Wildlife-Vehicle Collision and Crossing Mitigation Measures: A Literature Review for Parks Canada, Kootenay National Park

by

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16. Abstract

This report reviews mitigation measures aimed at reducing wildlife-vehicle collisions (WVCs) and at maintaining or improving habitat connectivity for wildlife. This review represents the first task of a project that aims to identify, prioritize, and develop a highway mitigation plan for Highway 93 South in Kootenay National Park and adjacent road sections. The mitigation measures reviewed are aimed at either influencing driver behavior or animal movements with regard to large mammals and mammals that are of conservation concern. For each mitigation measure the report includes a general description of the measure, species that may benefit from the measure, the effectiveness of the mitigation measure in terms of reducing WVCs, examples of studies examining the effectiveness of the mitigation measure in terms of reducing WVCs, the effectiveness of the mitigation measure in terms of reducing the barrier effect of roads and traffic, potential disadvantages or undesired side effects of the measure, maintenance requirements of the mitigation measure, and the range of costs for construction, installation and/or maintenance of the mitigation measure, if available. The authors of this report consider animal detection systems and wildlife fencing, in combination with animal detection systems and wildlife underpasses and overpasses, to be potential primary mitigation measures that should be considered for the reduction of WVCs along Hwy 93 South through Kootenay National Park and adjacent road sections.

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EXECUTIVE SUMMARY

Highway 93 South is a major two-lane highway that extends 106 km from the Trans-Canada Highway in Banff National Park in Alberta to the Columbia River Valley at Radium Hot Springs in British Columbia. Kootenay National Park is a relatively long, narrow park with Hwy 93 South bisecting its major valley bottoms. Rapidly growing human populations in Alberta and British Columbia along with growing recreational interest in the Columbia Valley have contributed to substantial increases in traffic volume on Hwy 93 South. Traffic consists mainly of through traffic. Given the strong increase in traffic volume over the last decade, the relatively high numbers of road-killed wildlife, and the expected further increase in traffic volume in the near future, Parks Canada is concerned about human safety and the impacts of the road and traffic on wildlife.

Parks Canada asked the Western Transportation Institute at Montana State University (WTI) to investigate and recommend strategies to reduce Wildlife-Vehicle Collisions (WVCs) and maintain or improve habitat connectivity for wildlife. The specific tasks of the work included:

- Review mitigation measures aimed at reducing WVCs and at maintaining or improving habitat connectivity for wildlife;
- Identify and prioritize road sections for potential mitigation measures;
- Develop a mitigation plan;
- Review funding mechanisms and potential partnerships for the implementation of the mitigation measures; and
- Produce a final report on the abovementioned tasks.

This manuscript reviews mitigation measures aimed at reducing WVCs and at maintaining or improving habitat connectivity for wildlife. The mitigation measures that are reviewed are aimed at large mammals, including ungulates (deer size and larger, including bighorn sheep and mountain goat) and large carnivores (e.g., black bear, grizzly bear, Canada lynx, and wolf). While other reports have reviewed close to 40 different types of mitigation measures, the review in this report is restricted to the following:

- Mitigation methods aimed at influencing driver behavior
    - Vehicle speed reduction
    - Wildlife warning signs, including animal detection systems
    - Public information and education
- Mitigation methods aimed at influencing animal movements
    - Vegetation management
    - Reflectors or mirrors
    - Alternatives to road salt
    - Boulders in right-of-way
    - Wildlife fencing and safe crossing opportunities (wildlife crossing structures)

For each mitigation measure, this report lists:

- A general description of the measure, including species the measure may affect;
- The effectiveness in terms of reducing WVCs;
- Examples of studies examining the effectiveness of the mitigation measure in terms of reducing WVCs;
- The effectiveness in terms of reducing the barrier effect of roads and traffic;
- Potential disadvantages or undesired side effects of the measure;
- Maintenance requirements of the mitigation measure; and
- The range of costs for construction, installation and/or maintenance of the mitigation measure, if available.

Although there have been many mitigation measures suggested to reduce WVCs, only a few of the measures reviewed in this report have the potential to substantially reduce WVCs. Only wildlife fencing and animal detection systems have shown, to be able to substantially reduce WVCs with large mammals (>80%). It is important to note however, that animal detection systems should still be considered experimental, whereas the estimate for the effectiveness of wildlife fencing in combination with wildlife underpasses and overpasses is more robust. Large boulders in the right-of-way as an alternative to wildlife fencing appear to have potential as a barrier to ungulates and may be an alternative to wildlife fencing. However, this measure should still be considered experimental. Using less sodium chloride, or replacing sodium chloride with alternative deicing or anti-icing substances, may substantially reduce the time certain species such as bighorn sheep spend on or alongside the road. However, such alternative substances may have other negative side effects and their implementation should also be considered experimental. The effectiveness of other mitigation measures in reducing WVCs is relatively low (<50%), impractical, or unknown.

Wildlife fencing and the use of large boulders in the right-of-way increase the barrier effect of the road. These measures should typically only be used if safe crossing opportunities for wildlife are also provided. Such crossing opportunities could consist of at-grade crossings at a gap in the barrier, with or without additional warning signals for drivers (e.g., animal detection systems), or wildlife underpasses and overpasses.

Providing a combination of different types of crossing opportunities appears to serve a greater diversity of wildlife species than a single type of crossing opportunity. The authors of this report consider animal detection systems and wildlife fencing, in combination with animal detection systems and wildlife underpasses and overpasses, to be potential primary mitigation measures for the reduction of WVCs along Hwy 93 South through Kootenay National Park and adjacent road sections. The authors of this report also consider public information and education, experiments with alternatives to road salt, and experiments with large boulders in the right-of-way mitigation measures to have potential for reducing WVCs along Hwy 93 South through Kootenay National Park and adjacent road sections. However, these mitigation measures are classified as "supportive" measures rather than primary measures, and some of them are also considered experimental rather than a proven mitigation measure.

1. INTRODUCTION

Wildlife-vehicle collisions (WVCs) affect human safety, property and wildlife, and the number of WVCs has substantially increased across much of North America over the last decades (Hughes et al. 1996, Romin & Bissonette 1996, Khattak 2003, Tardif & Associates Inc. 2003, Knapp et al. 2004, Williams and Wells 2005, Huijser et al. 2007b). The number of WVCs along Highway 93 South in Kootenay and Banff National Parks appear to show a similar trend and are a concern to Parks Canada, both because of human safety and the conservation of natural resources (Parks Canada 2007).

Hwy 93 South is a major two-lane highway that extends 106 km from the Trans-Canada Highway in Banff National Park in Alberta to the Columbia River Valley at Radium Hot Springs in British Columbia. Kootenay National Park is a relatively long, narrow park with Hwy 93 South bisecting its major valley bottoms. Rapidly growing human populations in Alberta and British Columbia along with growing recreational interest in the Columbia Valley have contributed to substantial increases in traffic volume on Hwy 93 South. Traffic consists mainly of through traffic, including many one-time visitors, commercial truck traffic, and recreational commuters (Parks Canada 2007). Large truck traffic makes up 5-13 percent of total traffic volume, depending on the season, and is believed to be responsible for a disproportionate number of the WVCs on Hwy 93 South (Parks Canada 2007). Annual traffic volume rose from 700,000 in 1997 to 852,000 in 2004, and increased 28.6 percent between 1997 and 2006.

Data from Parks Canada (2007) showed that of 444 WVCs recorded between 1997 and 2006, the species most frequently involved were white-tailed deer (n=233; 52.5%), moose (n=51; 11.5%), bighorn sheep (n=31; 6.9%), mule deer (n=29; 6.5%), and black bear (n=27; 6.1%). In addition, relatively rare or sensitive species have been reported as road kill, including grizzly bear, Canada lynx, wolf, and mountain goat.

Given the strong increase in traffic volume over the last decade, the relatively high numbers of road-killed wildlife, and expected further growth in traffic volume in the near future, Parks Canada is concerned about human safety and the impacts of the road and traffic on wildlife. Therefore, Parks Canada asked the Western Transportation Institute at Montana State University (WTI) to investigate and recommend strategies to reduce WVCs and maintain or improve habitat connectivity for wildlife. The specific tasks of the work included:

- Review mitigation measures aimed at reducing WVCs and at maintaining or improving habitat connectivity for wildlife;
- Identify and prioritize road sections for potential mitigation measures;
- Develop a mitigation plan;
- Review funding mechanisms and potential partnerships for the implementation of the mitigation measures; and
- Produce a final report on the abovementioned tasks.

This manuscript reviews mitigation measures aimed at reducing WVCs and at maintaining or improving habitat connectivity for wildlife. While other reports have reviewed close to 40 different types of mitigation measures (see, e.g., Knapp et al. 2004, Huijser et al. 2007a, b), the review in this report is restricted to the following:

Mitigation methods aimed at influencing driver behavior

- Vehicle speed reduction
- Wildlife warning signs, including animal detection systems
- Public information and education

Mitigation methods aimed at influencing animal movements

- Vegetation management
- Reflectors or mirrors
- Alternatives to road salt
- Boulders in right-of-way
- Wildlife fencing and safe crossing opportunities

2. METHODS

2.1. Species

The mitigation measures reviewed are aimed at large mammals, including ungulates (deer size and larger, including bighorn sheep and mountain goat) and large carnivores (e.g., black bear, grizzly bear, Canada lynx, and wolf).

2.2. Review of Mitigation Measures

Each mitigation measure was reviewed with regard to the following topics or parameters:

- General description of the measure;
- The effectiveness in reducing WVCs (including examples of case studies, if available);
- The effectiveness in reducing the barrier effect of roads and traffic (including examples of case studies, if available);
- Potential disadvantages or undesired side effects of the mitigation measure;
- Maintenance requirements of the mitigation measure; and
- Installation and maintenance costs for the mitigation measure.

2.3. Sources

Literature sources reviewed included peer reviewed journal articles, proceedings, manuscripts, books and synthesis documents such as the NCHRP synthesis (Evink 2002), the COST 341 guide (Iuell et al. 2003), the book on road ecology by Forman et al. (2003), the deer-vehicle crash toolbox (Knapp et al. 2004), and the review report by Donaldson (2006). Furthermore WTI consulted with individual experts.

3. MITIGATION METHODS AIMED AT INFLUENCING DRIVER BEHAVIOR

This broad category of WVC mitigation strategies relates to those that attempt to help drivers avoid a WVC through influencing driver behavior.

3.1. Reduce Vehicle Speed

For areas with high WVC frequency, reducing vehicle speed is occasionally suggested as a mitigation strategy. Before discussing the methods and implications of this strategy, it is important to understand the different types of speeds associated with the design and operation of a highway:

- The **design speed** is "a selected speed used to determine the various geometric design features of the roadway" (AASHTO 2004). Certain minimum design standards are used for different design speeds. A higher design speed typically means higher minimums for curve radius, lane widths, shoulder widths, clear zone widths, and other design parameters. Higher design speeds also mean lower maximums for the number of access points (e.g., intersections, driveways, or interchanges) per mile.
- After a road is built, a spot speed study is done. **Operating speed** is determined as "the speed at which drivers are observed operating their vehicles during free-flow conditions. In the United States, the 85th percentile of the distribution of observed speeds is the most frequently used measure of the operating speed associated with a particular location or geometric feature" (AASHTO 2004). Speed studies are typically done before speed limit signs are installed, or speed limit signs are covered during the study. The theory assumes that drivers are the best judge of a safe driving speed of a roadway and 85 percent of the people will travel at reasonable speeds.
- The enforceable **posted speed limit** is the maximum legal speed at which a vehicle is allowed to travel. These are typically set near the operating (85th percentile) speed.
- When a portion of the roadway has characteristics where the design speed is less than that of the rest of the road, an **advisory speed** can be posted. Advisory speeds are lower than the posted speed limit and are not enforceable other than by using basic "reasonable and prudent" laws.

Under ideal circumstances, the design speed, operating speed, and posted speed should be very similar for a given roadway. Here we discuss three ways to reduce operating vehicle speed: 1) reduce the posted speed, 2) reduce the design speed through traffic calming or redesign, and 3) post an advisory speed.

3.1.1. Posted Speed Limit

General Description

The ability to reduce the posted speed depends on who owns the roadway (state, county, city), as well as the legislation and guidelines governing those agencies. Once approval for the reduced speed is obtained, this mitigation is implemented by replacing the existing speed limit signs.

Direct benefits in terms of reduced WVCs are unknown, though reduced vehicle speed and increased driver alertness may reduce WVCs. At relatively high speeds (e.g., ≥80 km/h), a speed reduction of even a few kilometers per hour can be beneficial as it leads to a disproportionate decrease in the risk of a severe collision. Kloeden et al. (2001) estimated that even a 5 km/h reduction in speed from 80 km/h on undivided roads could lower casualty crashes by 31-32 percent. In addition, lower vehicle speeds lead to shorter stopping distances, which may not only reduce the severity of a crash, but may also help avoid a collision altogether.

Species: Reducing speed does not target WVCs for specific species.

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: unknown

> The effect of reducing vehicle speed on WVCs is unclear. However, for all crashes, reducing vehicle speeds generally reduces the frequency of severe crashes involving human injury or fatality (National Research Council 1998). Though data are limited, road mortality may only substantially decrease with relatively low posted speed limits (e.g. ≤45 mi/h (≤72 km/h) (Gunther et al. 1998).

Examples of studies or applications:

- One location where posted vehicle speeds were reduced to mitigate WVCs is on the Yellowhead Highway in Jasper National Park, Alberta. This roadway is a rural two-lane highway, with 3.7 m (12 ft) lane widths, and 3 m (10 ft) shoulders (Bertwistle 1999). Passing sight distance exists for most of its length. Passing sight distance is "determined on the basis of the length needed to complete normal passing maneuvers in which the passing driver can determine that there are no potentially conflicting vehicles ahead before beginning the maneuver" (AASHTO 2004). Prior to the mitigation, the speed limit for the roadway was 90 km/h. Traffic in 1998 was 1.2 million vehicles per year with a high percentage of trucks, buses and recreational vehicles. The area includes grizzly bear, white-tailed deer, mule deer, bighorn sheep, and elk. In 1991, the speed limit was reduced from 90 km/h to 70 km/h on three sections of the road that were 2.5 km, 4 km, and 9 km in length. Bertwistle (1999) reported that, on average, 5,475 speeding tickets are issued each year (although he was not specific as to whether these were in the 70 km/h zones or on the highway as a whole). Even with the speed limits and enforcement, a speed study in 1995 at two of the speed reduction locations showed that less than 20 percent of the vehicles obeyed the 70 km/h speed limit. Bertwistle (1999) reported that bighorn sheep collisions actually increased in the reduced speed zones and decreased in the control areas where the limit remained 90 km/h. Elk collisions were monitored at one reduced-speed location and both the control and the reduced-speed zones had increases in elk-vehicle collisions. The data presented by Bertwistle (1999) appear to be inconclusive.

- A report by Biota Research and Consulting, Inc. (2003), summarized WVCs in the Jackson, Wyoming, area. On a 1.4 km stretch of highway the authors suggested highway lighting as a solution, because even with the posted speed limit reduced to 35 mi/h (56 km/h), drivers continued to strike and kill deer. The report does not state whether there was a decrease in WVCs as a result of the posted speed limit reduction.
- In Yellowstone National Park, a 55 mi/h (88 km/h) road with higher annual traffic levels had comparatively more road kill than lower speed (≤45 mi/h; ≤72 km/h) and lower volume roads (Gunther et al. 1998). Based on the length of roads, the road sections with a posted speed limit of 55 mi/h (88 km/h) had 5.4 times more road killed animals than expected and the road sections with a posted speed limit of ≤45 mi/h (≤72 km/h) had 33.2 percent fewer road killed animals than expected (Gunther et al. 1998).
- On State Route 29 and U.S. Hwy 41 in southern Florida, the night speed limit has been lowered from 60 mi/h (97 km/h) to 45 mi/h (72 km/h) to reduce collisions with the Florida panther (*Puma concolor coryi*) (Figure 1). However, actual vehicle speeds are around 70-75 mi/h (113-121 km/h) during the day and 60-65 mi/h (97-105 km/h) during the night (Deborah Jansen, Big Cypress National Preserve, personal comment).

Figure 1: Reduced nighttime speed limit to protect the Florida panther along State Route 29 in southern Florida (© Marcel Huijser).

Effectiveness in reducing the barrier effect of roads and traffic

Reduced vehicle speed and increased driver alertness may increase the number of successful road crossing events for all species. Reducing vehicle speeds does not necessarily address potential road and traffic avoidance behavior displayed by certain individuals or species. Nonetheless, signs do not physically restrict animal movements.

Potential disadvantages or undesired side effects

Extreme caution should be taken in reducing the posted speed limit substantially below the operating speed. Such a reduction can set up a situation where motorists are encouraged to break the law and it may lead to increased speed dispersion (the variability of vehicle speeds) and associated safety risks. Speed dispersion can also lead to a transition from a normal distribution of vehicle speeds to a bimodal distribution: one group of vehicles traveling at about the posted speed limit and another traveling at about the operating speed. It has been shown that speed dispersion increases crash rates even if average speeds decrease. Solomon (1964) and Cerrelli (1981) found that vehicles traveling close to the average speed had the lowest crash involvement rates, while rates increased for both faster and slower vehicles. Garber and Gadiraju (1988) found a similar U-shaped relationship, where the further the posted speed was from the design speed, the higher the crash rate for the roadway. Speed dispersion is a particularly serious issue on two-lane rural roads (where WVCs occur most often), because it increases the number of vehicles passing in unsafe situations. Another disadvantage of lower posted speeds is an increase in travel time.

Maintenance requirements

Signs may require maintenance from vehicle- or weather-related damage and vandalism.

Installation and maintenance costs

Costs include:

- The cost of a speed limit sign (24 x 30 inches; 61x76 cm) (about US$55, USA Traffic Signs 2008);
- The cost of vehicle speed enforcement.

3.1.2. Design Speed and Traffic Calming

General Description

Reducing the design speed of a road may be more effective in reducing operating vehicle speed than reducing the posted speed limit. A lower design speed typically relates to sharper horizontal and vertical curves, narrow lane widths, narrow or no shoulders, and narrow clear zones (i.e., obstructions such as trees closer to the roadway). In addition to the basic highway geometrics, there are numerous traffic calming methods used to slow vehicles down. These are typically used in residential neighborhoods or on a highway approaching a town, and rarely on major highways in rural areas where most WVCs occur. Traffic calming treatments include speed bumps/humps, traffic circles, curb extensions, sidewalk extensions, raised medians and rumble strips. Reduced vehicle speed and increased driver alertness may reduce road kill for all road crossing wildlife species.

Species: Reducing speed does not target WVCs for specific species.

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: unknown

Direct benefits in terms of reduced WVCs are inconclusive.

Examples of studies:

- In Yellowstone National Park, roads that were designed and reconstructed for higher speeds resulted in increased road kill. Although it was not implemented, extensive modeling on the potential impacts of design speed reductions led to recommendations for not upgrading design speed of roadways during planned reconstruction (Gunther et al. 1998).
- Four "slow points" were installed on a road in Tasmania that had experienced a dramatic increase in collisions with eastern quolls (*Dasyurus viverrinus*) and Tasmanian devils (*Sarcophilus laniarius*) after the road section in a national park was widened and sealed and modal speed increased by 20 km/h (Jones 2000). In addition, after the initial widening the population size of the two species declined substantially and the eastern quoll population became extinct. The "slow points" consisted of concrete barriers with a "Give Way" sign that constricted traffic to a single lane in the center of the road in or close to locations that had a concentration of road kill (Jones 2000). The tight curves and the merging of traffic forced vehicles to slow down. After the installation of the "slow points", the median vehicle speed in the center of the road section dropped by about 20 km/h (17-35 percent reduction), while vehicle speed at the outer two "slow points" close to the park boundary and wildlife zone boundary was only reduced by 1-7 percent. In addition, road mortality became more sporadic; the eastern quoll population was reestablished and two years after installing the "slow points," reached 50 percent of its previous size before the road was widened and sealed 2 years after the installation of the 'slow points' (Jones 2000). Furthermore there was some indication the Tasmanian devil population was recovering as well.
- Figure 2 shows an example of where speed bumps are used to reduce vehicle speed for cassowaries (*Casuarius casuarius*), a large bird species in Queensland, Australia. The top sign originally displayed a warning for a speed bump, but was vandalized with a black marker to depict a dead cassowary.

Figure 2: Speed bumps (lower right in picture) are used to reduce WVCs in Queensland, Australia (© Marcel Huijser). Please disregard graffiti on signs.

- In southern Florida, mitigation measures were installed including: 1) rumble strip patches in combination with 2) a black-on-yellow warning sign that reads "PANTHER CROSSING NEXT [X] MI" that has 3) a permanently activated flashing amber light installed on top of the warning sign (Figure 3). These mitigation measures were designed to reduce collisions with the Florida panther by increasing driver alertness and reducing vehicle speed.

Figure 3: Patches of rumble strips accompany a panther warning sign along State Route 29 in southern Florida (© Marcel Huijser).

Effectiveness in reducing the barrier effect of roads and traffic

Reduced vehicle speed and increased driver alertness may increase the number of successful road crossing events for all road crossing wildlife species. However, it does not necessarily address potential road avoidance behavior displayed by certain individuals or species. Signs do not restrict animal movements.

Potential disadvantages or undesired side effects

- While roads with lower design speeds may encourage lower vehicle speeds, the narrower clear zones associated with such designs have been associated with higher levels of WVCs and other types of collisions.
- Utilizing less-than-desirable geometric features (sharper horizontal curves, reduced lane widths, narrow or no shoulders, and more narrow clear zones) may reduce the overall safety of the roadway. The reduction in safety may be greater if these features violate driver expectancy.
- Depending on the road, its function, and traffic volume, traffic calming may lead to greater congestion and driver frustration.
- Traffic calming options are not viable for through traffic and most high speed state highways.

Maintenance requirements

Some traffic calming designs may result in snow removal difficulties and maintenance issues.

Installation and maintenance costs

No costs were identified in the literature review. Redesigning roads for lower speeds is likely relatively expensive unless they are done as part of a reconstruction project, but the authors were unable to locate documented costs.

3.1.3. Post Advisory Speed Limit

General Description

When a portion of a roadway has characteristics that result in a design speed that is lower than adjacent road sections, advisory speed limits may be useful. Advisory speeds are not enforceable, except by basic reasonable and prudent laws. Posted advisory speed limits have been used (or have the potential to be used) in conjunction with other mitigation measures, such as animal detection systems, in-vehicle technologies, and wildlife warning signs (e.g., Figures 4 and 5). Reduced vehicle speed and increased driver alertness may reduce road kill for all road crossing wildlife species.

Species: Reducing speed does not target WVCs for specific species.

Figure 4: Advisory speed limits accompany a deer warning sign near 't Harde, The Netherlands (© Marcel Huijser). Note: The LED part of the warning sign is linked to an animal detection system, but the advisory speed limit reduction sign is always visible in daylight, regardless of the presence and detection of large animals.

Figure 5: The same sign as shown in Figure 4 when triggered at night (© Marcel Huijser).

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: unknown

> Evidence for whether advisory speed limits are effective at reducing WVCs remains sparse.

Examples of studies:

- In Saudi Arabia, enhanced camel (*Camelus dromedarius*) warning signs with reduced advisory speed limits resulted in relatively small, but statistically significant reductions of vehicle speed (3-7 km/h), whereas standard camel warning signs did not. Enhanced signs were also larger than the standard warning signs, had diamond reflective material, had a yellow camel on a black background, and/or were accompanied by text message "camel-crossing" signs (Al-Ghamdi and AlGadhi 2004).
- In Montana, wildlife advisory messages posted on permanent and portable Dynamic Message Signs reduced vehicle speeds. The greatest effect occurred during dark conditions, when the number of WVCs is higher (Hardy et al. 2006).
- In The Netherlands, advisory speed limit signs accompany gaps in exclusionary wildlife fencing (Figures 4 and 5). See also section 4.6 Wildlife Fencing With Gaps, and Figures 39 and 40.

Effectiveness in reducing the barrier effect of roads and traffic

Reduced vehicle speed and increased driver alertness may increase the number of successful road crossing events for all road crossing wildlife species. However, it does not necessarily address potential road avoidance behavior displayed by certain individuals or species. Signs do not restrict animal movements.

Potential disadvantages or undesired side effects

Advisory speed limits are not enforceable.

Maintenance requirements

Signs must be installed in specific locations, and may require maintenance from vehicle- or weather-related damage and vandalism.

Installation and maintenance costs

The cost of an advisory speed limit sign is about US$70 (USA Traffic signs 2008).

3.2. Wildlife Warning Signs

Roadway wildlife warning signs are perhaps the most commonly applied WVC mitigation measure (Forman et al. 2003, Sullivan & Messmer 2003). The signs alert drivers to the potential presence of wildlife on or near the road, and urge them to be more alert, to reduce the speed of their vehicle, or a combination of both. These signs attempt to prevent a collision, or to reduce the severity of a collision through lower vehicle speeds at impact (Figure 6).

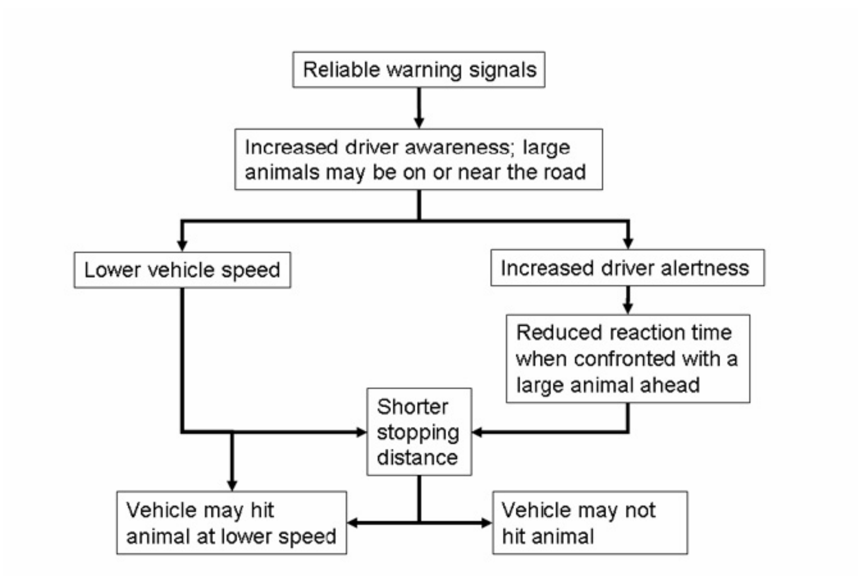

Figure 6: Flow chart of the effect of reliable warning signals.

Driver response is split into two components: increased alertness and lower vehicle speed (Figure 6). Increased alertness can reduce driver reaction time to an unusual and unexpected event from 1.5 sec to 0.7 sec if drivers are warned (Green 2000). Assuming a constant vehicle speed of 88 km/h (55 mi/h) before and after warning signals have been presented to a driver, increased driver alertness could reduce the stopping distance of the vehicle by 21 m. This reduction in reaction time and stopping distance, however, has not been specifically tested with respect to the presence of large animals in rural areas, let alone for warning signals that may apply to road sections of many miles rather than a point or short road section. Lower vehicle speed allows for more reaction time, and should a collision still happen, it is likely to be less severe (Kloeden et al. 1997). At relatively high speed, even small reductions in vehicle speed matter because the relation between vehicle speed and the risk of a severe accident is exponential; small reductions in vehicle speed result in a disproportionate decrease in the risk of a severe accident (Kloeden et al. 1997).

Since the effectiveness of warning signs depends on driver response, it is critical that warning signs are reliable (i.e., the driver is warned when there is a relatively high chance of WVCs on specific locations). The warning signs discussed below (standard warning signs, large or enhanced warning signs, seasonal wildlife warning signs, and animal detection systems) should be placed in road sections that exceed a certain minimum risk of WVCs.

3.2.1. Standard

General Description

The standard deer warning sign in the United States is a diamond-shaped panel with a black deer symbol on a yellow background. These signs are intended to inform drivers that the upcoming road section has a history of a higher-than-average number of deer-vehicle collisions. Sometimes signs include text that informs drivers of the length of applicable road section (Figure 7).

Figure 7: Standard deer warning sign on Highway 83 in Montana includes the length of the road section that the warning sign applies to (© Marcel Huijser).

Species: Standard signs can be used for specific species for areas with a higher-than-average number of species-specific wildlife-vehicle collisions. However, standard signs do not necessarily address potential road avoidance behavior displayed by certain individuals or species.

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: 0%

Based on the available data, standard deer warning signs are considered to be ineffective in reducing WVCs, in general, and deer-vehicle collisions, in particular. Most authors doubt the effectiveness of standard warning signs (Williams 1964, cited in Pojar et al. 1975, Putman 1997, Sullivan & Messmer 2003, Putman et al. 2004), but only two studies were found that investigated their effectiveness, confirming a basis for those doubts (Rogers 2004, Meyer 2006).

Examples of studies:

- Meyer (2006) investigated the effectiveness of standard deer warning signs in Kansas by comparing the accident data before and after sign installation. After taking all available accident data before sign installation and other road and landscape parameters into consideration, there was no evidence that the presence of the deer warning signs had reduced deer-vehicle collisions (Meyer 2006).
- In Saudi Arabia, the installation of standard camel-crossing signs did not result in reduced vehicle speed. Standard warning signs were triangular, with all sides measuring 110 cm, had a white interior with black camel silhouette and red border, and did not have diamond-shaped reflective material (Al-Ghamdi and AlGadhi 2004).
- The installation of deer warning signs did not reduce the number of deer-vehicle collisions in Michigan (Rogers 2004).
- In a driving simulator study, a standard deer warning sign resulted in an average vehicle speed of 123.2 km/h (76.6 mi/h), just over the posted speed limit of 120.7 km/h (75 mi/h) (Stanley et al. 2006). This result showed that standard deer warning signs failed to reduce the average vehicle speed to the posted speed limit.

Effectiveness in reducing the barrier effect of roads and traffic

Reduced vehicle speed and increased driver alertness may increase the number of successful road crossing events for all road crossing wildlife species. However, it does not necessarily address potential road avoidance behavior displayed by certain individuals or species. Signs do not restrict animal movements.

Potential disadvantages or undesired side effects

As a general rule, unnecessary signs should be removed as they may distract drivers and require maintenance. However, one may choose not to remove standard warning signs if WVCs have been substantially reduced. One reason for this is potential liability for the transportation agency in case of a WVC (Arizona Court of Appeals 2004).

Maintenance Requirements

Signs must be installed in specific locations, and may require maintenance from vehicle- or weather-related damage and vandalism.

Installation and maintenance costs

One study (Pojar et al. 1975) estimated costs at US$94 per sign (not adjusted for inflation). USA Traffic Signs (2008) reports the following costs: US$45 (61 cm x 61 cm; 24 in x 24 in), US$68 (76 cm x 76 cm; 30 in x 30 in), US$100 (91 cm x 91 cm; 36 in x 36 in).

3.2.2. Non-Standard

General Description

Large or enhanced animal warning signs may take many forms. They can be larger than the standard wildlife warning signs, include graphic images of a vehicle hitting wildlife, and may have permanently activated flashing amber warning lights, light emitting diodes (LEDs), red or orange flags attached to the signs, or messages displayed on Variable Message Signs (VMS) (Figures 8-15). Such signs are designed to attract the attention of the driver and to relay a stronger message than standard wildlife warning signs. However, uniformity across the country is desirable so that drivers learn and understand what different signs represent.

Figure 8: Enhanced standard deer warning sign on State Highway 75 in Idaho (© Marcel Huijser).

Figure 9: Non-standard elk warning sign on the TransCanada highway, Alberta (© Marcel Huijser).

Figure 10: A VMS updates motorists on moose casualties near Hoback Junction in Wyoming (©Angela Kociolek).

Figure 11: Large enhanced warning sign for bighorn sheep along State Highway 75 in Idaho (© Marcel Huijser).

Figure 12: Large warning sign for wildlife along Hwy 93 south of Radium Hot Springs in British Columbia (© Marcel Huijser).

Figure 13: Large warning sign for bighorn sheep along Hwy 93 south of Radium Hot Springs in British Columbia (© Marcel Huijser).

Figure 14: Warning sign for deer along Hwy 93 in Kootenay National Park in British Columbia (© Marcel Huijser).

Figure 15: Warning sign for elk along Hwy 93 in Kootenay National Park in British Columbia (© Marcel Huijser).

Species: Non-standard signs can be used for specific species in target areas with a higher-than-average number of species-specific WVCs. However, non-standard signs do not necessarily address potential road avoidance behavior displayed by certain individuals or species.

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: unknown

> Observed reduction in vehicle speed suggests that large or enhanced wildlife warning signs may be somewhat effective, but the limited available data on WVCs indicate that the speed reduction through such signs may not really be effective in reducing WVCs (Pojar et al. 1975).

Examples of studies:

- Hammond and Wade (2004) conducted an experiment in a driving simulator and exposed drivers to standard deer warning signs and to enhanced deer warning signs, which were standard warning signs with a flashing light on top. The average vehicle speed with standard deer warning signs was 99.6 km/h. The enhanced sign with the light turned off resulted in similar speeds of 99.5 km/h, but the enhanced sign with the light turned on resulted in a significantly lower vehicle speed of 95.9 km/h, a reduction of 3.7 km/h (Hammond & Wade 2004).
- Hardy et al. (2006) found that wildlife advisory messages on permanent and portable Dynamic Message Signs reduced vehicle speeds and corresponding safe-stopping sight distances by 1–9 percent (1.8–21.9 m), with the greatest effect occurring during dark conditions.

- Lighted animated deer crossing signs reduced vehicle speed by 4.8 km/h compared to the same signs when they were turned off (Pojar et al. 1975). The presence of deer carcasses as a "supplement" to the signs resulted in a much greater reduction in vehicle speed: 12.6 km/h (lights turned off) and 10.0 km/h (lights turned on) (Pojar et al. 1975). Despite the successful speed reduction of the lighted animated signs, they did not result in a reduction of deer-vehicle collisions (Pojar et al. 1975).
- Stanley et al. (2006) conducted experiments with a driving simulator and found that enhanced wildlife warning signs resulted in lower vehicle speeds and earlier braking when drivers were confronted with a deer in the simulated environment.
- Enhanced camel warning signs in Saudi Arabia resulted in a significant reduction of vehicle speed whereas standard camel warning signs did not (Al-Ghamdi & AlGadhi 2004). The standard warning signs were triangular where all sides were 110 cm, with a red border and white interior with black camel silhouette, and did not have diamond reflective material. The enhanced signs were larger than the standard warning signs, had diamond reflective material, had a yellow camel on a black background, and/or were accompanied by the text message "camel-crossing" and a reduced advisory speed limit. The enhanced signs reduced vehicle speed by 3 to 7 km/h (Al-Ghamdi & AlGadhi 2004).

Effectiveness in reducing the barrier effect of roads and traffic

Reduced vehicle speed and increased driver alertness may increase the number of successful road crossing events for all road crossing wildlife species. However, it does not necessarily address potential road avoidance behavior displayed by certain individuals or species. Signs do not restrict animal movements.

Potential disadvantages or undesired side effects

By their very nature, non-standard warning signs diminish the uniformity of warning signs generally. Standard warning signs are desirable so that drivers learn and understand what different signs represent (known as "driver expectancy"). While non-standard signs may draw attention, a potential downside is that it takes drivers longer to interpret the sign, simply because it is non-standard.

Maintenance Requirements

Signs must be installed in specific locations, and may require maintenance from vehicle- or weather-related damage and vandalism.

Installation and maintenance costs

One cost estimate (Pojar et al. 1975) reported in the literature was US$2,000 per sign (not adjusted for inflation). A portable Digital Message System is estimated to cost at least US$15,000 and permanent DMS designs are much more expensive.

3.2.3. Seasonal

General Description

Seasonal wildlife warning signs are designed to deliver time-specific messages to drivers. They are displayed at certain times of the year when animals cross the road most frequently, such as during a seasonal migration (Figures 16-18). Seasonal signs can be used for specific species for areas with a higher-than-average number of species-specific WVCs.

Figure 16: Seasonal warning signs for bison in Yellowstone National Park (© WTI file photo).

Figure 17: A permanent deer warning sign in Idaho has hinges, allowing for its seasonal use (© Marcel Huijser).

Figure 18: Seasonal deer migration sign in Utah (© Marcel Huijser).

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: 26%

> Seasonal wildlife warning signs may result in a 26 percent reduction in deer-vehicle collisions. However, these types of signs are only applicable in situations where deer (or other large animals) display road crossing behavior that is concentrated in space and time.

Examples of studies:

- Sullivan et al. (2004) erected temporary warning signs with reflective flags and permanently flashing amber lights in locations that were known to be used by mule deer (*Odocoileus hemionus*) during their seasonal migration. The number of deer-vehicle collisions was reduced by 51 percent (from a range of 41.5 to 58.6 percent for individual test areas) compared to control areas. The signs reduced the percentage of speeders from 19 percent to 8 percent during their first season of operation, but the effect was less pronounced in the second season, perhaps due to driver habituation (Sullivan et al. 2004).
- Rogers (2004) investigated the effect of enhanced deer warning signs (black on yellow sign showing a deer and a car symbol, combined with a black on orange sign stating "HIGH CRASH AREA") on the number of deer-vehicle collisions. The signs were deployed between October and January (the peak time for deer-vehicle collisions) for three consecutive years. Rogers (2004) found no effect of the seasonal signs on the number of deer-vehicle collisions.

Effectiveness in reducing the barrier effect of roads and traffic

Reduced vehicle speed and increased driver alertness may increase the number of successful road crossing events for all road crossing wildlife species. However, it does not necessarily address potential road avoidance behavior displayed by certain individuals or species. In addition, the location and time of road crossings by threatened and endangered species may not be the same as those for the most frequently hit species, such as deer.

Potential disadvantages or undesired side effects

This mitigation measure is site-, species-, and population-specific, with limited use otherwise. The signs reportedly are subject to vandalism and theft (Sullivan et al. 2004).

Maintenance Requirements

As seasonal signs are temporary, maintenance is required to install and remove them. They may also require maintenance from vehicle- or weather-related damage and vandalism.

Installation and maintenance costs

Sullivan et al. reported a cost of US$270 per km (US$435 per mile).

3.2.4. Roadside Animal Detection Systems

General Description

Animal detection systems use sensors to detect large animals that approach the road. Once a large animal is detected, warning signals are activated to inform the drivers that a large animal may be on or near the road at that time (Figures 19 – 20). Once a driver is aware that a large animal may be on or near the road ahead, the driver may lower the speed of the vehicle. The warning signals are extremely time specific.

Figure 19: An animal detection system on U.S. Highway 191 in Yellowstone National Park (© Marcel Huijser).

Figure 20: An animal detection system in action in Kootenay National Park, British Columbia (© Alan Dibb).

Two broad categories are commonly used in animal detection systems: area-cover systems and break-the-beam systems. Area-cover systems detect large animals within a certain range of a sensor. Area-coverage systems can be passive or active. Passive systems detect animals by only receiving signals. The two most common systems are passive infrared and video detection. These systems require algorithms that distinguish between, for example, moving vehicles with warm engines and moving pockets of hot air and movements of large animals. Active systems send a signal over an area and measure its reflection. Break-the-beam systems use transmitters and receivers for a beam of microwave radio, infrared, or laser signals. When an animal's body blocks or reduces the signal strength, a detection occurs and the warning signs are activated. Other less common detection systems include a system that depends on radio-collared animals in conjunction with receivers placed in the right-of-way, and a system that uses seismic sensors to detect vibrations in the soil as large animals approach (Huijser et al. 2006).

Species: Animal detection systems detect large animals only; small- to medium-sized mammal species such as Canada lynx and gray wolf may rarely or never be detected, depending on the height of the sensors and potential interference of objects, including vegetation, close to the ground.

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: 82%

> Data on the effectiveness of animal detection systems are very limited. One of the few studies showed an 82 percent reduction in collisions with large animals (review in Huijser et al. 2006). However, animal detection systems should still be considered experimental and the estimate on the effectiveness of this mitigation measure may change as more data become available. The effectiveness of animal detection systems has been investigated with regard to a potential reduction in vehicle speed and a potential

reduction in WVCs. Previous studies have shown variable results: substantial decreases in vehicle speed (greater than or equal to 5 km/h; Kistler 1998, Muurinen & Ristola 1999, Kinley et al. 2003); minor decreases in vehicle speed (less than 5 km/h; Kistler 1998, Muurinen & Ristola 1999, Gordon & Anderson 2002, Kinley et al. 2003, Gordon et al. 2004, Hammond & Wade 2004); and no decrease or even an increase in vehicle speed (Muurinen & Ristola 1999, Hammond & Wade 2004). This variability of results appears to be related to a number of conditions, such as type of warning signal and signs, whether the warning signs are accompanied with advisory or mandatory speed limit reductions, road and weather conditions, whether the driver is a local resident, and perhaps also cultural differences that may cause drivers to respond differently to warning signals in different regions (Huijser et al. 2006).

Examples of studies:

- Kistler (1998, 2002), Romer and Mosler-Berger (2003), and Mosler-Berger and Romer (2003) have reported on the number of WVCs before and after seven infrared area-cover detection systems were installed in Switzerland (Table 1). These systems reduced the number of WVCs by 82 percent on average (1-sided Wilcoxon matched-pairs signed-ranks test, P=0.008, n=7) (see also Huijser et al. 2006). All seven sites showed a reduction in collisions after an animal detection system was installed, and three of the seven sites did not have a single collision after system installation (as of 6-7 years after installation). The data relate to collisions with roe deer (*Capreolus capreolus*) and red deer (*Cervus elaphus*), and collisions that occurred during the day when the systems were not active were excluded from the analyses.

Table 1: Collisions with large animals before and after detection system installation in Switzerland.

	Before Installation			**After Installation**			**Reduction**	
Location	Coll. (N)	Yrs	Coll./yr	Coll. (N)	Yrs	Coll./yr	Coll./yr	%
Warth	14	7	2.00	3	10	0.30	1.70	85.00
Soolsteg	8	11	0.73	1	6	0.17	0.56	77.08
Val Maliens	7	3	2.33	6	5	1.20	1.13	48.57
Marcau	12	4	3.00	6	5	1.20	1.80	60.00
Schafrein	26	8	3.25	0	6	0.00	3.25	100.00
Duftbächli	18	8	2.25	0	6	0.00	2.25	100.00
Grünenwald	6	8	0.75	0	7	0.00	0.75	100.00
Average Reduction								**81.52**

- Huijser et al. (2006) listed more than 30 locations in North America and Europe where animal detection systems were installed, and they describe experiences with installation, operation and maintenance, reliability and effectiveness. However, some of the systems were removed because the systems were not reliable enough. Other systems were removed because the landscape surrounding the road changed causing animals to reduce the crossing frequency at that location. While the limited data on system effectiveness are encouraging, animal detection systems should still be regarded as experimental rather than an established mitigation measure (Huijser et al. 2006).

- Since August 2007, a number of additional locations have been equipped with an animal detection system, including along State Route 260 near Payson, Arizona (David Bryson, Electrobraid Fence Ltd, personal communication; Norris Dodd, Arizona Game and Fish Department, personal communication). Here an animal detection system was combined with electric fencing.
- Huijser et al. (2007c) tested the reliability of nine different animal detection systems from five different manufacturers. The test site was not alongside a road. The site consisted of an enclosure with horses and llamas. The individual detection systems logged the date and time of each detection while infrared video cameras recorded all animal movements with a date and time stamp. Some of the animal detection systems proved highly reliable in detecting large animals.

Effectiveness in reducing the barrier effect of roads and traffic

Reduced vehicle speed and increased driver alertness may increase the number of successful road crossing events for all large road crossing species (including grizzly bear). However, it does not necessarily address potential road avoidance behavior displayed by certain individuals or species. Medium-sized mammal species such as Canada lynx and gray wolf may rarely or never be detected. Animal detection systems do not restrict animal movements. However, animal detection systems are often used in combination with other measures such as wildlife fencing that increase the barrier effect of a road.

Potential disadvantages or undesired side effects

Animal detection systems can reduce collisions with large animals, but the presence of poles and equipment in the right-of-way is a potential hazard to vehicles that run off the road (see Huijser et al. 2006). Animal detection systems do not usually benefit small- or medium-sized species (i.e., smaller than deer). Furthermore, some of the systems are not operational during the day. Finally, curves, drops and rises in the right-of-way, access roads, pedestrians, winter conditions (including snow spray from snow plow and snow accumulation, can cause problems with the installation, maintenance and operation of animal detection systems.

Maintenance requirements

Most of the systems have or had problems with the reliability of the sensors, although some of the manufacturers seem to have overcome these problems (Huijser et al. 2006, 2007c).

Despite substantial installation costs, animal detection systems are somewhat portable compared to wildlife underpasses or overpasses, and could be moved if/when animals select new crossing sites because of changes in the surrounding landscape.

Installation and maintenance costs

Estimated costs of these systems are US$40,000 to US$96,000 per km of coverage area (excluding installation costs) (Huijser et al. 2006, unpublished data, Marcel Huijser, WTI). Equipment costs are higher if the road section concerned has curves or slopes, or if the line of sight in the right-of-way is blocked by objects.

3.3. Public Information and Education

General Description

Public information and driver education seek to reduce death and serious injury by increasing motorist awareness of the causes of WVCs, high-risk locations, and preventive measures. Videos, brochures, posters, bumper stickers, road signs, and general messages in the media have been used (Figure 21). Public information and driver education efforts are believed to be most beneficial when used in combination with other WVC-reduction measures (Walker 2004, Hardy et al. 2006). Given a receptive audience, campaigns have great potential to inform a public that seeks to more fully understand the dangers of WVCs, the actions they can take as drivers to avoid accidents, and the locations of high-risk roadways.

Figure 21: Public education appears to have inspired this warning sign in Banff National Park (© Marcel Huijser).

Deer are the most commonly hit species in North America (Huijser et al. 2007b). Deer-vehicle collision (DVC) education and information efforts can be divided into two categories. In one category are efforts that provide information describing DVC significance, such as the local rates of DVCs or locations of roadway segments with high rates of DVCs. In the second category are efforts that provide information on DVC avoidance - namely, actions drivers can take to avoid wildlife if they appear on or near the roadway (Knapp et al. 2004).

Species: Public information and education can focus on specific target species, species groups, or all wildlife species. However, most efforts are related to DVCs.

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: unknown

Many transportation professionals and researchers have discussed driver education and public information campaigns as a means to help reduce WVCs (Evink 1996, Jacobs 2001, Pynn & Pynn 2004, Rogers 2004, Knapp 2005) or have conducted research to incorporate their findings into motorist education efforts (Biggs et al. 2004). However, there are no known studies indicating the statistical effectiveness of driver education or public information/awareness efforts that have directly, by themselves, decreased the incidence of WVCs (Knapp 2005). Driver education and public information campaigns are considered good practice, but these campaigns are not necessarily effective in reducing WVCs.

Examples of studies:

- A national phone survey indicated driver respondents believe WVCs are a serious problem and more than 97 percent believe driver education and media information to the general public would be helpful in reducing WVCs (Jacobs 2001).
- Respondents to a Michigan survey (1,653 questionnaires) were receptive to getting more information on what actions to take to reduce their probability of being involved in a WVC. They indicated newspapers as the preferred medium, although they also chose eight other avenues of communication (Riley & Marcoux 2006).
- In British Columbia, a survey of 1,882 licensed drivers indicates respondents strongly (81 percent) believe wildlife warning signs reduce WVCs (Buckingham 1997).
- The Iowa Departments of Transportation, Public Safety, and Natural Resources, in conjunction with insurance agencies and local law enforcement, have developed the "Don't Veer for Deer" campaign. Public information maps, brochures, public service announcements, and a poster can be found at http://www.dps.state.ia.us/commis/gtsb/deercrashes/index.shtml (accessed 25 January 2007). The campaign may not be effective in reducing WVCs, however (Michael Pawlovich, Iowa Department of Transportation, personal communication).
- The Parks Canada "Drivers for Wildlife" program in Jasper National Park combines public education, including bumper stickers (Figure 22) and roadway billboards (Figure 23), with two digital signs that record speed and advise drivers to slow down in the high risk wildlife zone. The number of road-killed animals along park highways decreased by about 15 percent after the first 10 months of the public education and roadside sign program; however, the signs were given the most credit for the reduction of WVCs (Walker 2004).

Figure 22: Example of bumper sticker for a driver awareness campaign to reduce WVCs in Jasper National Park (© Parks Canada).

Figure 23: Roadside billboard along Highway in Jasper National Park (© Parks Canada).

- The Maine Department of Transportation's Safety Office has a public information campaign to increase awareness of WVCs (Figure 24). It has developed a video, brochures, and crash maps for moose and deer at http://www.maine.gov/mdot/safetyoffice/maine-crash-data.php (accessed 25 January 2007).
- The "Colorado Wildlife on the Move" campaign reached more than 3 million people through television, magazines, and other media and included 58,000 driver safety tip sheets and 500 posters distributed in welcome centers, national parks, and Enterprise Rent-A-Car offices in 175 locations in 85 cities (DiGiorgio 2006).
- Responses to a Montana survey indicates public awareness of WVCs increased from 21 percent to 33 percent as a result of a local outreach campaign (Hardy et al. 2006).
- In July of 2005, the space shuttle Discovery hit a vulture during take-off. Initially NASA formed an "Avian Abatement Team" to address this safety issue. The program has been expanded to include the reduction of road-killed animals (which attract the birds) in concert with the Merritt Island National Wildlife Refuge, which is a 140,000-acre overlay of the Kennedy Space Center. The refuge provides a buffer zone for NASA. The Space Center has developed a website with a video, posters (Figure 25), stickers and updates on the latest road-kill statistics at http://environmental.ksc.nasa.gov/projects/roadkill.htm (accessed 25 January 2007). The campaign also included the installation of roadside warning signs (Figure 26).

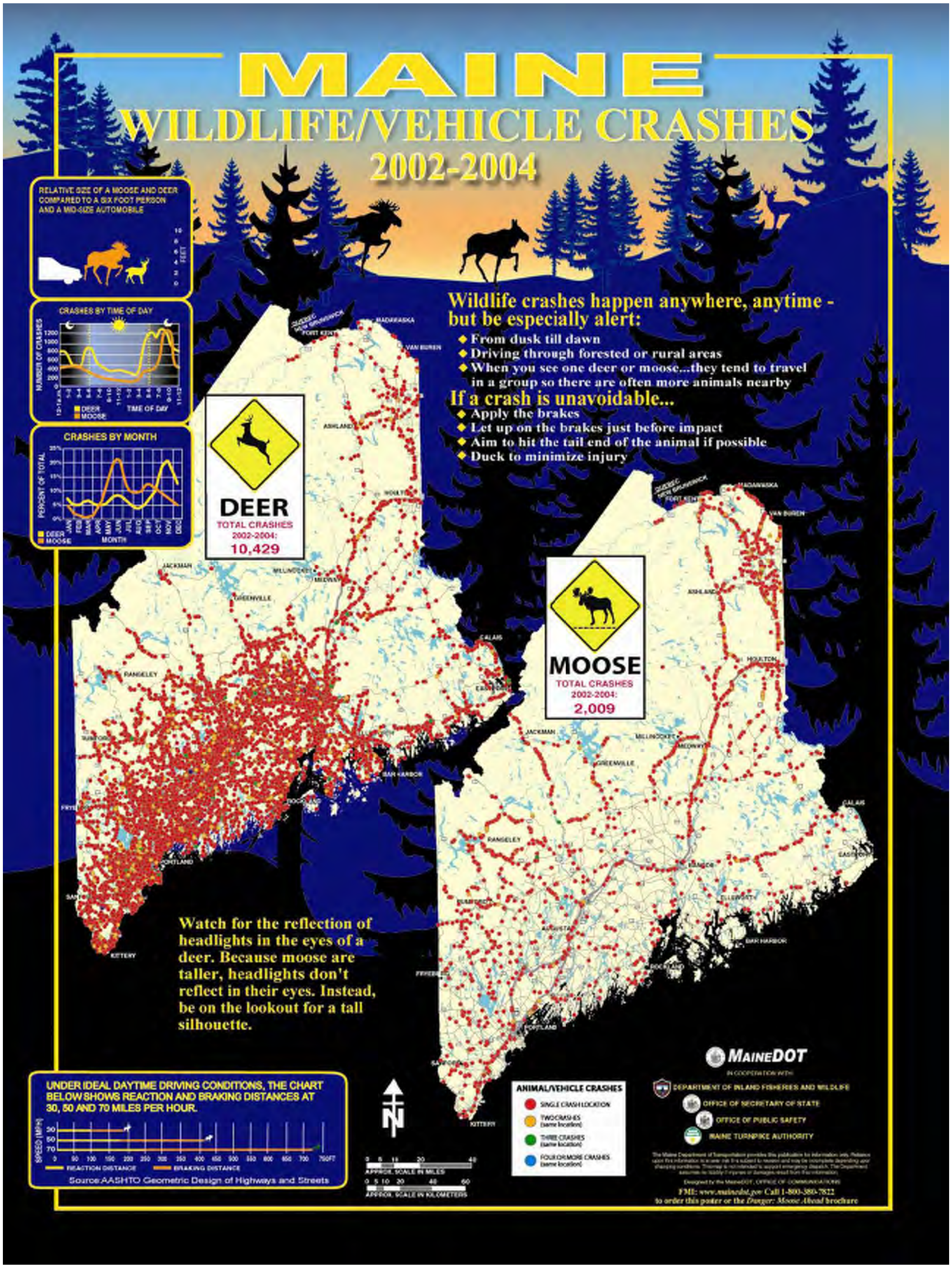

Figure 24: Poster produced by the Maine Department of Transportation (© Maine DOT).

Figure 25: Poster created by NASA's John F. Kennedy Space Center as part of its road kill prevention program (© NASA).

Figure 26: Wildlife warning sign on Merritt Island National Wildlife Refuge, Florida (© Marcel Huijser).

Effectiveness in reducing the barrier effect of roads and traffic

Driver education or public information efforts aimed at reducing the barrier effect of roads and traffic are likely to be ineffective, apart from the potential beneficiary effect that would result from speed reduction and increased driver alertness.

Potential disadvantages or undesired side effects

In the Canadian mountain parks public education and outreach may be challenging because many highway users are one-time visitors from other countries (many not speaking either of Canada's two official languages), so there is little cumulative benefit compared to a high percentage of frequent visitors. On the other hand, experience suggests that most regular road users (through traffic) do not stop at the gates and may not be exposed to a public information and outreach campaign if it is limited to the gates only.

Maintenance requirements

New campaigns can be designed with research objectives that are capable of identifying the effectiveness of public information and education efforts on the reduction of WVCs.

Installation and maintenance costs

Costs for statewide public information campaigns were low compared to other mitigation methods. Maine has spent about US$6,500 for its moose and deer crash maps and moose safety brochures. This investment provided an adequate outreach supply to last for about three years (Duane Brunell, Maine Department of Transportation, personal communication). In Colorado, the “Wildlife on the Move” campaign cost US$16,335. Most expenses were in two categories: 1) printing of publications (a little more than US$10,000), and 2) contract labor for outreach (a little more than US$4,500) (Monique DiGiorgio, Southern Rockies Ecosystem Project, personal communication). Costs for the “Don’t Veer for Deer” campaign in Iowa were negligible (Michael Pawlovich, Iowa Department of Transportation, personal comment).

4. MITIGATION MEASURES AIMED AT INFLUENCING ANIMAL MOVEMENTS

4.1. Vegetation Management in the Right-of-Way

4.1.1. Vegetation Removal

General Description

Visibility may be improved by reducing roadside vegetation that may obscure wildlife approaching the road. Whitetailed deer-vehicle collisions are associated with wooded areas and edge habitat, and are negatively correlated with the distance between roadway and forest cover (Puglisi et al. 1974, Gleason and Jenks 1993, Finder et al. 1999). Removing roadside vegetation, especially shrubs and trees, may allow motorists to see wildlife approaching the road, thereby avoiding collisions. However, in forested areas the clearance of shrubs and trees in the right-of-way may also result in the creation of edge habitat.

Species: Vegetation removal may have the most impact on foraging animals such as ungulates. Increased visibility for drivers may reduce road kill for all road crossing species. Those species that avoid open areas may be negatively affected through an increase of the barrier effect of the widened road corridor.

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: 38%

> There is evidence that vegetation removal is somewhat effective in reducing WVCs. The effects, however, may be temporary and more study is needed.

Examples of studies:

- In a study of DVC mortalities in east central South Dakota, Gleason and Jenks (1993) found that deer were killed more often than expected in areas adjacent to shelterbelts with canopy vegetation.
- Puglisi et al. (1974) found that DVC occurrences were less common where wooded areas were more than 23 m (25 yards) away from a highway in Pennsylvania.
- Clearing vegetation from roadsides resulted in a 20 percent reduction in moose-vehicle collisions in Sweden (Lavsund & Sandegren 1991).
- In Sweden, predictive models showed moose-vehicle collisions were more common on roads that cross through clear-cuts and young forests (Seiler 2005). Collisions may be reduced by 15 percent where the distance between forest cover and the road is greater then 100 m (Seiler 2005).
- While it is recognized that the results may not translate to a highway setting, the clearing of vegetation across a 20 to 30 m swath on each side of a Norwegian railway reduced moose-train collisions by 56 percent (+/-16 percent; Jaren et al. 1991).
- In Norway, a study evaluating the effect of scent-marking, intercept feeding and forest clearing demonstrated that forest clearing resulted in a 49 percent reduction in moose-vehicle collisions (Andreassen et al. 2005).

- Thomas (1995) stated that vegetation clearing is one of the most commonly applied measures to reduce moose-vehicle collisions, and recommended it be used to address moose-vehicle collisions in Alaska.
- Increasing distance between the roadway and forest cover has been shown to be negatively correlated to DVCs in Illinois; recommendations from that study included removing vegetation to provide an open width of the road corridor of at least 40 m in areas where DVCs are particularly high (Finder et al. 1999).
- In addition to affecting visibility, roadside vegetation management may be directed to reducing the attractiveness of roadside forage to animals. While vegetation management to increase visibility and reduce the draw of animals to the right-of-way may be complementary goals in some cases, Putman et al. (2004) summarize the potentially conflicting outcomes of reducing vegetation along roadways:

  "The management of roadside vegetation - and specifically, the clearance of woodland or scrub from a margin at the road edge - may have benefits both in increasing driver awareness of deer at the roadside, and increasing visibility of oncoming traffic to the deer themselves. In addition, removal of such vegetation and the cover that it provides may also reduce the probability of deer approaching so close to the road edge in the first place. The method and timing of removal of such vegetation may however be critical. While the removal of vegetation within transportation corridors may help improve driver and animal visibility, simple cutting of encroaching shrub and tree growth may at the same time increase the subsequent attractiveness of these cut-over areas as foraging sites by deer. Such measures might thus actually result in an increase in the number of deer utilizing the roadside - ultimately increasing the risk of accident."

Effectiveness in reducing the barrier effect of roads and traffic

Shrub and tree clearing may increase the barrier effect of the transportation corridor for species that avoid open areas and, as a result, such clearing practices can be harmful in otherwise forested areas.

- One study found that the width of the right-of-way affected crossing of the Trans Canada highway by wolverines (Austin 1998). Wolverines were more likely to cross the highway in areas with cover closer to the road than in areas with longer distances between cover.

Potential disadvantages or undesired side effects

Removal of brush or trees may result in fresh growth of attractive forage (e.g. grasses) that draws grazing animals to the right-of-way (Groot Bruinderink & Hazebroek 1996), potentially counteracting the safety gains of better visibility with increased probability of wildlife encounters. This appears to be the case in Kootenay National Park too, after each annual mowing session (Alan Dibb, Parks Canada, personal communication).

Maintenance requirements

Vegetation removal requires a long-term maintenance commitment.

Installation and maintenance costs

Vegetation removal requires a long-term maintenance commitment and may involve expenses to acquire right-of-way in order to manage vegetation as desired. Jaren et al. (1991) calculated that if collisions are reduced by at least 50 percent as a result of removing vegetation, then vegetation removal would be economically beneficial if applied in areas where more than 0.3 per km moose-train collisions occur. Andreassen et al. (2005) estimated forest clearing for 18 km at US$500 per km, showing that the number of moose saved using this technique could result in a profit of US$1,080. Andreassen et al. (2005) stated that forest clearing may be more economical than scent-marking and supplemental feeding, pointing out that the initial cutting is the main expense.

4.1.2. Minimize Nutritional Value or Influence Species Composition of Right-of-Way Vegetation

General Description

Roadside vegetation can attract wildlife to roads and increase their vulnerability to WVCs (Case 1978, Cain et al. 2003) (Figures 27 and 28). The practice of planting trees near roadways for landscaping reasons can attract ungulates to the right-of-way and increase the risk of WVCs (Putman 1997). Several sources recommend managing vegetation in the right-of-way so that it does not serve as an attractant to wildlife (e.g., by planting unpalatable species, reducing forage quality, or applying noxious chemicals) (Groot Bruinderink & Hazebroek 1996, Putman 1997, Hyman & Vary 1999 as cited in Evink 2002, Wells et al 1999, Rea 2003, Riley & Sudharsan 2006), while others focus on improving roadside habitat for wildlife (Varland & Schaefer 1998).

Figure 27: Bighorn sheep foraging along roadside on U.S. 93 near Darby, Montana (© Marcel Huijser).

Figure 28: Deer foraging along roadside in the Salmon River Valley, Idaho (© Marcel Huijser).

Species: Minimizing nutritional value or influencing species composition of right-of-way vegetation generally targets herbivores, especially ungulates.

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: unknown

> Techniques employing forage repellents, unpalatable species and roadside brush removal have been used with limited effectiveness on reducing WVCs or are not cost-efficient when broadly applied (Rea 2003). The need to properly study the safety impact of vegetation management along roadways remains (Knapp 2005).

Examples of studies:

- A detailed literature review on roadside vegetation management, plant response to tissue removal, and ungulate foraging behavior yielded recommendations for more carefully designed cutting regimes as a countermeasure for reducing moose-vehicle collisions (Rea 2003).
- Willows cut in mid-July were found to be high in digestible energy and protein compared to plants cut at other times of the year and uncut controls, suggesting that summer brush cutting regimes may inadvertently be attracting moose with nutritious re-growth (Rea & Gillingham 2001, Rea 2003). Cutting in early June results in browse with significantly less nutritional value for the first two years after cutting compared to plants cut later in the growing season and uncut controls (Rea & Gillingham 2001, Rea 2003). Rea (2003) recommended cutting roadside brush in early spring soon after leaves develop to keep nutritional value and palatability to a minimum but recognized operational challenges and limitations (i.e., ground too wet for tractor use, different ungulate species-specific

responses to same management regime, etc.) and cautions that this countermeasure may not be suitable for all management areas.

- No studies were found that specifically analyze the WVC safety impacts of roadside management policies or plantings (Knapp 2005), however, a 1999 report by the Arizona Department of Transportation describes a future five-year monitoring plan to address the effectiveness of a number of mitigation measures (including those related to vegetation/habitat changes) on reducing WVCs (Brown et al. 1999).

Effectiveness in reducing the barrier effect of roads and traffic

Reducing habitat quality may increase the barrier effect of roads and traffic for certain species (Forman & Alexander 1998).

Potential disadvantages or undesired side-effects

Minimizing the nutritional value of vegetation in right-of-ways may affect native vegetation along the roadside, but this is not necessarily the case.

Maintenance requirements

High levels of maintenance may be required for management techniques such as roadside brush cutting, planting of undesirable species, and applying herbicides. There are operational challenges and limitations to roadside brush cutting regimes (e.g., ground moisture early in season, species-specific responses to same management regime, etc.) (Rea 2003).

Installation and maintenance costs

No costs were identified in the literature review.

4.2. Reflectors and Mirrors

General Description

Deer mirrors and reflectors (Figure 29) are roadside installments intended to act as visual wildlife repellents. Mirrors directly reflect vehicle headlights off the roadway and into the surrounding right-of-way (Danielson & Hubbard 1998). Reflectors beam colored reflected light from headlights into roadside habitat (Swareflex, D. Swarovski & Co., Wattens, Austria, http://www.swareflex.com/ (accessed 26 January 2007)) or onto the roadway itself (Strieter-Lite, Strieter Corp., Rock Island, Illinois, http://www.strieter-lite.com/ (D’Angelo et al. 2006)).

Figure 29: Deer reflector along Hwy 93 in British Columbia (© Marcel Huijser).

Species: Reflectors and mirrors are mostly designed to deter deer from the road and right-of-way.

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: 0%

Most studies testing the effectiveness of mirrors and/or reflectors on reducing WVCs found that they had: 1) no effect (Waring et al. 1991, Ford & Villa 1993, Reeve & Anderson 1993, Cottrell 2003, Rogers 2004), 2) mixed results (Pafko & Kovach 1996, Barlow 1997), or 3) inconclusive results (Gulen et al. 2000). Differences in experimental design and in the variety of models tested confound the comparison of results (D'Angelo et al. 2004). However, Schafer and Penland (1985) did find a significant reduction (88 percent) in WVCs using Swareflex reflectors in Washington State. Pafko and Kovach (1996) found in Minnesota that reflectors reduced the incidence of rural WVCs by 50-97 percent, but suburban metropolitan WVCs increased.

Examples of studies:

- In Wyoming, 39 percent of Swareflex reflectors showed deterioration after three years (Reeve and Anderson 1993).
- The Strieter-Lite company suggests there is scientific proof that their reflectors reduce DVCs by 78-90 percent (Grenier 2002, unpublished) and that reflective luminance, or brightness, is not a major factor because wild animals have acute night vision (Sielecki 2001). Sivic and Sielecki (2001) conducted a spectrometric evaluation of Swareflex and Strieter-Lite wildlife warning reflectors and noted operational implications of low-light reflection intensities.

- Utah DOT discontinued use of reflectors due to an increase in deer kills and difficulty in keeping reflectors clean; high installation and maintenance/cleaning costs were also factors (Page 2006).

Effectiveness in reducing the barrier effect of roads and traffic

Wildlife mirrors and reflectors are designed to deter animals when traffic is present. Therefore, wildlife mirrors and reflectors are likely to increase the barrier effect of the transportation corridor, but this effect may be lessened or absent when no vehicles are present.

Examples of studies:

- Studies testing the influence of reflectors on animal behavior found little or no evidence of avoidance (Zacks 1986, Waring et al. 1991, D'Angelo et al. 2006). Ramp and Croft (2002), however, found Swareflex reflectors produced a weak fleeing response in kangaroos. Ujvari et al. (1998) found that deer initially responded to reflectors with alarm and flight but then became habituated to the light reflection.
- D'Angelo et al. (2006) studied Strieter-Lite wildlife warning reflectors in four colors (red, white, blue-green and amber) and found them to be ineffective at altering white-tailed deer behavior so that DVCs might be prevented. Interestingly, data indicated that deer moved toward vehicles in the presence of some of the reflectors. D'Angelo et al. (2006) recommended that future development of deer-deterrent devices for WVC mitigation be based on empirical knowledge of deer senses and behavior.

Potential disadvantages or undesired side effects

Deer have been documented to move toward vehicles in the presence of reflectors (D'Angelo et al. 2006). Reflectors require suitable placement, alignment maintenance and regular cleaning (Sielecki 2004); however, in a roadside application it is challenging to keep reflectors clean at all times (Sielecki 2001, Page 2006). Reflectors have been stolen and vandalized (Sielecki 2004).

Maintenance requirements

Reflectors have installation guidelines, and they must be regularly aligned and cleaned.

Installation and maintenance costs

A manufacturer advertises the total cost of installation with reflectors, posts, equipment, and labor to be US$4,000-US$6,000 per km. The average life of reflectors is 12.5 years, so costs amount to US$169 to US$199 per km per year. Maintenance costs are estimated at US$300 per km per year (Strieter-Lite, Strieter Corp., Rock Island, Illinois, http://www.strieter-lite.com/.

In British Columbia, reflectors cost approximately US$10,000 per km to install along both sides of a highway, and maintenance costs range in the order of US$500 to US$1,000 per km annually (Sielecki 2004).

4.3. Reduce or Find Alternatives to Road Salt Usage

General Description

The use of chloride salts in winter maintenance can attract wildlife to the right-of-way (Figure 30) and may increase WVCs (Danielson & Hubbard 1998, Brownlee et al. 2000, Knapp 2005), especially in areas without natural salt licks (Groot Bruinderink & Hazebroek 1996).

Figure 30: Bighorn sheep licking road salt along Hwy 93, just south of Radium Hot Springs, British Columbia (© Marcel Huijser).

- A study of the pattern of moose-vehicle collisions in relation to the presence of roadside saltwater pools showed that 43 percent of moose-vehicle collisions occurred within 100 m of a saltwater pool, higher than what would randomly be expected (Fraser & Thomas 1982). About the same number of collisions happened more than 300 m from a roadside saltwater pool (Knapp 2005). Knapp (2005) questions the assumption of the study (i.e., all locations have an equal chance for a collision).
- A study of 11 radio-collared moose in New Hampshire determined that all of their home ranges converged on an area containing roadside salt (NaCl) licks formed by runoff of road salt. Implications associated with these roadside salt licks include increased moose-vehicle collisions and increased brain worm infections in moose and white-tailed deer (Miller & Livaitis 1992).

- The intake of road salt has been found to be toxic to several bird species, porcupines, rabbits, deer, and moose that ingest it (D'Itri 1992; Brownlee et al. 2000). Reduction or elimination of road salt may reduce or eliminate this toxicity.

Reducing the amount of salt (especially NaCl) or using alternative deicers (without salt) may eliminate this attractant, especially for ungulates, from the road and right-of-way and, as a result, may reduce WVCs (Feldhamer et al. 1986).

The deicers used by highway agencies often contain chloride-based salts including sodium chloride (NaCl), calcium chloride ($CaCl_2$), and magnesium chloride ($MgCl_2$) because of their cost effectiveness (Xianming Shi and Laura Fay, WTI, personal communication). NaCl, or "salt," is generally available in large quantities and is relatively inexpensive. It can be used as either rock salt (for deicing) or as salt brine (for anti-icing). $CaCl_2$ or $MgCl_2$ is often used by many DOTs in a brine solution for anti-icing. Both work at lower temperatures than salt brine but cost more (Laura Fay, WTI, personal communication).

There are several alternatives to chloride-based salt deicers. These alternatives function similarly to chloride, by lowering the freezing temperature of water. Acetates and formates can replace NaCl or other chloride-based materials, though there are related tradeoffs, particularly cost (Laura Fay, WTI, personal communication).

DOTs have begun to prefer acetate-based deicers such as potassium acetate (KA), sodium acetate, calcium magnesium acetate (CMA), or calcium-magnesium-potassium acetate (CMAK). Acetates offer attractive alternatives to chloride-based chemicals and have been extensively studied for their reduced environmental impacts (Laura Fay, WTI, personal communication). They tend to decompose quickly, do not contain chloride, and they have non-corrosive characteristics, benign impacts on surrounding soils and ecosystems, and minimized adverse human health effects (Buckler and Granato 1999, Laura Fay, WTI, personal communication). CMA works as a deicer similar to salt, yet it can require 50 percent more by weight than salt to achieve the same results, with higher costs (Laura Fay, WTI, personal communication). However, new technologies have been developed to reduce the cost of CMA (Basu 1999, Yang 1999). KA provides quicker results than CMA at lower temperatures, but is more costly than CMA; fewer studies have been done to examine its impacts on the environment (Wegner and Yaggi 2001).

Formates (sodium formate and potassium formate) have also emerged as potential alternative deicers. However, they have not been widely used, mainly due to concerns over their high cost (Laura Fay, WTI, personal communication).

Biobased products are available for snow and ice control. They are often solid or liquid mixtures containing chloride salts and organic products from fermentation and processing of beet juice, molasses, corn, or other agricultural products. Recently, glucose/fructose and unrefined sugar have been mixed in sand to prevent freezing and added to salt brine for anti-icing (Hallberg et al. 2007). They are often mixed with common deicers or anti-icers including chlorides, acetates and abrasives to significantly lower their freezing point and inhibit their corrosivity, as biobased products are generally non-corrosive. Such products can be very expensive if used on their own. The common biobased products are proprietary products and include trade names such as IceBan, Caliber, and Dow Armor. Since biobased deicers often include a salt/chloride component, chloride use is reduced but not eliminated, and there are concerns over their possible attraction to wildlife or high phosphorus content (Laura Fay, WTI, personal communication).

Deicers, which are composed of glycols, including propylene glycol and ethylene glycol, are generally used only as airplane and runway deicers. These are found in commercial automobile antifreeze products and therefore pose acute toxic risk to wildlife and humans and are known endocrine disrupters (Kawasaki et al. 2003). Urea products are still used as deicers on runways of airports and have considerable environmental impacts (Laura Fay, WTI, personal communication).

Changes in snow and ice control management can reduce costs, moving from reactive traditional strategies (e.g., deicing and sanding) to proactive strategies for snow and ice control, such as anti-icing. When conducted properly, anti-icing can reduce the required plowing and decrease the quantity of chemicals required (U.S. EPA 1999). In many conditions, anti-icing eliminates the need for abrasives, because it eliminates the cause of slipperiness as ice would be unable to bond with cement (Williams 2001). Reliable weather forecasts are key to a successful anti-icing program, as the pavement surface temperature dictates the timing for anti-icing applications and the appropriate application rate. Less time, money, and materials are needed with this proactive technique.

Current research is examining the possibility of using chemical repellents to discourage ungulates from licking road salt (Newhouse and Kinley 2001, Laura Fay, WTI, personal communication).

Species: Reducing or finding alternatives to road salt (especially NaCl) targets animals attracted to road salt, such as ungulates. Bighorn sheep are of particular interest in the Rocky Mountains. Bighorn sheep may congregate on roadsides, resulting in road mortality, crowding and range depletion, altered distribution, and encouraging habituation to humans (Demarchi et al. 2000).

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: unknown

- Road salt and deicing alternatives are addressed in literature reviews (e.g. Danielson & Hubbard 1998, Brownlee et al. 2000, Knapp 2005); however, whether the reduction or replacement of the road salt would reduce WVCs involving ungulates remains unknown (Knapp 2005, Levelton Consultants Limited 2007).

Examples of studies that indicate how well the alternatives have worked in reducing or replacing NaCl:

- Attempts at discouraging animals from road salt using the deicer calcium-chloride CaCl were unsuccessful in Jasper National Park, Canada (Bertwistle 1997).
- Researchers have proposed use of deicing salts that are less attractive to Cervids (deer) than NaCl (e.g., urea, ethylene glycol, or CaCl2; Fraser and Thomas 1982); however, LeBlond et al. (2007) note that the cost of these alternative salts can be prohibitive, especially where winter conditions are severe.
- One study found sheep did not consume $MgCl_2$ when provided, suggesting it could be an alternative to NaCl as a road salt if the goal was to reduce licking by bighorn sheep and associated road mortality (Newhouse and Kinley 2001). This study also noted that $MgCl_2$ would be more expensive to apply than NaCl, but the difference would be relatively modest.

- On the North Island of New Zealand, CMA is used for both anti-icing and deicing. Testing of soil, vegetation, and streams has shown no negative impacts of CMA. The cost of the product was listed as a principal disadvantage (Burkett and Gurr 2004).
- O'Keefe and Shi (2006) noted that anti-icing as a management tool led to decreased applications of chemicals and abrasives, decreased maintenance costs, improved level of service, and lower accident rates.
- Lithium chloride, a gastrointestinal toxicant, was found to effectively discourage captive caribou from eating treated food and may prove useful in reducing WVCs by discouraging ungulates from licking road salt (Brown et al. 2000b).
- Addition of chemical repellents (e.g., putrescent compound, creosote, and isobutyric acid) was found to be a short-term solution to reduce moose attendance at salt pools that required frequent reapplication (Fraser and Hristienko 1982).

Effectiveness in reducing the barrier effect of roads and traffic

It is unknown whether the reduction or replacement of the road salt would reduce or increase the barrier effect of roads and traffic.

Potential disadvantages or undesired side effects of alternatives to NaCl

- NaCl effectiveness is minimal below pavement temperatures of -12°C (10°F). Adverse impacts on roadway structures, pavements, vehicles, soil, terrestrial flora and fauna, water, and air quality may render the use of salt-sand mixture impractical due to the possible presence of harmful substances and additives (Laura Fay, WTI, personal communication).
- While the reduction or elimination of road salt may benefit certain species, alternatives to chloride salts may also be toxic to wildlife (Xianming Shi, WTI, personal communication), but this has not yet been specifically studied.
- Acetate decomposition may result in anaerobic soil conditions. It also leads to an increase in the biological oxygen demand (BOD), which reduces the available oxygen for organisms in the soil and aquatic environments (Sucoff 1975).
- Sodium acetate/formate deicer (Ice Shear™) was reported to cause apparent fish disorientation, concave abdomen and spinal curvature, observed gill distention, and death (Hellsten et al. 2005).
- In general, CMA has low aquatic toxicity while potassium acetate, sodium acetate, and CMA-potassium (K) have greater aquatic toxicity (Sucoff 1975). Acetate and formate have been shown to promote bacterial growth (Hellsten et al. 2005), while CMA was found to stimulate bacteria and algae growth (Bang and Johnston 1998).
- Both CMA and CMAK have been reported to have deleterious effects on concrete pavement as they react with cement (Buckler and Granato 1999). Other disadvantages of CMA include air quality impacts, high cost of applications, and poor performance in temperatures below -5ºC (23°F) and in thick accumulations of snow and ice (Laura Fay, WTI, personal communication).

- One thoroughly studied biobased product is IceBan, a mix of MgCl2 and agricultural byproducts. In a report evaluating deicers, it was determined that IceBan exceeds Pacific Northwest Snow Fighter (PNS) specifications for copper, zinc, and sulfate. IceBan has a pH less than 4.0, which could result in acidification of soils and cause leaching of metals into surrounding waters (Fischel 2001).
- The organic materials of biobased byproducts may cause temporary anaerobic soil conditions when broken down, as well as oxygen depletion in surface waters. These concerns over their toxicity to the aquatic ecosystems adjacent to highways (due to high phosphate, nitrogen, or total organic content) and high cost have hindered the deployment of commercially available biobased products (Laura Fay, WTI, personal communication).
- Increased BOD and carcinogenic effects to stream fauna are environmental issues associated with glycol-based deicers (Laura Fay, WTI, personal communication).
- Mixing cayenne pepper with NaCl has several drawbacks, including cost, possible habituation of wildlife to the effects of cayenne, reduced effectiveness over time, human health concerns, and possibly acting as an attractant to bears (Newhouse and Kinley 2001).
- If alternatives to road salt are less effective in deicing or anti-icing abilities, road safety may be impacted. Before implementing alternatives to road salt one should be thoroughly familiar with the effectiveness and guidelines for use.
- Reviewed alternatives cost substantially more than road salt.

Maintenance requirements

Alternatives to road salt could require increased maintenance. If liquids are not already used, appropriate equipment is needed including a storage tank and a truck for hauling and spraying liquids. If turning to solids and salt storage is already developed, solids can be stored in the same facility.

Deicer companies will train how to apply and use their product.

A “Maintenance Decision Support System” (MDSS) can be used to determine the product, quantity, and timing of appropriate deicing or ant-icing techniques (Laura Fay, WTI, personal communication).

Installation and maintenance costs

Reviewed alternatives may cost substantially more than road salt. However, cost effectiveness should include the tradeoffs associated with using NaCl or any alternatives.

4.4. Wildlife Fencing without Gaps

General Description

Fencing is one of the most commonly applied measures to physically separate wildlife from motorists (e.g., Romin & Bissonette 1996) (Figures 31-33). Wildlife fences in North America typically consist of 2.0-2.4 m (6.5-8 ft) high wire mesh fence material. Several types of fence material are used, but page-wire or cyclone fence material is most common. Wooden or metal fence posts are typically used; the latter are particularly important when fencing over rock substrates. To keep other species from climbing over fences (e.g., cougars, bears), fences can be taller, mesh size can be smaller, and overhangs can be incorporated into the design (Jones and Longhurst 1958, Gloyne and Clevenger 2001) (Figure 34).

Figure 31: Wildlife fence along Interstate 90 near Bozeman, Montana (© Marcel Huijser).

Figure 32: Wildlife fencing along the TransCanada Highway (©Marcel Huijser).

Figure 33: A 3.4 m high chain link fence along SR 29 in southern Florida designed to prevent Florida panthers from entering the roadway and to guide them toward underpasses (© Marcel Huijser).

Figure 34: A 3.4 m high chain link fence along SR 29 in southern Florida was equipped with three strands of outrigged barbed wire to prevent Florida panthers from climbing the fence (© Marcel Huijser).

Species: Wildlife fencing can be used to reduce wildlife-vehicle collisions for a range of target species. Modifications may be required, depending on size and climbing abilities of target species. Wildlife fencing is often intended for large mammals, especially those that cannot easily climb or otherwise cross wildlife fencing. However, fencing, screens, concrete walls or other barriers have also been applied for smaller species, including reptiles, amphibians and medium-sized mammals.

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: 87%

> When installed and maintained correctly, wildlife fencing can form a nearly impermeable barrier to large mammals, eliminating or substantially reducing the number of wildlife-vehicle collisions. Most studies report an 80-95 percent reduction in wildlife-vehicle collisions. Since fencing creates an almost absolute barrier to wildlife movements, fencing should typically be combined with safe wildlife crossing opportunities (e.g., wildlife underpasses and wildlife overpasses). Since some animals still breach fences and walk around fence ends, escape opportunities and fence end treatments are also considered good practice.

Examples of studies:

- Woods (1990) reported a 94-97 percent reduction in ungulate-vehicle collisions along a fenced section of the Trans-Canada Highway in Alberta, Canada. Along the same road, Clevenger et al. (2001b) showed that fences were effective in reducing vehicle collisions with ungulates by 80 percent. Clevenger et al (2001b) also found that WVCs were closer to fence ends than expected; however access points (gaps in the fence) were not hotspots for WVCs.
- In Pennsylvania, Feldhamer et al. (1986) concluded that a 2.7 m (8.9 ft) high fence was more effective than the 2.2 m (7.2 ft) high fence, but that deer permeated both types of fences, and overall DVCs were not reduced. They suggested that fencing may be effective if properly maintained to fix holes that people cut into it, and repair gaps that develop under the fence. They also suggested that the size of the openings in the woven wire mesh be decreased.
- In Sweden, fencing reduced moose-vehicle collisions by 80 percent (Lavsund & Sandegren 1991).
- In British Columbia, exclusion fencing (2.4 m high) was 97-99 percent effective at reducing accidents with large wildlife (Sielecki 1999).
- Reed et al. (1982) reported an average reduction of 78.5 percent for DVCs in Colorado as a result of the installation of wildlife fencing.
- Ward (1982) reported a reduction of greater than 90 percent for mule deer in Wyoming.
- Boarman and Sazaki (1996) found that new or properly maintained fences significantly reduced mortality for several wildlife species, including the desert tortoise. They found 93 percent fewer tortoise carcasses and 88 percent fewer vertebrate carcasses along a fenced section compared to an unfenced section of highway.
- The effectiveness of electric fencing (ElectroBraid™) in keeping deer off runways at airports was studied by Seamans and VerCauteren (2006), and their results could be applicable to preventing deer from accessing highways. The authors found that fencing as low as 1.3 m (4.3 ft) was sufficient to exclude deer, unless deer were pressured across it. Fences were highly effective (90 percent) when turned on and maintained.
- In a theoretical study investigating how full fencing (no wildlife crossings) with the intent of keeping wildlife off of roadways and reducing wildlife mortality might affect the long-term viability of animal populations, Jaeger and Fahrig (2004) modeled population responses to a range of scenarios. Their models showed that when no fencing was in place, traffic mortality had a stronger effect on population viability than the effect of animals avoiding the road. The authors concluded that fencing could improve viability in populations with high road mortality. They discouraged the use of fencing (without crossing structures) when the population size was stable.

Effectiveness in reducing the barrier effect of roads and traffic

With wildlife fencing, animal movements across the road are blocked or nearly completely blocked. This increases the barrier effect of the road, disrupting daily, seasonal and dispersal movements, and potentially reducing the population survival probability of the species concerned. Species that cannot easily penetrate, climb or otherwise cross wildlife fencing are confronted with an increased barrier effect of the transportation corridor, unless sufficient safe crossing opportunities are provided.

Potential disadvantages or undesired side effects

Wildlife fences, when installed correctly, form a nearly impermeable barrier to large mammals. While this can nearly eliminate collisions with large mammals or at least reduce the number of collisions substantially, wildlife fences result in several undesirable side effects. For example:

- Animal movements across the road are strongly reduced or completely blocked, which strongly increases the barrier effect of the road. Daily, seasonal and dispersal movements are all strongly reduced or eliminated. For some species, and in certain situations, this may severely reduce the population survival probability of the species concerned. The species affected may include some that are not a safety threat or that may not have a population in the immediate vicinity of the transportation corridor. Therefore, absolute barriers, such as wildlife fencing, when applied over long distances, should typically be accompanied with safe crossing opportunities for a wide array of species.
- Animals are more likely to break through the wildlife fencing if safe crossing opportunities are not provided or if there are too few, or if they are too small, or too far apart. Even if safe crossing opportunities have been provided for, animals may still end up in between the fences, caught in the transportation corridor, and these animals may pose a safety risk and expose the species concerned to road mortality after all. Animals may end up between the fences around fence ends by digging under the fence (coyotes have been known to slip beneath the fence along the Trans-Canada Highway in Banff National Park), through gaps in the fence, or they may be able to climb the fence. Therefore, absolute barriers such as wildlife fencing should typically be accompanied with escape opportunities for animals that end up between the fences.
- Animals can and do cross the road where fences end. In some cases it can result in a concentration of WVCs at fence ends (Clevenger et al. 2001b, Norris Dodd, Arizona Game and Fish Department, personal communication). Therefore, consideration should be given to measures that mitigate a potential concentration of WVCs at fence ends.
- Wildlife fencing can have a negative impact on landscape aesthetics; many people perceive tall wildlife fences as ugly. The Utah DOT has painted wire mesh fencing dark brown which camouflages the wire mesh to some extend. A chain link fence for Key deer on Big Pine Key in southern Florida (Figure 35) and a similar fence for the American crocodile and people along U.S. Hwy 1 between Florida City and Key Largo (Figure 36) have been coated with black plastic to reduce the impact of the fence on landscape aesthetics. However, camouflaging fencing because of landscape aesthetics may conflict with increasing risks for wildlife (see next bullet).

Figure 35: A 2.44 m (8 ft) high chain link fence along U.S. Hwy 1 on Big Pine Key, Florida, has been coated with plastic to make the fence blend in with its surroundings (© Marcel Huijser).

Figure 36: A 1.83 m (6 ft) high chain link fence along U.S. Hwy 1 between Florida City and Key Largo, Florida, has been coated with plastic to make the fence blend in with its surroundings (© Marcel Huijser).

- Wildlife fencing may pose a direct or indirect mortality risk for certain species. Large mammals may get tangled up in the fence, or fences may injure them, potentially resulting in a slow death. In addition, wildlife fences may also be exploited by predators when pursuing prey. After the addition of two lanes on the Trans-Canada Highway and installation of fencing that cut off escape terrain for bighorn sheep, coyotes, wolves and possibly cougars learned to stampede sheep into the fence (Cliff White, Parks Canada, personal communication). About 40 bighorn sheep were killed this way in the first two years after fencing until a mitigation measure was put in place that made the fence more visible to the bighorn sheep (Cliff White, Parks Canada, personal communication).. In addition, wolves, bears and other predators have also occasionally been seen running prey species into wildlife fences (Leeson 1996). Finally, birds may collide with fences and die (Baines & Summers 1997, Dobson 2001). Thus, camouflaging fencing because of landscape aesthetics may conflict with increasing risks for wildlife.

- Access roads to the main road require a disruption of the wildlife fencing, resulting in an opening that has to be mitigated in order to avoid animals getting caught inside the fences along the transportation corridor.
- Access for people (e.g., for hiking, biking, or fishing) may be blocked by wildlife fencing.

Wildlife underpasses and overpasses are tunnels and vegetated bridges designed to allow wildlife to cross the road. In addition, wildlife jump-outs are usually integrated with wildlife fencing. These features allow animals that do manage to cross the fence to escape from the fenced road and right-of-way.

Maintenance requirements

If properly installed, fence material (wire and posts) should last 20 years or more without replacement (Grande et al. 2000; Terry McGuire, Parks Canada, personal communication).

Regular fence maintenance is critical in order to keep it functioning properly. Earth slumping on hill slopes, inadequate installation techniques resulting in gaps between ground and fence bottom, and breaches of the fence by the public (e.g., access for fishing, hunting, or snowmobiling) allow animals to gain entry to the right-of-way. Fence maintenance is a major concern because priorities and budgets change over time. Fence maintenance is often neglected shortly after construction; meanwhile fence damage and gaps are a recurrent problem.

Installation and maintenance costs

- Wildlife fencing (2.4 m, or 8 ft high) in Banff National Park, Alberta, cost Can$30 per m (Can$9 per ft) for one side of the highway during the phase 3A Trans-Canada Highway expansion in 1997 (Terry McGuire, Parks Canada, personal communication). For the entire 18 km section of highway, fencing both sides cost roughly Can$1 million. ElectroBraid™ fencing used in the study by Seamans and VerCauteren (2006) consisted of five rope strands at 25 cm (9.7 in) and cost US$9 per m (US$2.7 per ft) (Seamans & VerCauteren 2006). 1.2 m high (4-ft), 5-Braid™ ElectroBraid™ Deer Exclusion Fence is advertised at US$4300 per km (US$7,000 per mile) while 1.5 m (5 ft) high, 5-Braid™ ElectroBraid™ Moose Exclusion Fence is advertised at US$4750 per km (US$7,500 per mile) (ElectroBraid 2006).
- Sielecki (1999) compared the benefits to costs of fencing over different time spans (20-30 years) and given different levels of potential damage prevented. He concluded that benefits of the wildlife fencing outweighed potential costs in 12 of 16 cases. Fencing in his study ranged from Can$40,000-80,000 per km.
- The cost of wildlife fencing along U.S. Highway 93 on the Flathead Reservation in Montana varied depending on the road section concerned: US$26, US$38, US$41 per m (US$7.9, US$11.6, US$12.5 per ft) (Pat Basting, Montana Department of Transportation, personal communication). A finer mesh fence was dug into the soil and attached to the

wildlife fence for some fence sections at a cost of US$12 per m (US$6.7 per ft) (Pat Basting, Montana Department of Transportation, personal communication).

- Fencing could be impractical in dense vegetation areas, where there is little or no public roadside right-of-way.

4.5. Boulders in the Right-of-Way

General Description

Large boulders have been placed in the right-of-way, outside of the clear zone, as an alternative to wildlife fencing. Large boulders are thought to make it hard for animals, especially ungulates, to walk across an area.

Species: Boulders in the right-of-way is intended for ungulate species and/or other animals that cannot cross large boulders.

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: unknown

The large boulders are believed to be an effective alternative to wildlife fencing if all the gaps are eliminated. In contrast to wildlife fences, large boulders are natural and, depending on the landscape, can address the landscape aesthetics concern associated with wildlife fences.

Examples of studies:

- Boulders have been used for this purpose along State Route 260 in Arizona (Terry Brennan, U.S. Forest Service, personal communication; Norris Dodd, Arizona Game and Fish Department, personal communication) (Figures 37 and 28). The boulder barrier was not extended through areas with steep slopes, since it was thought that wildlife would not move through these steep areas. However, animals have traveled through these areas. The barrier is thought to be effective with exception of the gaps in the steep areas (Norris Dodd, Arizona Game and Fish Department, personal communication).

Figure 37: Large boulders placed in the right-of-way as a barrier to elk and deer along State Route 260 in Arizona (© Marcel Huijser).

Figure 38: Large boulders placed in the right-of-way as a barrier to elk and deer with a view of State Route 260 (under construction) in Arizona (© Marcel Huijser).

Effectiveness in reducing the barrier effect of roads and traffic

If boulders are indeed an absolute barrier to ungulates and/or other species groups, animal movements across the road are strongly reduced or completely blocked. This increases the barrier effect of the road. Daily, seasonal and dispersal movements may be strongly reduced or eliminated, and depending on the species and local situation, may reduce the population survival probability of the species concerned. Large species (e.g., ungulates) that cannot cross boulders are likely to be confronted with an increased barrier effect of the transportation corridor, unless sufficient safe crossing opportunities are provided for.

Potential disadvantages or undesired side effects

- If boulders are indeed an absolute barrier to ungulates and/or other species groups, safe passage may have to be provided for wildlife at selected locations.
- The barrier effect effects of large boulders would have to be carefully evaluated for other species.

Maintenance requirements

Debris may need to be removed from boulder fields.

Installation and maintenance costs

Costs for the Arizona case study were less than US$197 per m (less than US$60 per linear foot) (Norris Dodd, Arizona Game and Fish Department, personal communication).

4.6. Wildlife Fencing with Gaps

General Description

Absolute barriers such as wildlife fences increase the barrier effects of a road, disrupting daily, seasonal and dispersal movements, and potentially reducing the population survival probability of the species concerned. The species affected may include species that are not a safety threat or that may not even have a population in the immediate vicinity of the transportation corridor. Therefore absolute barriers, such as wildlife fencing, should typically be accompanied with safe crossing or escape opportunities for wildlife.

Gaps in fences on opposite sides of the road allow animals to cross the road. In most cases such gaps are accompanied with wildlife warning signs, crosswalks for wildlife, wildlife warning signs in combination with mandatory or advisory speed limit reductions, or animal detection systems. These can inform the drivers that a large animal may be on or near the road at that time. Once a driver is aware that a large animal may be on or near the road ahead, the driver may lower the speed of the vehicle or may become more alert or both.

Species: Wildlife fencing can be used to reduce WVCs for a range of target species. Modifications may be required, depending on the size of the target species. Wildlife fencing is often intended for large mammals, especially those that cannot easily climb or otherwise cross wildlife fencing. Small- or medium-sized animals are not detected by animal detection systems. Species that avoid open areas or unnatural substrate (e.g., pavement) may not benefit from an at-grade crossing opportunity.

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: with warning signs and crosswalk—40 percent; with animal detection systems—82 percent.

- Wildlife fences may reduce road mortality by 80-99 percent, but may increase the barrier effect of the road. Gaps in the wildlife fence allow animals to cross the road, but mortality can occur since they cross at grade, thereby reducing the effectiveness of the wildlife fence. Data are not available on the road kill that occurs at a gap with or without warning signs, but a gap in a wildlife fence that is combined with wildlife warning signs and a crosswalk reduced the effectiveness of the wildlife fence from 80-99 percent to 42.3 percent (four-lane highway) and 36.8 percent (two-lane highway) (Lehnert & Bissonette 1997). Animal detection systems have been used at gaps in wildlife fences, but there are not data on the effectiveness of this measure in combination with a gap in a fence. As a stand-alone mitigation measure, however, animal detection systems may reduce collisions with ungulates by 82 percent on average (review in Huijser et al. 2006).

Examples of studies:

- A system of wildlife fences and gaps was installed to reduce vehicle collisions with mule deer (*Odocoileus hemionus*) along a two-lane and divided four-lane highway in northeastern Utah (Lehnert & Bissonette 1997). The gap had warning signs for motorists and a crosswalk was painted on the road surface as an additional sign for motorists. Road mortality was reduced by 42.3 percent (four-lane highway) and 36.8 percent (two-lane highway) compared to the expected road mortality. However, statistical significance of this reduction could not be demonstrated.
- Along State Route 260 near Payson, Arizona, a gap in an electric fence has been combined with an animal detection system (Dodd & Gagnon 2008). Preliminary results indicated that activated warning lights reduced vehicle speeds by about 20 percent and that elk-vehicle collisions may have been reduced by about 92 percent (Dodd & Gagnon 2008).
- The Netherlands has installed animal detection systems at gaps in wildlife fencing at two locations (‘t Harde and Ugchelen) (Huijser et al. 2006) (Figures 39 and 40).
- Similar to wildlife fences, median barriers can be an absolute or partial barrier to certain species (Clevenger & Kociolek 2006). In some cases gaps have been created in the median barrier to allow animals to cross the road. However, the effectiveness of these gaps has largely been untested (Clevenger & Kociolek 2006).

Figure 39: Gap in a wildlife fence accompanied by wildlife warning signs and advisory speed limit reduction, the Netherlands (© Marcel Huijser).

Figure 40: Gap in a wildlife fence combined with an animal detection system, wildlife warning signs and advisory speed limit reduction, the Netherlands (© Marcel Huijser).

Effectiveness in reducing the barrier effect of roads and traffic

Large mammal species that cannot easily climb or otherwise cross wildlife fencing are likely to be confronted with an increased barrier effect of the transportation corridor because their movements across the road are restricted to certain locations. However, the percentage of successful crossings may increase, as the gaps allow for at-grade road crossing in restricted areas.

Potential disadvantages or undesired side effects

At gaps in fences, animals cross the road at grade, exposing the drivers and wildlife to potential collisions. This may reduce the effectiveness of the wildlife fence, but to what extent depends on the type of warning signals that are presented to drivers at the fence gap. No data have been located about the risk of gaps that have static warning signs, but the available data for wildlife warning signs in combination with crosswalks suggest that the effectiveness of wildlife fencing may be reduced from about 87 percent to about 40 percent. The available data for animal detection systems suggest that a gap with an animal detection system may reduce the effectiveness of the wildlife fencing from 87 percent (on average) to 82 percent. In addition, once through a gap, animals may wander along the road or in the right-of-way, becoming trapped between the wildlife fences, exposing the drivers and wildlife to other potential collisions. Measures that allow animals to escape from the road and right-of-way should typically be implemented (see further information later in this section).

Maintenance requirements

Regular fence maintenance is critical in order to keep it functioning properly. Earth slumping on hill slopes, inadequate installation techniques resulting in gaps between ground and fence bottom, and breaches of the fence by the public (e.g., for fishing, hunting, or snowmobiling) allow animals to gain entry to the right-of-way. Fence maintenance is a major concern because priorities and budgets change over time. Fence maintenance is often neglected shortly after construction; meanwhile fence damage and gaps are a recurrent problem.

Reliability of the sensors used in animal detection systems have shown problems, although some of the manufacturers have overcome these problems (Huijser et al. 2006; Huijser et al 2007c).

Installation and maintenance costs

- The costs of crosswalks across a two-lane road and a four-lane road (excluding wildlife fencing and escape from right-of-way measures) were reported at US$15,000 and US$28,000, respectively (Lehnert & Bissonette 1997).
- The estimated cost of animal detection systems at a gap in the fence is US$50,000 (including installation and fence) (Huijser et al. 2006).

4.7. Wildlife Fencing with End Treatments

Wildlife fencing eventually stops somewhere. To prevent animals from walking around fence ends onto the right-of-way between the fences or onto the road, some form of end treatment may be required. Angled fencing away from the road may reduce the problem, but additional mitigation measures such as constructed boulder fields or animal detection systems may be required.

4.7.1. Mitigation for Fence Ends: Boulders Between Fence and Roadway

General Description

To discourage ungulate species from entering the fenced sections of the Trans-Canada Highway in Alberta, rock impediments or boulder fields were placed at the ends of the fence between the roadway and the fence, as shown in Figure 41 (Clevenger et al. 2002a). Boulders, roughly the size of bowling balls, were laid out uniformly to create a boulder field. The boulders are thought to discourage animals, especially ungulates, from walking across them.

Figure 41: The boulder field at the fence end at Dead Man's Flats along the Trans-Canada Highway east of Canmore, Alberta (© Bruce Leeson).

Species: Boulders in the right-of-way are intended for ungulate species and/or other animals that do not easily cross large boulders.

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: unknown

> Clevenger et al. (2002a) found that the combination of the boulder field and wildlife fencing were effective in reducing WVCs. The boulders were believed to be an effective deterrent in keeping ungulates from wandering between the fences (Clevenger et al. 2002a).

Examples of studies:

- In Banff National Park, Canada, DVCs on a particular road segment were reduced after the installation of fencing in combination with a boulder field. The boulders were credited as an effective deterrent in keeping ungulates from walking around the fence onto the right-of-way (Clevenger et al. 2002a). The boulder field begins at the fence end, sits on the margin of the paved edge of the highway, and is approximately 15 m wide and 20-25 m long (16.4 x 21.9-27.3 yard). Placing a guardrail between the road and boulder field provided for highway safety compliance in Alberta (and probably most states).

- The boulder field at Dead Man's Flats wildlife underpass along the Trans-Canada Highway east of Canmore, Alberta, is 100 m (328 ft) long with the width varying from about 8 to 20 m, (26 to 66 ft), depending on how close the fence is positioned to the roadway, with the boulders extending right from the pavement edge to the fence (Bruce Leeson, personal communication). In addition, a 19 m (62 ft) wide strip of boulders was placed in the median. The boulders are subangular, quarried rock, ranging in size from 20 to 60 cm (7.8 to 23.6 in) (about 75 percent are larger than 30 cm (11.8 in). The boulder apron, at a depth of about 40-50 cm (15.7-19.7 in), is installed on geofabric on sub-excavated smoothed ground. The boulders project about 20-30 cm (7.8-11.8 in) above the local ground surface (Bruce Leeson, personal communication).

Effectiveness in reducing the barrier effect of roads and traffic

With wildlife fencing, animal movements across the road are blocked or nearly completely blocked. This increases the barrier effect of the road, disrupting daily, seasonal and dispersal movements, and potentially reducing the population survival probability of the species concerned. Large species (e.g., grizzly bear, gray wolf) that cannot easily climb or otherwise cross wildlife fencing are likely to be confronted with an increased barrier effect of the transportation corridor, unless sufficient safe crossing opportunities are provided.

Potential disadvantages or undesired side effects

In areas of regular snowfall, the boulder fields become covered with snow, which allows ungulates to travel across them. There may be some motorist safety issues for some states by having an obstruction (and hazard) within the clear zone. In Alberta these safety issues were addressed by placing a guardrail at the road edge.

Maintenance requirements

Debris may need to be removed from boulder fields.

Installation and maintenance costs

The material and labor for the installation of boulders at the fence end at Dead Man's Flats wildlife underpass along the Trans-Canada Highway east of Canmore, Alberta, was estimated to cost Can$65,000 (installed in 2005, cost estimate for 2007) (Bruce Leeson, personal communication).

4.7.2. Mitigation for Fence Ends: Animal Detection Systems

General Description

Animals may cross the road where fences end, which can in some cases result in a concentration of WVCs. Installing animal detection systems (see section 3.2.4) at fence ends may reduce WVCs at these points.

Species: Animal detection systems detect large animals (i.e., deer and larger), while small- to medium-sized mammal species such as Canada lynx and gray wolf may rarely or never be detected.

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: unknown

> The benefits of using animal-vehicle detection systems at fence ends are unknown, but as a stand-alone mitigation measure, animal detection systems can reduce collisions with large ungulates by 82 percent (review in Huijser et al. 2006). The application of animal detection systems at fence ends can be expected to result in a similar reduction in WVCs, but data on effectiveness are relatively scarce and may vary.

Examples of studies:

- In Arizona, an experiment is currently being conducted with animal detection systems at fence ends to mitigate a concentration of deer- and elk-vehicle collisions (Dodd & Gagnon 2008).

Effectiveness in reducing the barrier effect of roads and traffic

Species that cannot easily climb or otherwise cross wildlife fencing are confronted with an increased barrier effect by the transportation corridor because their movements across the road are restricted to certain locations. However, the percentage of successful crossings may increase. Only larger-sized species (i.e., deer and larger) may benefit from the presence of an animal detection system. Animal detection systems do not restrict animal movements.

Potential disadvantages or undesired side effects

No undesirable effects were identified in the literature review.

Maintenance requirements

Fences and animal detection systems may require maintenance (see relevant sections above).

Installation and maintenance costs

No costs were identified in the literature review.

4.8. Wildlife Fencing with Escape Opportunities

Animals may end up between fences or other barriers placed along the transportation corridor posing a safety risk and exposing the species concerned to road mortality. Therefore, absolute barriers, such as wildlife fencing, should typically be accompanied with escape opportunities for animals that have ended up between the fences (Reed et al. 1974; Ludwig & Bremicker 1983; Feldhamer et al. 1986; Bissonette & Hammer 2000).

4.8.1. Jump-outs or Escape ramps

General Description

Jump-outs or “escape ramps” are sloping mounds of soil placed against a backing material on the right-of-way side of the fence (Figure 42 and 43). The highway fence is tied in to the edges of the jump-out. Jump-outs are designed to allow animals caught between the fences to jump out of the right-of-way. At the same time, jump-outs should not allow animals to jump into the right-of-way area. Little is known about the appropriate height for jump-outs. The appropriate height of jump-outs is likely dependent on the main species of interest and the terrain (e.g., up-slope or down-slope), but they are typically 1.6-2.2 m (5-7 ft) in height.

Figure 42: A jump-out along a 2.4 m (8 ft) high fence along U.S. Highway 93 in Montana (© Marcel Huijser).

Figure 43: A jump-out along a 2.4 m (8 ft) high fence along U.S. Highway 93 in Montana (© Marcel Huijser).

To prevent injury to the animals that jump out, the landing spot at the bottom of the jump-out should consist of loose soil or other soft material (Bruce Leeson, personal communication). Where bears are present the walls must be smooth to prevent them from climbing into the right-of-way (Bruce Leeson, personal communication) (Figure 44). Furthermore, it is thought to be best for jump-outs to be positioned in a set-back in the fence, in an area protected with tree cover, where animals may calm down and have time to decide whether to jump off the jump-out (Bruce Leeson, personal communication). A short fence on the jump-out itself, perpendicular to the road and the right-of-way fence, may also help guide animals to the jump-outs. For additional guidelines see Bissonette and Hammer (2000).

Figure 44: A jump-out along a 2.4 m (8 ft) high fence with smooth metal to prevent bears from climbing into the right-of-way along the Trans-Canada Highway, Lake Louise area, Banff National Park, Canada (© Marcel Huijser).

Species: The vertical drop off on the backside of escape ramps is designed to preclude deer and other large mammals from gaining access to the right-of-way from the non-highway side of the fence. Deer and elk are the most common users of jump-outs along the Trans-Canada Highway in Banff National Park, but moose and bighorn sheep have also used these structures (Bruce Leeson, personal communication).

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: 29%

> Based on Bissonette and Hammer (2000), jump-outs were effective in allowing deer to escape the right-of-way and in reducing DVCs. Using jump-outs or "escape ramps" along two fenced road sections reduced collisions by 28.6 percent on average (Bissonette & Hammer 2000). Jump-outs were eight to eleven times more effective than one-way gates (Bissonette and Hammer 2000).

Examples of studies:

- Bissonette and Hammer (2000) studied the effectiveness of earthen escape ramps (jump-outs) and one-way gates along a fenced section of U.S. Highway 91 and U.S. Highway 40 in northern Utah. The 2.4 m (8 ft) fence was not 100 percent effective, due to human vandalism and gaps under the fence, so additional measures were necessary to help get deer off the highway. The authors noted peaks in DVCs in spring and fall, and noted that DVCs declined after installation of the jump-outs. Jump-outs were eight to eleven times more effective than one-way gates. The authors calculated that if the ramps offset even 2 percent of deer mortality, they would be considered cost-effective within one to two years. They recommended jump-outs instead of one-way gates, and concluded that (with fencing) these are effective mitigation measures for removing deer from highway rights-of-way and minimizing accidents with motorists.

- Clevenger et al. (2002a) documented use of jump-outs by deer, elk and coyote on the Trans-Canada Highway.

Effectiveness in reducing the barrier effect of roads and traffic

While jump-outs are not intended as a crossing structure, they do allow animals that are trapped between the fences in the right-of-way to escape. Thus they reduce the trapping and potential road mortality of the individuals involved.

Potential disadvantages or undesired side effects

If the jump-outs are not high enough, animals may jump up and end up in the right-of-way between the fences. On the other hand, if jump-outs are too high, animals will not use them to escape from the transportation corridor. Furthermore, jump-outs need to be well away from the travel lanes and clear zone to avoid the danger of cars that have run off the road crashing into them.

Maintenance requirements

Debris may need to be removed from on or under jump-outs.

Installation and maintenance costs

Reported costs for one jump-out range from US$11,000 (Bissonette & Hammer 2000) to US$6,250 (Pat Basting, Montana Department of Transportation, personal communication).

4.8.2. One-way Gates

General Description

One-way gates allow animals to enter from the road side and go through the fence, providing a possible opportunity for escape from the transportation corridor.

Species: Gates (Figures 45 and 46) have been built for different sized species, ranging from moose, elk, and deer to the Eurasian badger (Ludwig & Bremicker 1983, Bissonette & Hammer 2000, Kruidering et al. 2005).

Figure 45: One-way elk gate in British Columbia, (© Marcel Huijser).

Figure 46: One-way Eurasian Badger gate, the Netherlands (© Marcel Huijser).

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: unknown

> In general, one-way gates are no longer recommended as wildlife can learn how to use them to get into the right-of-way (Clevenger et al 2002b), sometimes aided by hikers, fishermen, equestrians and bikers who propped and tied the gates open (Bruce Leeson, personal communication). Jump-outs appear more effective than one-way gates in allowing ungulates to escape from the right-of-way (Bissonette & Hammer 2000).

Examples of studies:

- One-way gates were believed to be relatively effective for deer (Reed et al. 1974a); however, in a later study, only 17 percent of deer that approached one-way gates actually used them (Lehnert 1996).
- In Banff National Park, Canada, an elk herd not only learned how to go through the gate the "wrong way" but they also destroyed the gate within a week after they learned how to enter the gate from the "wrong side" (Bruce Leeson, personal communication). In the same area, coyotes learned to crawl through the tines to feed on mice that became more abundant in the right-of-way now that it was no longer grazed by ungulates (Bruce Leeson, personal communication).
- At another location, at least one elk has been observed "taking a gate out" as the gate was too small for its body size (Monique DiGiorgio, Southern Rockies Ecosystem Project, personal communication), and at least one moose has been observed getting its antlers stuck and damaging its velvet (Rick Sinnott, Alaska Fish and Game, personal communication).

Effectiveness in reducing the barrier effect of roads and traffic

While one-way gates are not intended as a crossing structure, they do allow some animals that are trapped between the fences in the right-of-way to escape. Thus they reduce the trapping and potential road mortality of the individuals involved. However, jump-outs appear to be used more readily by animals than one-way gates, and one-way gates have been observed to be a safety hazard for some wildlife species. They are no longer recommended.

Potential disadvantages or undesired side-effects

There are undocumented reports that animals tried to reverse course by backing up once they had entered elk gates, after which they got stuck and wounded themselves, and later died.

Maintenance requirements

Gates may be impaired or destroyed by wildlife, requiring repair or replacement. Gates may need to be monitored to ensure they remain closed and not propped open by human users.

Installation and maintenance costs

Estimated costs were reported at US$8,000 per one way gate (Bissonette & Hammer 2000).

4.9. Wildlife Fencing Intersecting with Access Roads

Access roads that intersect with the main road disrupt wildlife fencing, resulting in a gap where animals can walk around a fence end and enter the right-of-way.

4.9.1. Gaps Caused by Access Roads: Gates

General Description

Gates (Figure 47) can be opened when leaving or accessing the main road. This approach is an inconvenience to drivers, as they have to stop and get in and out of their vehicle. Gates are normally only installed at access roads that have very low traffic volume.

Figure 47: Gate on a low volume access road along U.S. Highway 93 in Montana (© Marcel Huijser).

Species: Gates at access roads are intended to be a barrier for species that cannot cross a wildlife fence or gate.

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: unknown

For species that cannot cross a wildlife fence or gate, direct road mortality is likely to decrease compared to having an opening through which animals can readily access the road and right-of-way. The use of gates results in no further reduction in collisions compared to an undisrupted wildlife fence (presuming the gates are closed by users).

Examples of studies:

- Access road gates are used for the U.S. Highway 93 reconstruction project in Montana to retain the integrity of wildlife fencing.

Effectiveness in reducing the barrier effect of roads and traffic

Unknown, however, the barrier effect of the transportation corridor is likely to increase.

Potential disadvantages or undesired side effects

Gates are an inconvenience to drivers, and they may potentially increase WVCs if they are left open.

Maintenance requirements

Gates may be impaired or destroyed by wildlife, requiring repair or replacement. Gates may need to be monitored to ensure they remain closed and not propped open by human users.

Installation and maintenance costs

Costs for single- and double-panel gates along U.S. Highway 93 on the Flathead Indian Reservation in Montana were US$300-360 and US$350-US$550, respectively (Pat Basting, Montana Department of Transportation, personal communication).

4.9.2. Wildlife Guards

General Description

Cattle or wildlife guards are designed to discourage wildlife, especially ungulates, from walking through a gap in the fence (Figure 48 and 49).

Figure 48: Wildlife guard along U.S. Highway 93 on the Flathead Indian Reservation, Montana (© Marcel Huijser).

Figure 49: Wildlife guard along U.S. Highway 1 for Key deer on Big Pine Key, Florida (© Marcel Huijser).

Species: Wildlife guards are designed for animals that do not easily cross cattle guards, especially ungulates. Wildlife guards may not be as effective for other species, such as bears.

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs:

> Cattle or wildlife guards offer no additional benefits in reducing WVCs compared to undisrupted wildlife fencing. Depending on the type of cattle or wildlife guard, the guard may be ineffective at discouraging certain species, or it may be only partly effective (e.g., 75-99 percent for Florida Key deer), depending on the type of wildlife guard (Peterson et al. 2003). Intrusions result in wildlife ending up on the road or between the fences along the right-of-way, posing a threat to traffic safety and putting the animal's life in danger.

Examples of studies:

- Standard cattle guards may be easily passable by Florida Key deer and mule deer (Reed et al. 1974b), dangerous to pedestrians and cyclists (Peterson et al. 2003), and special designs may be needed (for example, those developed for the Florida Key deer (Peterson et al. 2003)) (Figure 49).
- In some cases, such as along a side road of the TransCanada Highway in Banff National Park, Canada, a wildlife guard has also been put under electric current to discourage bears from walking across it.
- An electrified mat across an access road has been used to discourage ungulates from using a gap in a fence at an access road to approach a larger road with higher traffic volume and vehicle speeds (David Bryson, Electrobraid Fence Ltd, personal communication).

Effectiveness in reducing the barrier effect of roads and traffic

Unknown, however, if the wildlife guards work as intended, it is a serious barrier to the target species. As such, the measure is not intended to reduce the barrier effect of the road and associated fencing.

Potential disadvantages or undesired side effects

Depending on the design, cattle or wildlife guards may be dangerous to pedestrians and cyclists and unpleasant to drivers.

As mentioned above, depending on the design and target species, some cattle or wildlife guards may be fully or partially passable to certain wildlife species.

Maintenance requirements

Silt, debris, and snow must be cleared from beneath the wildlife guard, possibly requiring regular maintenance.

Installation and maintenance costs

The reported cost of a specially designed wildlife guard was US$30,000 (Pat Basting, Montana Department of Transportation, personal communication).

4.10. Wildlife Underpasses and Overpasses

General Description

Wildlife underpasses and overpasses are used extensively by a wide array of species to get from one side of the road to the other side (Falk et al. 1978, Ludwig & Bremicker 1983, Feldhammer et al. 1986, Clevenger et al. 2002b) (Figures 50-56). The performance of these structures in reducing WVCs and creating crossing opportunities is linked to associated wildlife fencing that keeps animals off the road and funnels them toward the wildlife overpasses and underpasses (Clevenger et al. 2002b). In some cases wildlife fencing is only installed over relatively short distances funneling wildlife toward a crossing structure (e.g. Dodd et al. 2003). The use of wildlife fencing was found to increase the use of underpasses by elk (*Cervus elaphus*) and to substantially increase the permeability of a road (Dodd et al. 2007). In other cases wildlife underpasses and overpasses have no or very limited wildlife fencing, making them the primary measure to reduce WVCs on short road sections.

Figure 50: Wildlife overpass along the Trans-Canada Highway in Banff National Park, Alberta (© Marcel Huijser).

Figure 51: Red Earth Overpass on the Trans-Canada Highway (©Tony Clevenger).

Figure 52: A large wildlife crossing culvert along the Trans-Canada Highway in Banff National Park, Alberta (© Tony Clevenger).

Figure 53. Bighorn sheep using an underpass along the Trans-Canada Highway near Canmore, Alberta (© Tony Clevenger).

Figure 54: Wildlife underpass along U.S. Highway 93 on the Flathead Indian Reservation, Montana (© Marcel Huijser).

Figure 55: Underpass in southern Florida that allows for ecosystem processes (hydrology) as well as wildlife use, including the Florida Panther (© Marcel Huijser).

Figure 56: Underpass in southern Florida that allows for ecosystem processes (hydrology) as well as wildlife use, including the Florida Panther. Note the vegetation that provides cover (© Marcel Huijser).

The use of wildlife underpasses and overpasses depends on many parameters, including their location in the landscape, their dimensions, the habitat surrounding the structures, human co-use, and the time since installation (learning curve for the animals) (Clevenger et al. 2002b). These factors also depend on the species concerned (Clevenger et al. 2002b).

Species: A wide variety of species has been shown to use wildlife underpasses and overpasses (Falk et al. 1978, Ludwig and Bremicker 1983, Feldhammer et al. 1986, Clevenger et al. 2002a). The location, type, and dimensions of wildlife crossing structures must be carefully planned with regard to the species and surrounding landscape. For example, grizzly bears, deer and elk tend to use wildlife overpasses to a greater extent than wildlife underpasses, while black bears and mountain lions use underpasses more frequently than overpasses (Clevenger et al. 2002b). In addition, different species use different habitats, influencing their movements and where they want to cross the road.

Guidelines for different wildlife taxa in Europe and North America can be found in Iuell (2003), Foster and Humphrey (1995), Clevenger and Waltho (2000), Clevenger and Waltho (2005), and Kruidering et al. (2005). If large species are involved that are sensitive to human disturbance, or if multiple habitats have to be provided for on an overpass, wildlife overpass structures are generally recommended to be at least 50-70 m (164-230 ft) wide. Further rationale for this width is provided by Pfister et al. (2002) who showed that the increase in use of wildlife overpasses increases linearly until a width of about 50 m (164 ft) at which point the increase in wildlife use starts to taper off.

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: 87%

> Wildlife overpasses and underpasses increase the effectiveness of wildlife fencing, or other barriers alongside the road, in reducing WVCs. If no safe crossing structures are provided, animals are more likely to break through the wildlife fencing (or other barrier) and thereby reduce the effectiveness of the wildlife fencing. Wildlife fencing in combination with underpasses or overpasses can reduce ungulate-vehicle collisions by 80 percent or more (Sielecki 1999, Clevenger et al. 2001).

Examples of studies:

- In North America, wildlife tunnels and overpasses are far less common than in Europe, affording fewer opportunities for experience and study. Only six of the latter are found in North America, and only two, in Banff, have been studied with regard to their effectiveness in reducing road mortality and allowing for safe crossing opportunities.
- Numerous species have been documented to regularly use 26 wildlife underpasses and two overpasses on the TransCanada Highway in Banff National Park. Almost 101,000 wildlife crossings have been recorded between 1996 and 2007 with almost 12,000 crossings at the overpasses. Species documented using underpasses include black bear, bobcat, cougar, coyote, deer, elk, fox, goat, grizzly bear, moose, bighorn sheep, and wolf. Species documented using overpasses include black bear, bobcat, cougar, coyote, deer, elk, fox, grizzly bear, moose, bighorn sheep, and wolf (Adam Ford, WTI, personal communication) (Figure 57). While Canada lynx and wolverine have also been observed using underpasses and while Canada lynx has been observed using an overpass, the number of observations are too low to conclude that these species will readily use crossing structures.

Figure 57: Wildlife use of wildlife overpasses on the TransCanada Highway in Banff National Park. Clockwise from upper left: moose, grizzly bear, gray wolf, and elk (© Tony Clevenger).

- In Banff National Park, Canada, grizzly bears, deer and elk tend to use overpasses to a greater extent than underpasses, while black bears and mountain lions tend to use underpasses more than overpasses (Clevenger et al. 2002a).
- Twenty-four underpasses along a 64 km (39.7 mi) long section of Interstate 75 in southern Florida were installed to allow for water flow and movement of animals, including the Florida panther (Foster and Humprey 1995).
- In Montana, wildlife underpasses and one wildlife overpass along U.S. Hwy 93 on the Flathead Indian Reservation, and one wildlife overpass across State Hwy 83 near Salmon Lake are planned, under construction or completed.

Effectiveness in reducing the barrier effect of roads and traffic

A wide variety of mammal species have been observed using wildlife underpasses and overpasses, apparently in relatively large numbers. As such, these crossing structures appear to substantially reduce the barrier effect of a wildlife fence. Much depends, though, on the location, concentration and dimensions of the crossing structures.

Potential disadvantages or undesired side effects

No apparent disadvantages or unintended side effects. However, if overpasses are not designed properly, the species for which they were intended may use them less than desirable or not at all.

- Little is known about the effect of wildlife fencing, with or without associated safe crossing opportunities, on individuals or species that do not live in the immediate vicinity of the road, fence and crossing structures. Species that show seasonal migration or individuals that disperse over long distances may not have the time to become familiar with the location of safe crossing opportunities, and, if they do encounter them, they may choose not use them.

Maintenance requirements

Maintenance is likely to be similar to other types of bridges and underpasses. However, soil and moisture may require specific attention with wildlife overpasses.

Installation and maintenance costs

- Costs vary widely depending on dimensions of the structures. Some estimated costs for different underpass structures are: box culverts (3.0 m high x 2.5 m wide (9.8 ft x 8.2 ft)) = Can$2,800 per m length (Can$854 per ft); elliptical culverts (4 m high x 7 m wide (13 ft x 23 ft)) = Can$5,400 per m length (Can$1,646 per ft); open span bridge underpass (5 m high x 13 m wide (16 ft x 43 ft)) = Can$55,000 per m length (Terry McGuire, Parks Canada, unpublished data).
- In The Netherlands, large underpasses (7-10 m wide (23-33 ft)) are estimated to cost €30,000 - €50,000 per m (Kruidering et al. 2005).
- Tunneling and overpass structures can cost approximately Can$33,650 per m (Can$10,259 per ft) for a 50 m (164 ft) wide overpass to Can$119,300 for a 27 m (88 ft) wide and 200 m (656 ft) long tunnel (Terry McGuire, Parks Canada, unpublished data). Actual overpasses were estimated at Can$1,750,000 (Anthony P. Clevenger, WTI, personal communication).
- A proposed overpass across Montana Highway 83 near Salmon Lake (two-lane road) is estimated to cost between US$1.5 million and US$2.4 million.
- The costs for seven wildlife overpasses in The Netherlands ranged between €1,400.000 and €5,600,000 (Kruidering et al. 2005).

5. DISCUSSION AND CONCLUSION

5.1. Effectiveness of Mitigation Measures in Reducing WVCs

The effectiveness of the mitigation measures in reducing WVCs with large mammals (specifically deer) is summarized in Table 2. Only wildlife fencing and animal detection systems have shown to be able to reduce WVCs with large mammals substantially (>80%). However, animal detection systems should still be considered experimental, and the estimate on their effectiveness may change as more data may become available. The effectiveness of other mitigation measures in reducing WVCs is substantially lower (<50%) or unknown. Wildlife fencing increases the barrier effect of the road and should typically only be used if safe crossing opportunities for wildlife are also provided. Animal detection systems, when applied as a stand-alone mitigation measure, do not restrict animal movements across a road. Even though the effect of some mitigation measures on WVC reduction is unknown, and even though some of the measures are considered experimental, the authors of this report may suggest advisory speed limit reduction, non-standard or seasonal warning signs, public information and education, alternatives to road salt, boulders and wildlife fencing for implementation and further research on Hwy 93 through Kootenay National Park. Only a few of the mitigation measures—animal detection systems, boulders and wildlife fencing—are expected to be able to substantially reduce WVCs and could serve as the primary mitigation measure. The other mitigation measures are not expected to reduce WVCs substantially or they may only be implemented at selected locations. This classifies them as “supportive” rather than primary mitigation measures for WVCs.

Table 2: The suitability of different mitigation measures to reduce collisions and to provide safe crossing opportunities for different species and species groups.

Measure	Effectiveness in reducing WVCs, in percent	Effect on permeability	Recommended for Hwy 93 south?	Category
Vehicle speed				
• Reduce posted speed	?	?	No[1]	Supportive
• Design speed and traffic calming	?	?	No[2]	Supportive
• Advisory speed	?	?	Yes[3]	Supportive
Wildlife warning signs				
• Standard	0	0	No	
• Non-standard	?	0	Yes[3]	Supportive
• Seasonal	26%	0	Yes[4]	Supportive
• Animal detection system	82%	0	Yes[5]	Primary
Public information and education	?	0	Yes[6]	Supportive
Vegetation management				
• Vegetation removal	38%	?	No[3,5]	Supportive
• Nutritional value	?	?	No[3,5]	Supportive
Reflectors or mirrors	0%	–	No	
Alternatives to road salt	?	?	Yes[5]	Supportive
Boulders	?	–	Yes[5,7]	Primary
Wildlife fencing	87%	–	Yes[7]	Primary

[1] Lower posted speed limits appear to conflict with design speed, and would result in increased travel times for this through road. [2] Unless it is applied to the entire road corridor and if increased travel times are acceptable. [3] Where appropriate; for short road sections only. [4] Only if movements are specific in time and place, further research recommended. [5] Experimental, further research recommended. [6] Effectiveness unknown, but considered good practice. [7] When used in combination with safe crossing opportunities for wildlife, jump-outs, etc.

5.2. Costs and Benefits of Mitigation Measures

There are substantial costs associated with WVCs. Recent research (Huijser et al. 2007a) estimated the average cost for each deer, elk, and moose collision at US$8,015, US$17,475 and US$28,600 respectively. The estimates include costs associated with vehicle repair, human injuries, human fatalities, towing, accident attendance and investigation, hunting and recreational value of the animal concerned, and carcass removal and disposal. The costs associated with other species may be different. For example, bighorn sheep are a major tourist attraction in Radium Hot Springs and, when hunted, some hunters pay large sums to be able to kill bighorn sheep. Thus the costs associated with bighorn sheep–vehicle collisions may be substantially higher than e.g. for a deer.

Table 3 summarizes the costs of the mitigation measures identified in this report and their effectiveness in reducing WVCs, specifically DVCs. The costs are presented (where possible) as cost per km of road length per year. The same method was used for quantifying the potential benefits as a result of reducing DVCs. For this analysis, researchers used a hypothetical 1 km (0.62 mi) road section of a two-lane road (one lane in each direction) that had five DVCs per year. The cost associated with one DVC was estimated at US$8,015 (previous paragraph). Finally, the balance (dollar amount saved per km road length per year) was calculated (benefits – costs). It is important to note that the costs for these mitigation measures are primarily the responsibility of transportation agencies, while the benefits are mostly for insurance companies. Thus, a positive balance between benefits and costs for a given mitigation measure generally indicates that the mitigation measure concerned could be a wise investment for society as a whole, but the costs and benefits are paid for or received by different groups in society.

It should be noted that the costs and benefits in Table 3 are based on the literature reviewed in Huijser et al. (2007a). The costs do not necessarily include all costs, such as maintenance, financing, and impact of construction on traffic. Furthermore, costs and benefits can vary widely for different sites and situations (e.g., geographic locations, effectiveness, frequency of WVCs, surrounding terrain).

In some cases the costs could not be translated to costs per km per year, and no further cost-benefit calculations were conducted for these mitigation measures. However, this does not necessarily mean that these mitigation measures are not effective in reducing DVCs or that they are not a wise investment. Instead, it may only indicate that further research or analysis would be necessary to quantify the potential benefits.

The calculations presented here do not include inflation indexes and discounting was not applied. Table 3 provides the best guess about costs, effectiveness, and benefits, based on the information currently available. Nonetheless, the calculations provide an initial insight into the balance between the costs and benefits of different mitigation measures and how this balances compares between measures.

The remainder of this section discusses the values in Table 3 for each mitigation measure for which sufficient data were available.

Table 3: Summary cost/benefit of mitigation measures

Mitigation measure	Costs (US$/km/yr)	% WVC reduction	Benefits (US$/km/yr)	Balance (US$/km/yr)
Reduce vehicle speed	?	?	?	?
Standard wildlife warning signs	$12	0%	$0	-$12
Non-standard wildlife warning signs	$249	?	?	?
Seasonal wildlife warning signs	$27	26%	$10,420	$10,393
Animal detection systems (ADS)	$31,300	82%	$32,862	$1,562
Public information and education		?	?	?
Vegetation removal	$500	38%	$15,229	$14,729
Nutritional value	?	?	?	?
Reflectors or mirrors	$495	0%	$0	-$495
Alternatives to road salt	?	?	?	?
Boulders				
Fence (incl. dig barrier)	$3,760	87%	$34,865	$31,105
Boulders in right-of-way	$2,461	?	?	?
Long bridges	$781,250	100%	$40,085	-$741,165
Long tunnels	$1,500,000	100%	$40,085	-$1,459,915
Fence with gap and warning signs	$4,303	0%	$0	-$4,303
Fence with gap and crosswalk	$5,041	40%	$16,030	$10,989
Fence with gap and ADS	$10,036	82%	$32,862	$22,826
Fence with underpasses	$5,754	87%	$34,865	$29,111
Fence with overpasses	$26,378	87%	$34,865	$8,487
Fence with underpasses and overpasses	$7,403	87%	$34,865	$27,462
KEY: The Table assumes one km with five DVCs per year. ?=unknown or uncertain.				

The costs and the potential reductions in WVCs resulting from a reduction in traffic speed are unknown. Furthermore, if actual vehicle speeds would be reduced to the posted speed limit in Kootenay National Park (90 km/h), it is unlikely to result in a substantial reduction of WVCs (see section 3.1.1). Therefore this mitigation measure was not included in the analysis.

Standard wildlife warning signs are relatively inexpensive: US$94 per sign. The costs per km per year (two signs per km, one sign for each travel direction, assumed life span of 10 years, no maintenance) are US$12, but since standard wildlife warning signs are considered ineffective in reducing WVCs (i.e., US$0 benefit), the final cost for this mitigation measure remains at US$12 per km per year. The effectiveness of non-standard wildlife warning signs is largely unknown, causing them to be excluded from the analysis. Seasonal wildlife warning signs (two signs per km, one sign for each travel direction, and an assumed life span of 10 years, no maintenance) may result in a 26 percent reduction of DVCs, and could end up saving US$10,393 per km per year. Bear in mind, however, that these types of signs are only applicable in situations where deer (or other large animals) display road crossing behavior that is concentrated in space and time. Animal detection systems (life span 10 years, costs include maintenance) cost more, but may still result in a positive balance of US$1,562 per km per year because of their ability to reduce WVCs by 82 percent. Note that the estimate on the effectiveness of animal detection systems may change as more data become available; they should still be considered experimental.

There is insufficient data available for public information and education programs, and influencing the nutritional value of the vegetation in the right-of-way. Vegetation removal, however, demonstrates more potential and may result in a positive balance of US$14,729 per km per year.

Assuming that deer reflectors and mirrors (life span 12.5 years, costs includes maintenance) are indeed not effective in reducing DVCs, they have a negative balance of US$495 per km per year.

There are insufficient data available to conduct a cost-benefit analysis for reducing or replacing road salt and using large boulders in the right-of-way as a barrier for ungulates. However, the cost estimate on using boulders was provided by Norris Dodd (Arizona Game and Fish Department, personal communication).

Wildlife fences (life span 20 years or more, not including maintenance) can reduce collisions with ungulates by at least 80 percent and have a positive balance of US$34,712 per km per year. The costs for long bridges and long tunnels (at least several hundreds of meters long) were set at US$781,250 and US$1.5 million per km per year, respectively (80-year life span). Both long bridges and tunnels result in a strongly negative balance.

To accommodate for animal movements from one side of a road to the other, wildlife fences are often combined with measures that allow animals to cross the road at grade, or to cross under or over the road through crossing structures. This section focuses on crossing opportunities for large animals only (deer size and up). The cost benefit analysis assumed one crossing opportunity per 2 km (1.24 mi) (0.5 crossing opportunity/km). In addition, gaps were set at a width of 100 m (109.3 yard), and the number of escape ramps between gaps was set at 2.5 per roadside per km (one every 317 m (346.6 yard) between gaps). In addition, the animals could "escape" through the gaps. The number of escape ramps between crossing structures was set at 3.5 per roadside per km (two immediately next to a crossing structure (50 m on either side from center), and 5 in between at 317 m (346.6 yard) intervals between the crossing structures). The escape ramps on either side of a crossing structure are required because of the contiguous wildlife fencing and the assumption that animals will want to cross the road most often at the location of the crossing structures, as that should be one of the most important criteria for the placement of these crossing structures. The length of the fence was not reduced because of gaps or crossing structures because of possible additional fencing at gaps and overpasses, and the contiguous nature of fencing for underpasses. In addition, for at-grade crossings, it was assumed that all deer movements that would have taken place in the unmitigated road section (and that resulted in five DVCs per km per year) would be funneled through these gaps, and that the number of DVCs is not reduced as the result of a potential reduction in the number of deer crossings because of the presence of the wildlife fence.

The life span of the material associated with crosswalks (see Lehnert & Bissonette 1997) was set at 10 years, while the life span for wildlife crossing structures was set at 80 years. The cost for the mitigation measure that includes a combination of wildlife fencing with underpasses and overpasses was based on 0.5 crossing structures per km, all of them underpasses except for 1 overpass every 25 km (15.5 mi). The cost for an underpass (a wide culvert, ±7 m wide, ±5 m high) was set at US$200,000, while the cost for an overpass (50 m wide) was set at US$3.5 million. The cost for an escape ramp was set at US$8,500 (life span 80 years). Wildlife fences with gaps that are mitigated by warning signals (US$12/km/yr, 10-year life span) or a crosswalk (US$750/km/yr, 10-year life span) have a negative balance while wildlife fences in combination with animal detection systems, wildlife underpasses, wildlife overpasses, or a combination of wildlife underpasses and overpasses all have a positive balance.

Many of the mitigation measures showed a positive balance. Some of the mitigation measures (long tunnels, long bridges, and anti-fertility treatment) showed a strongly negative balance. Because of their strongly negative balance, these mitigation measures are, in general, not recommended to reduce WVCs, at least not from a strictly monetary perspective. However, if alternatives are not suitable given the local conditions, or if other factors besides WVC reduction play a role, these measures may be considered after all. All other mitigation measures for which the cost-benefit analyses could be conducted had a positive or only a slightly negative balance. However, it is also important to evaluate mitigation measures on the portion of the problem that may not have been solved. None of the mitigation measures are 100 percent effective in reducing collisions, and if a substantial number of collisions and associated costs remain, a mitigation measure may not be attractive, despite a potential positive balance.

Figure 58 shows the individual mitigation measures (excluding long tunnels, long bridges, and ant-fertility treatment) in relation to their balance and the costs associated with the DVCs that have remained. Based on the results, the authors of this report identified wildlife fencing, with or without wildlife underpasses or a combination of wildlife underpasses and overpasses, and animal detection systems with wildlife fencing, as the most cost-effective mitigation measures (measures identified by solid oval). These mitigation measures have a strongly positive balance with relatively few remaining DVCs and associated costs. Animal detection systems without wildlife fences or wildlife fences with a high density of wildlife overpasses (measure identified by dashed oval) are also cost-effective. However, their positive balance is less strong than for wildlife fencing with or without wildlife underpasses; wildlife overpasses; a combination of wildlife underpasses and overpasses; and animal detection systems with wildlife fencing. It is important to note though that these mitigation measures offer different levels of habitat connectivity and that this non-monetary value was not included in the analyses. Furthermore, the balance between costs and benefits of all the mitigation measures may change as new or better estimates become available or as prices change over time. Nonetheless, based on the assumptions and estimates, the mitigation measures listed above are among the most attractive, at least from a monetary perspective.

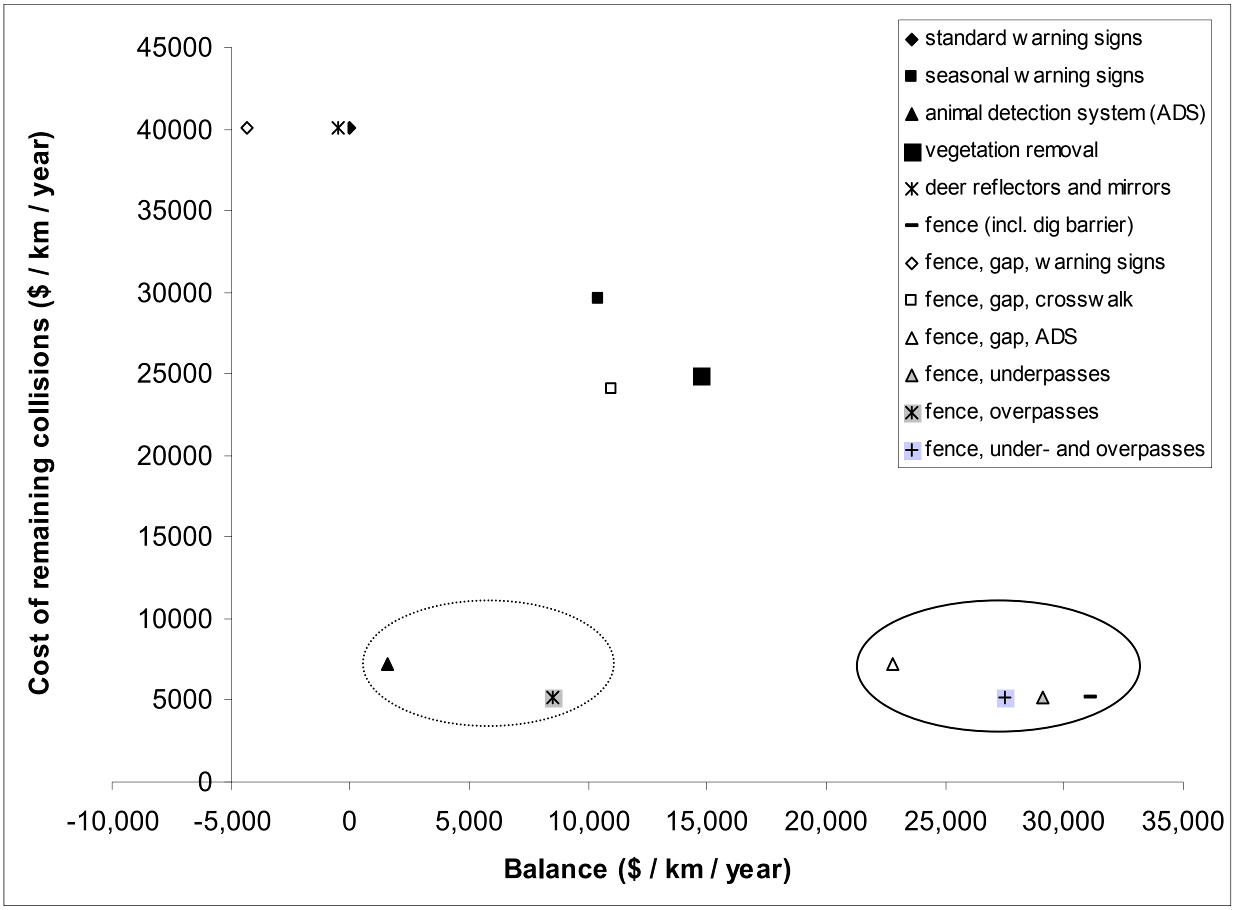

Figure 58: Balance and remaining costs for the different mitigation measures (further explanation in text).

5.3. Species-Specific Performance of Wildlife Fencing and Safe Crossing Opportunities

Wildlife fencing may be recommended for implementation along Hwy 93 through Kootenay National Park. However, wildlife fencing increases the barrier effect of the road and should typically be combined with safe crossing opportunities for wildlife. Table 4 rates the performance of different types of safe crossing opportunities in combination with wildlife fencing for a range of species with regard to collision reduction and safe crossing opportunities. Wildlife fencing (on the left in the table) serves as a reference.

Information on bighorn sheep, mountain goats, wolverine, bobcat, and Canada lynx with regard to their use of wildlife underpasses and overpasses is limited, hence the question marks (= unknown) in Table 4. However, bighorn sheep, mountain goats, and Canada lynx have been observed using underpasses, and the Canada lynx has been observed using overpasses (Singer & Doherty 1985, Hewitt et al. 1998, Clevenger et al. 2002b, Tigasa et al. 2002, Plumb et al. 2003, Anthony P. Clevenger, WTI, personal communication). Bighorn sheep are expected to use overpasses (Epps et al. 2005, McKinney & Smith 2007), but the authors of this report are unaware of actual data that show bighorn sheep have used overpasses. Coyotes do not appear to have a clear preference for overpasses or underpasses and seem to readily use a variety of crossing structure types (Anthony P. Clevenger, WTI, personal communication). Wolverines, which are extremely rare in the area, have used a creek bridge underpass and a 4 x 7 m elliptical culvert along the Trans-Canada Highway in Banff National Park, Alberta, (Anthony P. Clevenger, WTI, personal communication).

Table 4: The suitability of different mitigation measures for reducing collisions and providing safe crossing opportunities for different species and species groups.

Species	Fence (incl. dig barrier)		Fence with gap and ADS		Fence with underpasses		Fence with overpasses		Fence with underpasses and overpasses	
	Collisions	Crossings	Collisions	Crossings	Collisions	Crossings	Collisions	Crossings	Collisions	Crossings
White-tailed deer	O	N	O	O	O	U	O	O	O	O
Mule deer	O	N	O	O	O	U	O	O	O	O
Elk	O	N	O	O	O	U	O	O	O	O
Moose	O	N	O	O	O	U	O	O	O	O
Bighorn sheep	O	N	O	O	O	U	O	?	O	U
Mountain goat	O	N	O	O	O	U	O	?	O	U
Black bear	U	N	O	O	U	O	U	U	U	O
Grizzly bear	O	N	O	U	O	U	O	O	O	O
Wolverine	O	N	U	O	O	U	O	?	O	U
Mountain lion	U	N	U	O	U	O	U	U	U	O
Canada lynx	U	N	U	O	U	?	U	?	U	?
Bobcat	U	N	U	O	U	O	O	?	O	O
Gray wolf	O	N	U	O	O	U	O	O	O	O
Coyote	U	N	U	O	U	O	O	O	O	O
Points	23	0	22	27	23	17	25	16	25	23
Points combined	23		49		40		41		48	

O= Optimal, U = Usable, possibly with adaptations, N = Not suitable, ? = Unknown.
Points: O = 2 points, U = 1 point, N = 0 points.

5.4. Animal Detection Systems vs. Wildlife Crossing Structures

The pros and cons of animal detection systems versus wildlife crossing structures (such as underpasses and overpasses) in combination with wildlife fencing are summarized below (adapted from Huijser et al. 2006). Note that this section is based on having a reliable (Huijser et al. 2006, 2007c, Dodd & Gagnon, 2008) and effective (review in Huijser et al. 2006, Dodd & Gagnon 2008) animal detection system. Because data on the reliability and effectiveness is still limited, animal detection systems should still be considered experimental and the estimates on their reliability and effectiveness may change substantially as more data become available.

Pros for Animal Detection System*s*

- Animal detection systems have the potential to provide wildlife with safe crossing opportunities anywhere along the mitigated roadway, but wildlife crossing structures are usually limited in number and they are rarely wider than about 50 m (54.6 yard).
- Animal detection systems are less restrictive to wildlife movement than fencing or crossing structures. They allow animals to continue to use existing paths to the road or to change them over time.
- Animal detection systems can be installed without major road construction or traffic control for long periods.
- Animal detection systems are likely to be less expensive than wildlife crossing structures, especially once they are mass produced.

Cons for Animal Detection Systems

- Although the available data on the effectiveness of animal detection systems with regard to collision reduction are encouraging, animal detection systems currently are not as "tried and proven" as wildlife crossing structures.
- Currently, animal detection systems only detect large animals (e.g., deer, elk, or moose). Relatively small animals are not detected, and drivers are not warned about their presence on or near the road.
- Wildlife crossing structures can provide cover (e.g., vegetation, living trees, tree stumps) and natural substrate (e.g., sand, water) allowing better continuity of habitat.
- Some types of animal detection systems are only active in the dark and animals that cross during the daylight may not be protected.
- Animal detection systems usually require the presence of poles and equipment in the right of way, sometimes even in the clear zone, presenting a safety hazard of their own.
- Animal detection systems may substantially reduce the number of WVCs, but since they allow large animals to cross the road at grade, they will never completely eliminate WVCs.
- Animal detection systems can be aesthetically displeasing.
- Wildlife crossing structures are likely to have greater longevity and lower maintenance and monitoring costs.

The choice between animal detection systems (with or without wildlife fencing or wildlife crossing structures in combination with wildlife fencing) currently depends on whether the success of the project is defined as: 1) accomplishing a certain minimum result in terms of WVC reduction and/or safe crossing opportunities for wildlife, or 2) conducting research that helps to further evaluate the effectiveness of different mitigation measures. The choice also depends on the problem at hand (WVCs and/or lack of safe crossing opportunities for wildlife) and the species or species groups concerned, as well as the local situation, including road, right-of-way, and landscape characteristics. For additional considerations see Huijser et al. (2006).

5.5.Conclusion

Although there have been many mitigation measures suggested to reduce WVCs, only a few of the measures reviewed in this report have the potential to substantially reduce WVCs. Only wildlife fencing and animal detection systems have proven to be able to reduce WVCs with large mammals substantially (>80%). It is important to note, however, that animal detection systems should still be considered experimental, whereas the estimated effectiveness of wildlife fencing in combination with wildlife underpasses and overpasses is more robust. Large boulders in the right-of-way as an alternative to wildlife fencing appear to have potential as a barrier to ungulates and may be an alternative to wildlife fencing. However, this measure should still be considered experimental. Using less sodium chloride or replacing sodium chloride with alternative deicing or anti-icing substances may substantially reduce the time that certain species, such as bighorn sheep, spend on or alongside the road. However, such alternative substances may have other negative side effects and their implementation should also be considered experimental. The effectiveness of other mitigation measures in reducing WVCs is relatively low (<50%), impractical, or unknown.

Wildlife fencing and the use of large boulders in the right-of-way increase the barrier effect of the road. These measures should typically only be used if safe crossing opportunities for wildlife are also provided. Such crossing opportunities could consist of at-grade crossings at a gap in the barrier, with or without additional warning signals for drivers (e.g. animal detection systems), or wildlife underpasses and overpasses.

For the species evaluated (see section 5.3), a combination of different types of crossing opportunities appears better than providing a single type of crossing opportunity. The authors of this report believe animal detection systems with wildlife fencing, in combination with animal detection systems with wildlife underpasses and overpasses, are potential primary mitigation measures to be considered for the reduction of WVCs along Hwy 93 South through Kootenay National Park and adjacent road sections. However, animal detection systems should still be considered experimental, whereas the performance estimates for wildlife fencing and underpasses and overpasses are much more robust. The authors of this report also consider public information and education, experiments with alternatives to road salt, and experiments with large boulders in the right-of-way to be mitigation measures that have potential for reducing WVCs along Hwy 93 South through Kootenay National Park and adjacent road sections. However, these mitigation measures are classified as “supportive” measures rather than primary measures, and some of them are also considered experimental rather than a proven mitigation measure.

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