entered a fenced...

12. Please think of an escape design for a particular LARGE OR MEDIUM MAMMAL target species. From each of the drop down menus, please choose the option that best fits your opinion for best practice related to this target species.

You may enter up to three escape designs, each pertaining to a particular LARGE OR MEDIUM MAMMAL target species. We realize that there may be more than 1 species for which the mitigation is designed. In those cases name the most important or most abundant target species

Please note there are nine columns and you may have to widen your window or scroll sideways.

	Primary target LARGE OR MEDIUM MAMMAL species	Escape design	Distance between escapes on one side of road (in meters along road length)	If Jump-outs/escape ramps, height animals would have to jump down from fenced corridor to safe side fence (in meters)	If Jump-outs/escape ramps with bar/plank, height animals would have to jump up/into fenced corridor (in meters)	Effectiveness: % of animals on top that jump down	Effectiveness: % of animals at bottom that DO NOT jump up	Known potential for animal entanglement in escape itself	Total average cost per escape
Escape design #1									
Escape design #2									
Escape design #3									
Escape design #4									
Escape design #5									
Escape design #6									
Escape design #7									
Escape design #8									
Escape design #9									
Escape design #10									

Specificy Other 1, 2,3, Comments, including potential maintenance issues or solutions, and potential sources (reports, articles)

Experiences with and opinions on wildlife fencing and associated mitigation measures

Allowing human access in LARGE OR MEDIUM MAMMAL fencing scenarios

13. What types of access facilities would you consider suitable for various types of human traffic?

	Pedestrians	Bicyclists	Equestrian use	Motorized vehicles
Walk through gate for pedestrians (turns through "maze")				
Swing gate at grade (locked)				
Swing gate at grade (unlocked, manual open/close)				
Swing gate at grade (automatic open/close)				
Swing gate with steps for pedestrians (avoid snow blocking gate)				
Swing gates with lock chamber (2 gates and a "neutral zone")				
Carousel (rotating gate)				
Wildlife ("cattle") guard (round bars)				
Wildlife ("cattle") guard (flat bars)				
Wildlife ("cattle") guard (bars with edge pointing upwards)				
Wildlife ("cattle") guard (bridge grate material)				
Wildlife ("cattle") guard (electrified)				
Electric mat embedded in roadway				

Experiences with and opinions on wildlife fencing and associated mitigation measures

14. Do the projects you are familiar with have access points for agency personnel or contractors, and if so, are the access points actually being used by agency personnel and contractors?

- ◯ Not used at all
- ◯ Used infrequently
- ◯ Used sometimes
- ◯ Used often
- ◯ Used all the time

Other (please specify)

Experiences with and opinions on wildlife fencing and associated mitigation measures

LARGE OR MEDIUM MAMMALS - General questions

15. Do you think it is good practice to, in principle, always accompany wildlife fencing along highways in combination with safe crossing opportunities (e.g., overpass, underpass) for LARGE OR MEDIUM MAMMALS ?

	Yes	No	I don't know
LARGE MAMMALS (deer and larger)	○	○	○
MEDIUM SIZED MAMMALS (e.g. coyote size)	○	○	○

Comments

Experiences with and opinions on wildlife fencing and associated mitigation measures

16. LARGE OR MEDIUM MAMMAL fencing projects and associated measures have the potential for negative, unintended consequences. Please indicate those with which you have direct experience. Select all that apply.

- ☐ Target species entangled resulting in injury or death
- ☐ Non-target species entangled resulting in injury or death
- ☐ Bird strikes (e.g. fly into fence)
- ☐ Barrier for non-target species for which no safe crossing opportunities exist
- ☐ Decrease of human access onto or across roadway
- ☐ Unacceptable effect on landscape aesthetics

Other (please specify)

Experiences with and opinions on wildlife fencing and associated mitigation measures

17. Do you have any standard specifications or technical drawings of LARGE OR MEDIUM MAMMAL fencing or associated mitigation measures you would be willing to send to us?

If so, please send to PatM@coe.montana.edu (406) 994-6529

Thank you!

- ◯ Yes
- ◯ No

Thank you! Please send specs and drawings to Pat McGowen at the Western Transportation Institute at patm@montana.edu.

Experiences with and opinions on wildlife fencing and associated mitigation measures

REPTILES/AMPHIBIANS

***18. Do you have knowledge of REPTILE/AMPHIBIAN fencing and associated measures?**

○ Yes

○ No

Experiences with and opinions on wildlife fencing and associated mitigation measures

Keeping REPTILES/AMPHIBIANS off the road

19. Please think of an exclusionary fence design that has been or will be implemented for a particular REPTILE/AMPHIBIAN target species. From each of the drop down menus, please choose the option that best fits your opinion/knowledge of the best design criteria and associated information related to this target species.

You may enter information for up to ten fence designs, each pertaining to a particular REPTILE/AMPHIBIAN target species. We realize that there may be more than 1 species for which the mitigation is designed. In those cases name the most important or most abundant target species.

Please note there are nine columns and you may have to widen your window or scroll sideways.

	Primary target REPTILE/AMPHIBIAN species	Fencing material	Fence height (meters)	Post material	Climbing (over fence) deterrent	Digging (under fence) deterrent	Effectiveness in reducing wildlife-vehicle collisions or roadkill	Known potential for animal entanglement in fence itself	Total average fence construction cost per meter (per 3.3 ft) (US$) - includes all elements particular to target species requirements
Fence design #1									
Fence design #2									
Fence design #3									

Experiences with and opinions on wildlife fencing and associated mitigation measures

Fence design #4									
Fence design #5									
Fence design #6									
Fence design #7									
Fence design #8									
Fence design #9									
Fence design #10									

Specificy Other 1, 2,3, Comments, including potential maintenance issues or solutions, and potential sources (reports, articles)

Experiences with and opinions on wildlife fencing and associated mitigation measures

20. If you have experienced maintenance issues with the REPTILE/AMPHIBIAN fence, what are the problems and potential solutions?

	Falling trees	Erosion	Flooding	Heavy snow load or accumulation	Freeze-thaw cycles	People creating holes in fence	Faulty fence material	Poor fence installation	Too much vegetation mowing or cutting required	Too many general fence inspections required	Other
Fence design #1											
Fence design #2											
Fence design #3											
Fence design #4											
Fence design #5											
Fence design #6											
Fence design #7											
Fence design #8											
Fence design #9											
Fence design #10											

Other (please specify), comments including potential solutions, and potential sources (reports, articles)

Experiences with and opinions on wildlife fencing and associated mitigation measures

21. Please think of a fence gap (e.g., driveways, side roads) design for a particular REPTILE/AMPHIBIAN MAMMAL target species. These gaps are not intended for at grade crossing opportunities for wildlife. From each of the drop down menus, please choose the option that best fits your opinion/knowledge of good design criteria for this target species.

You may enter information for up to tem fence gap designs, each pertaining to a particular REPTILE/AMPHIBIAN MAMMAL target species. We realize that there may be more than 1 species for which the mitigation is designed. In those cases name the most important or most abundant target species.

Please note there are six columns and you may have to widen your window or scroll sideways.

	Primary target REPTILE/AMPHIBIAN species	Fence gap treatment	If gate, are there provisions to keep animals from crawling under gate?	Effectiveness in excluding target species	If wildlife ("cattle") guard, known potential for animal entrapment in pit	If wildlife ("cattle") guard, is there an escape for the animals should they fall in pit?	Average cost per gap treatment
Fence gap design #1							
Fence gap design #2							
Fence gap design #3							
Fence gap design #4							
Fence gap design #5							
Fence gap design #6							
Fence gap design #7							
Fence gap design #8							
Fence gap design #9							
Fence gap design #10							

Specificy Other 1, 2,3, Comments, including potential maintenance issues or solutions, and potential sources (reports, articles)

Experiences with and opinions on wildlife fencing and associated mitigation measures

22. Please choose what you think is good practice for where to end a fence to reduce a large number of REPTILE/AMPHIBIAN crossings at-grade (i.e., reduce fence end run). Select all that apply.

- ☐ Anywhere, regardless of slope or landscape features
- ☐ At road cut with steep slopes (e.g., cliff, rock outcrop)
- ☐ At road fill with high roadbed and steep slopes
- ☐ At edge of water body
- ☐ At drainage structure (e.g., culvert, bridge)
- ☐ At road feature (e.g., guardrail, concrete barrier)
- ☐ At road junction

Other (please specify)

Experiences with and opinions on wildlife fencing and associated mitigation measures

23. Please think of a fence end treatment or fence gap (if gap is designed for at grade wildlife crossing opportunity) that you consider good practice between the PAVEMENT EDGE AND FENCE LINE (SHOULDER/BERM) to discourage wildlife from entering the fenced road corridor.

You may enter information for up to three fence end designs, each pertaining to a particular REPTILE/AMPHIBIAN target species. We realize that there may be more than 1 species for which the mitigation is designed. In those cases name the most important or most abundant target species.

Please note there are seven columns and you may have to widen your window or scroll sideways.

	Primary target REPTILE/AMPHIBIAN species	Fence end treatment	Distance animal would have to cross to clear barrier (boulder field, wildlife guard, electric mat)	Measure to reduce impact of vehicle crash with fence end treatment	Effectiveness in excluding target species	Average cost per fence end treatment
Fence end/gap treatment #1						
Fence end/gap treatment #2						
Fence end/gap treatment #3						
Fence end/gap treatment #4						
Fence end/gap treatment #5						
Fence end/gap treatment #6						
Fence end/gap treatment #7						
Fence end/gap treatment #8						
Fence end/gap treatment #9						
Fence end/gap treatment #10						

Specificy Other 1, 2,3, Comments, including potential maintenance issues or solutions, and potential sources (reports, articles)

Experiences with and opinions on wildlife fencing and associated mitigation measures

24. Please think of a fence end treatment or fence gap (if gap is designed for at grade wildlife crossing opportunity) on the PAVED SURFACE (TRAVEL LANES) to discourage wildlife from entering the fenced road corridor.

You may enter information for up to ten fence end designs, each pertaining to a particular REPTILE/AMPHIBIAN target species. We realize that there may be more than 1 species for which the mitigation is designed. In those cases name the most important or most abundant target species.

Please note there are six columns and you may have to widen your window or scroll sideways.

	Primary target REPTILE/AMPHIBIAN species	Fence end treatment	Distance animal would have to cross to clear barrier (wildlife guard, electric mat)	Effectiveness in excluding target species	Average cost per fence end treatment
Fence end/gap treatment #1					
Fence end/gap treatment #2					
Fence end/gap treatment #3					
Fence end/gap treatment #4					
Fence end/gap treatment #5					
Fence end/gap treatment #6					
Fence end/gap treatment #7					
Fence end/gap treatment #8					
Fence end/gap treatment #9					
Fence end/gap treatment #10					

Specificy Other 1, 2,3, Comments, including potential maintenance issues or solutions, and potential sources (reports, articles)

Experiences with and opinions on wildlife fencing and associated mitigation measures

Escape opportunities for REPTILES/AMPHIBIANS that have entered a fenced roa...

25. Please think of an escape design for a particular REPTILE/AMPHIBIAN target species. From each of the drop down menus, please choose the option that best fits your opinion for best practice related to this target species.

You may enter up to three escape designs, each pertaining to a particular REPTILE/AMPHIBIAN target species. We realize that there may be more than 1 species for which the mitigation is designed. In those cases name the most important or most abundant target species.

Please note there are nine columns and you may have to widen your window or scroll sideways.

	Primary target REPTILE/AMPHIBIAN species	Escape design	Distance between escapes on one side of road (in meters along road length)	If Jump-outs/escape ramps, height animals would have to jump down from fenced corridor to safe side fence (in meters)	If Jump-outs/escape ramps with bar/plank, height animals would have to jump up/into fenced corridor (in centimeters)	Effectiveness: % of animals on top that jump down	Effectiveness: % of animals at bottom that DO NOT jump up	Known potential for animal entanglement in escape itself	Total average cost per escape
Escape design #1									
Escape design #2									
Escape design #3									
Escape design #4									
Escape design #5									
Escape design #6									
Escape design #7									
Escape design #8									
Escape design #9									
Escape design #10									

Specificy Other 1, 2,3, Comments, including potential maintenance issues or solutions, and potential sources (reports, articles)

Experiences with and opinions on wildlife fencing and associated mitigation measures

Allowing human access in REPTILE/AMPHIBIAN fencing scenarios

26. What types of access facilities would you consider suitable for various types of human traffic?

	Pedestrians	Bicyclists	Equestrian use	Motorized vehicles
Walk through gate for pedestrians (turns through "maze")				
Swing gate at grade (locked)				
Swing gate at grade (unlocked, manual open/close)				
Swing gate at grade (automatic open/close)				
Swing gate with steps for pedestrians (avoid snow blocking gate)				
Swing gates with lock chamber (2 gates and a "neutral zone")				
Carousel (rotating gate)				
Wildlife guard (round bars)				
Wildlife guard (flat bars)				
Wildlife guard (bars with edge pointing upwards)				
Wildlife guard (bridge grate material)				
Wildlife guard (electrified)				
Electric mat embedded in roadway				

Experiences with and opinions on wildlife fencing and associated mitigation measures

REPTILE/AMPHIBIAN - General questions

27. Do you think it is good practice to, in principle, always accompany wildlife fencing along highways in combination with safe crossing opportunities (e.g., overpass, underpass) for REPTILES/AMPHIBIANS ?

- Yes
- No
- I don't know

Comments

Experiences with and opinions on wildlife fencing and associated mitigation measures

28. REPTILE/AMPHIBIAN fencing projects and associated measures have the potential for negative, unintended consequences. Please indicate those with which you have direct experience. Select all that apply.

- [ ] Target species entangled resulting in injury or death
- [ ] Non-target species entangled resulting in injury or death
- [ ] Bird strikes
- [ ] Barrier for non-target species for which no safe crossing opportunities exist
- [ ] Decreased human access onto or across roadway
- [ ] Unacceptable effect on landscape aesthetics

Other (please specify)

Experiences with and opinions on wildlife fencing and associated mitigation measures

29. Do you have any standard specifications or technical drawings of REPTILE/AMPHIBIAN fencing or associated mitigation measures you would be willing to send to us?

If so, please send to PatM@coe.montana.edu (406) 994-6529
Thank you!

- ◯ Yes
- ◯ No

Thank you! Please send specs and drawings to Pat McGowen at the Western Transportation Institute at patm@montana.edu.

Experiences with and opinions on wildlife fencing and associated mitigation measures

30. If you agree to be contacted for more information, please provide your contact information.

Name (First Last)	
Affiliation	
State/Province	
Email	
Phone number	

Thank you very much for participating in this survey. You can help improve the design of future mitigation measures by sharing your STANDARD SPECIFICATIONS and TECHNICAL DRAWINGS. (We realize this may require some effort by you - for example, going into the as-built archives).

We are only interested in standard specifications and technical drawings (either standards or those included in as-builts) that are specifically related to wildlife fencing and associated lateral control measures.

Please send to:

Patrick McGowen
Western Transportation Institute

patm@coe.montana.edu (20 MB max)

2327 University Way #6
Bozeman, MT 59715

Please indicate your state, project name, location and any copyright restrictions. Thank you!

9. APPENDIX B: "OTHER" RESPONSES AND COMMENTS

The following include "Other" responses and/or free text comments for those questions which allowed for such entries. Free text comments may pertain to potential maintenance issues or solutions, and potential sources (reports, articles). Note: all entries are unedited, appearing exactly as entered by the respondent with the exception of deleting extra spaces. Please refer to Appendix A for entire survey tool.

Question 5: Please think of an exclusionary fence design that has been or will be implemented for a particular LARGE OR MEDIUM MAMMAL target species. From each of the drop down menus, please choose the option that best fits your opinion/knowledge of the best design criteria and associated information related to this target species.

You may enter information for up to ten fence designs, each pertaining to a particular LARGE OR MEDIUM MAMMAL target species. We realize that there may be more than 1 species for which the mitigation is designed. In those cases name the most important or most abundant target species.

Please note there are nine columns and you may have to widen your window or scroll sideways.

1	Primary species is pronghorn, secordary is mule deer, the elk, followed by predator species
2	#4: Barbed-wire right-of-way fence retrofit design - with 5 strands of barbed wire above the standard 42" ROW game fence standard (thus the fence is semi-permeable to smaller animals) All 4 designs have proven effective; Arizona's standard "wildlife fence" is probably over-engineered to sustain the impact of elk and other ungulate impact, as well as the impact of tree fall in Ponderosa pine forests.
3	Fence Design #1 - CrossTek design and constructed (contact: Tim Hazlehurst) Built this fence in Florida just east of St Johns River on SR 415 for Deer, Bear, Cattle, Reptiles & Amphibians. 4 feet of fine 1/4" mesh heavily galvanized buried 1 foot supported by 4 feet of 4"x5" Black no-climb mesh 4 feet above ground. Top 4 feet with 5 strands of black electric braided rope. Used pressure treated wood for braces. Green Fiberglass line and support posts. Gates sealed to ground with Neoprene rubber flaps. Potential maintenance issues are: vegetation growth providing herps with climbing ladders over the fence and heavy vegetation shorting the electric portion of fence. DOT has implemented a regular vegetation management schedule with spray and weed eating to solve this potential problem. Fence located along new scenic run/bike walk trail. This Black relatively transparent (low density) fence is an effective and attractive barrier for a wide range of species. Bears not expected to climb due to upper electric strands. Gates also have electric strands on top portion. 2 Jumpouts also with electric strands to prevent climbing by bears into road from backside of jump. Observed tree (6" diameter) fallen on the tensioned electric braid

	(upper half of fence). When tree was removed, the fence sprung back into normal tensioned position like new, without need for any further maintenance or repair to fence. This is one advantage of tensioned braided or tensioned high tensile smooth wire. Contact Steve Tonjes at Florida DOT in Deland, FL for more information or Dan Smith. Fence Design #2 - CrossTek design and constructed (contact: Tim Hazlehurst). Built this fence on both sides of Interstate 80 in Nebraska (Near Gretna, NE). Combination fence with 4" x 5" wire mesh on bottom 4 feet. Electric Rope Braid on top 4 feet (5 strands). All fiberglass including braces. This fence has effectively eliminated high rate of deer vehicle collisions on this section of roadway. Tied into river and bridge on each end. Maintenance yard has a supply of materials for conducting repairs due to vehicles running off road into the fence. Otherwise a low maintenance fence. Solar operated fence energizing on one side of road. Battery replacement expected every 5-7 years ($80). Plug in side of road expect energizer replacement in 15 years ($350). Period brush control advised. Fence Design #3 - CrossTek design and constructed (contact: Tim Hazlehurst or Jeff Gagnon AZ Game and Fish). Retrofit of existing metal barbwire fence. Increased height to 8 feet. Added electric braided rope. Very difficult terrain for building fence (rock, steep grades). Effectiveness of this fence has been carefully studied for many years. Maintenance issues primarily due to hunters cutting the fence. Easy fence to maintain over otherwise very difficult terrain for both foot and vehicle travel. Both solar and plug-in energized portions of fence. Fence Design #4 - CrossTek maintained and constructed (contact: Tim Hazlehurst or Mark Watson NM Game and Fish). 9 Strand Braided Electric Rope Fence. 110VAC power source. Well documented results preventing WVC's and directing deer and other mid to large animals including bears to at-grade wildlife crossing and underpass in Tijeras canyon area. Low maintenance. Some holes created by people. Some erosion under fence creating small gaps easily filled by hanging electrified chain.
4	Primary species black bear Secondary species mule deer

5	Question -am I asked what wildlife fencing has been used or what I think is ideal?? Fence 1 is a Florida fence I think is ideal for black bear Fence 2 is NCDOT US 64 washington county fence Fence issues wildlife going under and around ends, ~1/2 mile of fencing. No jump-outs, gates were provided to free trapped wildlife but no documented "freeing" on trapped wildlife. Effectiveness of Wildlife Underpasses and Fencing to Reduce Wildlife–Vehicle Collisions No Access Matthew F. McCollister 1a and Frank T. van Manen was unable to get costs
6	We have experience errosion issues with the fencing and it is requiring regular maintence to repair holes. Additionally, human use and destruction of one-way gates has been a problem.
7	Contractor did not install chain link gates properly so that there was no gap underneath the gates. Our inspectors did not catch it during construction and now we have gates near the culverts with huge gaps underneath and essentially no way to fix the problem.
8	In Rhode Island, we generally install 5' or 6' right-of-way fence to discourage small and medium sized animals, and people, from entering freeway rights-of-way. The primary large animal of concern in Rhode Island is the white tail deer, which can easily clear our largest, standard fence - the 6' fence. We do not generally install right-of-way fence on our other (no limited access) roadways. Our standard fencing is a galvanized chain link style.
9	This item didn't fit your categories: An experimental hybrid multi-species fences has also been constructed that includes three materials--uniform large animal galvanized mesh to 5 ft, electrobraid above that to 8 ft and 1/4 in grid herp-mesh at the base buried 1 ft and above ground to 3 ft designed to address all herps/small mammals and medium to large mammals. Includes escape jump-outs. Fence #s 1 and 2 are the same fence, but applied for two different target species in diff areas of the state. Fence #s 4 and 5 is the same fence designed for both bear and deer.
10	Fence # 2, 3, 4 and 6 are welded, not woven, wire, 2" horizontal X 4" vertical mesh size. Please see the special details. No breaches of fence #1, and roadkill has been reduced, but bears are still being hit at the ends.

11	In Washington, barrier fences have been built according to various designs yet targeted to prevent deer and elk from getting out onto highways. Eight foot tall woven wire fences are typically built but post type varies and dig barriers are generally not included in the design. The I-90 East project has established a fence design standard that includes treated wood posts, eight foot high woven wire, graduated mesh fence fabric and a 3 foot long piece of attached chain link fence material buried 1.5 feet underground as a dig barrier.
12	Fence Design Costs - Varied greatly since 2002, for example 8' woven wire ranged from \$27/m to \$111/m, Costs for all projects and fencing types varied quite a bit so all my costs are based on what I am seeing today plus a small buffer. Another big difference is cost of standalone fence projects versus those rolled into a highway reconstruction, usually much cheaper during reconstruction unless its an add on after construction starts then it becomes the most expensive. Fence Design #2 - This was actually a standard ROW fence with electric extensions and electric kicker, did not know which of the choices was best so I selected this one. Fence Design #4- Put inconclusive, we did monitor accidents and had zero, however the 5' version was used in areas where sheep frequented less and 7' in areas where sheep were known to cross thus I would not feel confident with the 5' version being deemed effective without further evaluation. Fence Design #6 (no design that fits this so left blank) - We have used an extended right-of-way fence (8' barbed wire fence) on four separate occasions and where built properly have seen as high as 100% reduction, where not built properly it is lower, the estimates are an average. Also in areas with higher incentive (clover, etc..) the success rates go down as elk tend to force their way through versus areas with lower incentive and just a highway with lots of traffic, we see very few attempts to enter the ROW. Maintenance- Of the fence types we see , it seems the 8' woven wire with metal posts appears to be the most effective and lowest maintenance. One of the biggest concerns in AZ are wash outs and how to reduce these through effective flood gate designs.
13	This is two projects wih the same fence type. Roads were new roads on new alignment, so no history of crashes
14	Damage from falling trees, Animals still entering enclosed area at ends where highway traffic runs into the enclosed area.
15	Annual maintenance is approximately 10% of construction costs
16	We built miles of deer fence for a specific project here in Ohio. We include 14 deer jump out areas and now have a research project underway to study how effective the overall site is.

17	#1 - 2013 fencing in Kootenay National Park, BC. Cost of fencing is approximate as engineering, fence end treatments, etc. Nominal value for 4.7 km of fenced highway (9.4 km of fencing) was $CAD950k. Includes high-tensile top cable to deflect falling trees. #2 - refers to original phases of fencing in Banff National Park, built in early 1980s. Cost unknown. No buried apron, no top cable.
18	Fence Design #2 - turtles, small amphibians, adult snakes
19	Answers to Question 5 are directly related to mitigation measures implemented in the state of Nevada. Notes for fence design 1 & 2; Where Nevada installed 8' fencing in conjunction with wildlife crossings, we documented a 50% decrease in the number of wildlife-vehicle collisions with each subsequent migration for a large migratory population of mule deer. After 3 years the effectiveness to reduce collisions fluctuates between 95-100%. Notes for fence design 3; 7' fencing has been used for bighorn sheep in southern Nevada, but I have not been able to find any information about the costs. Notes for fence design 4; Other = Feral Horses, Fencing is 4' tall and use cable wires with a separation of approximately 1'.
20	We are evaluating StayLock fencing fabric. It's like ordinary field fencing fabric but the strands cannot be stretched.
21	The areas of unknown effectiveness mentioned above are currently under construction and have not been completed yet. All exclusionary fences are associated with either designed bridges for wildlife use under roads or tied to existing culverts that have shown wildlife use in the past and post construction.
22	In reference to the potential for digging, the electric fence has the lowest "hot" line at 16" off the ground and a 2"x4"x60" 14-gage wire vinyl coated mesh starting 3" off the ground. The woven wire fence is also 3" off the ground with a single barb wire strand.

Question 6: If you have experienced maintenance issues with the LARGE MAMMAL OR MEDIUM MAMMAL fence, what are the problems and potential solutions?

1	Much of the area is wetland, prone to spring surface flooding. Bracing, fence location and perhaps longer post lengths may be solutions.
2	Many of our problems with people cutting holes in the fence relate to locations where old roads ("2-trackers") have been fenced off. We had one retrofit application where poor fence materials were used; otherwise, our experience with retrofit option has been excellent.

3	Although Falling trees, erosion and holes cut by people are problems, we have found that Electric Fence is generally lower maintenance cost and easy to trouble shoot fallen trees and holes from a remote location vs labor time to inspect entire fence. Electric fences indicate problems located somewhere along the fence by simply monitoring voltage at the end of the fence. Electric braided rope and some high tensile smooth wires tend to spring back to original shape when tress are removed without further repair or maintenance due to elastic nature and strength of material. Steel mesh is usually deformed by trees and requires further repair after tree removal. Snow loads less of a problem on braided rope and high tensile wire. Flooding a problem for wire mesh if there is a current and debris build-up. Less of a problem for electric wire, debris less likely to build up. Automatic Current Limitors prevent shorting of electric fence in folded areas. Heavy snow and ice less of a problem with HT Wire and Braided Electric Rope (flexible and small diameter for accumulation). Wire mesh tends to accumulate large loads, particularly with freeze thaw cycles weighing down on buried fence. When people create holes in fence, this can often be detected as a drop in voltage on the end of an electric fence. Mesh fence requires thorough fence inspection to detect the hole.
4	Several fence repairs after vehicles hit the fence.
5	1 same as fence 2 in Question 5 fence had gates which people left open 2 ROW fence used on project with wildlife crossings installed for black bear - solution taller better maintained fence with spring loaded one-way gates for people
6	Poor fence design (e.g., designing in without consideration of end-runs; installation in areas subject to falling trees).
7	Not installed yet
8	Fence #s 3, 4, 5 and the experimental fence have not been evaluated for effectiveness or maintenance issues as of yet. These are new installations (less than 1 yr).
9	In the more heavily forested portions of Washington State, damage to fences from falling trees or limbs is a constant problem and regular inspections or cutting of threatening trees is always more than over-taxed maintenance crews can accomplish. People are a huge problem because they don't like being blocked and know how to cut or otherwise get through a fence. Often, they breech a fence at a bridge because they want access to the stream that is bridged. This creates a hole for animals to go through at locations where we want animals to move safely under the road. Animals that have been successfully "funneled" to a bridge may now decide to pop up onto the highway instead of moving under the bridge.

10	Fence designs 3 and 4 are in areas with no trees, falling trees would be a concern for all fence types in my opinion. I am not sure if "flooding" means the fence being underwater, if so than I would put flash "floods" that AZ experiences under erosion. In these cases, designs for effective water gaps may be a solution.
11	The deer fence is located adjacent to Wayne National Forest. We have ATV user who have cut the fence to get access to other land.
12	Answers to Question 6 are directly related to mitigation measures implemented in the state of Nevada. Notes for fence design 1 & 2; Coyotes have been digging holes under the fence on a regular basis and this can prove difficult for maintenance crews to keep up on them. The amount of digging has decreased with time since the animals learn where the crossings or fence ends are located. Notes for fence design 3; The fencing is located near the Hoover Dam so there are thousands of people in the area on a daily basis which creates damage frequently. Additionally, the terrain is very rough so the fencing is not checked on a regular basis. Holes can remain open for long periods of time before they are documented and repaired.
13	Staylock fence fabric should eliminate most of the maintenance issues and at a lower cost than chain-link.
14	The design that I listed as poor fence design above has been rectified. Deer were crawling along the narrow strip between the fence and the cattle guard. Maintenance has placed fencing in this location to keep the deer out. We have also had issue with sanding material build up on cattle guards allowing deer to walk over the cattle guards in some locations. More timely maintenance has helped.
15	The hole created by a person was a drunk driver diverting from roadway and then striking the electric fence and a deer exit ramp. Probably saved his life because if vehicle had continued would have then crossed a field access and dropped into stream. Erosion on fence #2 was mediated by extending a concrete ditch liner inside the state ROW, then under the woven wire fence (between posts) and then draining into the county ditch.

Question 7: Please think of a fence gap (e.g., driveways, side roads) design for a particular LARGE OR MEDIUM MAMMAL target species. These gaps are not intended for at grade crossing opportunities for wildlife but they are for people in vehicles. From each of the drop down menus, please choose the option that best fits your opinion/knowledge of good design criteria for this target species.

You may enter information for up to three fence gap designs, each pertaining to a

particular LARGE OR MEDIUM MAMMAL target species. We realize that there may be more than 1 species for which the mitigation is designed. In those cases name the most important or most abundant target species.

Please note there are six columns and you may have to widen your window or scroll sideways.

1	Again, pronghorn is primary species, then mule deer which have been escaping into the ROW via gaps, around the sides of cattle guards (the angled up bars away from the guard). Gaps between posts, or post and gate frame could possible allow young to pass thru the barrier (per WYDOT and WG&F observations and discussions)
2	#1: No reliable monitoring of elk and other ungulate use of "wildlife" guards has been undertaken until Spring 2014; AZDOT is funding AZ Game and Fish to do an evaluation of cattle guard, electrified mat, painted cattle guards, etc. efficacy at an experimental/controlled test site. Entanglement in cattle guards by elk was noted early on in this research, which otherwise would not have been determined in a typical highway application setting. #2: AZ Game and Fish monitoring of SR 260 electrified mat (in the mainline highway) has shown it to be largely effective in deterring elk and white-tailed deer entry into the fenced corridor. #3: Monitoring of bighorn sheep "wildlife" guards by AZ Game and Fish along US 93 has found that sheep can jump over the cattle guards, as well as walk along the concrete crib sides/walls. We are hoping to install electrified mats in front of the cattle guards to deter passage.
3	See Report Tom Seamens and Helon 2008 USDA publication CattleGuards vs Electric Mats - White Tail Deer
4	Still collecting data that will be summarized in a final analysis fall 2015. To date the four electric mats appear to be effective for black bear and no bears have attempted to jump the mats. Bears have only breached mats that were not turned on. Also feral pigs are in the area and no pigs have been observed at the mats. The narrow mats are less effective for mule deer and some individual deer are walking across the mats at 2 out of 4 locations. Since we aren't able to identify individual deer, it's difficult to know if it's the same doe breaching the mat at a specific location or multiple does are breaching the mat. Buck have also been observed walking across the mat as well as medium to small mammals. Retrofitting the mats so they are wider and the space between the positive/negative metal strips is closer together may be helpful.
5	We do not have a particular target species to the best of my knowledge. That said, we have created wildlife underpasses on freeways with concrete median barriers. The idea is to provide safe passage for small animals that cannot clear the solid, concrete barrier.
6	design #s 4 and 5 is the same fence, it has one electrified mat and several manual gates. None have been evaluated yet, the fence is newly installed.

7	Washington has built perhaps 20 wildlife guards on intersecting side roads that create a break in a wildlife barrier fence. The designs vary a little bit, mainly in terms of the material used for the crossing bars. We've had motion-triggered cameras on a few of these guards and we've observed quite a few wildlife species walking or jumping over them. Cougar and Bobcats seem to get past them easily. Deer and Bighorn Sheep tend to respect them but we've seen deer walk over them, dropping to their shoulders in the pit below, or falling forward in what looks like a painful fall between the bars. Still, they persist and get out to the highway. So, performance is imperfect at best though I understand that quantitative analysis of similar styles has found effectiveness to be generally very high for ungulates.
8	Fence Gap design 3- Have seen sheep jump these Fence Gap design 4-Anectdotal evidence of sheep walking across however no accidents in areas where these are used so they are effective to some degree.
9	Have been issues with gates being left open by recreational trail users.
10	While the electrified mats have not been rigorously studied they anecdotally have been shown to be ineffective and frequently non-functional. While the target species have no potential for entanglement, other species have been found electrocuted, specifically toads.
11	Cattle guards must be cleaned of sand and other debris every year. Design must consider other road users, motorcycles and cyclists.
12	This was a limited access highway, so no gaps were necessary. At bridge crossing, the fencing tied into our structure to prevent ANY access onto our project.
13	Cattle guards - various widths - highly effective for ungulates, hit-and-miss for carnivores Electromat - avg 6', in testing mode - intermittently do not seem to have power or to shock animals Electromat - testing for possible railway use - approx 15' - has been successful from limited sample to date of wolves and bears
14	Answers to Question 7 are directly related to mitigation measures implemented in the state of Nevada. Fence gap design #2; Gates match the exclusionary fencing at either 7' or 8' tall (not wide). Fence gap design #5; Other = Feral Horse
15	The treatment for elk and grizzly above has not been studied because the fence is currently under construction. We are typically using double cattle guards at all at grade crossings.

16	This project was along I-80 and no vehicle gaps were created. The only fence gaps were deer exit ramps placed every 1/2 mile on both sides of the interstate. Costs were $7200/each for the electric fence and $8375/each for the woven wire.

Question 8: Please think of an AT GRADE CROSSING OPPORTUNITY designed for a particular LARGE OR MEDIUM MAMMAL target species WITHIN FENCED ROAD CORRIDOR. From each of the drop down menus, please choose the option that best fits your opinion/knowledge of good design criteria for this target species.

You may enter information for up to three at grade crossing opportunity designs, each pertaining to a particular LARGE OR MEDIUM MAMMAL target species. We realize that there may be more than 1 species for which the mitigation is designed. In those cases name the most important or most abundant target species.

Please note there are six columns and you may have to widen your window or scroll sideways.

1	N/A to my project
2	#1: The SR 260 "crosswalk" project with its animal detection system has proven effective for >6 years, and has effectively deterred animal encroachment into the fenced ROW, and reduced the wildlife-vehicle collision rate by 98%. This project has radio-activated VMS signs at the approaches and flashing elk warning signs at the actual crosswalk zone. The
3	See AZ 260 Reports - Norris Dodd, Jeff Gagnon - Crosswalk Maintained by CrossTek (Contact: Tim Hazlehurst) CrossTek is currently designing and testing a detection system with low initial cost, equivalent reliability to AZ SR 260 system and with low maintenance requirements.
4	Primary target species black bear. Secondary species mule deer and feral pigs.
5	N/A
6	At grade not recommended
7	In Florida: black bears and panthers-- at grade crossings only applicable in combination with roadside animal detection system.
8	Liability concerns related to the agency purposely funneling animals to a particular location for an at-grade crossing have prevented much consideration of this as a viable option.
9	These are results from the AZ Preacher Canyon final report and more recent research on the same at-grade crossing.
10	Don't promote at-grade crossings, but assumed that moose/deer will cross road after fencing sections have ended.
11	None.

12	Nevada does not have any areas that are designated as at grade crossings at this time. We have had discussions about a few locations were we would like to implement them, and have considered utilizing animal detection systems, but only in rural areas with low traffic volume and seasonal movements.
13	At present we do not have any electronic warning systems, but we are considering using them.

Question 9: Please choose what you think is good practice for where to end a fence to reduce a large number of LARGE OR MEDIUM MAMMAL crossings at-grade (i.e., reduce fence end run). Select all that apply.

1	I believe that fencing needs to be tied into something to make it the most effective; this can be a problem in the rolling sage hills of WY. If we had the $$, animal detection systems would be nice *(maybe- last one was junk and pricey to maintain). Signage is our treatment at ends currently.
2	High roadbed/fill slopes we found to NOT be effective deterrents to elk or deer passage onto the roadway. Animal detection systems are a good measure but very expensive and very maintenance intensive, so they really don't have an "anywhere" application potential; they do effectively alert motorists and reduce liability. Running fence into a different habitat type (e.g., grassland) for some species like elk is an option, as is ending fence in highly visible situations and installing special warning signs.
3	With animal detection and driver warning system the crossing at fence end could be anywhere as long as animal crossing is concentrated to specific, limited length areas and the location must satisfy certain criteria such as; road conditions, grade, sight lines and visibility distance, traffic volume, traffic speeds, number of lanes, warning system type, and all criteria which affect motorist ability to respond safely to animals crossing the roadway.
4	ideally at end of suitable habitat
5	Site and species-specific distance beyond habitat edge.
6	This is a problem area for fenced highways. There will always be an end to the barriers we build. Tying a fence into an impassable landscape feature is usually a false sense of finding resolution to the problem. In reality, it just moves the end of the barrier to the other side of the landscape feature. Having the fence end at a safe crossing opportunity like a bridge or large culvert makes the most sense since an animal looking to cross is giving an opportunity to do so and, hopefully, will not continue searching for a place to cross at grade.

7	I can't call any of these "good", they are just options to try and hinder animals from wanting to continue on. I'm not sure I feel comfortable recommending a good practice; we have tried many of them. I think the detection system is the best option, however I would not place them "anywhere." I think careful consideration should be taken, straight sections of road with higher visibility, 2-lane, lower traffic. Aside from these scenarios this not the best option either. I have been pretty pleased with one of our road junction fence ends, however it includes heavy people use and street lights, I would not use just any road junction.
8	Ideally, there should be good visibility of the roadway beyond the fence for drivers approaching from either direction, and there should be an effective electrical mat across the road. Although not ticked above, the "anywhere, regardless of ..." option is better than having no fence at all. Often there is no good fence end location, and/or not enough funding for a detection system or electromat, and/or the fence is being built in stages so the fence end point is not critical.
9	When discussing where fencing should be stopped, we try to look at driver visibility in conjunction with topography and animal behaviors to best predict a reasonable end point. We try to avoid 1) high roadbeds and steep slopes since driver and wildlife visibility is greatly reduced at these locations, 2) road junctions since there are typically higher traffic volumes, and 3) landscape features that create hiding spots for wildlife to buildup and surprise drivers.
10	We also sometimes end a fence at a wildlife crossing underpass structure.
11	I usually try to tie the fence ends with some topographic feature on the landscape (cliff, large talus slope, etc.) that would deter animal ends runs. Sometimes there are no effective topographic features to tie into so the fence ends with no "deterrent" to tie into. In these cases I try and end the fence in a location with lots of sight distance, no steep slopes where animals can jump up onto the roadway with little to no warning, and place signing to alert drivers of an animal crossing.

12	The fence was constructed along a segment of I-80 which had four existing bridge structures that were reconstructed and modified to become wildlife undercrossings. The Platte River separates the projects with electric fence running for 3 miles to the east and a woven wire for 1 mile to the west. Within the project, the fence would tie to the bridge abutments to funnel deer to the undercrossing. The woven wire ended at an interchange with the south fence line following the cross road for 400' then using a 200' J-hook back down the first driveway. On the north side, the fence ends near the exit ramp terminus with the cross road. A 10' wide stretch of riprap between the fence end and the roadway was constructed to deter deer from accessing the roadway. The electric fence had both sides tying into the abutment of a bridge structure crossing over I-80. A 200' long j-hook was placed perpendicular to the fence at the toe of the cross road slope on the south side as there is more habitat conducive to the deer. The north side is fields with a county road parallel to I-80.

Question 10: Please think of a fence end treatment or fence gap (designed for at grade wildlife crossing opportunity) that you consider good practice between the PAVEMENT EDGE AND FENCE LINE (SHOULDER/BERM) to discourage wildlife from entering the fenced road corridor.

You may enter information for up to three fence end designs, each pertaining to a particular LARGE OR MEDIUM MAMMAL target species. We realize that there may be more than 1 species for which the mitigation is designed. In those cases name the most important or most abundant target species.

Please note there are seven columns and you may have to widen your window or scroll sideways.

1	antelope and deer

2	#1: We have used angled fence away from a fence end to force animals approximately 250-400 feet away from the roadside (I-17); as part of a comprehensive set of elements, this has appeared to be reasonably effective (no collisions at end of fence in 2+ years). #2: Electrified mats to deter animal passage around fence ends has worked well, especially when integrated with electric fence on frangible posts. We have extended electrified mats off the roadway approximately 2 feet or so, and then tied it into the electric fence. #3: Used in conjunction with electrified mats, but could also be used with cattle ("wildlife") guards. #4: AZDOT experimented with large boulder "elk rock" along SR 260 and found that if installed correctly (not gaps between rocks) that it could deter elk and deer passage; it was done to eliminate maintenance that was associated with fence, but proved to be very expensive with trucking in rock and placing it properly with heavy equipment. It has not been used beyond the 1st and only section where tried on SR 260. This is not to be confused with rock "rip-rap" applications as the rock are much larger (3+ feet in diameter). Also, where guard rails were not present, we had to pull the rock outside of the roadway/shoulder area and thus had issues with integration to prevent end runs.
3	The combination of answer options is a bit confusing in my opinion. When possible to place a guardrail at the road edge to join with a fence treatment, I believe this is the best option for all species that are not able to "walk down the guardrail." This option is lowest cost and allows the fence treatment to meet the edge of the road without concern for vehicles colliding with the fence. Next best option is bringing fence as close as can be allowed to the edge of roadway with breakaway fence posts and either electric mat or electric CG.
4	black bear, mule deer, feral pig
5	Where we have constructed wildlife "culverts", we have flared the right-of-way fence into a funnel at either end.
6	My answer only applies to breaks in fence associated with intersecting side roads, places where WSDOT installs wildlife guards. WSDOT has tied fencing material into steep cliff walls as well, using bolts in the rock.
7	In AZ, anything within the "clear zone" has to be frangible so the other options are not feasible. Also, reluctance from maintenance to use standard cattle guards on main roads in areas where plows are needed.
8	For most projects, have angled fence away from road, but on some projects we have used the method of angling away and bringing fence close to paved surfaced, and we have used boulder fields. Have yet to study effectiveness of end of fence treatments.

9	#1 and #2 apply to both w.t. deer and wolves. The boulder field appears to have some deterring effect, but animals regularly walk on boulders. Likely boulder size not large enough/inadequately sorted to exclude smaller, stabilizing material. We have recently tied the fence end directly to the Jersey barriers and will be monitoring effectiveness.
10	Nevada has only used angled fencing with a mandatory clear zone. The clear zone creates a large gap at the end of the fence which the animals have been documented to go into the gap and end up between the fences.
11	Have not completed construction, but we are not doing anything for end treatments aside for angling the fence away from the roadway.
12	See #9 discussion for the other end treatments.

Question 11: Please think of a fence end treatment or fence gap (designed for at grade wildlife crossing opportunity) on the PAVED SURFACE (TRAVEL LANES) to discourage wildlife from entering the fenced road corridor.

You may enter information for up to three fence end designs, each pertaining to a particular LARGE OR MEDIUM MAMMAL target species. We realize that there may be more than 1 species for which the mitigation is designed. In those cases name the most important or most abundant target species.

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1	NA - we only have signage for highway travelers
2	Slower speed roadways could use an electrified wildlife cattle guard for the same species. Many more species than shown above are deterred from crossing the barrier based on anecdotal evidence. Maintenance is generally low when the electric mat is installed by qualified professionals. Early designs were less robust due to material selection and install procedures. Current designs by CrossTek are good for 20 years depending on traffic volume.
3	Still collecting data that will be summarized in a final analysis fall 2015. To date the four electric mats appear to be effective for black bear and no bears have attempted to jump the mats. Bears have only breached mats that were not turned on. Also feral pigs are in the area and no pigs have been observed at the mats. The narrow mats are less effective for mule deer and some individual deer are walking across the mats at 2 out of 4 locations. Since we aren't able to identify individual deer, it's difficult to know if it's the same doe breaching the mat at a specific location or multiple does are breaching the mat. Buck have also been observed walking across the mat as well as medium to small mammals. Retrofitting the mats so they are wider and the space between the positive/negative metal strips is closer together may be helpful.
4	N/A

5	As indicated earlier, WSDOT has been reluctant to consider designing any at grade wildlife crossing.
6	Not applicable.
7	To date, have used cattle guards and electromats at road junctions (gaps), not at fence ends.
8	These answers are based on communications with other professionals.
9	We are looking at potentially using the electric mat on the cross road in the future if a hot spot is created at the interchange.

Question 12: Please think of an escape design for a particular LARGE OR MEDIUM MAMMAL target species. From each of the drop down menus, please choose the option that best fits your opinion for best practice related to this target species.

You may enter up to three escape designs, each pertaining to a particular LARGE OR MEDIUM MAMMAL target species. We realize that there may be more than 1 species for which the mitigation is designed. In those cases name the most important or most abundant target species

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1	for pronghorn and deer primarily. Guessing a 5' jump height - didn't work on this part of the project, WG&F did
2	#1: One-way gates did not perform well, but location selection was a critical issue. Gates must be field located with biologists to ensure that they are effective. They have not been used since the first 2 (of 5) sections along SR 260. #2: Height of escape ramps is critical. At less than 5.5. feet high, elk can jump up onto the ramps. AZ Game and Fish is not conducting a formal study of escape ramp effectiveness as part of an ADOT-fenced research project. The substrate at the landing is also critical and needs to be relatively soft material free of excessive rock. AZDOT has used 3 designs: concrete stem wall ramps, pressure-treated wood ramps, and rock gabion basket ramps; the latter is the most cost effective, though there have been erosion issues and the fill material can migrate through the baskets/rocks. #3: AZ Game and Fish evaluated escape ramps on US 93 with cameras and found that sheep were climbing the rock gabion baskets and breeching the corridor; this problem was readily corrected with a PVC pipe overhanging extension at the top to the jump. Game and Fish would have the relative %'s of effectiveness of the ramps before and after the pipes were installed. #4. Mule deer (and white-tailed deer) also used SR 260 ramps and they were largely effective for this species/

3	Some Maintenance Issues if ramps not properly constructed. Otherwise generally low maintenance. Add electric strands (solar powered) to prevent entrance to roadway by climbing animals (bears, etc) CrossTek (contact: Tim Hazlehurst) is beginning experiments with automatic electric escape gates (sensor activated).
4	Final analysis will be completed in fall 2015. The jump outs are actually 6.5 feet in height from the base to the top, however, the distance to jump down varies somewhat with the location depending on the topography. To date both does and bucks have been documented using the jumpouts to escape the highway. However, deer have also been observed hanging out on the ramps for the jumpouts. To date one black bear was observed looking over the edge of the jumpout and deciding not to jump down. The bear then walked back to the electric mat at that location and was observed leaping off the mat as it got shocked leaving the roadway.
5	We have not installed or contemplated any escape treatments.
6	#4 above includes 3 strands of electrobraid along the top edge on habitat side to prevent bears climbing up the back side.
7	Jump-out #1 is electrified.
8	WSDOT has built jump downs for deer and Bighorn Sheep. A special design was used to attract Bighorn Sheep to a rock outcrop with the ramp on top. We know that they reportedly work but our motion-triggered cameras, on a few of them, haven't picked up any use yet.
9	The bighorn sheep info is in ICOET 2013 proceedings, Gagnon et al., also some anecdotal sheep and cattle guard info. Escape design 4 is a lowered bar on a slope or what we call a "slope jump", its height is dependent on slope to create effective height. We are currently studying these so they are inconclusive. Distance between jumps - This is somewhat of a guess, we tend to place our escape mechanisms in suitable terrain so distances vary and orientation vary. Many time we are limited in the number of escape mechanisms so there is no consistency here.
10	On most projects, dual one-way ungulate gates are used. "Dual" meaning if a highway is travelling South to North, one gate would allow ungulate to escape corridor in generally a northern direction, or in a southern direction. Price given is for a set of dual one-way ungulate gates. Some fencing projects have not provided escapes.
11	Jumpouts may represent a safety risk for cyclists, ATV riders, pedestrians, snowmobiles, and motorcyclists.

12	#1 refers to wolves, wt deer, moose, grizzly bears #2 - coyotes use jumpouts to exit, but at least 1 individual repeatedly uses one to enter the fenced area, by jumping at an angle from the pit side so that height is much reduced
13	I would suggest adding a bar at 45 degrees from the top of the jump-out to allow movement down and away from the top, but that would create a visual barier to deter animals from jumping up from below on all of the above mentioned BMPs.

Question 14: Do the projects you are familiar with have access points for agency personnel or contractors, and if so, are the access points actually being used by agency personnel and contractors?

1	Project installed 4 access points. Don't know how frequently they are used.
2	My answer to #13 is specific to authorized personnel only. In Rhode Island, it is illegal for a pedestrian, cyclist, or equestrian to cross a freeway line.
3	WSDOT has built some swing gates that are hinged at the top and fall closed by force of gravity. They swing out from right-of-way with mere pressure but have to be lifted outward to go the other direction, a feature that tends to keep wildlife from going through them in the wrong direction. This eliminates the problem of people leaving a gate open though some people apparently don't like going through them so they cut a hole in the fence nearby.
4	gates for structure maintenance, electric company, removal of livestock used infrequently
5	Access for bridge inspections occurs regularly.
6	No specific access points installed into the fence.
7	We built in locked gates at several locations, but only for ODOT and Federal staff to access.
8	No access points
9	These are almost always at the end of a fence.
10	For bridge inspectors and maintenance we usually install a gate that is either locked or can be closed with some sort of clasp.

Question 15: Do you think it is good practice to, in principle, always accompany wildlife fencing along highways in combination with safe crossing opportunities (e.g., overpass, underpass) for LARGE OR MEDIUM MAMMALS ?

1	In Minnesota we utilize benches in river bridge abutment riprap. Fencing has not been a targeted need, though typical right of way fence may have limited directional success.
2	Yes - where practical.
3	Yes, if it's barrier fencing. I've heard the term wildlife fencing used to refer to livestock fencing that was wildlife friendly, allowing wildlife to pass.

4	These animals need to get across the roads safely

Question 16: LARGE OR MEDIUM MAMMAL fencing projects and associated measures have the potential for negative, unintended consequences. Please indicate those with which you have direct experience. Select all that apply.

1	As a landscape architect I think aesthetics CAN be mitigated with darker materials, dark posts, though DOTs usually balk at that. ODOT used a black fence south of Bend that is nearly invisible - great results! Don't have anything special, just common 8' wood post and 6" mesh fence standard - which I'm sure you have.
2	We attempt to provide human access where possible, but it has to be done so as to minimize the risk of gates being left open, etc. (use electrified mats or cattle guards). We haev seen relatively few unintended consequences of fencing with passage structures.
3	I don't have any actual experience with the problem of creating a barrier to smaller animal movements but it seems potentially important when crossing structures are quite far apart, like one mile or more apart.
4	Only one known incident of a bird strike so I would not call it a serious problem so far. I'm not sure in the DOT eyes that decrease of human access is a negative thing, possibly even positive. For #17 which doesn't have a place to comment, The fence designs will likely have to come from the DOT so I put a no on sending to Pat.
5	Have not encountered these consequences for our very limited number of fencing projects.
6	- unlikely that crossing rate is 100% of previous, even with crossing structures present - decreases human egress off the highway into surrounding land
7	Target species can become trapped between the fences and cannot locate or refuse to use an escape ramp or gate. These individuals tend to panic with time and get hit by motorists.
8	WE have had some issues with historic fishing access along the interstate being blocked because FHWA would not allow a gate because of trespass issues. "Creative" solutions were used to allow pedestrian access via a jumpout with a ladder.
9	The 8' woven wire fence is more pronounced in appearance and some have stated that it has a "prison" feeling associated to it. The electric fence is black and is virtually invisible.

Question 19: Please think of an exclusionary fence design that has been or will be implemented for a particular REPTILE/AMPHIBIAN target species. From each of the drop down menus, please choose the option that best fits your opinion/knowledge of the best design criteria and associated information related to this target species.

You may enter information for up to ten fence designs, each pertaining to a particular REPTILE/AMPHIBIAN target species. We realize that there may be more than 1 species for which the mitigation is designed. In those cases name the most important or most abundant target species.

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1	30 m rolls of 24" black aqua culture mesh with 15 mm rebar posts, 4" UV ties (with 15mm rebar for top rails)
2	#1: Flat-tailed horned lizard fence - used in sand dune prone areas so drifting sand is a huge issue with maintenance. #2: Desert tortoise fence applications - very extensive applications in state, of fairly consistent design. Maintenance is an issue from debris blockage during rain events, erosion, washouts, etc.
3	Maintenance Issue - 1/4" mesh heavily galvanized but short life span expected when buried in the ground Other 1: This fence intended for a wide variety of snakes, turtles and frogs
4	Typical 5ft chain link fence installed tight to the ground, and up to bridge abutments. This a typical MnDOT right of way fence, with provisions for tight ground and abutment contact.
5	Fence is actually 1/4" mesh designed primarily for snakes, turtles and frogs. Has not been tested for effectiveness on turtles. Some short experiments on several species of frogs and snakes, height selected was based on inability of snakes to climb and frogs to jump over at this height. May benefit by an overhang device.
6	Large and medium mammal fences # 2,3,4 and 5 are combination fences with 1/4" mesh added for herptiles.
7	He have used standard silt fence
8	For the fence design # 3-6 I have no choice in column "Effectiveness in reducing wildlife-vehicle collisions or roadkill" to put anecdotally ineffective... we did test for reptiles, using a BACI, and we did make field notes on the amphibians however the hard numbers were not recorded. Ultimately I can tell you that there was tons of DOR toads, frogs and salamander both before and after installation of the fencing (this is a fact), but I did not collect the hard number to claim it was PROVEN.
9	Source: experience (in project reports). Maintenance issues: vegetation management, annual repair after winter

10	Fencing material = hard Polymer plastic, ACO fencing brand Digging deterrent = backfill fencing
11	Only heard about this project through a colleague (since it was before my employment began here). Sorry I don't have more information!
12	WE installed miles of snake fence on one specific project here in Ohio. So far, it has been effective.
13	vegetation grows on concrete wall and there was no plan for maintenance of this vegetation, so small animals could climb the vegetation and avoid the culvert under the roadway.
14	The target species was Northern Diamondback Terrapin, which is a State listed species in RI. The fencing was mitigation for potential impacts to the single documented breeding population within RI from a neaby, but off-site, bridge replacement project. We included an extra quantity of the fencing material in the construction contract in order to provide a stockpile for our own maintenance forces to be able to perform repairs when needed. The fence was attached to an existing guardrail. The shallow burial depth was chosen to avoid potential for Section 106 actions. The fence was installed early in 2012, and there was 0 observed terrapin mortality in 2013. That was only the 2nd time in 20+ years of monitoring (by a local conservation group) that there was no observed mortality.
15	Fence installed to prevent turtles from accessing roadway is subject to winter slide-off or vehicles and must be inspected and repaired annually. The fence is installed on an embankment running through a large wetland. Plastic pipe to be installed behind guardrail section on embankment has not yet been installed as project will be built in the near future. This is the first installation of its type by MDOT and it will be evaluated as time allows.
16	Problems with vegetation growing over low concrete or wooden fencing, and not maintained so animals crawled over accumulated dead veg over time. Some problems with snowplows taking out fencing or accidents damaging fence that was not replaced and therefore ineffectual. One other problem with muskrats digging under fences by bridges and tunnel collapsed and left opening under fence.
17	All our fences are exclusionary and installed only for T/E species
18	These fences were installed on project when I worked for Caltrans. I have since left and do not know the cost or effectiveness of fencing. Anecdotally the tortoise fence worked great when we used it during construction with animals using the fence to find culverts under the roadway. I was not around to evaluate the final product.

Question 20: If you have experienced maintenance issues with the REPTILE/AMPHIBIAN fence, what are the problems and potential solutions?

1	1: Flat-tailed horned lizard fence - used in sand dune prone areas so drifting sand is a huge issue with maintenance. #2: Desert tortoise fence applications - very extensive applications in state, of failrly consistent design. Maintenance is an issue from debris blockage during rain eents, erosion, washouts, etc.
2	General inspections were not carried out by individuals that were willing, or trained, or funded to fix the problems with the fence. As the wide array of issue with this style of fence require high maintenance attentions, far beyond the scope of general road maintenance schedules. Maintaining the effectiveness of a mitigation structure should not be left up to the members of "pothole patrol."
3	Experience (described in reports). Need for regular vegetation management and annual spring inspection and repair essential.
4	Due to the nature of the desert environment where desert tortoise are found, fencing is always being damaged from flash floods; primarily in washes.
5	Vehicles leaving roadway and crashing into fence under winter conditions.
6	We no longer construct wooden, concrete or drift type fences, only wire mesh or chain link. Some legislators questioned the cost of fencing, especially if along a wide expanse of wetlands.

Question 21: Please think of a fence gap (e.g., driveways, side roads) design for a particular REPTILE/AMPHIBIAN MAMMAL target species. These gaps are not intended for at grade crossing opportunities for wildlife. From each of the drop down menus, please choose the option that best fits your opinion/knowledge of good design criteria for this target species.

You may enter information for up to tem fence gap designs, each pertaining to a particular REPTILE/AMPHIBIAN MAMMAL target species. We realize that there may be more than 1 species for which the mitigation is designed. In those cases name the most important or most abundant target species.

Please note there are six columns and you may have to widen your window or scroll sideways.

1	#1: Again sand accumulation on concrete "door-steps" is an issue that prevents gates from being closed. Over time, the fence material flaps become misshapen and need to be replaced.
2	Automatic Gate With Flap on bottom and sides and tight fit with flap if double gate good for many species of Amphib/Reptile
3	Total exclusionary fencing, no gaps
4	Fence turnbacks were installed where solid contact was not possible

5	Not sure about any of these. We have used 20 m + 'wings' angled back away from the road. These are only partially effective.
6	No gap. End terminis are built into the bridge abutments.
7	We did not provide gaps. There is nesting habitat between the water and the fence & the fence is along a 4 lane divided highway. The fence is only on a section of road that is very close to the shoreline, and which was identified as a "hot spot" for mortality. At either end of the fence the shoreline is farther from the edge of the road & there has not been observed terrapin mortality along the stretches of road beyond the ends of the fence. There is no brackish or estuarine habitat on the inland side of the fence. The primary nesting area for the population is on the opposite, undeveloped shore of the tidal river.
8	We place 'turnarounds' at the ends of fences to redirect the turtles and snakes back to where they came from, and hopefully they will not go around the end of the fence and onto the road. This has not been studies to see how effective it is, but has been observed to turn the turtles back to the wetlands.
9	This section not particularly applicable because fence gaps are mainly for driveways so we can't obstruct them with gates or structures. When possible, the end of the fence is angled to direct the tortoises/turtles away from the road. Other gaps in fences that target terrestrials generally occur where there is not suitable habitat and usually a geographical barrier/deterrent (Swamp bottom, creek, etc.).

Question 22: Please choose what you think is good practice for where to end a fence to reduce a large number of REPTILE/AMPHIBIAN crossings at-grade (i.e., reduce fence end run). Select all that apply.

1	The extent of salamander movement distance. Typically this is not that long since they are usually focused on one breeding pool.
2	site and species specific distance beyond habitat edge.
3	At grade crossing not attempted for Herps
4	Fencing for reptiles and amphibians should not end where suitable habitat does. We know that these animals are driven migrators (turtle are an excellent example). If the fencing is to be effective it must extend beyond the habitat (e.g. wetland/water way) a distance beyond the dispersal distance of the target species (using a measure such as the square root of the average home range size for that local population). This ensures that the fencing is extending past the distance that the animal is willing to travel to circumvent the fencing. Building anything short of that will merely result in individuals circumnavigating the fencing and entering the road. Fences can be terminated into large (obvious) natural barriers (e.g., cliffs, rock cuts, etc), bit it is important to note that many reptile and amphibian species have been noted to climb, nest, and forage of extremely rough terrain (include steep slopes and high road beds) anything below a 90 degree angle will still allow some of the more tenacious individuals to cross. High road beds and steep slope are traverse-able, just as mesh fencing, hardware cloth, and woven fencing are climbable. Walls (manufactured and natural) are required to prevent many reptile and amphibian species from crossing.

5	Often constrained to about 10 to 50 m past a wetland. In such cases, must use 'wings' to guide animals away from the road and discourage walking around the fence.
6	At the end of suitable habitat. Ending at the edge of a water body would probably be a little short, so an extension to capture all the individuals coming towards the water body at an angle would be useful.
7	Typically extend fence past edge of wetland whenever possible; this still leaves opportunity to animals willing to travel quite some distance the ability to go around the end of the fence. But, it has to stop somewhere, typically at the end of another type of ROW fencing.

Question 23: Please think of a fence end treatment or fence gap (if gap is designed for at grade wildlife crossing opportunity) that you consider good practice between the PAVEMENT EDGE AND FENCE LINE (SHOULDER/BERM) to discourage wildlife from entering the fenced road corridor.

You may enter information for up to three fence end designs, each pertaining to a particular REPTILE/AMPHIBIAN target species. We realize that there may be more than 1 species for which the mitigation is designed. In those cases name the most important or most abundant target species.

Please note there are seven columns and you may have to widen your window or scroll sideways.

1	Experience (entailed in a report).
2	This group of questions is not generally applicable to what we have used fencing or plastic culvert for interms of preventing wholesale access to the ROW.
3	Fencing is tied into bridge abutment or culvert sidewalls at water body crossings when possible.
4	Cost is the same as installation - $10-$15 per foot. All our fences are placed on the ROW line.

Question 24: Please think of a fence end treatment or fence gap (if gap is designed for at grade wildlife crossing opportunity) on the PAVED SURFACE (TRAVEL LANES) to discourage wildlife from entering the fenced road corridor.

You may enter information for up to ten fence end designs, each pertaining to a particular REPTILE/AMPHIBIAN target species. We realize that there may be more than 1 species for which the mitigation is designed. In those cases name the most important or most abundant target species.

Please note there are six columns and you may have to widen your window or scroll sideways.

1	Not evaluated structurally for high-traffic, high truck roadways.
2	No experience with this.
3	Not applicable to our situation in general.
4	N/A

Question 25: Please think of an escape design for a particular REPTILE/AMPHIBIAN target species. From each of the drop down menus, please choose the option that best fits your opinion for best practice related to this target species.

You may enter up to three escape designs, each pertaining to a particular REPTILE/AMPHIBIAN target species. We realize that there may be more than 1 species for which the mitigation is designed. In those cases name the most important or most abundant target species.

Please note there are nine columns and you may have to widen your window or scroll sideways.

1	Total exclusionary fencing
2	small mesh funnels with smaller end toward habitat side. earth ramp backfill on road side of low (3' or less) herp barrier.
3	Both sides of roads are fenced to direct amphibians to underpass structures.
4	Earthen ramps along roadway side of the fencing as a jump-out to habitat side, in cases where amphibians have found their way onto the road either through gaps or fence-ends.
5	We really designed it to ensure snakes don't enter the highway and we provided crossings a dry culverts and large deer/bear crossings.
6	We don't use escape designs. We try to keep the animals off the road and funnel them to a designated crossing.
7	The current design recommended by USFWS does not have any form of an escape ramps or gates.
8	Tortoises don't move fast enough to make an escape structure feasible. If they get on the road surface, the Division of Wildlife Resources needs to come to the site and remove the animal.
9	We have not figured out a way to get the turtles or snakes off the road if they get past the fence, they can always 'escape' to the nonpaved side of the road but must then go along the fence or cross the road.
10	No escape designs...If a gopher tortoise burrows in the ROW, we relocate it.

Question 27: Do you think it is good practice to, in principle, always accompany wildlife fencing along highways in combination with safe crossing opportunities (e.g., overpass, underpass) for REPTILES/AMPHIBIANS?

1	For desert tortoise, we can integrate effective drainage structures for passage, but in many instances, fencing is used to prevent mortality, as is the case with flat-tailed horned lizard. Often, rock "rip-rap" is used at concrete box culverts and negates the potential for effective

	tortoise use - need to consider other drainage applications (e.g., buried rip-rap, Armorflex hydraulic block, etc.).
2	Absolutely Yes
3	In Minnesota, we do not have good information on local hotspots where fencing would be suitable. A separate issue that has become a concern is the use of erosion control blanket during construction that utilizes welded plastic mesh. This entangles retiles and amphibians with fatal outcomes. See chapter 1 of the Best Practices for meeting DNR permit requirements for MnDOT bridges and culverts. http://www.dnr.state.mn.us/waters/watermgmt_section/pwpermits/gp_2004_0001_manual.html
4	We would not generally consider these two strategies together, as the size and scope of each effort is different with different issues
5	As the majority of reptile mitigation measures are constructed due to the presence of rare, imperiled or endangered species, it is always important to maintain connectivity. Now exception can be made if there is a massive abundance of habitat on either side of the road, and if the population are substantial on either side as well, this require extensive (multi-year, full season) research on the population size (mark-recap) and spatial ecology of the local population. In the end, without this information an appropriate decision on whether or not to install connectivity structures cannot be achieved... in the end it likely is more time and cost effective to simply install the structure and shoot for overall benefit for the target species, and similar "common" species alike.
6	Good practice, yes. But not always essential - depends on the species and location.
7	Yes, where reptiles and amphibians are found.
8	Fencing creates a barrier to migration routes, crossing structures create permeability.
9	In most cases the answer would be "yes”...but....In our case, the object was to prevent access to the road altogether. There was ample opportunity for individuals from the target population to access habitat required for all life stages on "their" side of the fence, and very little opportunity on the "other" side of the fence. There was only a relatively short stretch of roadway which was acting as a barrier to movement
10	These judgments can only be made on a location specific basis. Most often opportunities to cross animals at the ROW are limited. Often the best that can be done is to try to reduce mortality.
11	Crossings need fencing to direct the animals from their usual crossings and learn to use the new over/underpass
12	Not applicable to our situations
13	Only for sensitive or listed species.

Question 28: REPTILE/AMPHIBIAN fencing projects and associated measures have the potential for negative, unintended consequences. Please indicate those with which you have direct experience. Select all that apply.

1	Cost.
2	Snakes in 1/2" mesh.
3	We found that the permeability and failures of the fences type (due to washouts, flooding, poor installation, rips, tears, etc.) created another threat to wildlife crossing.

	Reptiles and amphibians would find access to the road (a task which may have taken many minute to hours, to days) and then crossed the fence due to the gap and entered the road. |Unlike normal road crossing (which typically have a high risk) these animal now not only had to cross, but find another gap on the other side. The time spent looking for the gap on the far side of the road increase exposure time to traffic. Post-mitigation, we saw an increase in the mortality rate for both snakes (25% rise) and turtles (20% rise). The corralling effect cause by gaps in the fence, allowed animals to get on to the roads, but did not provide fast escape off the road. This demonstrated the importance for regularly place escape (jump outs) to be installed with exclusions structures, or better yet install exclusion structure that are 'at grade' on the road side of the barrier, and obviously not of the wild side of the barrier, so that the entire exclusion structure is a continuous escape options to prevent mitigation from becoming another new threat.
4	Most negative impacts are from snowmobile access, and for convenience of roadside verge vegetation management.
5	Predation. Example: corvid predation on desert tortoises. Poaching by humans. This seems to be a greater concern for herps than for mammals, probably because herp poachers use fences as trap lines and most herps are slower.
6	All tortoise fencing has a gap above the mess and then 2-3 strands of woven wire at the top of the fence. The gap is supposed to allow for wildlife movement, but an occasional bighorn gets tangled in the wires.
7	Flooding in underpasses has made then unpassable seasonally
8	Item selected only because all our fences are associated with T/E species and require USFWS approval for new access driveways.
9	Ravens have been known to follow fence lines and target tortoise. Not much to do about that, but interesting.

10. APPENDIX C: ADDITIONAL INFORMATION FOR EFFECTIVE OR INEFFECTIVE DESIGNS

10.1. C-1: Mammal Fence Designs

Refer to Figure 10 for cost information.

MEDIUM AND LARGE MAMMALS	Percent effectiveness in reducing wildlife-vehicle collisions or roadkill	Fencing material	Fence height (meters)	Post material	Climbing (over fence) deterrent	Digging (under fence) deterrent	Known potential for animal entanglement in fence itself
Ungulates							
Bighorn Sheep	90	Woven wire: smaller mesh size at bottom	2.4 (8 ft)	Wood: pressure treated	NA	NA	No
	80	Woven wire: uniform mesh size throughout	1.7	Metal: T-post	NA	None	No
	80	Woven wire: uniform mesh size throughout	2.1 (7 ft)	Metal: T-post	NA	NA	No
Deer: Key	90	Woven wire: smaller mesh size at bottom	2.4 (8 ft)	Wood: pressure treated	NA	NA	No
	50	Chain link	2.4 (8 ft)	Galvanized steel	NA	NA	No
Deer: Mule	90	Chain link	2.4 (8 ft)	Wood: pressure treated	NA	None	No
	90	Electric: uniform spacing between strands	2.4 (8 ft)	Fiberglass	NA	None	Don't know
	90	Woven wire: smaller mesh size at bottom	2.4 (8 ft)	Galvanized steel	NA	Apron attached to main fence: buried <25 cm (<10")	Don't know
	90	Woven wire: smaller mesh size at bottom	2.4 (8 ft)	Wood: pressure treated	NA	NA	No
	80	Chain link	2.4 (8 ft)	Metal: C-post	NA	NA	No
	80	Electric: variable spacing between strands	2.4 (8 ft)	Metal: T-post	NA	Apron attached to main fence: buried <25 cm (<10")	No
	80	Woven wire: smaller mesh size at bottom	2.4 (8 ft)	Metal: C-post	NA	NA	No
	80	Woven wire: smaller mesh size at bottom	2.4 (8 ft)	Metal: T-post	NA	None	Yes
	80	Woven wire: smaller mesh size at bottom	2.4 (8 ft)	Galvanized steel	NA	None	Don't know
	80	Woven wire: uniform mesh size throughout	2.4 (8 ft)	Wood: pressure treated	NA	NA	No
	70	Chain link	2.4 (8 ft)	Wood: pressure treated	NA	NA	Don't know
	50	Woven wire: uniform mesh size throughout	2.4 (8 ft)	Wood: pressure treated	NA	None	No
	50	Woven wire: uniform mesh size throughout	2.4 (8 ft)	Galvanized steel	NA	None	No
Deer: White-tailed	90	Electric: variable spacing between strands	2.4 (8 ft)	Galvanized steel	NA	None	No
	90	Electric: variable spacing between strands	2.4 (8 ft)	Fiberglass	NA	None	Don't know
	90	Woven wire: smaller mesh size at bottom	2.4 (8 ft)	Wood: pressure treated	NA	Apron attached to main fence: buried >1 m (>40")	Don't know
	90	Woven wire: uniform mesh size throughout	2.4 (8 ft)	Don't know/no opinion	Don't know/no opinion	Main fence buried: 11-20 cm (4-8")	Don't know
	80	Woven wire: smaller mesh size at bottom	2.4 (8 ft)	Wood: pressure treated	NA	NA	No
	70	Woven wire: smaller mesh size at bottom	2.4 (8 ft)	Galvanized steel	NA	None	No
	60	Woven wire: smaller mesh size at bottom	2.8	Galvanized steel	Outrigger angled away from road: 45 degrees	Apron attached to main fence: buried 51-75 cm (20-30")	No
Elk	90	Electric: uniform spacing between strands	2.4 (8 ft)	Fiberglass	NA	None	No
	90	Electric: uniform spacing between strands	2.4 (8 ft)	Metal: T-post	NA	None	Don't know
	90	Electric: variable spacing between strands	2.4 (8 ft)	Fiberglass	NA	NA	No
	90	Woven wire: smaller mesh size at bottom	2.4 (8 ft)	Metal: T-post	NA	None	No
	90	Woven wire: smaller mesh size at bottom	2.4 (8 ft)	Wood: pressure treated	NA	NA	No
	90	Woven wire: smaller mesh size at bottom	2.4 (8 ft)	Wood: pressure treated	NA	NA	No
	90		2.4 (8 ft)	Metal: T-post	Barbed wire at top of fence	None	No
	80	Woven wire: uniform mesh size throughout	2.4 (8 ft)	Metal: T-post	NA	NA	No
	80	Woven wire: uniform mesh size throughout	2.4 (8 ft)	Wood: pressure treated	NA	NA	No
	80		2.4 (8 ft)	Metal: T-post	NA	NA	Don't know
Moose	90	Woven wire: smaller mesh size at bottom	2.4 (8 ft)	Galvanized steel	NA	NA	No
	90	Woven wire: smaller mesh size at bottom	2.4 (8 ft)	Galvanized steel	NA	NA	No
	80	Woven wire: smaller mesh size at bottom	2.4 (8 ft)	Galvanized steel	NA	None	Don't know
Pronghorn Antelope	80	Woven wire: uniform mesh size throughout	2.4 (8 ft)	Wood: pressure treated	NA	NA	No
Carnivores							
Bear: Black	100	Chain link	3.0 (10 ft)	Galvanized steel	Outrigger angled away from road: 45 degrees	Main fence buried: 21-50 cm (8-20")	No
	60	Chain link	3.0 (10 ft)	Galvanized steel		None	Don't know
Canine: Coyote	80	Chain link	1.8 (6 ft)	Don't know/no opinion	Don't know/no opinion	Main fence buried: 21-50 cm (8-20")	No
Cougar/Florida Panther	100	Chain link	3.0 (10 ft)	Galvanized steel	Outrigger angled away from road: 45 degrees	Main fence buried: 21-50 cm (8-20")	No
Mustelid: Otter	80	Woven wire: uniform mesh size throughout	1	Plastic lumber	NA	NA	No

10.2. C-2: Mammal Escape Designs (Jump "Down" to the Safe Side of the Fence)

Refer to Figure 17 for cost information.

MEDIUM AND LARGE MAMMALS	Percent effectiveness (% of animals on top that jump down)	Escape design	Distance between escapes on one side of road (in meters along road length)	If Jump-outs/escape ramps, height animals would have to jump down from fenced corridor to safe side fence (in meters)	If Jump-outs/escape ramps with bar/plank, height animals would have to jump up/into fenced corridor (in meters)	Effectiveness: % of animals at bottom that DO NOT jump up	Known potential for animal entanglement in escape itself
Ungulates							
Bighorn Sheep	91-100	Jump-outs/escape ramps, both sides road, opposite of each other	801-850 (2,625-2,789 ft)	1.8 (6 ft)	2.2	Proven effective - 91-100% exclusion	No
Deer: Mule	1-10	Jump-outs/escape ramps, both sides road, opposite of each other	>1000 (>3,281 ft)	1.8 (6 ft)		Proven effective - 1-10% exclusion	
	1-10	One-way gate, one side of road only				Proven effective - 91-100% exclusion	Yes
	31-40	Jump-outs/escape ramps, both sides road, alternating (zig-zag) formation	>1000 (>3,281 ft)	1.9	1.9	Proven effective - 91-100% exclusion	Don't know
	31-40	Jump-outs/escape ramps, both sides road, opposite of each other	301-350 (984-1,148 ft)	1.8 (6 ft)	NA	Proven effective - 91-100% exclusion	No
	31-40	Jump-outs/escape ramps, one side of road only	301-350 (984-1,148 ft)	1.8 (6 ft)	NA	Proven effective - 91-100% exclusion	No
Deer: White-tailed	91-100	Jump-outs/escape ramps, both sides road, opposite of each other	401-450 (1,312-1,476 ft)	1.7	Don't know/no opinion	Proven effective - 91-100% exclusion	Don't know
Elk	Ineffective	One-way gate, both sides road, opposite of each other	401-450 (1,312-1,476 ft)	NA	NA		No
Mountain Goat	61-70	Jump-outs/escape ramps, both sides road, alternating (zig-zag) formation	501-550 (1,640-1,804 ft)	2	1	Proven effective - 1-10% exclusion	No

10.3. C-3: Mammal Escape Designs (Do Not Jump "Up" into the Fenced Corridor)

Please refer to Figure 18 for cost information.

MEDIUM AND LARGE MAMMALS	Percent effectiveness (% of animals at bottom that DO NOT jump up)	Escape design	Distance between escapes on one side of road (in meters along road length)	If Jump-outs/escape ramps, height animals would have to jump down from fenced corridor to safe side fence (in meters)	If Jump-outs/escape ramps with bar/plank, height animals would have to jump up/into fenced corridor (in meters)	Effectiveness: % of animals on top that jump down	Known potential for animal entanglement in escape itself
Ungulates							
Bighorn Sheep	91-100	Jump-outs/escape ramps, both sides road, opposite of each other	801-850 (2,625-2,789 ft)	1.8 (6 ft)	2.2	Proven effective - 91-100% success	No
Deer: Mule	91-100	Jump-outs/escape ramps, both sides road, alternating (zig-zag) formation	>1000 (>3,281 ft)	1.9	1.9	Proven effective - 31-40% success	Don't know
	91-100	Jump-outs/escape ramps, both sides road, opposite of each other	301-350 (984-1,148 ft)	1.8 (6 ft)	NA	Proven effective - 31-40% success	No
	91-100	Jump-outs/escape ramps, one side of road only	301-350 (984-1,148 ft)	1.8 (6 ft)	NA	Proven effective - 31-40% success	No
	91-100	One-way gate, one side of road only				Proven effective - 1-10% success	Yes
	1-10	Jump-outs/escape ramps, both sides road, opposite of each other	>1000 (>3,281 ft)	1.8 (6 ft)		Proven effective - 1-10% success	
Deer: White-tailed	91-100	Jump-outs/escape ramps, both sides road, opposite of each other	401-450 (1,312-1,476 ft)	1.7	Don't know/no opinion	Proven effective - 91-100% success	Don't know
Mountain Goat	1-10	Jump-outs/escape ramps, both sides road, alternating (zig-zag) formation	501-550 (1,640-1,804 ft)	2	1	Proven effective - 61-70% success	No
Carnivores							
Wolf	91-100	Jump-outs/escape ramps, both sides road, opposite of each other	951-1000 (3,117-3,281 ft)	2.1 (7 ft)		Inconclusive	No
Other	91-100	Jump-outs/escape ramps, both sides road, alternating (zig-zag) formation	751-800 (2,461-2,625 ft)	1.8 (6 ft)	1.8 (6 ft)	Anecdotally effective	No

10.4. C-4: Mammal Fence Gap Treatments

Please refer to
Figure 23 for cost information.

MEDIUM AND LARGE MAMMALS	Percent effectiveness in excluding target species	Fence gap treatment	If wildlife ("cattle") guard or electric mat, what is the distance animal would need to jump to clear barrier	Known potential for animal entanglement in fence gap treatment
Ungulates				
Bighorn Sheep	Ineffective	Wildlife ("cattle") guard: bars	1.6-2.0 m (5-7 ft)	No
Deer: Key	81-90	Wildlife ("cattle") guard: bridge grate material	More than 7.0 m (>23 ft)	Don't know
Deer: Mule	91-100	Electrified mat	2.6-3.0 m (9-10 ft)	No
	91-100	Wildlife ("cattle") guard: bars	4.6-5.0 m (15-16 ft)	No
	81-90	Wildlife ("cattle") guard: bars	2.6-3.0 m (9-10 ft)	
	81-90	Wildlife ("cattle") guard: bars	2.6-3.0 m (9-10 ft)	Yes
	Ineffective	Wildlife ("cattle") guard: only painted lines	2.6-3.0 m (9-10 ft)	No
Deer: White tailed	91-100	Animal detection/driver warning system	More than 7.0 m (>23 ft)	No
	91-100	Electrified mat	2.1-2.5 m (7-8 ft)	No
	41-50	Wildlife ("cattle") guard: bars	3.1-3.5 m (10-12 ft)	No
Elk	91-100	Animal detection/driver warning system	More than 7.0 m (>23 ft)	No
	81-90	Electrified mat	1.0-1.5 m (3-5 ft)	No
	81-90	Wildlife ("cattle") guard: bars	2.6-3.0 m (9-10 ft)	
Pronghorn Antelope	61-70	Wildlife ("cattle") guard: bars	2.6-3.0 m (9-10 ft)	
Carnivores				
Bear: Black	91-100	Gate: manual open/close		No

10.5. C-5: Mammal Fence End and Gap Treatments (Pavement Edge and Fence Line)

Please refer to
Figure 32 for cost information.

MEDIUM AND LARGE MAMMALS	Percent effectiveness in excluding target species	Fence end treatment	Distance animal would have to jump to clear barrier (boulder field, wildlife ("cattle") guard, electric mat)	Measure to reduce impact of vehicle crash with fence end treatment	Known potential for animal entanglement in fence end treatment
Ungulates					
Deer: Mule	91-100	Electrified mat	4.6-5.0 m (15-16 ft)	Not applicable	No
	91-100	Wildlife ("cattle") guard: bars	4.1-4.5 m (13-15 ft)	Not applicable	No
	81-90	Electrified mat	1.6-2.0 m (5-7 ft)	Break away fence poles	No
Deer: White-tailed	Ineffective	Boulder field	2.6-3.0 m (9-10 ft)	Not applicable	No
Elk	91-100	Electrified mat	1.6-2.0 m (5-7 ft)	Break away fence poles	No
	81-90	Bring fence close to paved surface	NA	Break away fence poles	No
	81-90	Electrified mat	1.0-1.5 m (3-5 ft)	Not applicable	No
	61-70	Boulder field	More than 7.0 m (>23 ft)	Guardrail (incl. cables) between pavement and fence end treatment	No

10.6. C-6: Mammal Fence End / Gap Treatments on Travel Lanes

Please refer to Figure 34 for cost information.

MEDIUM AND LARGE MAMMALS	Percent effectiveness in excluding target species	Fence end treatment	Distance animal would have to jump to clear barrier (wildlife ("cattle") guard, electric mat)	Known potential for animal entanglement in fence end treatment
Ungulates				
Bighorn Sheep	51-60	Electrified mat	1.0-1.5 m (3-5 ft)	No
Deer: Mule	Ineffective	Wildlife ("cattle") guard: only painted lines	NA	No
Deer: White-tailed	91-100	Electrified mat	2.1-2.5 m (7-8 ft)	No
Elk	81-90	Electrified mat	1.0-1.5 m (3-5 ft)	No
	91-100	Electrified mat	2.1-2.5 m (7-8 ft)	No

10.7. C-7: Amphibian / Reptile Fence Designs

Refer to Figure 42 for cost information

AMPHIBIAN OR REPTILE SPECIES	Percent effectiveness in reducing wildlife-vehicle collisions or roadkill	Fencing material	Fence height (meters)	Post material	Climbing (over fence) deterrent	Digging (under fence) deterrent	Known potential for animal entanglement in fence itself
Amphibians							
Frog: Tree frog	70	Hard polymer plastic	0.40 (16")	Plastic lumber	Other overhang		No
	Ineffective	Polyethylene netting	0.80 (31")	Galvanized steel	Don't know/no opinion	Main fence buried: 11-20 cm (4-8")	Don't know
Frog: Other	80	Woven wire: mesh < 1 cm (<0.5")	0.60 (24")	Wood: not pressure treated	Other overhang	Main fence buried: 11-20 cm (4-8")	Yes
	80	Concrete wall	1.10 (43")		Other overhang	Main fence buried: 21-50 cm (8-20")	No
	20	Woven wire: mesh < 1 cm (<0.5")	0.60 (24")	Metal: T-post	Outrigger angled away from road: 45 degrees	Main fence buried: <10 cm (<4")	No
	Ineffective	Polyethylene netting	0.80 (31")	Galvanized steel	Don't know/no opinion	Main fence buried: 11-20 cm (4-8")	Don't know
Salamander	100	Hard polymer plastic	0.40 (16")	Plastic lumber	Other overhang		No
	Ineffective	Polyethylene netting	0.80 (31")	Galvanized steel	Don't know/no opinion	Main fence buried: 11-20 cm (4-8")	Don't know
Toad	90	Hard polymer plastic	0.40 (16")	Plastic lumber	Other overhang		No
	80	Woven wire: mesh < 1 cm (<0.5")	0.60 (24")	Wood: not pressure treated	Other overhang	Main fence buried: 11-20 cm (4-8")	Yes
	80	Woven wire: mesh < 1 cm (<0.5")	0.60 (24")	Wood: pressure treated	Other overhang	Main fence buried: <10 cm (<4")	Yes
	Ineffective	Polyethylene netting	0.80 (31")	Galvanized steel	Don't know/no opinion	Main fence buried: 11-20 cm (4-8")	Don't know
Reptiles							
Snake	Ineffective	Polyethylene netting	0.80 (31")	Galvanized steel	Don't know/no opinion	Main fence buried: 11-20 cm (4-8")	Don't know
Turtle: Aquatic	90	Chain link	0.90 (35")	Galvanized steel	NA	Main fence buried: 11-20 cm (4-8")	No
	20	Woven wire with vinyl coating: mesh 1.1-2 cm (0.5-1.0")	0.60 (24")	Metal: T-post	Outrigger angled away from road: 45 degrees	Main fence buried: <10 cm (<4")	No
	90	Woven wire with vinyl coating: mesh 1.1-2 cm (0.5-1.0")	1.25 (49")	Galvanized steel	Flashing mounted on fence	Main fence buried: >50 cm (>20")	No
	80	Chain link	0.90 (35")	Metal: C-post	Flashing mounted on fence	Main fence buried: 21-50 cm (8-20")	No
	Ineffective	Polyethylene netting	0.80 (31")	Galvanized steel	Don't know/no opinion	Main fence buried: 11-20 cm (4-8")	Don't know
	80	Chain link	1.00 (39")	Galvanized steel	NA	Main fence buried: 11-20 cm (4-8")	No
Turtle: Terrestrial (Tortoise)	100	Concrete wall	0.45 (18")	Concrete	NA	Main fence buried: 21-50 cm (8-20")	No