Measures to reduce bighorn sheep collisions – Highway 93/95 Mile Hill and Radium, British Columbia

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Content

SUMMARY

Background

Previous studies were conducted to identify mitigation measures aimed at reducing wildlife- vehicle collisions and providing safe crossing opportunities for wildlife along Hwy 93/95 in and around Radium Hot Springs, British Columbia.

The objective of this report is to provide an updated report similar to the 2008 report and recommend types and dimensions of crossing structures suitable for bighorn sheep, including recommendations regarding highway fencing, jump-outs and fence ends.

Collisions trends and economic costs

The number of road-killed bighorn sheep per year was similar between 2001-2010 (average 11.30, SD 2.67) and 2011-2020 (average 10.50, SD 3.51).

The economic costs associated with road-killed bighorn sheep per year in the Radium Hot Springs area was similar between 2001-2010 (avg US$ 74,772) and 2011-2020 (avg US$ 69,479). This is a conservative estimate. Values associated with biological conservation are likely substantial, but they were not part of this analysis.

Mitigation measures – A review

We reviewed the current science behind mitigation tools with different objectives. This is a review of the literature only and does not necessarily relate to bighorn sheep specifically. This chapter does not contain recommendations.

Case studies

Six case studies of road mitigation projects to reduce bighorn sheep-vehicle collisions and facilitate safe passage and movements across roads are presented from the US and Canada, including projects relatively close to the project area: Kicking Horse Pass, BC and Highway 3 Crowsnest Pass, Alberta.

Impact Mitigation: Wildlife Crossing Structures

Basic principles, land use planning considerations, design and planning, and best management practices are discussed.

Bighorn Sheep Mitigations

Criteria de determine type of crossing structure and designs and dimensions per guidelines in the FHWA Wildlife Crossing Handbook are covered.

Recommendations

We provide recommendations for highway mitigation in two distinct sections of Highway 93/95: (1) Mile Hill and (2) the Radium Hot Springs urban area.

Focal species in the project area is bighorn sheep, while secondary species include deer, coyote, cougar, bobcat and assorted small and medium sized mammals. All wildlife species in the project area will benefit from mitigation measures.

Mile Hill

Two crossing types are considered for the Mile Hill segment:

- Overpasses are the preferred structure type for bighorn sheep. Recommended width of the overpass: at least 35m up to 50m.
- The recommended dimensions of wildlife underpass on the Mile Hill section is ≥15m wide x ≥4.5 m high, per guidelines set out in Clevenger and Huijser (2011) and current research.

The locations of the two crossing structures were based on analysis of sheep-vehicle collision data and a site visit (30 Nov 2020) with key stakeholders. The location of the proposed wildlife overpass is primarily guided by the through-cut road profile that would facilitate the construction of a wildlife overpass compared to locations at-grade (McGuire et al. 2020). The overpass and underpass location are shown in Figures 5 and 7.

The dimensions are the *minimum* required for bighorn sheep as indicated in the FHWA guidelines. Given the FHWA guidelines are based on design for crossings on 4-lane highways, the recommended dimensions can be relaxed given the shorter structure length.

Fencing - The recommended extents of fencing are presented, including fence termination points, jump-outs or escape ramps for wildlife and Texas gates and an electrified wildlife guard. We strongly recommend that one-way gates not be used on this project.

Urban Radium Hot Springs

The objectives and urban context are vastly different than Mile Hill. Sheep tend to be habituated to human activity and vehicle traffic more than Mile Hill area. There are attractants of urban environments like Radium Hot Springs (fertilized lawns, local parks, nearby golf course) that bring them into area frequently.

There will be no fencing or crossing structures to keep sheep off the road and urban section of Highway 93/95.

The new traffic configuration is a concern and appears to have created more sheep-vehicle collisions and conflicts in the urban area. These changes consist of 1) a traffic roundabout replacing a single-lane, four-way stop, 2) reconfiguring the urban section of Highway 93/95 consisted also of widening the road surface by increasing lanes of traffic from 2 lanes (one southbound, one northbound) to 3 lanes of traffic (two southbound and one northbound).

Additional concern and central to the sheep-vehicle collision problem in the urban area is the design speed and posted speed limit and speed of traffic coming north, down from Mile Hill into the urban area in a transition zone between Mile Hill and town of Radium Hot Springs. The speed is currently 60 km/hour in the transition area, prior to entering and within the urban area. The posted change of speed limit from 90 km/hour at Mile Hill to reduced speed (60 km/hour) approaching the urban area, occurs only 400 m from the entrance to Radium Hot Springs. We recommend measures to slow down traffic a greater distance to the urban area, and lowering design speed and posted speed limits entering and within town limits.

The recommendations are the following:

- Reduce current 60 km/hour speed limit within and outside urban area to 40 km/hour.
- Creating an effective "speed zone" by posting change from 90 km/hour to 40 km/hour further from urban area, 1000 m from town boundary as opposed to current location of only 400 m.
- Reverting to single lane traffic (two lanes) in urban area. Returning to single lane configuration on southbound lane will slow down traffic by decreasing vehicle occupancy and limiting southbound traffic to one lane rather than two lanes.
- Reduce width of traffic lanes. Create a more narrow "driveable" section of road for motorists in urban area by using established traffic calming methods.
- Ensure proper lighting is in place to minimize incidence of collisions.

Monitoring performance

Rigorous year-round monitoring of the mitigation measures implemented on Highway 93/95 will be instrumental in adjusting design types and implementing "lessons learned" on future MoTI projects aimed at mitigating roads for wildlife populations in BC. Monitoring recommendations are provided and described for Mile Hill and urban Radium Hot Springs area.

1. Introduction

In 2008 a study was conducted to identify mitigation measures aimed at reducing wildlife- vehicle collisions and providing safe crossing opportunities for wildlife along Hwy 93S through Kootenay and Banff National Park and roads in and around Radium Hot Springs, British Columbia (Huijser et al. 2008). The report identified and prioritized road sections for potential mitigation measures, provides a mitigation plan aimed at reducing wildlife-vehicle collisions and providing safe wildlife crossing opportunities, and reviews potential funding mechanisms for such mitigation measures.

As a follow-up to the above report, Huijser (2010) updated the mitigation plan for Kootenay National Park (KNP) and the roads around Radium Hot Springs, British Columbia. The work consisted of the following tasks:

1. Present the 2008 study results to Parks Canada staff in KNP.
2. Conduct a field site review with Park personnel.
3. Update the effectiveness of potential mitigation measures for roads in KNP and Radium area.
4. Review additional road mortality data and wildlife observation data.
5. Interview Parks Canada management staff to receive opinions of suggested mitigation measures.

The 2008 report provided mitigation recommendations for KNP and the Radium area and a rationale for where and how to start with the implementation of the mitigation measures.
For the Radium section 4 mitigation options were suggested:

1. Alternative to de-icing agent
2. Wildlife fence constructed around Radium Hot Springs
3. Wildlife fence and wildlife underpass on Hwy 93/95 Mile Hill
4. Wildlife fence and wildlife overpass on Hwy 93/95 Mile Hill

The objective of this report is to provide an updated report similar to the 2008 report and recommend types and dimensions of crossing structures suitable for bighorn sheep, including recommendations regarding highway fencing, jump-outs and fence ends.

Specific objectives include:

1. **Bighorn sheep collision data**: 1) Review and synthesize bighorn sheep collision data (numbers, locations, intensities. *This will be done by Parks Canada*. 2) Monetary costs to society based on collision data.
2. **Current science and efficacy** – Review with regards to mitigation measures applicable to bighorn sheep collision reduction objectives on the Radium/Mile Hill project.
3. **Case studies** from other jurisdictions dealing with similar problems of bighorn sheep and vehicle collisions.
4. **Recommendations** for 1) mitigating road-related mortality of bighorn sheep in Radium and Mile Hill area, and design of data collection to assess performance of mitigation measures.

The project area for this report consists of roughly 4.5km section of Highway 93/95, from the junction of the two highways in Radium Hot Springs to the Radium Hill Road-Dry Gulch area to the south (Figure 1).

Figure 1. Location of project area on Highway 93/95. The area extends from the town intersection of Highways 93 and 95 (roundabout) in the north to Radium Hill Road-Dry Gulch area in the south.

Bighorn sheep (Ovis canadensis) warning sign with flashing amber lights, Radium Hot Springs, BC

2. Collisions trends and economic costs

2.1. Bighorn sheep-vehicle collisions

Records of the number of reported road-killed bighorn sheep are maintained by Parks Canada. The number of road-killed bighorn sheep per year was similar between 2001-2010 (average 11.30, SD 2.67) and 2011-2020 (average 10.50, SD 3.51) (Figure 2).

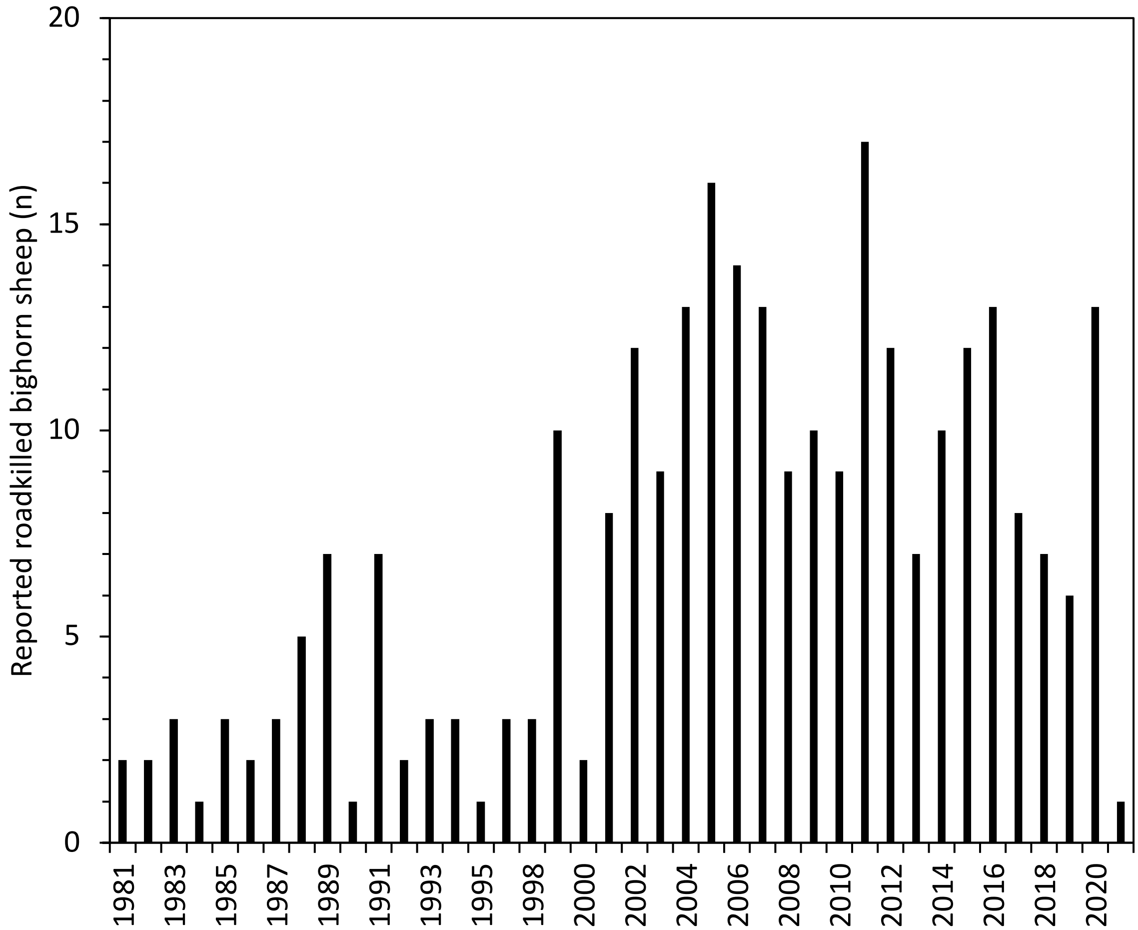

Figure 2. Number of reported road-killed bighorn sheep in the Radium Hot Springs area, 20 Dec 1981 and 5 Jan 2021 (Data provided by Parks Canada).

2.2. Economic costs

Collisions with bighorn sheep result in vehicle repair costs, costs associated with human injuries and human fatalities, towing, crash attendance and crash investigation, carcass removal, loss of hunting value of the animals concerned, other costs associated with the loss of wild animals and decrease biodiversity values (see e.g. Huijser et al., 2009; ICBC, 2021). Costs associated with deer, elk, and moose-vehicle collisions were compiled by Huijser et al. (2009). The size and weight of bighorn sheep is somewhat comparable to "deer", and less so to elk or moose. The costs for an average deer-vehicle collision was estimated at US$ 6,617 in 2009 (Huijser et al., 2009). The costs were predominantly with vehicle repair costs and human injuries and human fatalities. However, the hunting value, and values associated with biological conservation can be very high for bighorn sheep. For example: when auctioned, hunting tags for bighorn sheep can sell for tens or even hundreds of thousands of dollars; a single bighorn sheep tag for Arizona sold for $380,000 (Wild Sheep foundation, 2016). The 2021 British Columbia mountain sheep special hunting permit was sold for US$ 275,000 (Online Hunting Auctions. 2021). Punishment for the poaching of bighorn sheep may include the loss of hunting privileges for many years and thousands of dollars in fines (e.g. US$ 4,000 in restitution for a poached bighorn sheep (Bozeman Daily Chronicle, 2020) or US$ 32,000 in restitution for a poached bighorn sheep (Bozeman Daily Chronicle, 2001). In British Columbia, two hunters were fined a total of CAN$ 14,375 in fines, and had their hunting licenses and firearms taken away for a combined total of five years after shooting a bighorn sheep out of season (CBC, 2018). The maximum fine for poaching a bighorn sheep in British Columbia is CAN$ 100,000 (CBC, 2020). Furthermore, citizens are willing to pay annually to avoid losing wild bighorn sheep populations (Duffield & Neher, 2019), and they are willing to pay to be able to interact with wildlife and have wilderness in British Columbia too (Reid et al., 1995; Reid, 1998). Finally, natural resource management agencies often describe bighorn sheep as having a “high conservation value” (e.g. NPS, 2019).

To estimate the economic costs associated with bighorn sheep-vehicle collisions, the number of road-killed bighorn sheep per year was multiplied by US $ 6617 (based on their similarity in size to “deer” in Huijser et al., 2009) (Figure 3). The economic costs associated with road-killed bighorn sheep per year in the Radium Hot Springs area was similar between 2001-2010 (average US$ 74,772, SD 17,659) and 2011-2020 (average US$ 69,479, SD 23, 186) (Figure 3). Note that this is a conservative estimate, primarily based on costs associated with vehicle repair costs, and costs associated with human injuries and human fatalities. Values associated with biological conservation are likely substantial, but they were not part of this analysis.

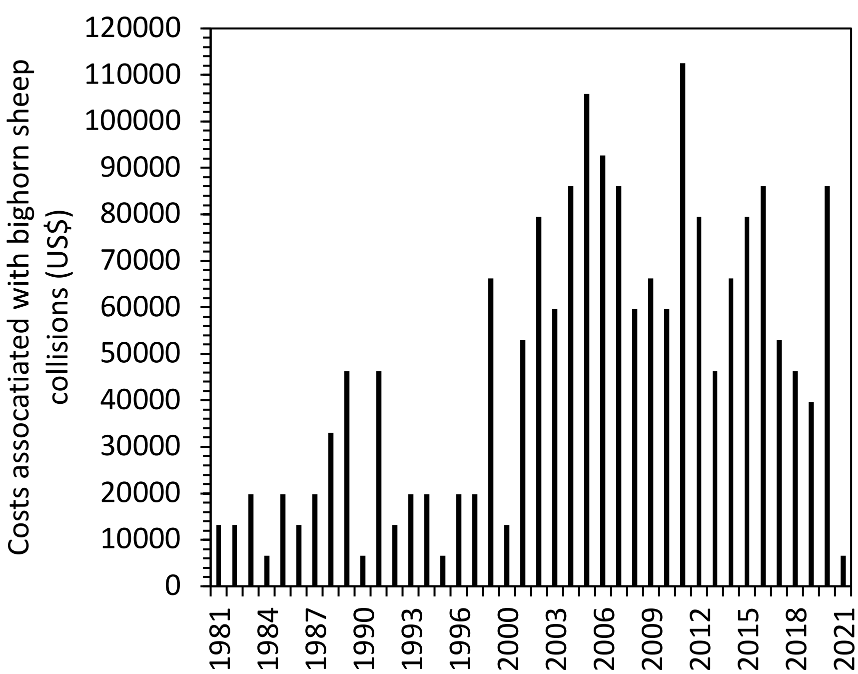

Figure 3. The costs (in US$) per year associated with bighorn sheep-vehicle collisions in and around Radium Hot Springs (based on Huijser et al., 2009).

3. Mitigation Measures – A review

In this section we review the current science behind mitigation tools with different objectives. This chapter is a review of the literature only. This chapter does not necessarily relate to bighorn sheep specifically. This chapter does not contain recommendations for the bighorn sheep issues along the highway near Radium Hot Springs.

3.1. Measures reducing time bighorn sheep spend on or near road

A. Reduce or eliminate the use of road salt

Summary

While removing road salt pools is likely to reduce collisions with moose, there were no studies identified that evaluated the potential benefits of reducing the amount of road salt or applying alternatives to road salt on collisions with large mammals in general. Eliminating or reducing road salt, or applying alternatives to road salt, does not reduce the barrier effect of the transportation corridor. If road salts or alternative deicers are combined with repellents, they have the potential to increase the barrier effect of the transportation corridor.

Background Information

Road salts (e.g. sodium chloride (NaCl)) are substances used on roads to combat slippery conditions as a result of snow and ice. Distributing salt to the road surface results in a lower freezing point of water, and allows for better grip of the vehicles' tires on the pavement. Some animal species, especially moose (*Alces americanus*) and bighorn sheep (*Ovis canadensis*), are known to be attracted to roads and adjacent rights-of-ways because of road salt (Huijser et al. 2008, Laurian et al. 2008, Grossman et al. 2011). The animals are attracted to the salt licks because they provide essential minerals. Animals that spend more time on and adjacent to highways are at increased risk of being hit by vehicles. While reducing or eliminating road salt can result in fewer collisions with large wild mammals, road safety for people would deteriorate. Therefore, potential alternative deicers have been investigated over the last few decades. The objective is to identify alternative deicers that are at least as effective in combatting slippery road conditions as road salt, but that are not, or far less, attractive to wildlife. However, many alternatives to road salt are also detrimental to the environment and quantitative data on the potential to reduce collisions with large wild mammals are lacking.

Chloride salts are often added to sand or gravel in winter road maintenance to combat slippery roads. While such chemicals reduce snow and ice on the road surface, they can also attract some wildlife species to the road surface and adjacent rights-of-way. This can result in an increase in collisions with vehicles, especially in areas where natural salt licks are limited (Brownlee et al. 2000). Examples of large mammal species known to be attracted to roads and adjacent rights-of-ways because of road salt are moose (*Alces americanus*) and bighorn sheep (*Ovis canadensis*) (Huijser et al. 2008, Laurian et al. 2008, Grossman et al. 2011). However, the use of road salt is also known to negatively affect water quality, aquatic species (e.f. amphibians), vegetation, and birds (e.g. Mineau and Brownlee 2005, Laurian et al. 2012, Cosentino et al. 2014).

A study of radio-collared moose in New Hampshire determined that their home ranges converged on the area containing roadside salt (NaCl) licks formed by runoff of road salt (Miller and Litvaitis 1992). These roadside salt licks increased the probability of moose-vehicle collisions and increased brain worm infections in moose and white-tailed deer (Miller and Litvaitis 1992). Based on modeling GPS movements of moose in relationship to salt pools, there was an estimated 49% reduction in road crossings when salt pools were removed (Grosman et al. 2009). Statistical models estimate a 22-79% reduction in moose road crossings with the removal of salt pools (Grosman et al. 2011). While reducing or eliminating chlorides and favoring the use of alternative deicers (without salt) seems an advisable strategy to reduce the attractiveness of road corridors to certain wildlife species, great care must be given to the effectiveness to combatting slippery road conditions in winter. Road salt (NaCl) can be mixed with calcium chloride ($CaCl_2$) or magnesium chloride ($MgCl_2$) and organic additives. Some of the alternatives or mixtures have greater melting ability and penetrates ice faster (Government of Canada 2001). These mixtures have a lower freezing point. Some additives to road salt can reduce the attractiveness to ungulates while others do not, or evidence is lacking (Brown et al. 2000, Cryotech 2019), but no evidence is provided. However, in a trial with domestic sheep, capsaicin, the "hot" ingredient in cayenne (90,000 heat unit concentration; 0.5625% capsaicin), may reduce salt (NaCl) consumption in high concentration (18:1 NaCl:cayenne), but the difference was not significant (Newhouse & Kinley 2001). Replacing salt (NaCl) with magnesium chloride ($MgCl_2$) resulted in only very little consumption (Newhouse & Kinley 2001). Given these two treatments, the authors suggested further experiments with replacing salt (NaCl) with magnesium chloride ($MgCl_2$) (Newhouse & Kinley 2001). Organic matter is also being tested as a sustainable deicer, with current applications including organic waste, wastewater, cheese brine, pickle brine, potato juice, and beet juice (EDI 2015, Reddington 2018, Schuler and Relyea 2018). There were no studies identified that directly evaluated the effect of road salts, reducing road salts, or the application of alternatives to road salt on collisions with large wild mammals.

Collision Reduction/Direct Road Mortality Reduction

While removing road salt pools is likely to reduce collisions with moose, there were no studies identified that evaluated the potential benefits of reducing the amount of road salt or applying alternatives to road salt on collisions with large mammals.

Barrier Effect Reduction

Eliminating or reducing road salt, or applying alternatives to road salt, does not reduce the barrier effect of the transportation corridor. If road salts or alternative deicers are combined with repellents, they have the potential to increase the barrier effect of the transportation corridor.

Potential Undesirable Side Effects

Some deicing alternatives may be similarly damaging to the environment as traditional road salt (Hanslin 2011, Harless et al. 2011, Nutile and Solan 2019) while others can be more damaging and reduce oxygen concentration in water, have detrimental effects on aquatic species and the ecosystem (e.g., Jouiti et al. 2003, Harless et al. 2011, Schuler et al. 2017, Schuler and Relyea 2018). Application should be carefully evaluated (Kinley & Newhouse, 2003)

Costs of the Measure

The cost to remove salt pools can be expensive, as some will require earth-work and additional changes to the geometric design of the road. The costs for de-icing alternatives is highly variable. However, acetates maybe about 10 times as expensive as traditional road salts (Kelting and Laxson 2010). Nonetheless, cost-benefit ratios can be complex depending on the parameters included (Fay et al. 2015).

Cayenne added to NaCl (90,000 heat unit concentration; 0.5625% capsaicin) in high concentration (18:1 NaCl:cayenne) was estimated to cost CAD $68/km per application (Newhouse & Kinley 2001). Replacing salt (NaCl) with magnesium chloride ($MgCl_2$) was estimated at CAD $19/km per application (Newhouse & Kinley 2001).

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B. Intercept feeding or providing minerals (salt)

Summary

Intercept feeding is a specific form of habitat alteration; instead of reducing the quantity or quality of the habitat, food is provided away from the road with the intent that that will keep animals from coming close to the road where they may be hit by vehicles. For habitat alteration measures to result in a substantial reduction in collisions with large wild mammals, the activities would have to take place on a very large spatial scale and take a long time to take effect. For intercept feeding the benefits may be temporary, and result in negative side effects. The effectiveness of this measure in reducing AVCs is unknown. Habitat alterations away from the road do not decrease the barrier effect of the transportation corridor. However, if intercept feeding is successful, fewer individuals may approach and cross the road.

Background Information

Attempts at discouraging animals from accessing road salt using intercept mineral baiting were unsuccessful in Jasper National Park, Canada (Bertwistle 1997). Diversionary salt licks have been tested to reduce mortality of small populations of Mountain goats (*Oreamnus americanus*) (<50 individuals) in select locations in British Columbia, Canada. For these small populations, mortality of even a few individuals represents an unacceptable loss for the population (Harper 2019). Salt has also been used in an attempt to keep mountain goats off a highway in British Columbia (Sooke News Mirror, 2019), and it is also used to keep bighorn sheep from licking salt on highways. Intercept feeding is labor intensive and may create a dependency on supplemental food and may eventually increase population size (Wood & Wolfe 1988, Farrell et al. 2002). In addition, non-natural high concentrations of wildlife may also increase the transmission rate and spread of contagious diseases.

Collision Reduction/Direct Road Mortality Reduction

Insufficient information.

Barrier Effect Reduction

Habitat alterations away from the road do not decrease the barrier effect of the transportation corridor. However, if intercept feeding is successful, fewer individuals may approach and cross the road.

Potential Undesirable Side Effects

Intercept feeding may lead to dependency of wildlife on unnatural food sources and increased transmission of diseases.

Costs of the Measure

Unknown but likely highly variable.

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3.2. Measures that aim to change driver behaviour

A. Reduce posted speed limit

Summary

Speed management is often suggested as a strategy to reduce wildlife-vehicle collisions. However, speed management is complex, and not an effective strategy to reduce AVCs along through roads in rural areas. Furthermore, reducing vehicle speed does not necessarily reduce the barrier effect of the transportation corridor.

Background Information

Speed management is often suggested as a strategy to reduce wildlife-vehicle collisions. However, speed management is complex, and it is important to distinguish between three types of "speed":

- The design speed of a highway. This is used by engineers who then design the associated road characteristics such as lane and shoulder width, curvature, access density, and sight distance. These characteristics physically allow drivers to drive a certain speed in a safe and responsible manner.
- The posted speed limit. This is the legal speed limit depicted on signs. This is typically the 85th percentile of the vehicle speeds and should not exceed the design speed of a road.
- The operating speed of the vehicles. This is the speed that drivers drive their vehicles at.

Most collisions with large wild mammals happen between dusk and dawn when visibility is limited (Huijser et al. 2007). However, the design speed, posted speed limit and operating speed of major highways is typically too high and the head lights of vehicles do not shine far enough to detect large mammals early enough to allow drivers to stop their vehicle in time (Huijser et al. 2017). With median headlights (low beam) and a 1.5 second reaction time, drivers can, at a maximum, drive about 40 mi/h (64 km/h) and still avoid a collision (Huijser et al. 2017). Higher vehicle speeds do not allow most drivers with median headlights to avoid a collision with a large mammal on the highway, unless the animal moves out of the way, or unless the driver makes the vehicle depart its lane, which is typically not advisable. Since half the cars have headlights that have a shorter reach, an operating speed of 40 mi/h (64 km/h) would still not allow half the drivers to stop their vehicle in time. To allow (almost) all drivers to stop their vehicle in time, operating speed may need to be as low as 25-30 mi/h (Huijser et al. 2017). This is far lower than the design speed of most roads.

Most drivers drive a speed (operating speed) that is close to or higher than the design speed of a rural road (Fitzpatrick et al. 2003, Jiang et al. 2016, Donnell et al. 2018). If the posted speed limit is substantially reduced below the design speed for a rural road section through a sensitive area, and if the design speed remains the same for this road section, the following scenario is likely:

- Most drivers will ignore the lower posted speed limit and continue to drive a speed close to or higher than the design speed of the highway.
- Some drivers will adhere to the lowered posted speed limit.
- The mix of fast and slow-moving vehicles on a highway is referred to as "speed dispersion" and this is associated with more interaction between vehicles, dangerous driving behavior (e.g. irresponsible maneuvers to overtake slow vehicles) and an overall increase in crashes (Huang et al. 2013, Elvik 2014).

For these reasons alone, it is never a good idea to implement a posted speed limit that is substantially lower than the design speed of a highway. Transportation and law enforcement agencies typically respond to drivers who ignore the posted speed limit and who drive a speed that is close to the design speed of a road by increasing enforcement of the lowered posted speed limit (e.g. through radar measurements of vehicle speed and fining the speeders). If the radar posts are at fixed locations, drivers who travel the road section regularly will quickly learn about the location of the radar posts and lower the speed of their vehicle only in the immediate vicinity of the radar posts. This leads to further speed variation and associated risks, additional use of fuel through braking and acceleration, and the road sections in between the radar posts do not actually have slower moving traffic. Finally, drivers that do get "caught" are likely to experience the situation as "unjust". One cannot reasonably be expected to drive "slow" on a highway that has "wide" lanes, "wide" shoulders, "gentle" curvature and "long" sight distances. This is likely to eventually result in pressure to make the posted speed limit more consistent with the design speed of the road.

Suggestions and considerations:

- It is not an effective or wise mitigation strategy to implement a posted speed limit that is substantially lower than the design speed of a highway.
- Only consider lowering the posted speed limit if the design speed is reduced accordingly. Depending on the purpose of a highway, lowering the design speed and lowering the posted speed limit may be in direct conflict with the need for "efficient" transportation and this may therefore not be a viable strategy for most highways.
- For speed management to be substantially effective as a measure to reduce collisions with large mammals for more than half the drivers, the design speed, mandatory speed limit, and actual operating speed of the vehicles at night may need to be 35-40 miles per hour (56-64 km/h) at a maximum (Huijser et al. 2015, Huijser et al. 2017).

Collision Reduction/Direct Road Mortality Reduction

With median headlights (low beam) and a 1.5 second reaction time, about half the drivers can, at a maximum, drive 40 mi/h (64 km/h) and still avoid a collision with a large mammal (moose size) (Huijser et al. 2017). This is not a feasible mitigation measures for through roads that are also meant to provide efficient transportation (i.e. short travel times). However, reducing the posted speed limit on one road can also be used to encourage drivers to use other roads that are safer and better equipped to deal with high traffic volume, high vehicle speed, and that may have robust mitigation measures in place to reduce collisions with large mammals. In addition, reducing the posted speed limit or having a very low posted speed limit, can also be an option for "Park Roads" or other roads for which "efficient" transportation is not necessarily the most important purpose. For example, the main purpose of "Park Roads" is to allow for access to areas to experience the landscape and wildlife from the road, and to allow for access to trailheads and non-motorized forms of transportation. Two types of roads through Yellowstone National Park demonstrate this concept. "Park roads" (posted speed limit typically 45 mi/h (72 km/h)) had lower AVCs with large mammals than a road that is managed as a through-road rather than a park road (posted speed limit 55 mi/h (88 km/h)) (Gunther et al. 1998).

Barrier Effect Reduction (=provision of safe crossing opportunities)

Reducing vehicle speed does not necessarily reduce the barrier effect of the transportation corridor.

Potential Undesirable Side Effects

A posted speed limit that is substantially below the design speed of a highway results in speed dispersion; a mix of fast and slow-moving vehicles. This is associated with more interaction between vehicles, dangerous driving behavior (e.g. irresponsible maneuvers to overtake slow vehicles) and an overall increase in crashes (Huang et al. 2013, Elvik 2014).

Costs of the Measure

Not evaluated

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B. Standard, enhanced, and seasonal warning signs

Summary

Standard and enhanced wildlife warning signs are generally not effective in reducing wildlife-vehicle collisions, unless they are very time and location specific. Seasonal wildlife warning signs can reduce collisions with large wild mammals somewhat (9-50%), but data are sparse and variable. Warning signs do not reduce the barrier effect of roads and traffic.

Background Information

Standard wildlife warning signs are typically manufactured in the same style as other traffic warning signs, which is usually country dependent. Most signs depict a stylized large mammal species that is common, widespread and large enough to be a safety concern for motorists (e.g. white-tailed deer in the United States). Enhanced wildlife warning signs tend to be larger than standard signs, they may have flashing lights or bright flags attached to them, and they may also include eye-catching or perhaps even disturbing illustrations, images of certain species that the warning relates to, collision statistics or other customized text. These characteristics aim to capture the attention of motorists and educate them about the safety and nature conservation impact of wildlife-vehicle collisions. Enhanced warning signs are generally more frequently observed and recalled by drivers than standard warning signs (Summala & Hietamaki 1984). They are normally installed at road sections that have a relatively high number of collisions or in areas where species of conservation concern occur. Temporal wildlife warning signs warn drivers of wildlife presence during specific times of the year or day. These signs tend to be species specific and may only be visible to drivers during the most hazardous time of the year or day (e.g. signs that fold in half and are removed in the off season, or variable message signs that are activated at certain times of the year or day (i.e. electronic signs with programmable text or symbols)). Seasonal warning signs may be placed where roads intersect migration corridors (e.g. mule deer migration routes in the western United States) or where species are attracted to the highway during specific times of the year (e.g. bighorn sheep licking road salt in specific areas in the Rocky Mountains in North America). If the warning relates to certain hours of the day, the signs may be permanent, but their message may be enhanced during the time of the day with peak wildlife activity (e.g. flashing lights around dusk and dawn) or the message may only be visible during the most hazardous hours of the day.

Standard and enhanced wildlife warning signs are typically considered effective if they result in a reduction in the number of collisions with large wild mammals. Other parameters may also be used to measure effectiveness, such as a reduction in vehicle speed or other driver responses such as touching the brakes or being more alert. While drivers may reduce vehicle speed in response to standard and enhanced signs (Pojar et al.1975, Al‐Ghamdi & AlGadhi 2004, Rogers 2004, Sullivan et al. 2004), the majority of studies of the effectiveness of these sign types in reducing collisions concluded that they were not effective (e.g. Pojar et al. 1975, Coulson 1982, Rogers 2004, Meyer 2006, Bullock et al. 2011). However, some have found standard warning signs to be effective (34% reduction in collisions) immediately after installation at recently identified hot spots (Found & Boyce 2011), or in conjunction with a fake animal (a snake) on the road (Collinson et al. 2019). Data on the effectiveness of temporal signs suggest that they can be effective in reducing collisions. Temporal warning signs can reduce collisions, although effectiveness varies substantially (9–50%) (Sullivan et al. 2004, CDOT 2012). These pattern of when seasonal, enhanced or temporal signs are or can be effective seems to be associated with the signs being more precise in location and time. However, most standard or enhanced wildlife warning signs are applied over long road sections and are not necessarily only applied at the times with the highest risk (review in Huijser et al. 2015). Implementing standard or enhanced wildlife warning signs may still be required or desirable to limit liability concerns. While standard and enhanced signs have some educational value, one could also argue that drivers may wrongfully think that these sign types reduce collisions and consequently do not support more effective mitigation measures that may be more expensive.

Collision Reduction/Direct Road Mortality Reduction

Standard and enhanced wildlife warning signs: not effective in reducing wildlife-vehicle collisions, unless they are very time and location specific (Huijser et al. 2015). Seasonal wildlife warning signs can reduce collisions with large wild mammals somewhat (9-50%), but data are sparse and variable (Sullivan et al. 2004, CDOT 2012).

Barrier Effect Reduction

Wildlife warning signs aim to warn drivers and urge them to be more attentive to wildlife that may be on or near the road. The primary goal of wildlife warning signs is to improve human safety by reducing the rate and severity of wildlife-vehicle collisions. Wildlife warning signs do not help achieve safe and effective crossing opportunities for wildlife because: 1. Wildlife warning signs do not make it any more attractive for wildlife to approach and cross the road; 2. Warning signs do not change the fact that roads are linear open areas without cover with an unnatural substrate (usually asphalt or concrete) and traffic; 3. Wildlife warning signs do not reduce the traffic volume and animals still have to avoid vehicles while crossing the road; and 4. Wildlife warning signs should be located at wildlife-vehicle collision hotspots, not where wildlife crosses the road successfully or locations that need improved connectivity to enhance population viability. However, depending on the type of sign, drivers may be more attentive and may (slightly) reduce their speed. This may increase the rate of successful road crossings for some wildlife. However, in some situations, drivers feel that evasive maneuvers would be too dangerous to them or other humans, and they may choose to hit the animal. Other drivers will actually aim to hit and kill certain species, especially species that are small in body size and that are unlikely to result in vehicle damage (e.g. most reptile species including snakes), and they may use the information provided by the warning signs to be more alert and try and hit the animals (Ashley et al. 2007). In conclusion, wildlife warning signs do not reduce the barrier effect of a transportation corridor.

Potential Undesirable Side Effects

Signs cause distraction and this can lead to other crashes as drivers pay less attention to the road and other vehicles. This is especially true for enhanced wildlife warning signs that are designed to attract attention of the drivers, and this may be a reason to avoid implementing signs that are designed to attract more attention from drivers than “standard” wildlife warning signs. Signs that are relatively unique depicting unusual species are also frequently stolen (Gunson & Schueler 2012). Furthermore, warning signs for certain species may also make poachers more aware of where they should target their efforts.

Costs of the Measure

Seasonal wildlife warning signs were estimated at US$ 400 for a large sign, and US$ 80 for two flashing lights (Sullivan et al. 2004).

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C. Roadside animal detection systems

Summary

Animal detection systems use electronic sensors installed along the roadside to detect large animals (i.e. deer size and larger) that approach the road; signs are then activated to warn drivers. These signs are very specific in time and place. Animal detection systems can reduce wildlife-vehicle collisions with large mammals by 33-97% provided that the sensors detect the target species. However, animal detection systems should still be considered experimental and implementation should be regarded as a high-risk project as many projects fail because of technological, management, financial, or maintenance issues. Most animal detection systems are more difficult to develop for small or medium sized animal species because they are more difficult to detect reliably. Similar to standard, enhanced and seasonal warning signs, animal detection systems do not address the barrier effect of a highway and associated traffic.

Background Information

Animal detection systems use electronic sensors installed along the roadside to detect large animals (i.e. deer size and larger) that approach the road; signs are then activated to warn drivers (Huijser et al. 2015). These signs are very specific in time and place. However, current animal detection systems are more difficult to develop for small or medium sized animal species because they are more difficult to detect reliably. The effectiveness of animal detection systems is variable, but they appear to reduce wildlife-vehicle collisions with large mammals by 33-97% provided that the sensors detect the target species reliably (Mosler - Berger & Romer 2003, Huijser et al. 2006, Dai et al. 2009, Gagnon et al. 2010, 2019, Strein 2010, MnDOT 2011, Sharafsaleh et al. 2012). Since the risk of severe crashes increases exponentially with increasing vehicle speed (Kloeden et al. 1997), it is useful to also evaluate the potential effect of activated warning signs associated with animal detection systems on vehicle speed. Drivers tend to reduce their speed somewhat (<5 km/h) (Kistler 1998, Muurinen & Ristola 1999, Hammond & Wade 2004, Huijser et al. 2006, Huijser et al. 2017, Grace et al. 2017) or more substantially (≥5–22 km/h) in response to activated signs of animal detection systems (Kistler 1998, Kinley et al. 2003, Gordon et al. 2004, Gagnon et al. 2010, 2019, Sharafsaleh et al. 2012, Huijser et al. 2017). The greatest reductions in vehicle speed seem to occur when the signs are associated with advisory or mandatory speed limit reductions or if road conditions and visibility for drivers are poor (Kistler 1998, Muurinen & Ristola 1999, Huijser et al. 2017).

Actual and perceived reliability can differ as drivers may rarely see animals on or along the road when the warning signs are activated (Sharafsaleh et al. 2012), or they may see animals in the proximity of the road with the warning signs turned off as the animals are beyond the range of the sensors. Regardless, in order to inform the driver adequately, it is important that the warning signs are relatively close together. A driver should not pass a warning sign without being able to see and interpret the next warning sign should it be activated. This may require a modification of the guidelines for sign placement which tend to be based on static signs rather than signs that display no message at all unless a danger has been detected. Many animal detection systems have a portion of the warning signs visible all the time (e.g. an additional flashing light is activated after a detection has occurred). However, it is best if no message is displayed at all, unless an animal has been detected to minimize the likelihood that drivers ignore activated signs and to avoid oversaturating the roadside with signs. Additional standard signs spaced at relatively great distances can then still address potential liability issues.

Animal detection systems should still be considered experimental and implementation should be regarded as a high-risk project as many projects fail because of technological, management, financial, or maintenance issues (Huijser & McGowen 2003, Huijser et al. 2006, 2009a, 2009b, 2017, Sharafsaleh et al. 2012, Huijser et al. 2017). Detection systems are experimental with regard to the level of certainty that a system will be operating as desired by a particular date - especially in detecting the target species with sufficient reliability - and a relatively wide and variable range of effectiveness in reducing wildlife-vehicle collisions. The latter is probably associated with the different types of detection technologies and the great variability in the signs presented to drivers. Note that animal detection systems do not address the barrier effect of a highway and associated traffic.

Collision Reduction/Direct Road Mortality Reduction

Animal detection systems can reduce wildlife-vehicle collisions with large mammals by 33-97% provided that the sensors detect the target species reliably (Mosler‐Berger & Romer 2003, Huijser et al. 2006, Dai et al. 2009, Gagnon et al. 2010, Strein 2010, MnDOT 2011, Sharafsaleh et al. 2012). However, animal detection systems should still be considered experimental and implementation should be regarded as a high-risk project as many projects fail because of technological, management, financial, or maintenance issues. Most animal detection systems are more difficult to develop for small or medium sized animal species because they are harder to detect reliably, especially in tall vegetation.

Barrier Effect Reduction (=provision of safe crossing opportunities)

Similar to standard, enhanced and seasonal warning signs, animal detection systems do not address the barrier effect of a highway and associated traffic.

Potential Undesirable Side Effects

Since many animal detection system projects suffer from technological, management, financial, or maintenance issues, and because there can be a disconnect between perceived and actual reliability of the system by the public, animal detection systems are often viewed negatively by the public. Further, there are potential issues with liability if a system fails to detect a large mammal, or if sudden braking in response to an activated warning sign results in a rear-end collision. In addition, activated warning signs may also make poachers more aware of where and when they should target their efforts.

Costs of the Measure

Highly variable (e.g. $65,000-$333,000 per mile road length), depending on the technology topography, curvature, and access roads (Huijser et al. 2009c, Pers. comm. Deb Wambach, Montana Department of Transportation).

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3.3. Measures separating wildlife from vehicles

A. Fences

Summary

Long fences (>3 mi (5 km) road length) typically result in >80% (average 84%) reduction in collisions with large mammals. Short fences (≤ 3 mi (≤5 km) road length) have lower (52.7%) and more variable (0-94%) effectiveness, probably because of fence-end effects. A well designed, constructed and maintained wildlife fence (or other barrier type such as a wall) is a near absolute barrier for the target species and potential other species, fragmenting their populations, and putting them at higher risk of local or regional extirpation. Therefore, as a rule, wildlife barriers should only be implemented in combination with wildlife crossing structures. Fences increase the wildlife use of structures and thereby help decrease the barrier effect further compared to wildlife crossing structures that are not associated with fences. Fences in combination with wildlife crossing structures can result in higher permeability of a highway than an unmitigated highway.

Background Information

Wildlife barriers are designed to keep animals off the highway. Fences are the most frequently used barrier type, but in some cases walls or rows of boulders have been used. The type of barrier, the height of the barrier, fence material, posts, and potential fence overhang or fence dig barrier all depend on the target species' capability to jump, climb, dig, or push through obstacles. In most cases there are multiple target species that inform the design of a barrier. For example, it is not uncommon to also attach finer mesh fence for medium sized mammals or plastic sheets for reptiles or amphibians to a taller fence that is primarily designed for large ungulates. A well designed, constructed and maintained wildlife barrier is a near absolute barrier for the target species and potential other species, fragmenting their populations, and putting them at higher risk of local or regional extirpation. Therefore, as a rule, wildlife barriers should only be implemented in combination with wildlife crossing structures.

Wildlife barriers have two main objectives: 1) to keep animals off the highway, reduce collisions, improve human safety, and reduce unnatural mortality for wildlife, and 2) to guide animals to crossing structures that allow for safe daily, seasonal and dispersal movements between the areas on either side of a highway (Dodd et al. 2007a, Gagnon et al. 2010, Huijser et al. 2015, 2016a). Barriers for large mammals mostly consist of fences. Large ungulate fences are typically 2.4 m (8 ft) tall, have wooden posts and 6 x 9 inch (about 15x18 cm) openings in mesh wire fence material and vertical length of the mesh may be reduce closer to the bottom to exclude medium-sized mammals. Species that can climb or jump well such as black bear or mountain lions require taller fences (10-12 ft; 3.0-3.7 m) with metal poles, smaller mesh sizes (e.g. chain-link), and an overhang on top of the fence angled away from the road. The fence should be flush to the ground to prevent animals from crawling under the fence. Special attachments, rubber flaps or chains attached to the main fence may be required at stream crossings (Kruidering et al. 2005). If the target species are able to dig, a buried fence or "apron" may have to be attached to the main fence and dug into the soil, angling away (45°) from the road (Clevenger and Huijser 2011). The buried fence may consist of a 4-5 ft (1.0-1.2 m) wide galvanized chain-link fence that is attached to the bottom of the actual fence. The buried fence should extend approximately 3.5 ft (1.1 m) under the ground (Clevenger and Huijser 2011). Electric fencing for large ungulates can be lower than mesh wire fences; e.g. about 7 ft (2.1 m) (Leblond et al. 2007, Phillips et al. 2011, Clevenger and Huijser 2011).

Opaque fencing is also sometimes thought to be more effective than woven wire mesh fencing allowing for reduced fence height. However, if animals are not naïve and know what may be on the other side of an opaque fence, there may not be any measurable benefit from opaque fencing compared to woven wire mesh fencing, suggesting that fence height for ungulates would still have to be about 8 ft (2.4 m), even if the ungulates cannot see through the fence (Stull et al. 2011).

Fence height may have to be adjusted if the fence is positioned on a slope. For example, fence height may be measured about 3.3 ft (1 m) from the fence on the "safe side" of the fence (Kruidering et al. 2005). Note that swaths of large boulders (>30 inches (>0.75 cm) in diameter) have been used as an alternative to wildlife fencing for elk in Arizona, but the use of large rocks as a barrier should be considered experimental (Dodd et al. 2007b). In road sections where landscape aesthetics and an unobstructed view of the landscape from the road are important, wildlife fences may not be desirable. In such situations, consider barrier walls integrated into the roadbed instead.

Collision Reduction/Direct Road Mortality Reduction

Long fences (>3 mi (5 km) road length) typically result in >80% (average 84%) reduction in collisions with large mammals (Huijser et al. 2016a). Short fences (≤ 3 mi (≤5 km) road length) have lower (52.7%) and more variable (0-94%) effectiveness, probably because of fence-end effects (Huijser et al. 2016a).

Barrier Effect Reduction (=provision of safe crossing opportunities)

Fences, as a stand-alone measure, do not reduce the barrier effect of transportation infrastructure. A well designed, constructed and maintained wildlife barrier is a near absolute barrier for the target species and potential other species, fragmenting their populations, and putting them at higher risk of local or regional extirpation (Jaeger and Fahrig 2004). Therefore, as a rule, wildlife barriers should only be implemented in combination with wildlife crossing structures. However, fences can help reduce the barrier effect of highways if they are combined with wildlife crossing structures (see separate section). Fences can help guide animals to crossing structures that allow for safe daily, seasonal or dispersal movements between the areas on either side of a highway (Dodd et al. 2007a, Gagnon et al. 2010, Huijser et al. 2015, 2016). Fences increase the wildlife use of structures and thereby help decrease the barrier effect further compared to wildlife crossing structures that are not associated with fences (Dodd et al. 2007a, Gagnon et al. 2010). Fences in combination with wildlife crossing structures can result in higher permeability of a highway than an unmitigated highway (Huijser et al. 2016b).

Potential Undesirable Side Effects

A well designed, constructed and maintained wildlife barrier is a near absolute barrier for the target species and potential other species, fragmenting their populations, and putting them at higher risk of local or regional extirpation. Therefore, as a rule, wildlife barriers should only be implemented in combination with wildlife crossing structures. Furthermore, wildlife may be injured or killed in fences, e.g. through entanglement or low flying birds (especially grouse species) (e.g. Baines & Summers 1997, Dobson 2001). Careful design, oversight during construction, and fence maintenance is essential. Fences should have a tight connection to crossing structures or wingwalls associated with crossing structures, leaving no gaps for animals to access the fenced road corridor or places where they may get trapped between a fence and a wingwall. Access roads, and fence-end placement and treatments should be directed at reducing a fence end run (high number of animals crossing the highway at a fence-end) and intrusions into the fenced road corridor. These treatments may consist of wildlife guards (similar to cattle guards), electrified mats, or conductive concrete. Wildlife guards are typically a substantial barrier to ungulates (though there is concern about ungulates getting injured when they do try to cross), but not to species with paws (e.g. bears, canids, felids). Species with paws may require an electrified barrier. Despite these efforts, some animals will end up in the fenced road corridor. While wildlife jump-outs or escape ramps are often used to allow animals to jump to the safe side of the fence, their design (height and other features) may need to be improved upon, especially when there are different species that have different jumping and climbing ability (Huijser et al. 2015).

Costs of the Measure

The costs for 2.4 m (8 ft) high wildlife fencing along US Highway 93 on the Flathead Reservation in Montana varied depending on the road section concerned: US$26, US$38, US$41 per m in 2006 (material and installation combined) (Personal communication Pat Basting, Montana Department of Transportation; review in Huijser et al. 2009). A finer mesh fence was dug into the soil and attached to the wildlife fence for some fence sections at an additional cost of US$12 per m (Personal communication Pat Basting, Montana Department of Transportation; review in Huijser et al. 2009). In the Canadian National Parks in the Rocky Mountains, the costs for fences with wooden posts, including design and oversight during construction, varied between US$ 68.2/m (no apron) – US $ 88.0/m (with apron) (Personal communication Terry McGuire, McGuire Consulting) (in 2019 US$). With steel posts the costs varied between US$ 71.0/m (no apron) – US $ 96.8/m (with apron) (Personal communication Terry McGuire, McGuire Consulting) (in 2019 US$).

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B. Underpasses and overpasses

Summary

While wildlife crossing structures in combination with wildlife fences can substantially reduce collisions with large wild mammals, crossing structures as a stand-alone measure do not necessarily reduce collisions. Wildlife crossing structures can receive relatively high use by large wild mammals, regardless of whether the structures are connected to fences. Nonetheless, structures that are connected to fences tend to have increased use by wildlife. Wildlife crossing structures in combination with wildlife fences can maintain or improve habitat connectivity for large mammals.

Background Information

The term *wildlife crossing structure* describes a variety of structures that are designed or retrofitted to provide safe passage for wildlife above or below a highway (Clevenger and Huijser 2011). Although wildlife crossing structures are not standardized designs, they can be categorized as two major types; underpasses (which allow animals to pass under the road) and overpasses (which allow wildlife to pass over the road). Crossing structures are often used in combination with fencing to as fences help guide wildlife towards the structures. Wildlife underpasses range from very large structures to the small and obscure, hardly noticeable to drivers. Wildlife overpasses are some of the largest crossing structures. They extend habitat over highways and are considered to be the most effective means of re-connecting habitat over roadways.

The main objective of wildlife underpasses and overpasses is to connect wildlife populations or entire ecosystems and allow ecosystem processes to continue over or under a road. However, wildlife use of crossing structures increases when they are connected to wildlife fences. If sufficient structures are in place for the target species, and if they are at the correct locations, of the right type and dimensions, they can also help reduce collisions as animals are less likely to breach the fence to get to the other side of the road.

Both underpasses and overpasses can be used by a variety of wildlife species to cross roadways. How well underpasses and overpasses perform in providing connectivity for wildlife, and in reducing collisions with vehicles is largely dependent on wildlife fencing. These fences need to be impermeable to the target species, keeping animals off roads and funneling them to the crossing structures. Fencing may be continuous running long distances along highways (Clevenger and Barrueto 2014) or partial fencing that consists of disjunct fenced segments of highway with numerous fence ends (Gagnon et al. 2011, Huijser et al. 2016a, b). The use of wildlife fencing in combination with wildlife crossing structures can increase the use of underpasses by elk (*Cervus elaphus*) and deer (*Odocoileus* sp.) (Dodd et al. 2007, Sawyer et al. 2012). For wildlife crossing structures in combination with partial fencing to reduce collisions by at least 80%, road needs to be fenced over a minimum of 5000 m (3 mi) (Huijser et al. 2016a). Wildlife fences are reviewed in more detail elsewhere in this report.

The location, type, and dimensions of wildlife crossing structures must be carefully planned with regard to the species and surrounding landscape. For example, large carnivores, elk and moose (*Alces alces*) 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 and Waltho 2005, Clevenger and Barrueto 2014, Huijser et al. 2016b). In addition, different species use different habitats, influencing their movements and where they want to cross the road. Apart from habitat, other factors should be considered such as the vegetation and amount of cover adjacent to the crossing structure, amount of mixed use with humans and the level of their disturbance (e.g., motorized or non-motorized recreation).

When assessing the performance of wildlife crossing structures in passing animals, it is important to allow for an adaptation period as wildlife use increases with the age of the structure (Gagnon et al. 2011, Clevenger et al. 2009). Time allows wildlife to learn about the location of the structures and that it is safe to use them on a regular basis.

Collision Reduction/Direct Road Mortality Reduction

Wildlife crossing structures in combination with wildlife fences have a proven track record for reducing collisions with large wild mammals. Crossing structures and fences on the Trans-Canada Highway in Banff National Park reduced collisions involving all large mammals by >80% and ungulates >94% based on a comparison of a two-year pre-construction with a two-year post-construction analysis (Clevenger et al. 2001). A retrofit fencing project linking three existing crossing structures on Arizona SR 260 reduced elk-vehicle collisions by 98% over 6 years (Dodd et al. 2007). Seven small underpasses and fencing on US 30 in Wyoming reduced mule deer-vehicle collisions by 81% in the 3 years after their installation (Sawyer et al. 2012). However, wildlife crossing structures as a stand-alone measure do not necessarily reduce collisions with large wild mammals (Rytwinski et al. 2016).

In the United States alone, 1-2 million large wild animals are killed by cars every year. Wildlife-vehicle collisions in British Columbia are estimated at 11,000 per year (Wildlife Collision Prevention Program 2021). This mortality can impact wildlife populations and threaten long-term population persistence, especially for threatened and endangered species (Huijser et al. 2007). Highways are the leading cause of mortality for some wide-ranging mammals (Maehr et al. 1991, Brandenburg 1996). Crossing structures physically separate wildlife from traffic, and when wildlfie use these structures to go to the other side of the road they can not be hit by vehicles(Forman et al. 2003).

Barrier Effect Reduction (=provision of safe crossing opportunities)

Wildlife crossing structures have a proven track record *for promoting safe passage* across highways in North America and elsewhere. More than 15,000 crossings by 16 species of animals were recorded at six underpasses along State Route (SR) 260 in Arizona over a seven-year period (Dodd et al. 2007). More than 49,000 crossings by mule deer were recorded at seven large culvert underpasses along US 30 in Wyoming in the first three years (Sawyer et al. 2012). More than 4,300 desert bighorn sheep crossed three overpasses on US 93 in Arizona in just over two years (Arizona Game and Fish Department 2015). More than 150,000 crossings by 11 species of large mammals were detected between 1996-2014 at over two dozen crossing structures on the Trans-Canada Highway in Banff National Park, Alberta (Clevenger and Barrueto 2014).

Highways can act as barriers that can isolate wildlife populations and alter gene flow and diversity (Riley et al. 2006). A system of wildlife crossing structures can allow individual animals to disperse, colonize or re-colonize other areas, and mate with individuals in other populations. Grizzly bear populations across western Canada and the northern U.S. have been documented as being genetically isolated by highways (Proctor et al. 2005). Recent research provided compelling evidence that wildlife crossing structures maintain genetically viable populations of black and grizzly bears that otherwise would be isolated by a high-volume highway (Sawaya et al. 2014).

The US Highway 93 North (US 93 North) reconstruction project on the Flathead Indian Reservation in northwest included the installation of wildlife crossing structures at 39 locations and approximately 8.71 miles (14.01 km) of road with wildlife exclusion fences on both sides. After reconstruction, 29 crossing structures were monitored with wildlife cameras to record wildlife use (Huijser et al. 2016b). Deer highway crossings (white-tailed deer and mule deer combined) either remained similar or increased after highway reconstruction. Black bear highway crossings remained similar after highway reconstruction. Since there was no indication of an increase in deer population size after reconstruction compared to preconstruction, the researchers conclude that the highway reconstruction and the associated mitigation measures did not reduce habitat connectivity for deer. Instead, when the learning curve is considered, habitat connectivity for deer across the highway increased in the mitigated road sections. The researchers did not have data on potential changes in black bear population size before and after highway reconstruction. Assuming there were no substantial changes in the black bear population size, habitat connectivity for black bear across the highway was at least similar before and after reconstruction in the mitigated road sections. This suggests that, even though wildlife could no longer cross the highway anywhere, the mitigation measures maintained or improved habitat connectivity for deer and black bear.

Potential Undesirable Side Effects

Wildlife underpasses and overpasses are occasionally believed to be harmful to wildlife because of waiting predators (Hunt et al. 1987). However, this prey-trap theory was not confirmed in two separate studies, a literature review of the potential side effects of crossing structures as prey traps (Little et al. 2002) and using long term field data on predator-prey interactions (Ford and Clevenger 2010).

Costs of the Measure

As the rates of collisions with large wild mammals have increased over the past two decades, agencies are increasingly seeking to mitigate highways in more cost-effective ways. Wildlife crossing structures in combination with wildlife fences reduce collisions, thus effectively reducing the costs to society, e.g., human fatalities, human injuries, property damage, loss of hunting revenue, etc. (Conover et al. 1995, Huijser et al. 2009). These estimated annual benefits from reduced wildlife-vehicle collisions have exceeded $200,000/mile (Dodd et al. 2012).

The cost of a wildlife underpass or overpass varies greatly, even within the United States. Highway configuration (size, dimensions) obviously will affect the cost of crossing structures. But if configuration was controlled for, factors such as the terrain at the site, proximity to construction materials and disposal, local or regional economic status (high market or low market value for services and supplies) and cost of prime materials (e.g., steel) all influence final cost.

The cost of the mitigation measures is based on a review of the literature and interviews with researchers, manufacturers, and transportation agency personnel. The following are costs for the most standard crossing structures types across a 4-lane highway. The smallest underpass is a prefabricated concrete box culvert (2.6 x 2.8 m) and generally costs $US 600,000. Elliptical multi-plate steel culverts (4 x 7 m) are roughly 1 million dollars. Large open span bridge underpasses (3 x 12 m) generally cost $2 million. The most recently constructed 50-m wide wildlife overpasses cost approximately $6 million.

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4. Case Studies

Case study 1: State Hwy 200, Montana, USA

Location

State Highway 200, east of Thompson Falls, Montana, approximately between mile reference posts 56.3-59.0. The annual daily traffic (AADT) is about 2,000 vehicles/day.

The two fence ends, the existing bridge across the Thompson River, and the location of the underpass designed for bighorn sheep.

Background

This is a two-lane highway, and this road section has had a relatively high number of road-killed bighorn sheep (*Ovis canadensis canadensis*) (Huijser & Clevenger, 2013).

Mitigation measures

- Wildlife fence 2.4 m (8 ft tall) along both sides of a 4.3 km (2.7 mi) long road section between approximately mile post 56.3–59.0, 1.2 m (4 ft) tall right-of-way fence partially replaced in 2016, 2.4 m (8 ft) tall wildlife fence fully installed in November 2019.
- Wildlife jump-outs: about 1.68 m (5.5 ft) high, wooden bar 40.6 cm (16 in) above surface on top jump-outs, partially installed in 2016, fully installed in November 2019.
- Wildlife guards at driveways and access roads, partially installed in 2016, fully installed in 2019.
- Electrified barriers embedded in the pavement at the two fence-ends, installed in November 2019.
- Designated wildlife underpass (designed for bighorn sheep), constructed completed in November 2019. Dimensions from the animal's perspective: 46 ft (14 m) wide (but flat area is only 6 m (20 ft) wide), 3.5 m (11.5 ft) high, 13.7 m (45 ft) length (all measurements based on

field measurements). Costs was approximately US $177,000 in 2019 ((Personal comment Joe Weigand, Missoula District Biologist, Montana Department of Transportation, 27 April 2021).

- Note: there is an existing large bridge across Thompson River on the west end. The fence starts at the east side of the bridge, but the electrified barrier is located at the west side of the bridge to reduce the probability that bighorn sheep enter the bridge.

Gate through fence to provide access to wildlife underpass for maintenance and research, Thompson Falls, Montana

Wildlife jump-out, primarily for bighorn sheep, Thompson Falls, Montana

Wildlife jump-out, primarily for bighorn sheep, Thompson Falls, Montana

Wildlife guard and gate at access road, to keep wildlife, primarily bighorn sheep, out of fenced road corridor, Thompson Falls, Montana

Electrified barrier embedded in travel lanes to keep large mammals, including bighorn sheep, out of fenced road corridor, Thompson Falls, Montana

Push button on timer for pedestrians at an electrified barrier embedded in travel lanes to keep large mammals, including bighorn sheep, out of fenced road corridor, Thompson Falls, Montana

Wildlife underpass, primarily designed for bighorn sheep, Thompson Falls, Montana

Wildlife underpass, primarily designed for bighorn sheep, Thompson Falls, Montana

Bighorn sheep ram crosses the underpass.

Bighorn sheep ewes and lambs cross the underpass.

Effectiveness in collision reduction

In the years prior to mitigation, a substantial number of bighorn sheep were road-killed between approximately mile post 56.3–59.0 (Huijser & Clevenger, 2013). A query of the carcass databased showed no reported large mammal carcasses in 2019 and 2020 (Joe Weigand, Missoula District Biologist, Montana Department of Transportation, 19 January 2021). This suggests that the mitigation measures have been very effective (100%) at reducing collisions with large mammals, specifically with bighorn sheep. Note: Tracks indicated that a bighorn sheep entered the fenced road corridor in January 2021 (Joe Weigand, Missoula District Biologist, Montana Department of Transportation, 19 January 2021), and cameras placed at the east end of the fence recorded two white tailed deer leaving the fenced road corridor by crossing the electrified barrier between September 2020 and December 2020 (unpublished data Marcel Huijser, Western Transportation Institute – Montana State University). This indicates that large ungulates sometimes do access the fenced road corridor.

Effectiveness in habitat connectivity

The existing bridge across Thompson River was not monitored for wildlife use.

The designated underpass for bighorn sheep has been monitored by MDT since fall 2019. “Bighorns are readily using the structure as are numerous white-tailed deer, some elk, mule deer, turkeys, coyotes, black bears and two passages by mountain lion” (Personal comment Joe Weigand, Missoula District Biologist, Montana Department of Transportation, 19 January 2021).

Camera images from 8 Dec 2020 – 2 Mar 2021 showed that rams, ewes and lambs used the structure in both directions. During some periods, bighorn sheep used them just about every day, during other periods there were weeks in between (Personal comment Marcel Huijser, Western Transportation Institute, 3 Mar 2021).

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Case study 2: U.S. Hwy 93, Arizona

Location

U.S. Hwy 93, from the Nevada-Arizona border in the direction of Kingman, Arizona, between mile reference post 0-17 (Gagnon et al., 2017). From 2011 to 2015, the annual daily traffic (AADT) at MP 5.3 was 13,635 vehicles/day.

Background

The mitigation measures were associated with the upgrading of U.S. Hwy 93 from a two-lane highway to a four-lane divided highway. Phase 1 (mile reference posts 0-2) was completed in 2004 while phase 2 (mile reference posts 2-17) was constructed in 2008-2010) (Gagnon et al., 2017). Desert bighorn sheep (*Ovis canadensis nelsoni*) road mortalities were on average about 11 animals per year prior to reconstruction (Gagnon et al., 2017).

Mitigation measures

- Wildlife fencing (7-8 ft (2.1-2.4 m) tall).
- 19 escape ramps or jump-outs (6 ft (1.8 m) high retaining wall with a crossbar 16 inches (40.6 cm) above the edge of the jump-out.
- Single-wide and double-wide cattle guards at lateral roads and at on-and off-ramps.
- Three bridges primarily built for other purposes between mile reference posts 0-2:
    - Sugarloaf Mountain Bridge
    - Mike O'Callaghan-Pat Tillman Memorial Bridge, across the Colorado River
    - Kingman Wash Transportation Interchange (TI) Bridge
- 3 wildlife overpasses (costs for all three overpasses combined was $4.8 million in 2010 (Arizona Daily Star, 2015)
    - Overpass 3 (MP 3.3), 100 ft (30.5 m) wide.
    - Overpass 2 (MP 5.2), 50 ft (15.2 m) wide.
    - Overpass 1 (MP 12.2), 50 ft (15.2 m) wide.
- 3 drainage box culverts (each box culvert is about 8.5 x 8.5 ft (2.6 x 2.6 m), but the number of adjacent culverts varies at each location (Personal comment Jeff Gagnon, *Arizona* Game and Fish Department, 2 March 2021; for images see Gagnon et al., 2017).
    - MP 13.1
    - MP 6.0
    - MP 5.2
- 2 underpasses (bridges) at desert washes:
    - White Rock Canyon Bridge (MP 4.2).
    - Devils Wash Bridge (MP 8.0).

Wildlife fence designed for desert bighorn sheep, US Hwy 93, Arizona

Wildlife jump-out or escape ramp with bar, at wildlife underpass designed for desert bighorn sheep, US Hwy 93, Arizona.

Double wide wildlife guard at access road US Hwy 93, Arizona.

Wildlife overpass designed for desert bighorn sheep, US Hwy 93, Arizona. This particular overpass is about 30 m wide and it is the most northern of three wildlife overpasses in the area.

Wildlife overpass designed for desert bighorn sheep, US Hwy 93, Arizona. This particular overpass is about 30 m wide and it is the most northern of three wildlife overpasses in the area

Wildlife overpass designed for desert bighorn sheep, US Hwy 93, Arizona. This particular overpass is about 15 m wide and it is the most southern of three wildlife overpasses in the area.

Underpass for desert bighorn sheep at a desert wash, White Rock Canyon bridge, US Hwy 93, Arizona.

Effectiveness in collision reduction

After reconstruction, collisions with desert bighorn sheep reduced by approximately 85% (Gagnon et al., 2017). After addressing issues with the wildlife fence, a reduction of about 97% was obtained in collisions with desert bighorn sheep (Gagnon et al., 2017).

Effectiveness in habitat connectivity

Between March 2011 and March 2015 (a 4-year period), 94.6% (6,563 out of 6,936) wildlife crossings through the structures were by desert bighorn sheep (Gagnon et al., 2017). Use of the crossing structures by desert bighorn sheep increased substantially (ten-fold increase) between 2011 and 2015, particularly on the three overpasses (Gagnon et al., 2017).

The vast majority (89.9%; 5,894 out of 6,563) of the crossings by desert bighorn sheep were at the three overpasses (Gagnon et al., 2017). Of the 5,894 crossings by desert bighorn sheep at the overpasses, 2,201 (37.3%) occurred at overpass 1 (50 ft (15.2 m) wide), 2,286 (38.8%) occurred at overpass 2 (50 ft (15.2 m) wide), and 1,407 (23.9%) occurred at overpass 3 (100 ft (30.5 m) wide) (Gagnon et al., 2017). Other crossings occurred at the two underpasses for the desert washes (7.2%; 474 out of 6,563) and at the three culverts (3.0%; 195 out of 6,563) (Gagnon et al., 2017).

Overall, most of the desert bighorn sheep (70%) that approached the three overpasses completed the crossing to the other side (Gagnon et al., 2017). In the first year, the 100 ft (30.5 m) wide structure had higher acceptance rate (0.44 crossings per approach) than the two 50 ft (15.2 m) wide structures (0.16 (overpass 2) and 0.24 (overpass 1) crossings per approach) (Gagnon et al., 2017). However, by the second year the acceptance rate became similar between all three structures, and by the end of the study the acceptance rate was between 0.80-0.91 for all three structures (Gagnon et al., 2017). Passage rate of rams was initially much higher than that for ewes and lambs. However, these differences became small by the end of the study, and the total acceptance rate for rams, ewes and lambs was 0.74, 0.67, and 0.66 respectively, with no consistent differences between the three overpasses (Gagnon et al., 2017).

Effectiveness jump-outs

Most (90%) of the 150 desert bighorn sheep that used the escape ramps used them to escape from the fenced road corridor and only 10% used them to access the fenced road corridor (Gagnon et al., 2017). The probability that a bighorn sheep that appeared on the top of a jump-out used the jump-out to jump down to the safe side of the fence was not reported.

Effectiveness cattle guards

At single wide cattle guards, 840 desert bighorn sheep approached the fenced road corridor but only 124 (14.8%) of these sheep crossed the guard (Gagnon et al., 2017). Of the 54 desert bighorn sheep that approached a guard to exit the fenced road corridor, 44 (81.5%) crossed to the safe side of the fence (Gagnon et al., 2017). These single wide guards were later converted to double-wide guards (Gagnon et al., 2017).

Section References

Arizona Daily Star. 2015. Why the desert bighorn sheep crossed the road**.** Arizona Daily Star Oct 22, 2015 Updated Nov 5, 2015. https://tucson.com/news/local/why-the-desert-bighorn-sheep-crossed-the-road/article_e4534060-73a4-11e5-8a98-c7ad99006751.html

Gagnon, J.W., C.D. Loberger, K.S. Ogren, S.C. Sprague, S.R. Boe & R.E. Schweinsburg. 2017. Evaluation of desert bighorn sheep overpass effectiveness: U.S. Route 93 long-term monitoring. Report No. FHWA-AZ-17-710. Arizona Game and Fish Department, Phoenix, Arizona.

Case study 3: Interstate-11, Boulder City, Nevada

Location

I-11, three miles west of the Arizona-Nevada state line, near Boulder City, Nevada.

Background

The mitigation measures were associated with the construction of the four-lane I-11. Desert bighorn sheep (*Ovis canadensis nelsoni*) road mortalities and connectivity were a concern in this area (Gagnon et al., 2017).

Mitigation measures

- Wildlife fence, 8 ft (2.4 m tall)
- Wildlife jump-outs
- Overpass for bighorn sheep at Eldorado Ridge. 50 ft (15.2 m) wide Constructed in 2018, Overpass cost was $1.2 million (Las Vegas Review-Journal, 2018; (Personal comment Jeff Gagnon, *Arizona* Game and Fish Department, 2 March 2021).

Wildlife fence (8 ft tall (2.4 m)), primarily for desert bighorn sheep, I-11, near Boulder City, Nevada.

Wildlife jump-out, primarily for desert bighorn sheep, I-11, near Boulder City, Nevada.

Wildlife jump-out, primarily for desert bighorn sheep, I-11, near Boulder City, Nevada. The bar is about 17 inches above the top of the jump-out.

Wildlife jump-out, primarily for desert bighorn sheep, I-11, near Boulder City, Nevada. The bar is in-line with the fence, about 8-9 inches from the face of the jump-out.

Wildlife overpass for desert bighorn sheep at Eldorado ridge, I-11, near Boulder City, Nevada. The overpass is about 50 ft wide (15.2 m).

Effectiveness in collision reduction

Unknown or not reported at this time.

Effectiveness in habitat connectivity

Over 600 passages by bighorn sheep since the construction (Personal comment Jeff Gagnon, *Arizona* Game and Fish Department, 2 March 2021).

Section References

Las Vegas Review-Journal. 2018. I-11 near Boulder City features bridge, underpasses for sheep Las Vegas Review-Journal August 24, 2018. https://www.reviewjournal.com/news/i-11-near-boulder-city-features-bridge-underpasses-for-sheep/

Case study 4: Near Long X Bridge on U.S. Highway 85, North Dakota

Location

Near Long X Bridge, south of Watford City, U.S. Highway 85, North Dakota

Background

Traffic volume increase substantially over the last 10 years or more in association with oil and gas extraction in the area. This has resulted in about 15 collisions with bighorn sheep in the area (Personal comment *Brett* Wiedman, North Dakota Game and Fish Department, 4 March 2021). In response to the increased traffic volume, increased vehicle operating speed and associated road safety, the speed limit was raised from 55 MP to 65 MPH. This resulted in more collisions with wildlife, including bighorn sheep. Now the highway is in the process of being widened from two lanes to four lanes. Reducing wildlife-vehicle collisions, and maintaining habitat connectivity, are also among the objectives, particularly for bighorn sheep.

Mitigation measures

- Fences, not installed yet, planned for 2021 (situation March 2021). The design plans are for an 8 ft (2.4 m) tall woven wire fence with 2 additional high tensile wires on top (total height of the fence would be about 10 ft (3 m)) (Personal comment Greg Schonert, North Dakota Department of Transportation, 3 March 2021). The relatively tall fence is specifically for bighorn sheep and only in the area frequented by bighorn sheep (about 2 mi (3.2 km) in road length). The rest of the project area (total length about 4.75 mi (7.6 km)) would have 8 ft (2.4 m) tall wildlife fences.
- Wildlife jump-outs, not installed yet, planned for 2021 (situation March 2021). The design plans are for an 8 ft (2.4 m) high wall, with a bar about 16 inches (about 40 cm) above the top of the jump-out (Personal comment Greg Schonert, North Dakota Department of Transportation, 3 March 2021). The relatively high wall would be specifically for bighorn sheep.
- Double wide cattle guards at access roads, not installed yet, planned for 2021 (situation March 2021).
- Underpass, arched culvert (constructed 2020) 18 m (60 ft) wide (12 m/40 feet wide flat area), 19 ft tall. Cost for the underpass was $3,122,400 (Personal comment Greg Schonert, North Dakota Department of Transportation, 3 March 2021).

Effectiveness in collision reduction

Unknown or not reported at this time.

Effectiveness in habitat connectivity

Unknown or not reported at this time.

Section References

Inforum 2020. How will western North Dakota's bighorn sheep cross the road? A highway tunnel. https://www.inforum.com/news/traffic-and-construction/6583731-How-will-western-North-Dakotas-bighorn-sheep-cross-the-road-A-highway-tunnel

Case study 5: Kicking Horse Pass, Trans-Canada Highway, British Columbia, Canada

Location

Kicking Horse Pass. Lower Kicking Horse Pass between the Park Bridge and the Yoho Park boundary to the east, Trans-Canada Highway, Canada

Background

The construction of fences and wildlife crossing structures along the Kicking Horse Pass was motivated by concerns for human health risks and vehicle insurance costs associated with moose, elk and bighorn sheep-vehicle collisions as well as concern with the impacts of traffic mortality on the viability of ungulate populations.

Silvatech Consulting Ltd. was contracted to assess wildlife use of overpasses and underpasses in the project area. The majority of this monitoring was conducted, at the Hunter Creek Bridge and two wildlife overpasses constructed to allow wildlife to pass across the Trans-Canada Highway. Monitoring included use of remote digital cameras triggered by infrared and movement sensors and by field visits to assess tracks.

Margaret Langley since 2016 is monitoring sheep population, movements and behaviour with respect to mitigation measures (below).

Mitigation measures

- Fencing along entire project area (2.4 m high)
- Overpasses and underpasses (dimensions not noted)
- One-way gates and jump-outs
- Cattleguards/Texas gates

Effectiveness in collision reduction

Unknown. Not measured pre vs post changes in collisions.
Approximately 15 individuals in herd. Road mortality occurs on Trans-Canada Highway each year; main source of mortality.
<u>One-way gates were ineffective</u>, being used by sheep to access highway right of way.
Jump-outs were not monitored and uncertain whether they were effective.

Effectiveness in habitat connectivity

Structures were monitored between 2011-2013.
Dimensions of crossing structures were not reported.
Bighorn sheep used an overpass (Sharpe, 2013).

- South underpass (125+30) Hunter Creek Bridge: 2 bighorn sheep photos, “no use”.
- West overpass: 4 bighorn sheep photos, “use”.
- Other structures: 0 bighorn sheep photos, “no use”.

Section References

Langley, M. 2020. Limiting factors on a herd of about 15 Rocky Mountain bighorn sheep resident in the Kicking Horse Canyon. 2020 NWSGC (virtual) Biennial Symposium, Alberta.
Video of presentation: http://www.nwsgc.org/contents/2020contents.html

Sharpe, S. 2013. Kicking Horse Pass wildlife survey and remote camera interim report 2011-2013. For Ministry of Transportation and Infrastructure, British Columbia, Canada. Silvatech Consulting Ltd.

Case study 6: Crowsnest Pass, Hwy 3, Alberta, Canada

Location

Crowsnest Pass, Hwy 3, Alberta, Canada. Highway 3 is a two-lane, highway with 6,000-9,000 vehicles per day (Clevenger et al., 2010).

Background

Part of a highway mitigation assessment by Clevenger et al. (2010). Alberta Transportation had limited funding to install low cost mitigation to reduce sheep-vehicle collisions on Highway 3 at Crowsnest Lakes. Up until this time approximately 10% of the local bighorn sheep herd was removed each year due to collisions with vehicles on the highway at this specific location.

Mitigation measures

- Wildlife fences
- Jump-outs (JO)
- Existing underpass

This consisted of installing wildlife fencing from a vertical rock cliff on west end and running eastward into an existing large span bridge (viaduct) over Crowsnest Lake reservoir. This span bridge served as a wildlife underpass prior to fencing project, however, became a dedicated underpass with fencing on both sides of bridge funneling wildlife movement. Both sides of the underpass are dry and even during fluctuating water levels in reservoir, remains dry and passable for wildlife year-round (see photos). There are JO on this project and they appear to work after several adjustments of height.

Wildlife fences for bighorn sheep, Hwy 3, Crowsnest Pass, Alberta, Canada

Jump-out for bighorn sheep, Hwy 3, Crowsnest Pass, Alberta, Canada

Underpass for hydrology and bighorn sheep, Hwy 3, Crowsnest Pass, Alberta, Canada

Effectiveness in collision reduction

A reduction in collisions with sheep was observed despite less than expected use of jump-outs and occasional movement across the highway. Sheep were on the highway less than pre-mitigation, and use of underpass (see below) appeared to increase (D Paton, Anatum Consulting, personal communication).

Total of 15 cameras were stolen from project area, thus making it difficult to obtain data on mitigation efficacy (D Paton, Anatum Consulting, personal communication). Many of the jump-outs were believed to be too high (ca 2.0-2.4 m); however, sheep routinely used one jump-out which lined up with escape terrain on south side of highway.

Effectiveness in habitat connectivity

Wildlife underpass was used prior to mitigation work and post construction monitoring suggests that use didn't change and likely increased, thus providing important connectivity for sheep in the area (D Paton, Anatum Consulting, personal communication).

Section References

Clevenger, A., C. Apps, T. Lee, M. Quinn, D. Paton, D. Poulton, R. Ament. 2010. Highway 3: Transportation Mitigation for Wildlife and Connectivity. https://www.rockies.ca/files/reports/H3%20Final%20Report%200607_June8.pdf

5. Impact Mitigation: Wildlife Crossing Structures

5.1 Basic principles of function

Wildlife crossing mitigation has two main objectives: 1) to connect habitats and wildlife populations and 2) increase motorist safety and reduce mortality of wildlife on roads.

- *Objective 1: Facilitate connections between habitats and wildlife populations*
  To achieve this goal, wildlife crossing structures are designed to allow movement of wildlife above or below road, either exclusively for wildlife use, mixed wildlife–human use, or as part of other infrastructure, e.g., creeks, canals. Wildlife crossing structures come in a variety of shapes and sizes, depending on their specific objective, and can be divided into 11 different design types (Clevenger and Huijser 2011). Crossing structures connected to fencing have higher use (Gagnon et al. 2011, Dodd et al. 2007).
- *Objective 2: Improve motorist safety and reduce wildlife–vehicle collisions*
  Traffic-related mortality of wildlife can significantly impact some wildlife populations; particularly those that are found in low densities, slow reproducing, and need to travel over large areas. Crossing structures without fencing do not necessarily reduce collisions.

5.2 Land use planning considerations

The effectiveness of wildlife passage structures can be compromised if current land-use plans within a municipality or project area are not conducive to protecting wildlife movements through the area. Examples of this include residential development and human use and recreation near wildlife passages and in corridors used for sheep travel. In the project area this might consist of human disturbance (human presence and activity) and change of habitat quality (fragmentation, loss of habitat or alteration).

Alteration of a wildlife corridor by current and future development (e.g. commercial/industrial or residential) may negatively affect wildlife movement and, hence, the function and performance of wildlife passage structures. The life span of wildlife crossing structures is 70-80 years, therefore adjacent habitat needs to be managed for the long term for wildlife occurrence and movement. Wildlife passage structures should not be considered in areas where future development or increased human activity will negate the benefits of their construction.

5.3 Design and planning concerns

Just as important as the correct location of wildlife crossings is to have them properly designed to meet the performance objectives. Questions arise as to the size of the crossing and how species-specific behaviours should be incorporated into the crossing structure design. These concerns are offset by the logistics of the project, which include costs of the structure, available material and expertise, and physical limitations of the site, e.g., soil, terrain, hydrology.

Further, wildlife crossings generally require one or more types of specific measures designed to supplement the function of main measures like underpasses. These specific measures include fencing, escape ramps or jump-outs (Clevenger and Huijser 2011, Huijser et al. 2015).

5.4 Guidelines and Best Management Practices (BMP)

In the last decade there have been several books and reports that describe road impacts on wildlife and effective designs and case studies (NRC 2005, Beckmann et al. 2010, Van der Ree et al. 2015). There are few technical guidelines and BMPs available today in North America. These guidelines are useful tools for determining placement, design and evaluation of mitigation measures on roads. The most widely used and technical of guidelines is the US Federal Highway Administration (FHWA) Wildlife Crossing Structure Handbook, Design and Evaluation in North America (Clevenger and Huijser 2011).

The FHWA handbook provides technical guidelines for the planning, design and evaluation of wildlife crossing structures and their associated measures (fencing, gates, escape ramps). These measures facilitate the safe movement of wildlife across roads and increase motorist safety. It was prepared for transportation, natural resource and land management agencies responsible for planning, designing and implementing measures for mitigating the impacts of roads on wildlife populations.

The handbook is the product of an extensive collection and synthesis of current literature, knowledge, and science-based data with regard to the current practices in wildlife crossing mitigation. The handbook provides a sound scientific basis for effective planning, policy and implementation of mitigation aimed at reducing habitat fragmentation and mortality effects of roads on wildlife populations.

British Columbia Ministry of Transportation recognized the human safety and biological conservation costs associated with wildlife-vehicle collisions and the barrier effect roads and traffic present to wildlife. Crashes with large mammals are reported, and there is a wildlife program in place to implement mitigation measures associated with highways and wildlife (Sielecki, 2010; Sielecki et al., 2020).

6. Bighorn Sheep Mitigations

The need to provide wildlife passage across Mile Hill was identified within the reports described in the Introduction. The provision of safe wildlife passage in combination with wildlife fencing at this location is expected to help reduce sheep-vehicle collisions and maintain connections with important habitat nodes.

Although bighorn sheep are the focal species of this project, wildlife passages need to be designed to accommodate the full range of terrestrial wildlife species that have the potential to occur in the area. It is also important to note that design of wildlife crossing structures should contemplate potential species occurrence in the future, not restricted to species occurrence today, given the life-span of bridge structures is 70-80 years (Clevenger and Huijser 2011; McGuire et al. 2020). Crossing structures should be designed for maintaining functional connectivity for the long term.

6.1 Criteria to determine type of crossing

Determining the type of wildlife crossing structure most suitable for a given location will depend on several criteria. Selection begins by identifying a general wildlife crossing type that conforms to the wildlife habitat connectivity potential for the focal species and topography of the site chosen.

The selection of wildlife crossing type is generally based on parameters that ensure likelihood of use and function over the long term. Such criteria consist of alignment with travel corridors, quality of wildlife habitat, and terrain/topography that confers constraints or advantages to construction, i.e., constructability. In the case of Mile Hill there are several logical locations that stand out as suitable candidate areas for wildlife passage construction. These locations are associated with terrain features such as 'through-cut' sections of highway and areas of cut-and-fill, where fill is on previously natural drainage features.

6.2 Designs and dimensions

There are general design specifications for wildlife species and species groups. As a rule, wildlife crossings should be designed so they allow for movement of the greatest diversity of wildlife species or taxa possible. The diversity of taxa will strongly depend on location and adjacent land use and conservation status. Wildlife species groups and taxa can be associated with different structure types based on general design and dimensions (Clevenger and Huijser 2011).

The *recommended* and *minimum* dimensions for each of the 11 wildlife crossing types are provided in the FHWA guidelines (Clevenger and Huijser 2011). The measurements are for crossing structures <u>designed for 4-lane highways</u>. See Figure 4 for how crossing structure length, height and width are measured. The guidelines should be followed if the crossings are at minimum to allow for the simplest and most basic connectivity requirement of crossings structures, i.e., the exchange of individuals within populations. Crossings designed for exchange of individuals may not allow for normal demographic processes, thus allowing passage use by few individuals and biased towards male movement. Both genders need to mix freely across the highway for wildlife crossings to perform effectively, and post-construction monitoring should be able to verify use and performance.

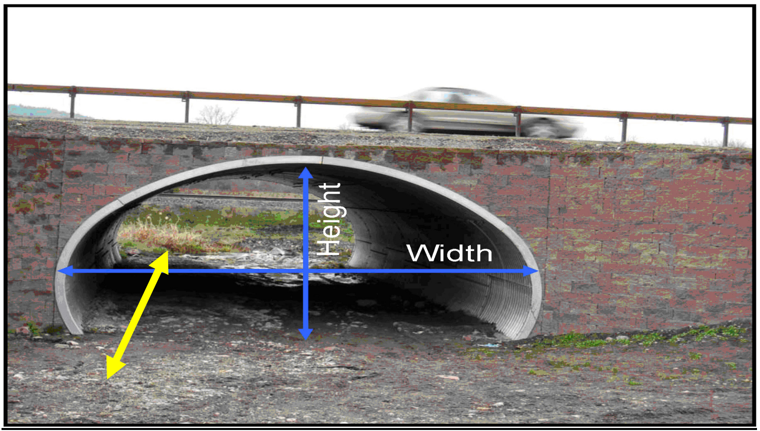


Figure 4: Width and height measurements of wildlife underpass structure. Length is shown as yellow arrow (Credit: Marcel Huijser/WTI).

Follow-up monitoring and evaluation is discussed below, but should determine whether the basic functions of the wildlife crossings are being met and provide demographic information on the number of individuals using the crossing structure and their gender. Whether the crossing is functional for local populations affected by Highway 93/95 will depend largely on how well the structure is planned and designed to integrate species' biological needs with the larger landscape and ecological context in which it is placed.

6.3 Examples of designs proven effective

There are few monitoring studies of wildlife crossing structures that are able to accurately quantify the attributes of crossing design that facilitate movement by bighorn sheep. The results of studies we found published in technical and journal articles were summarized above in Section 4. The findings of those monitoring projects have informed our recommendations for the Hwy 93/95 mitigations for bighorn sheep.

7. Recommendations

This section will cover recommendations for highway mitigation in two distinct sections of Highway 93/95: (1) Mile Hill and (2) the Radium Hot Springs urban area. Wildlife passage mitigation is recommended for Mile Hill and discussion will focus on specific measures and their location. Wildlife passages will not be a part of the mitigation plan for the urban area, however, other types of measures will be needed to reduce sheep-vehicle collisions in this urban setting.

7.1 Technical guideline prescriptions at Mile Hill

Focal species

Focal species in the project area is bighorn sheep, while secondary species include deer, coyote, cougar, bobcat and assorted small and medium sized mammals. All wildlife species in the project area will benefit from mitigation measures if they are effective in keeping them off the highway and connect habitats separated by highway 93/95.

General guidelines for wildlife crossings

The monitoring and research of crossing structures in North American during the last 15-20 years has yielded valuable information on design needs of a variety of wildlife species. Research results were published in scientific journals and internal agency reports. The research results were synthesized to determine the suitability of the 11 crossing structure types for the most common wildlife species or taxonomic groups in North America (Clevenger and Huijser 2011).

The suitability of wildlife crossing design types for distinct wildlife species is shown in the FHWA guidelines. The *Recommended* crossing design for bighorn sheep are Landscape Bridges, Wildlife Overpasses and Viaducts. For the Mile Hill mitigation the Wildlife Overpass is most logical and feasible for construction based on the scope of BC MoTI project. The underpass design – *Large Mammal Underpass* is also considered *Possible if Adapted to Local Conditions*. This classification refers to site-specific adjustments to design based on species needs and behaviour. *Multi-Use Overpass* is *Not Recommended* for bighorn sheep, thus need to minimize human activity and disturbance.

Two crossing types are considered for the Mile Hill segment. Below we find that the FHWA guidelines for *minimum* and *recommended* dimensions of the crossing types. Higher use of the wildlife overpass is expected, compared to the wildlife underpass.

- ***Wildlife Overpass***
  General description: Span bridge structure over highway (see Clevenger and Huijser 2011 and McGuire et al. 2020).
  Minimum: 40-50 m width
  Recommended: 50-70 m width
  Species-specific guidelines:

  Bighorn Sheep – Tend to prefer large, open structures with good visibility. Minimum dimensions may not be sufficient to ensure regular use by individuals of all gender and age classes.

- ***Large Mammal Underpass**:*
  General description: Open span bridge or large culvert design. Variety of designs and materials used; see Clevenger and Huijser 2011 and McGuire et al. 2020.
  Minimum: 4.5 m high x 12 m wide
  Recommended: >4.5 m high x >15 m wide
  Species-specific guidelines:

  Bighorn sheep – Need large open structure with good visibility. Minimum may not be sufficient to ensure regular use by all individuals of age and sex classes. Recommended width is based on successful wildlife underpass use in Arizona (See case studies).

Highway 93/95 Design recommendations

In this section we detail the location of recommended crossing structures for Mile Hill, design and dimensions that will provide most effective at reducing sheep mortality and providing safe passage over and under Highway 93/95.

Location

Two wildlife crossing structures are recommended on Highway 93/95 to help reduce sheep-vehicle collisions and ensure habitat connectivity for bighorn sheep. The locations of the two crossing structures were based on analysis of sheep-vehicle collision data (Larsen et al. in prep.), a site visit (30 Nov 2020) with Parks Canada biologists (Trevor Kinley, Seth Cherry) and BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD) wildlife biologist Irene Teske and contractor, Kent Kebe. Data on sheep-vehicle collisions over the past decade have been collected on Highway 93/95 by FLNRORD.

The location of the proposed wildlife overpass is primarily guided by the through-cut road profile that would facilitate the construction of a wildlife overpass compared to locations at-grade (McGuire et al. 2020). The overpass location is shown in Figure 5. This location is associated with high clusters of collisions with sheep and road crossing locations (Figure 6).

The location of the wildlife underpass is more flexible in placement. The underpass should not be in close proximity to the overpass, to allow for a greater area of permeability across Hwy 93/95. The two ravines (Sites A & B; Figure 7), consisting of fill material when constructing the highway, both at the south end of the project area, are suitable locations for a wildlife underpass. We recommend that the wildlife underpass be located at the southernmost ravine (Site B). Slopes and approaches are more suitable at this location compared to Site A, despite there being less fill at road profile.

Crossing Structures: Dimensions

North American guidelines indicate that bighorn sheep prefer large, open crossing structures with good visibility, primarily wildlife overpasses and to a lesser extent large span underpasses, e.g., 4.5 m high x 12 m wide (Clevenger and Huijser 2011).

The dimensions are at the *minimum* required for bighorn sheep as indicated in the FHWA guidelines (Clevenger and Huijser 2011). The length of the crossing structure will be determined by the width of

Highway 93/95 (underpass) and terrain features at through-cut (overpass). Given the FHWA guidelines are based on design for crossings on 4-lane highways, the recommended dimensions can be relaxed given the shorter structure length.

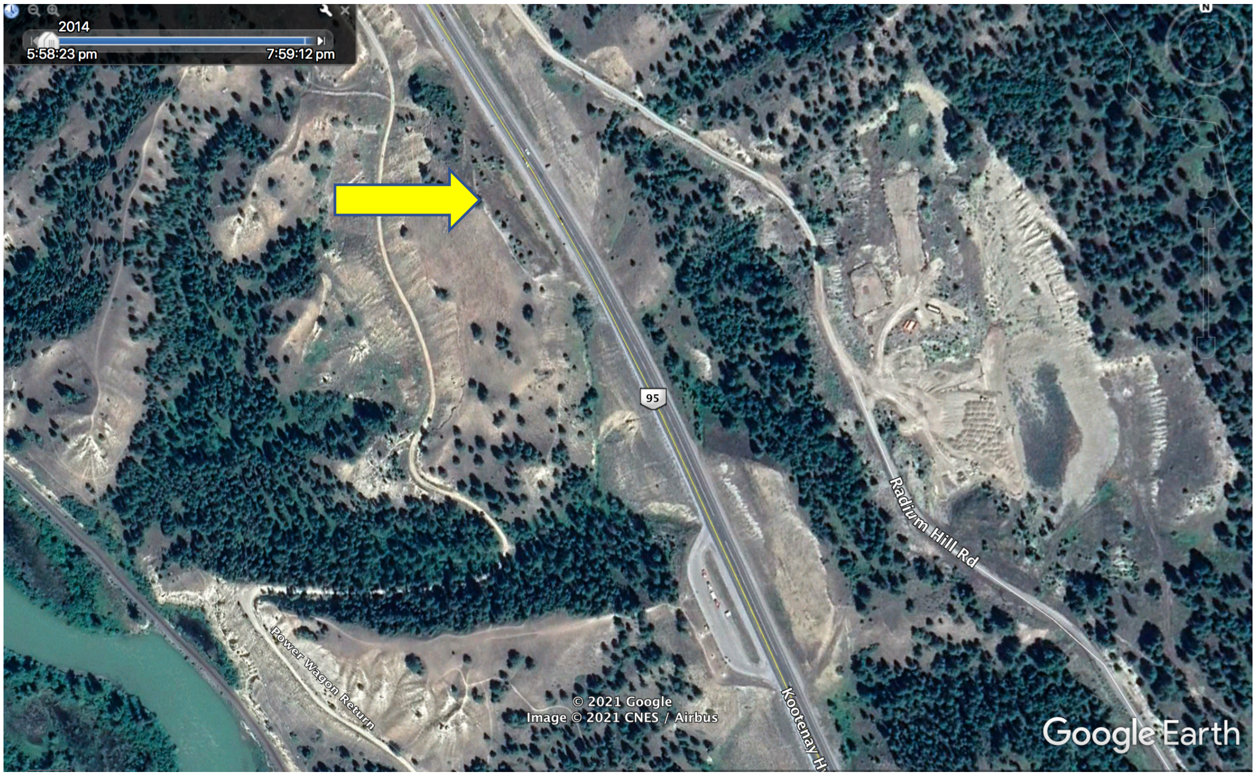


Figure 5. Location of proposed wildlife overpass (shown by arrow) at through-cut section of Highway 93/95.

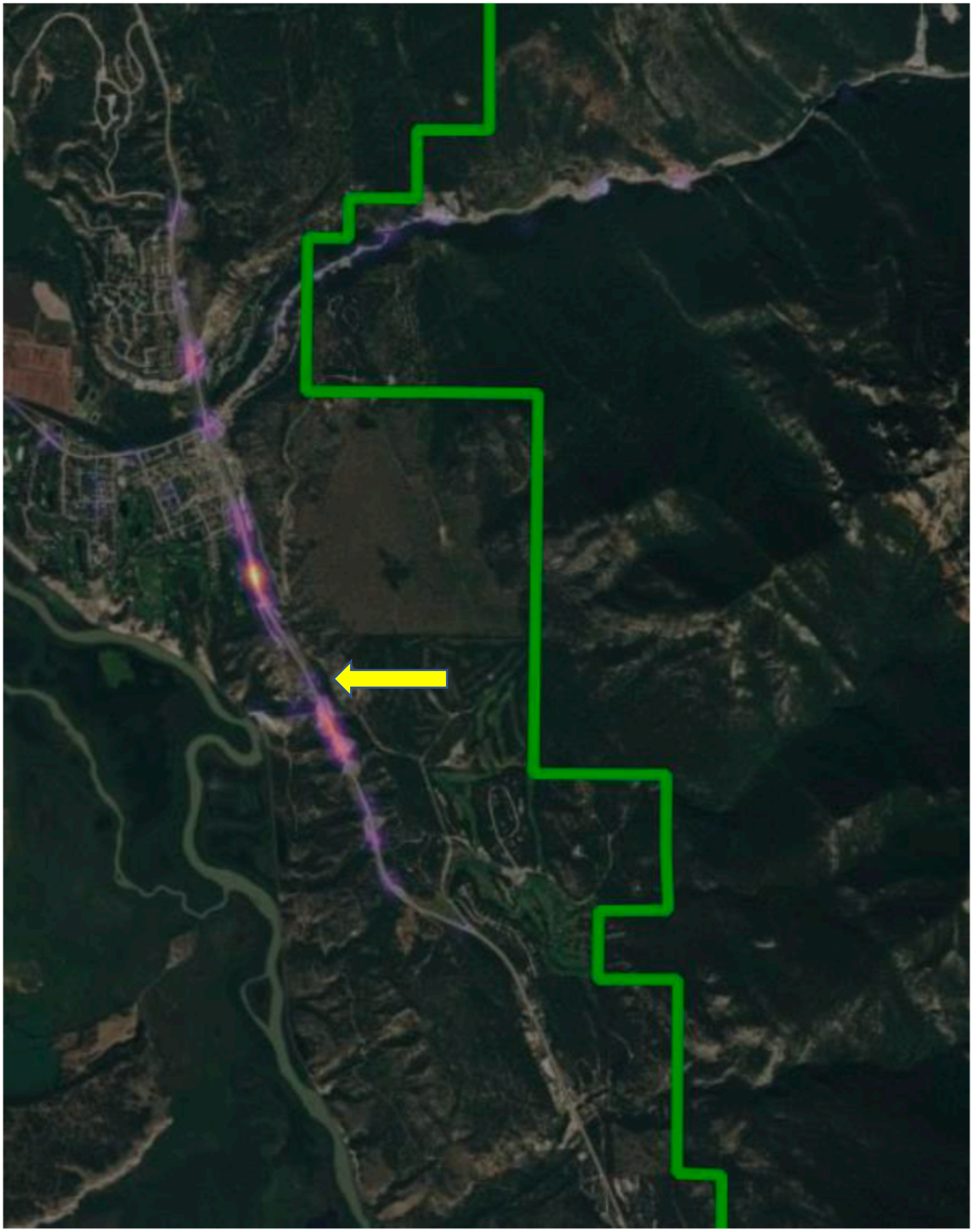


Figure 6. Location of bighorn sheep-vehicle collision clusters near proposed wildlife overpass (arrow) along Highway 93/95..

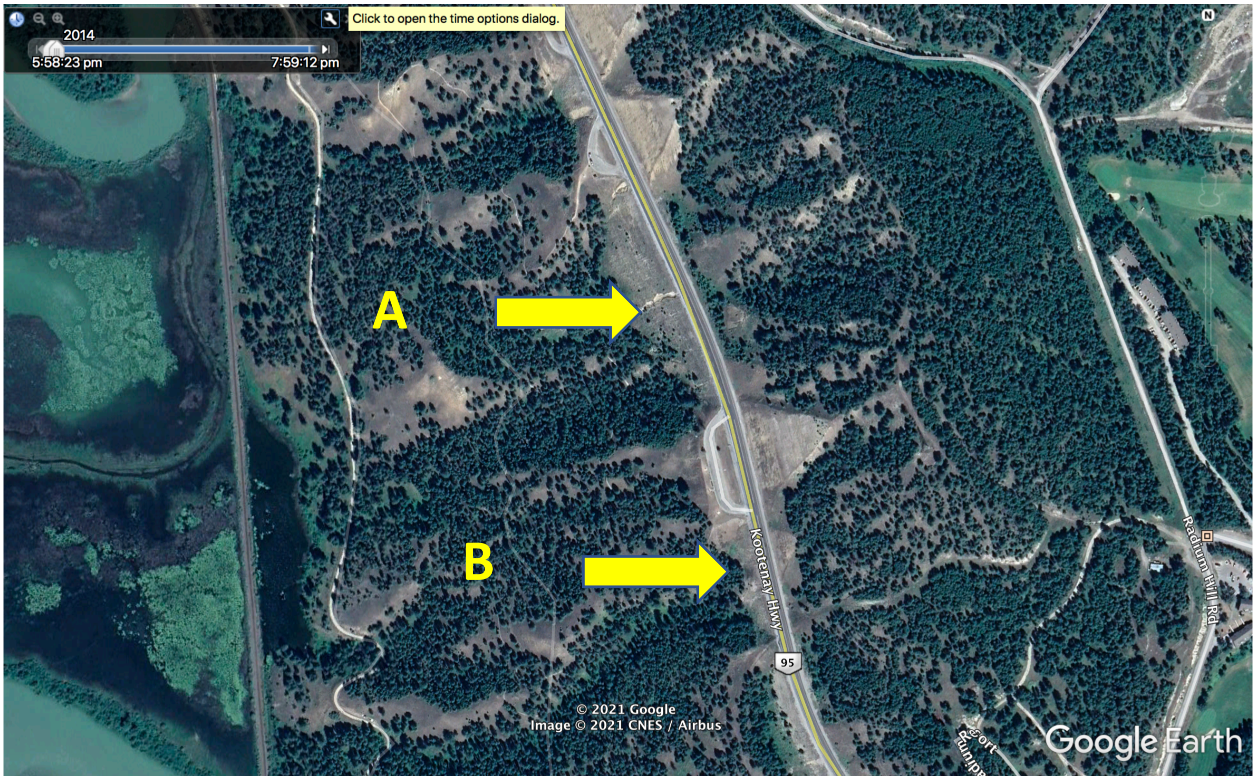


Figure 7. Location of proposed wildlife underpasses shown as option A and option B on Highway 93/95.

Wildlife Overpass

Overpasses are the preferred structure type for bighorn sheep. Recommended width of the overpass: at least 35m up to 50m. If other sensitive species are of concern (e.g. grizzly bears) overpass width should be minimum 50m wide (Ford et al. 2017).

Wildlife underpass

The recommended dimensions of wildlife underpass on the Mile Hill section is ≥15m wide x ≥4.5 m high, per guidelines set out in Clevenger and Huijser (2011) and current research. There is no evidence since time of the FHWA publication that would suggest recommended dimensions should be changed, larger or smaller in size.

Fencing, Jump-Outs & Access Roads

Specific site details for this aspect of project design can be prepared at a later date. For this stage of planning and budget estimation it is important to know: 1) Total fence length, 2) number of jump-outs, 3) number of Texas gates, 4) whether any additional measures are needed, e.g. animal detection systems.

We strongly recommend that one-way gates NOT BE USED on this project. One-way gates have been shown to be ineffective and allow animals to access right of ways (see Case Study 5. Kicking Horse Pass; Clevenger and Huijser 2011; M Langley, BC biologist, unpublished data). A replicated, controlled, before-and-after study found that earthen escape ramps (jump-outs) were used more often than were one-way gates to enable deer to escape highways with barrier fencing (Bissonette and Hamer 2000).

Fencing

Fencing is essential to substantially reduce road mortality and increase wildlife use of crossing structures. At least 2.4 m tall, potentially add to the height with tensile wires up to 3.0 m height in total (Huijser et al., 2015; case study North Dakota).

Fencing extents:

- <u>South-end (Dry Gulch)</u>: Recommend running fence all the way to the Dry Gulch residential/light commercial area (see figure below). The east side fence terminates at the top of hill cut on east side of the highway. On the west side, the fence angles into the woods at the margin of the parking area/residential and woodlot. Run the fence line into the forested area as far as property rights (MoTI) allow. This configuration would require two Texas gates: 1) East side: a Texas gate crossing the Radium Hill Golf Course Road and 2) West side: at the private ranch road entrance. The proposed location for the fence end is about 500 m further south than where bighorn sheep are known to spend time grazing along the road. The 500 m serves as a buffer zone, reducing the likelihood that bighorn sheep will walk to the fence end and end up in between the fences. Extending the fence further south leads to access and driveway issues and associated expenses.
- We do not recommend a (electrified) wildlife guard in the travel lanes for the southern end as a) The bighorn sheep do not frequent this area, there is about 500 m buffer to the area frequented, and b) the design, posted speed limit and operating speed of the vehicles is high (90 MPH posted).

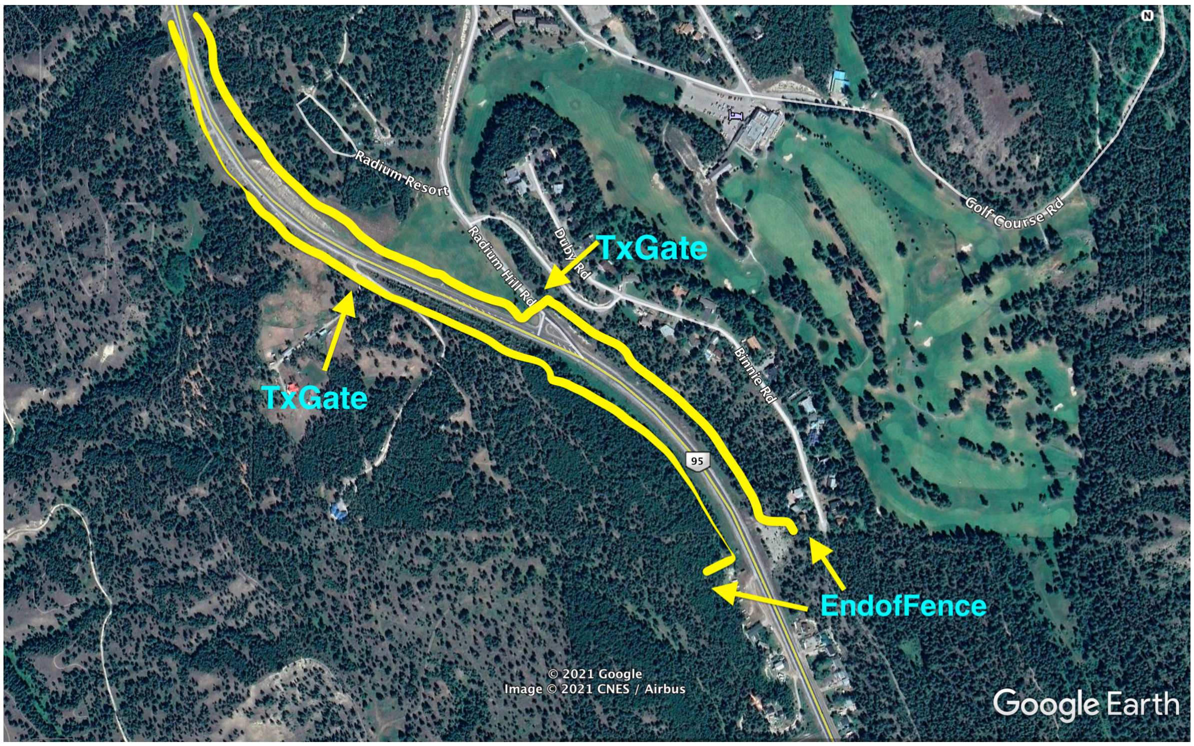
- <u>North-end (Urban transition</u>): North-end fencing is more complicated. We provide 3 recommendations for Alternatives in order of priority (Alternative 1 is preferred):

- 1) Recommend fence terminate at intersection of Stanley Road. No staggering of fence ends but both terminate at same location opposite side of the road. The fence must be as close to road edge as possible near the termination points. This is to prevent animals from slipping through the fence end and the road edge. Having a guard rail or jersey barrier on the road edge, the fence can be brought up to the barrier This is a common method used in Alberta (TCH Canmore) and British Columbia. There is a good example on Highway 93 South in Kootenay National Park at fence ends. At fence end, an electrified wildlife guard across highway is recommended to prevent animals entering the right of way.

- 2) Recommend fence terminate approximately at the level or location of Edelweiss Street, approximately 200 m uphill/south from the Alternative 1 at Stanley Road. The fence should not be staggered, and be as close to road as possible to reduce likelihood of animals walking in between fences in the right of way.
  This configuration also uses an electrified wildlife guard at the termination point.

- 3) Recommend fence terminate approximately 150 m south of Alternative 2. The fence should not be staggered, and be as close to road as possible to reduce likelihood of animals walking in between fences in the right of way. This configuration also uses an electrified wildlife guard at the termination point.

- The reason for the preferred alternative 1 is that the further the fence goes into the urban area of Radium Hot Springs, the less likely there will be end runs by sheep. Sheep may funnel or continue to cross highway at fence termination points. However, reduced design speeds (see below) is proposed to reduce the probability of crashes. We recommend the speed reduction approach rather than animal-detection system at fence end because most detection system projects fail (technical, funding, management, political issues), and there are practical issues if there are access roads (false detections or gaps in coverage of the system).



Fence end configuration at south end of project area near Dry Gulch. West fence should be as close to road edge as possible, with barrier (jersey, guardrail) between road edge and fence. East end of fence terminates at top of cut slope.

Fence end Alternatives 1, 2 and 3 as part of continuous fence along Highway 93/95. Electrified wildlife guard placed on highway at fence ends. Fence situated as close to highway edge as possible with barriers at road edge (guard rail or Jersey).

Wildlife jump-outs

Face of jump-out 2.1 - 2.4 m tall, add a bar 45-50cm above the top of the jump-out (Huijser et al., 2015; Gagnon et al., 2020). The bar reduces the likelihood that animals will jump up into the fenced road corridor. Animals on top of the jump-out can still take advantage of the relatively low height of the jump-out by stepping over the bar as they jump down. The face (wall) can be concrete or concrete blocks, but they should not allow for sheep to have edges or ridges which would allow them to climb the face; the face should be smooth without foot holds, or the face should be fenced off. The bar should be just inset from the face (see image in the case studies for BI-11, Nevada). Jump-outs should have similar number , on both sides of the highway, be located near fence ends and within the first 500 m from fence ends. They should be located in places where fence can be run further away from highway, preferably behind vegetative cover, in areas of reduced noise and disturbance from highway traffic. From these two locations associated with fence ends, jump-outs should be located approximately every kilometre along the project area. Jump-outs on opposite sides of the road do not have to be aligned, especially not if this would suggest to wildlife that they can leave the fenced road corridor on the other side before they jump up into the fenced road corridor. Designs and guidelines are found in Clevenger and Huijser (2011, Huijser et al. 2015). This aspect of project planning tends to occur at later stage and once fence alignment is confirmed, the location of jump-outs can be determined by site visit.

Recommended jump-out design with bar on top jump out.

Recommended face for jump-out: Gabion baskets behind the wildlife fence. Bighorn sheep cannot put their hooves on the rocks to get into the fenced road corridor.

Recommended smooth face (metal sheet) for jump-outs so that bighorn sheep cannot step up on edges on the face.

Not recommended: While the concept of concrete blocks is recommended for a jump-out, a design that allows for edges such as in the image above is NOT recommended. Sheep can place their hoofs on these edges helping them to gain access to the fenced road corridor.

Measures at access roads – Texas Gates

Double wide cattle guards, potentially (partly) electrified (Huijser et al., 2015; Gagnon et al., 2020), make concrete ledges of the walls around the pit inaccessible to wildlife. Consider electrifying the wildlife guards if species with paws are a concern as well (e.g. black bear, mountain lion, coyote, wolf).

General design details (per FHWA Guidelines)

1. <u>Overpass</u>

- Wildlife overpass for Mile Hill should be vegetated with few shrubs but mainly grasses. Species that match or are taxonomically close to existing native vegetation adjacent to structure should be employed. Site and environmental conditions (including climate) may require hardy, drought-tolerant species.
- Suggested design consists of planting shrubs on edges of overpass providing cover and refuge for small- and medium-sized wildlife. The center section of overpass should be left open with low-

lying or herbaceous vegetation. In arid areas, more piles of woody debris and rocks should be used to provide cover for small and medium-sized fauna.
- Soil depth on overpasses in arid regions is less than temperate forested areas. It should be sufficient to sustain shrubs and grasses, approximately 50 cm depth. Structure should generally be vegetated with grasses and shrubs of varying height. Soil must be deep enough for water retention for plant growth. Structure must have adequate drainage.
- Local topography can be created on surface with slight depressions and mounding of material used for fill.
- Earth berms (>2.0 m high) and/or solid walls, should be installed as sound- and light-attenuating walls on the sides of the structure (see Clevenger and Huijser 2011). If walls are used, they should extend down to approach ramps and curve around to wildlife exclusion fence. The minimum height of walls should be 2.4 m when joining fence and 2.0 m on overpass superstructure.

Local habitat management

- Shrubs should be located at the edges of approach ramps to guide wildlife to the structure entrance. The vegetation should integrate with the adjacent habitat. Adjacent lands should be acquired, zoned or managed as reserve or protected area into perpetuity.
- Wildlife overpasses are best situated in areas bordered by elevated terrain, enabling the approach ramps and surface of structure to be at the same level as the adjacent land. If the structure is built on level ground, then approach ramps should have gentle slopes (e.g., 5:1). One or both slopes may be steeper if built in mountainous areas.
- There is a trade-off between slope and retaining vegetative cover on approach ramps. A steep-sloped ramp will retain vegetative cover close to the overpass structure. Gentle slopes (3:1 or 4:1) generally require more fill, which extends the approach ramp farther out away from the structure and will bury vegetation, including trees. This may not be an issue on Mile Hill.
- Wildlife fencing is the most effective and preferred method to guide wildlife to the structure and prevent intrusions onto the right-of-way. Mechanically stabilized earth (MSE) walls, if high enough, can substitute for fencing and is not visible to motorists.
- Efforts should be made to avoid having roads or recreational trails of any type pass in front of or near the entrance to the wildlife overpass, as it will hinder use by wildlife.
- Large boulders can be used to block any vehicle passage on the overpass.
- Existing or planned human development in adjacent area must be at a sufficient distance to not affect long-term performance of underpass. Long-range planning must ensure that adjacent lands will not be developed and the wildlife corridor network is functional.

Maintenance

- Relatively low maintenance. Walls and any fences may need to be checked and repaired if necessary.
- During first few years it may be necessary to irrigate vegetation on the structure, particularly if there are extended periods with little rainfall. Sufficient watering (assisted or rainfall) will allow vegetation to settle and take root.
- Monitor and document any human use in the area that might affect wildlife use of the structure and take action necessary to control.

2. Underpass

These are underpass structures designed for large mammals, but use by some large mammals will depend largely on how it may be adapted for their specific crossing requirements. Small- and medium-sized mammals (including carnivores) generally utilize these structures, particularly if cover is provided along walls of the underpass by using brush or root wads. These underpass structures can be readily adapted for amphibians, semi-aquatic and semi-arboreal species.

- Being generally smaller than a viaduct or flyover, the ability to restore habitat underneath will be limited. Open designs can provide ample natural lighting will encourage greater development of native vegetation.
- To ensure performance and function, large mammal underpasses should be situated in areas with high landscape permeability and that are known wildlife travel corridors and experience minimal human disturbance.
- Motor vehicle or all-terrain vehicle use should be prohibited. Eliminating public or any other human use, activity or disturbance at the underpass and adjacent area is recommended for its proper function and for maximizing wildlife use.
- Underpass should be designed to conform to local topography. Design drainage features so flooding does not occur within the underpass. Run-off from roads near structure should not be directed toward the underpass.

Crossing structure

- Structures should be designed to meet the movement needs of the focal species (bighorn sheep in this project) but also consider the needs of a range of species that live in the area or might be expected to recolonize the area, e.g., high- and low-mobility species.
- Attempt to mirror habitat conditions found on both sides of the road and provide continuous habitat adjacent to and within the structure.
- Maximize microhabitat complexity and cover on the overpass and within the underpass using salvage materials (logs, root wads, rock piles, boulders, etc.) to encourage use by semi-arboreal mammals, small mammals, reptiles and species associated with rocky habitats.
- It is preferable that the substrate of overpass and underpass is of native soils.
- Revegetation is possible in areas of underpass closest to the entrance. Light conditions tend to be poor in the center of the structure.
- Design overpass and underpass to minimize the intensity of noise and light coming from the road and traffic.

Local habitat management

- Protect existing habitat. Design with minimal clearing widths to reduce impacts on existing vegetation. Where habitat loss occurs, reserve all trees, large logs, and root wads to be used adjacent to and within underpass.
- Wildlife fencing is the most effective and preferred method to guide wildlife to the structure and prevent intrusions onto the right-of-way. Mechanically stabilized earth (MSE) walls, if high enough, can substitute for fencing and is not visible to motorists.
- Encourage use of underpass by cutting trails leading to structure, if appropriate.
- Avoid building overpass and underpass in location with road running parallel and adjacent to entrance, as it will affect wildlife use.

- If traffic volume is high on the road above the underpass it is recommended that sound attenuating walls be placed above the entrance to reduce noise and light disturbance from passing vehicles.
- Overpass and underpass must be within cross-road habitat linkage zone and connect to larger corridor network.
- Existing or planned human development in adjacent area must be at sufficient distance to not affect long-term performance of overpass and underpass. Long-range planning must ensure that adjacent lands will not be developed and the wildlife corridor network is functional.

7.2. Technical guideline prescriptions at urban Radium Hot Springs

The objectives and urban context are vastly different than Mile Hill. Sheep tend to be habituated to human activity and vehicle traffic more than Mile Hill area. There are attractants of urban environments like Radium Hot Springs (fertilized lawns, local parks, nearby golf course) that bring them into area frequently.

Background and Context

There will be no fencing or crossing structures to keep sheep off the road and urban section of Highway 93/95. The main concern is that urban sheep are in town, on the road, and close to vehicle traffic and motorists that may speed or can be distracted by the urban environment. There appears to be an increase in road-kills in the last decade (see Figure 8). Some of the increase in road-kills in the last year in the urban area was suggested to be explained by the new configuration of the Highway 93 and 95 intersection (K Kebe, Radium Hot Springs; Trevor Kinley, Parks Canada; personal communications).

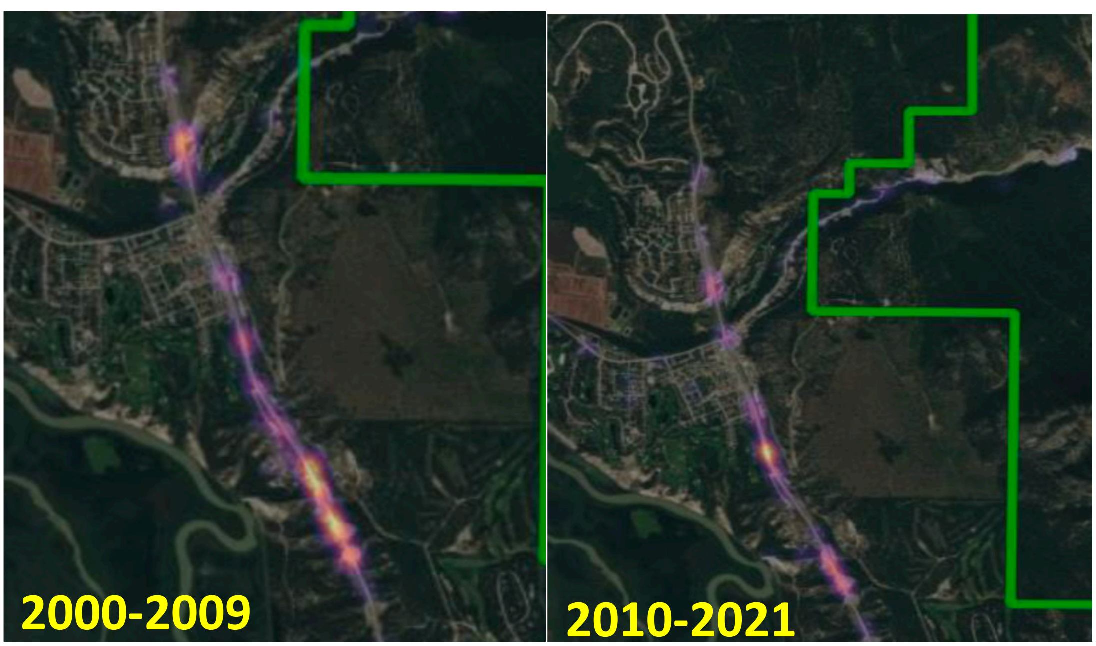


Figure 8. Bighorn sheep-vehicle collisions clusters in urban area during two periods: 2000-2009 and 2010-2021.

New Traffic Configuration

This new configuration consists of a new traffic roundabout replacing a single-lane, four-way stop. Reconfiguring the urban section of Highway 93/95 consisted also of widening the road surface by increasing lanes of traffic from 2 lanes (one southbound, one northbound) to 3 lanes of traffic (two southbound and one northbound). The expansion of the southbound lane from one to two lanes, may have resulted in vehicle speeds leaving the roundabout and traveling south increased in the urban section compared to pre-roundabout when it was a 4-way stop.

Unrelated to the new configuration of traffic is the design speed and posted speed limit and speed of traffic coming north, down from Mile Hill into the urban area in a transition zone between Mile Hill and town of Radium Hot Springs. The speed is currently 60 km/hour in the transition area, prior to entering and within the urban area. The posted change of speed limit from 90 km/hour at Mile Hill to reduced speed (60 km/hour) approaching the urban area, occurs only 400 m from the entrance to Radium Hot Springs. Slowing down traffic a greater distance to the urban area, and lowering design speed and posted speed limits entering and within town limits, is needed to ensure that motorists adhere to the posted speed limits (Gargoum et al. 2016).

There are key several parts to the urban context that we address and provide recommendations for mitigating current impacts.

Recommendations

Speed limit: Highway 93/95 transitioning to urban area

The reason speed reduction is suggested along the urban section of the highway is that fences can only extend to the first crossroads. Yet collisions with bighorn sheep have been reported further north, beyond where the fence would end. If collisions are to be reduced in this unfenced road section, a change has to be made. Speed management seems the most robust measures, allowing drivers longer reaction time and shorter braking distance, presumably leading to fewer collisions (see e.g. Huijser et al., 2017).

- Decrease the design speed and posted lower speed limits (Garrett and Conway 1999, Ramp et al. 2006, Tajchman et al. 2017).
- Outside urban area: Current posted speed limits on Highway 93/95 transition from 90 km/hour to 60 km/hour. This speed limit changes at a distance of only 400 m from entering urban area. We recommend the following:
- Reduce current 60 km/hour speed limit within and outside urban area to 40 km/hour.
- Create an effective “speed zone”. Post change from 90 km/hour to 40 km/hour further from urban area, 1000 m from town boundary as opposed to current location of 400 m. The current speed limit change location is too close to the urban boundary for speed limits to have a reduction effect, particularly northbound traffic coming downhill (Moreno and Garcia 2013).

Urban traffic configuration

- We recommend the following:

- *1. Reduce speed limit in urban area.* Current speed limit of 60 km/hour in the urban area allows for increased speeds (>60 km/hour) since not all drivers adhere to the speed limits; and allow for reduced braking distances to avoid collisions with wildlife and pedestrians (Bornioli et al. 2020).
  The most critical piece to reducing collisions with sheep and ensuring motorist safety in the urban area is to slow down traffic to reasonable speed to avoid accidents (Moreno and Garcia 2013). Urban areas with similar traffic configurations (adjacent commercial) have speed limits of 40 km/hour and some places as low as 30 km/hour (Banff, Alberta; see Bornioli et al. 2020). However, reducing posted speed limits is only effective if the design speed is also reduced (Marshall, 2018). Narrower lanes, curves, and curb extensions are examples of measures that reduce the design speed and that result in lower operating speed (Galante et al 2010, Jamson & Jamson, 2010, Moreno & García 2013, Bella & Silvestri 2015, Gargoum et al 2016).
- *2. Revert to two, single lane traffic in urban area.* Return to single lane configuration on southbound lane. This will slow down traffic by decreasing vehicle occupancy and limiting southbound traffic to one lane rather than two lanes.
- *3. Reduce width of traffic lanes.* Create a more narrow “driveable” section of road for motorists in urban area by using established traffic calming methods consisting of: 1) Moving white line at edge of road closer to centre-line; 2) moving curbs closer to centre-line; 3) installing stanchions on edge of roadway. All of these will have a “boulevard effect” which slows down traffic. The above techniques of moving white line closer to centre-line make the “driveable” portion of lanes narrower, without making the actual width narrow (Galante et al. 1994, Gargoum et al. 2016, Jameson et al. 2010).

Visibility of sheep to motorists

- Visibility is a major factor in wildlife-vehicle collisions. Proper lighting can minimize incidence or likelihood of collisions with wildlife in areas where weather or artificial lighting is substandard (Wanvik 2009, Mastro et al. 2010, Huijser et al. 2017). Many vehicle headlights do not allow drivers to see large mammals on the road in the dark early enough to be able to stop before hitting the animal when traveling at highway speeds (Mastro et al. 2010, Huijser et al. 2017). Roadway lighting may reduce wildlife-vehicle collisions by 57-68% (McDonald 1991, Wanvik 2009), but it is unclear if reductions in collisions along lighted roadways are because of increased visibility of the animals to drivers or because animals avoid the roadway lighting. Highway lighting may increase the barrier effect of roads and traffic for light-repelled species.
- Increase lighting and motorist visibility by changing (if not currently in place) lighting along urban section of Highway 93/95 aimed down, to minimize light pollution upwards and into surroundings, and more focused on roadway.

8. Monitoring performance

Performance evaluations were not a regular part of transportation projects with wildlife crossing structures for many years. However, most agencies see the need and find value in using lessons learned in future transportation projects (McGuire et al. 2020). Most monitoring efforts are largely short-term or sporadic. Monitoring typically is aimed at single species; consequently, such programs may not recognize the requirements of other non-target species and populations in the area. Further, monitoring is rarely conducted long enough to meet the adaptation periods (or learning curves) wildlife need to begin using crossings on a regular basis (Clevenger et al. 2009, Clevenger and Barrueto 2014, Gagnon et al. 2011, Huijser et al. 2016). Resources for developing monitoring programs to evaluate wildlife crossing structure performance can be found in Clevenger and Huijser (2011) and Roedenbeck et al. (2007).

The success of mitigation measures on Highway 93/95 will depend largely on management of human use in the area. It will also hinge on the importance of the general area and vicinity for meeting the daily, seasonal and annual biological requirements of the local bighorn sheep and other wildlife populations in this area.

To measures performance, monitoring of crossing structure passage by wildlife will be required to assess species and level of use. Data on incidence of bighorn sheep road-kills will be required to determine whether the combined measures of crossing structures and fencing are effective at reducing levels of sheep-vehicle collisions. Monitoring provides important information that will aid in determining if sheep and other wildlife are avoiding crossing structures and crossing at grade at fence ends.

Systematic or standardized methods of roadkill data collection will be an integral part of performance evaluations (Huijser et al. 2007). Current efforts are not systematic (daily surveys) in reporting wildlife-vehicle collisions, however, reporting by local community, particularly citizens that regularly drive highway 93/95, is comprehensive and there is a high level of confidence in reporting road-kills.

Monitoring of crossing structures should last minimum of 5 years to allow for adaptation and learning to occur. Shorter monitoring durations will not provide accurate assessment of crossing structure use and species response to design types. Rigorous year-round monitoring of the mitigation measures implemented on Highway 93/95 will be instrumental in adjusting design types and implementing "lessons learned" on future MoTI projects aimed at mitigating roads for wildlife populations in BC.

Monitoring recommendations

Mile Hill

Efficacy and performance of crossing structures

- Pre-construction: No recent pre-construction data on sheep movements in project area. No existing below-grade passages likely used by sheep to collect data on movements at potential passage structures pre-construction.
- Post-construction:
- Camera trap monitoring of bighorn sheep and other wildlife use of crossing structures. Collect data on movements in and around crossing structures. Camera traps located on at both entrances to crossing structures (movements within) and ca. 25m outside both entrances

(occurrence in area and approach data). This array at underpass would consist of minimum of 4 cameras. Overpass monitoring would require more cameras on top of overpass and in approach area to have sufficient coverage to capture occurrence and movements.

- Camera trap data in and near crossing structures: It will be important to collect data on following: 1) percentage of herd or individuals that approach and eventually use crossing structures; 2) sex and age of individuals (rams, ewe groups with young) approaching and using structures, absolute numbers and behavioural information collected.
- Camera trap monitoring of human use in area of crossing structures. Factors affecting wildlife use a crossing structure are not restricted to species behaviours alone. Human use in area adjacent to crossing structures can affect wildlife movement around crossing structures and ultimately whether wildlife use them. Monitoring of human use (trail counters, cameras etc) in area of crossing structures is required to fully assess their functionality and what management actions are needed to improve their performance.
- Monitoring duration. Minimum 5 years to ensure learning and adaptation has taken place and take into account changes in human use and any other possible land/human use management actions needed for ensuring crossings are functional.
- Education and awareness campaign. Important for raising awareness of local community and visitors of the importance of the mitigation measures, effects of human use on performance, and need to minimize human use in and around.
- Monitor fence, jump-outs and Texas gates in project area. This is as important as monitoring human use in area. Factors related to fence deficiencies (gaps, breaks), ineffective Texas gates or electrified mats, poorly designed jump-outs, will all effect how widlfie will use the mitigation measures and overall success of the mitigation project. Gaps in fences or ineffective Texas gates will lead wildlife to the highway right of way and likely result in road-kills.

Changes in bighorn sheep- and other wildlife-vehicle collisions

- Good pre-construction data on sheep- and other wildlife-vehicle collisions in project area. Post-construction data on collisions needs to continue in order to detect changes in collision rates and performance of the mitigation measures.

Urban Radium Hot Springs

There are no crossing structures or fencing proposed for the urban Radium Hot Springs area. Data collection for assessing performance of measures includes the following:

Changes in bighorn sheep- and other wildlife-vehicle collisions

- Good pre-construction data on sheep- and other wildlife-vehicle collisions in project area. Post-construction data on collisions needs to continue in order to detect changes in collision rates and performance of the mitigation measures.
- Data collection: Continue with current methods used (FLNRORD contractor, Parks Canada, RAPP line and local volunteers). Citizen Science involvement may be able to provide helpful and supplemental information on sheep occurrence and behaviours in urban area post-mitigation measure implementation. *Road-Watch in the Pass* is a good example of how citizens can contribute in collecting road-kill data (Lee et al. 2006). Many other examples are available today globally.

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