Mitigation assessment for the Trans-Canada Highway (Revelstoke to Golden): Improving motorist safety and meeting wildlife movement needs across the Columbia Mountains, British Columbia

An Assessment of Potential for Mitigating Impacts on Wildlife

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We would like to thank the following people that were instrumental in allowing us to conduct fieldwork and access the data required to address the management issue of safe and efficient highways between Revelstoke and Golden.

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1. Introduction

Highways and roads within the Columbia Mountains (Revelstoke to Golden, BC) contribute to habitat fragmentation and direct wildlife mortality from vehicle collisions. Anticipated highway improvements may exacerbate wildlife mortality numbers and may contribute to genetic isolation of some wildlife species. Throughout North America, the application of site-specific mitigations via the discipline of road ecology has reduced wildlife road mortality and improved means of habitat connectivity across highways.

In order to meet increasing traffic, safety, and reliability demands and improve overall highway standards in British Columbia the Ministry of Transportation and Infrastructure (MoTI) is currently exploring options to upgrade discrete sections of Highway 1 - Trans-Canada Highway (TCH) between Revelstoke and Golden. Potential areas under consideration are located in the following three sections[1]:

A. West: Revelstoke to west gate Mount Revelstoke National Park (length: 18 km from Victoria Rd intersection to the park gate)
B. Central: East Gate of Glacier National Park to Donald Bridge (length: 30 km)
C. East: Donald Bridge to Golden (length: 26 km)

Each of these sub-study areas contains different suite of focal species and wildlife-vehicle collision (WVC) issues.

- *West* is similar to the area previously analyzed (low WVC collisions, steep topography, relatively high snow packs, some avalanche paths).
- *Central* has more WVC collisions than West, starts to transition out of the highest snow pack and frequent avalanche path areas, and offers some potential opportunities for more traditional fencing over/underpass scenarios.
- *East* has high WVC rates, less snow pack, but more dispersed human settlements issues, e.g., rural properties, CPR mainline, private quarry operations, etc.

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[1] A mitigation assessment for the 18.5 km section of highway between the two national parks was conducted in 2014 (Clevenger et al. 2014).

We have adopted a similar approach to assessing mitigation potential as we used in the Mount Revelstoke-Glacier National Park assessment (Clevenger et al. 2014). We created report modules for these three areas using available WVC data from BC Forests, Lands, Natural Resource Operations & Rural Development (FLNRO&RD) and MoTI, existing provincial telemetry data from FLNRO&RD, biophysical map layers (from FLNRO&RD and Parks Canada) and created landscape connectivity models to identify key wildlife crossing areas/linkages across the TCH in these three areas. We have also included the information sheets for the mitigation emphasis sites located on the provincial section of the Trans-Canada Highway (TCH) between Mount Revelstoke and Glacier National Parks (**Appendix A**). This section of TCH lies between sections we cover in this report and therefore are included to present a complete set of measures recommended for the provincial section of TCH between Revelstoke and Golden, British Columbia.

The effects from a potentially larger TCH footprint from Revelstoke to Golden reach beyond individual wildlife populations and pose broader conservation, economic and social consequences, including a considerable motorist safety risk from WVCs. MoTI seeks to protect wildlife populations, while maintaining safe and efficient mobility of people, goods and services on provincial highways and important transportation corridors such as the TCH. Developing pro-active, cost-effective approaches to address these three objectives, including reductions in accidents, wildlife mortality, and fragmentation effects of the TCH will allow management to mitigate or minimize the effects of anticipated increases in traffic.

The purpose of the project is to develop science-based recommendations for mitigating provincial sections of the TCH in the Columbia Mountains for a suite of wildlife species that encompass a range of mobility, habitat needs, and ecological requirements. The work identifies the critical intersections of traffic, motorist safety and wildlife movement (mortality, connectivity) on the TCH. The focal species are large mammals, primarily ungulates for motorist safety and WVC reduction and fragmentation-sensitive carnivores for landscape connectivity.

Objectives

The objectives for each of the three study areas was to:

1. Compile, analyse and summarize WVC data.
2. Conduct a landscape resistance analysis that will model moose, wolverine, black bear and grizzly bear movements across the TCH and other potential barriers to movement, i.e. natural, anthropogenic. These four species were modeled because they are of interest and concern in the region and represent general forest connectivity in low elevations (moose, black bear), middle (grizzly bear) and high elevations (wolverine) across the highway (Landguth et al. 2012). Caribou were not modeled for this assessment due to the lack of road-kill data and the four abovementioned species were suitable surrogates for connectivity. Caribou connectivity could be modeled (with other species) in the future if desired.
3. Identify and prioritize key areas for ungulate mortality and carnivore movement and mitigation.
4. Provide recommendations for the extent and type of measures that potentially can be used to mitigate impacts on motorist safety, and wildlife mortality and movement in the Highway 1 -Trans-Canada Highway corridor.

2. Study area

The TCH study area is divided into 3 sub-study areas found in two discrete sections of the Columbia Mountains and Columbia River Valley (Figure 2-1). West and Central Areas are located in the Columbia Mountains (Selkirk and Purcell Mountain ranges), while East Area is in the Rocky Mountain Trench.

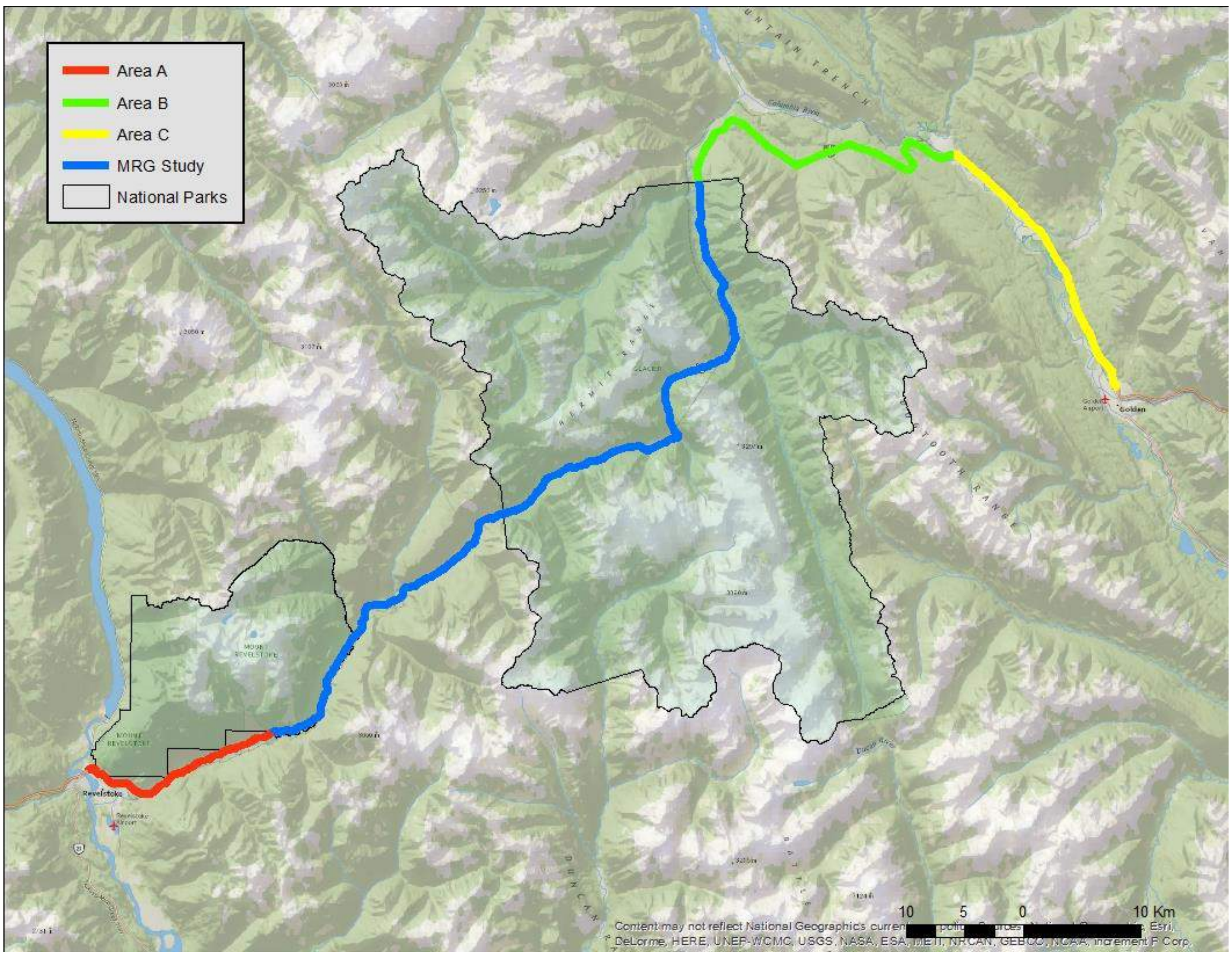

Figure 2-1. Map of Trans-Canada Highway, and the focal study areas between Revelstoke and Golden, B.C. in the Columbia Mountains of southeastern British Columbia. Boundaries are shown for Mount Revelstoke National Park (left) and Glacier National Park (right). A mitigation assessment for the "MRG Study area" was conducted in 2014 (Clevenger et al. 2014). The recommendations for mitigation measures on the provincial section of the study area are found in Appendix A.

Columbia Mountains

The climate is characterized by high annual precipitation, heavy snowfall, and relatively moderate winter temperatures. The study area has elevations ranging from 438 m to 3377 m. This range of elevation gives rise to three distinct biogeoclimatic zones: Interior Cedar-Hemlock (ICH), Engelmann Spruce-Subalpine Fir (ESSF), and Interior Mountain-heather Alpine (MacKillop et al. 2018). Dense stands of western hemlock (*Tsuga heterophylla*) and western red cedar (*Thuja plicata*) dominate the valley bottoms and Engelmann spruce (*Picea engelmanii*) and subalpine fir (*Abies lasiocarpa*) cover mid to upper elevations. Elevations above 2000 m are dominated by alpine environments which include herbaceous meadows, low shrubs, alpine tundra, non-vegetated habitats and glaciers. Rugged mountainous terrain with steep v-shaped valleys creates avalanche paths that comprise over 17% of the land cover. In snow free months, avalanche paths produce several food sources important to foraging bears including, glacier lilies (*Erythronium grandiflorum*), spring beauties (*Claytonia lanceolata*), and cow parsnip (*Heracleum lanatum).*

The highest traffic volumes on the TCH occur during summer and can exceed 12,000 vehicles per day with lower volumes during the rest of the year; from 5,000-7,000 vehicles per day in spring and fall (BC MoTI 2016, unpublished data). Summary data for daily and weekly traffic volumes on the TCH at Twin Slides, 47 km east of Revelstoke can be found in **Appendix B**.

Rocky Mountain Trench

The climate is characterized by moderate annual precipitation and snowfall, and relatively moderate winter temperatures. There are five distinct biogeoclimatic zones:

The study area includes the biogeoclimatic zones of Interior Douglas Fir (IDF, valley bottom to 1100 m), Montane Spruce (MS, 1100-1500 m), Engelmann Spruce – Subalpine Fir (ESSF, 1500-2400 m) and Interior Mountain–heather Alpine (IMA >2400 m) at upper elevations. The mean annual precipitation is 295-750 mm for IDF and 380-900 mm for MS (Braumandl and Curran 1992). The IDF and MS zones provide important early-season foraging habitat for grizzly bear and black bear, as well as connectivity and linkage habitat for bears and other wide-ranging carnivores, including wolverine and Canada lynx (MacKillop et al. 2018).The fifth zone, the Interior Cedar Hemlock (ICH) zone occurs north and west of Donald and the climate is typified by cool, wet winters and warm moist summers. The mean annual precipitation is 500-1200 mm of which 25-50% falls as snow (Braumandl and Curran 1992). The ICH typically grades into the ESSF zone throughout its range. The ICH is found from valley bottoms to approximately 1500 m. This shift in climate leads to greater snow depths in the areas adjacent to the Kinbasket Reservoir. Valley bottom sites are important winter range for moose, elk and deer, and form an important habitat component adjacent to the Columbia Wetlands.

3. Occurrence of Wildlife-Vehicle Collisions

Introduction

The TCH from Revelstoke to Golden, British Columbia (BC) takes a toll on animals crossing the road in the Columbia Mountains. Most wildlife agencies collect wildlife-vehicle collision (WVC) data as part of their routine objectives to monitor wildlife, but often data are patchy, inconsistent, and unreliable. The Ministry of Transportation began collecting WVC data consistently in BC in 1978 using the Wildlife Accident Reporting System (WARS). Parks Canada has also been collecting WVC data in the mountain parks and surrounding provincial lands for the past 40 years (Damas and Smith 1982, Bertch and Gibeau 2010). During the last 15 years the data has been spatially accurate as global positioning system (GPS) units were used in the field by Parks Canada staff (Gunson et al. 2009). WVC data can be used to identify locations where large animals are killed and public safety is at risk, and in some instances can be the primary driver of highway mitigation strategies. WVC data, along with connectivity models, help to identify locations of important habitat linkages and where animal movement corridors intersect highways. We examined spatial and temporal patterns of road mortality and highway strikes of large mammals on provincial lands between Revelstoke and Golden, BC.

Methods

We compiled WVC data for wildlife species between Revelstoke and Golden from all available sources provided by Parks Canada and BC Ministry of Transportation. We used all WARS data along with road-kill data from querying Parks Canada's mortality database for mortality types that were recorded as "highway" for road-caused mortality. In our tabulations we used confirmed "mortalities" and also records that were reported as "strikes" from outside parks. We included vehicle strikes because, in addition to confirmed mortality data, it provides important information where wildlife are interacting with and tend to cross highways. Records with erroneous spatial information (i.e. located >50 m from TCH) were removed from analysis.

The Parks Canada database is rich with information on the abundance and diversity of wildlife that have been recorded as road-kill on the TCH; however, the WARS data for this region was comparatively sparse. Many of the small and medium-sized vertebrate species found in the databases will benefit to some extent by having a mitigated highway for safe passage (Clevenger et al. 2001, 2003) and are of interest to exhibit as part of the report. We tabulated all recorded road-related mortality and strikes by decade for wildlife along the TCH.

We also examined the spatial and temporal patterns of road-caused mortality of large mammal species. We plotted locations of mortalities and strikes in NAD 83 UTM Datum using ArcGIS 10 (ESRI, Redlands, California, USA). Records from 2010-2017 were categorized as “recent”, while prior to 2010 were classified as “non-recent”. WARS data contained month and year, but not the day of the month. We used all records of large mammals in the databases collected between 1962 and 2017.

Results

The mortality locations with all wildlife species were evenly distributed throughout the provincial lands, though they were more clustered near national park entrances probably due to reporting bias (Figure 3.1). A total of 21 wildlife species were recorded as killed on the highway, including small and large mammals, and birds (Table 3.1).

We found a total of 111 useable records (29 recent records) for WVCs (1 strike, 110 mortalities) outside the national parks, including road-related mortality of numerous large mammal taxa in the database: Bears (black and unknown), canids (coyotes), deer (white-tailed and mule), felids (cougars), caribou, elk, moose and mountain goats. WVCs occurred between August 1962 and December 2017.

Table 3.1: Road-related mortality and strikes by decade for wildlife along the Trans-Canada Highway in provincial lands between Revelstoke and Golden, British Columbia.

Species	**Total**	**1960s**	**1970s**	**1980s**	**1990s**	**2000s**	**2010s***
American Marten	1	0	0	0	1	0	0
Bear Spp	5	0	0	0	0	0	5
Beaver	4	0	1	0	2	0	1
Black Bear	20	0	4	4	5	1	6
Caribou	1	0	0	0	1	0	0
Cougar	1	0	0	0	0	0	1
Coyote	2	0	0	0	0	1	1
Deer Spp	45	0	1	2	0	1	41
Elk	2	0	0	0	1	0	1
Fox	1	0	0	0	0	0	1
Great-horned Owl	1	0	0	1	0	0	0
Moose	6	1	0	1	1	0	3
Mountain Goat	4	0	0	0	0	0	4
Other	2	0	0	0	0	0	2
Pine siskin	1	0	0	1	0	0	0
Porcupine	8	0	1	5	2	0	0
Red Crossbill	2	0	2	0	0	0	0
Ruffed Grouse	1	0	0	0	1	0	0
Saw-whet Owl	1	0	0	1	0	0	0
Skunk	2	0	0	0	0	0	2
Varying Hare	1	0	0	0	0	0	1

*Decade is incomplete and only includes 2010-2017

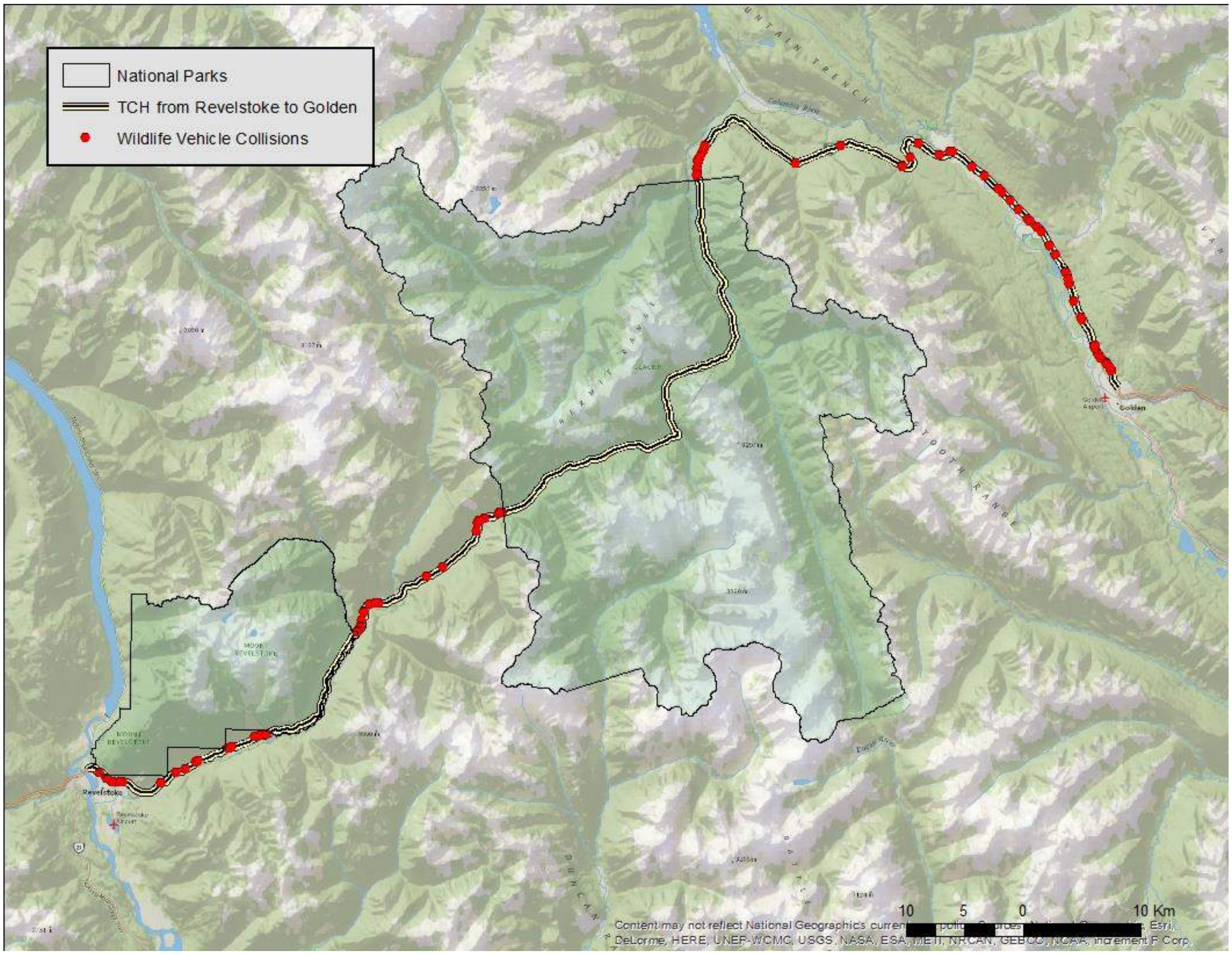

Figure 3-1: Road-related mortality and strikes of wildlife on the Trans-Canada Highway in provincial lands between Revelstoke and Golden, British Columbia, 1962-2017. Boundaries are shown for Mount Revelstoke National Park (left) and Glacier National Park (right).

West - Revelstoke to west gate Mount Revelstoke National Park

The West section of the mitigation project runs from the town of Revelstoke to the west boundary of Mount Revelstoke National Park (MRNP; Clachnacudainn Creek). In the WARS and Parks Canada’s mortality databases we found 15 total WVCs in this section including 7 deer, 5 black bears, 2 moose and 1 caribou (Figure 3.2). Deer mortalities were clustered in 3 spots, with the largest cluster (N=3) near the West entrance to MRNP. Black bear WVCs were concentrated near the town of Revelstoke (N=4); another mortality was located near the west entrance to MRNP. Moose mortalities were spread out with 1 in the middle of this section and 1 near the west entrance to MRNP, near the largest cluster of deer kills. The only caribou mortality that we found in the database occurred in February 1992 and was located in the center of this section, east of Greely Road. There were no cougar, elk, grizzly bear, mountain goat, wolf, lynx, or wolverine WVCs found along this section of highway. The most significant road mortality hot spot in this section is located just west of the west boundary of MRNP where a moose and 3 deer were killed.

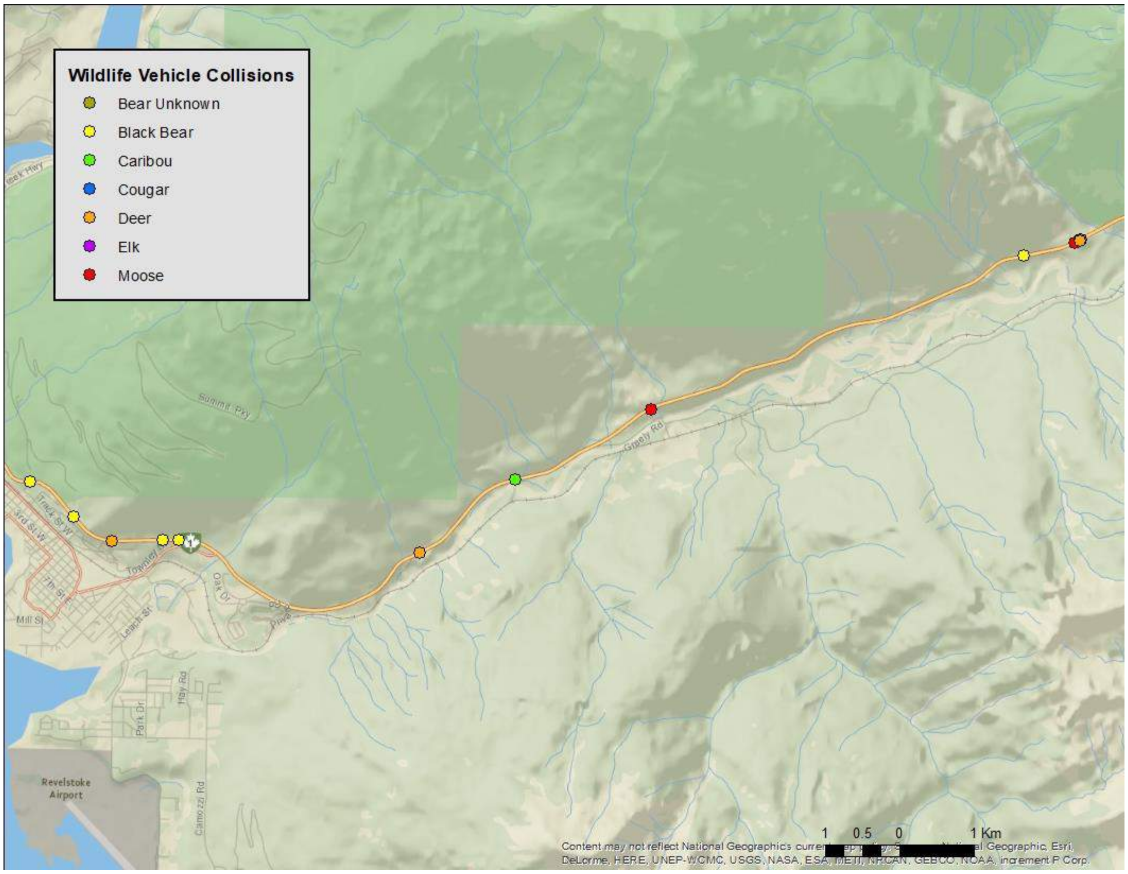

Figure 3-2: Road-caused mortalities of wildlife on the Trans-Canada Highway in TCH-West Area of study area between Revelstoke and west boundary of Mount Revelstoke National Park B.C..

Central - East Gate of Glacier National Park to Donald Bridge

The Central section of the mitigation project runs from the east boundary of Glacier National Park (GNP) to the Donald Bridge. In the WARS and Parks Canada's mortality databases we found 15 total WVCs in this section including 6 deer, 4 black bears, 3 moose and 2 unknown bear species (Figure 3.3). Deer mortalities were loosely clustered in 2 spots at opposite ends of this section, with the largest cluster (N=3) near the East boundary of GNP. Black bear WVCs were concentrated near the East boundary of GNP; the two mortalities of unknown bear species were spread out further east. There was a small cluster of moose mortalities (N=2) to the north of the East boundary of GNP and another moose mortality near the Quartz Creek Bridge. We found no caribou, cougar, elk, grizzly bear (maybe unknown), mountain goat, wolf, lynx, or wolverine WVCs along this section of highway. The most significant road mortality hot spot in this section is located just north of the East boundary of GNP where 3 black bears, 3 deer, and 2 moose were killed; however, this may be due primarily to reporting bias towards the parks.

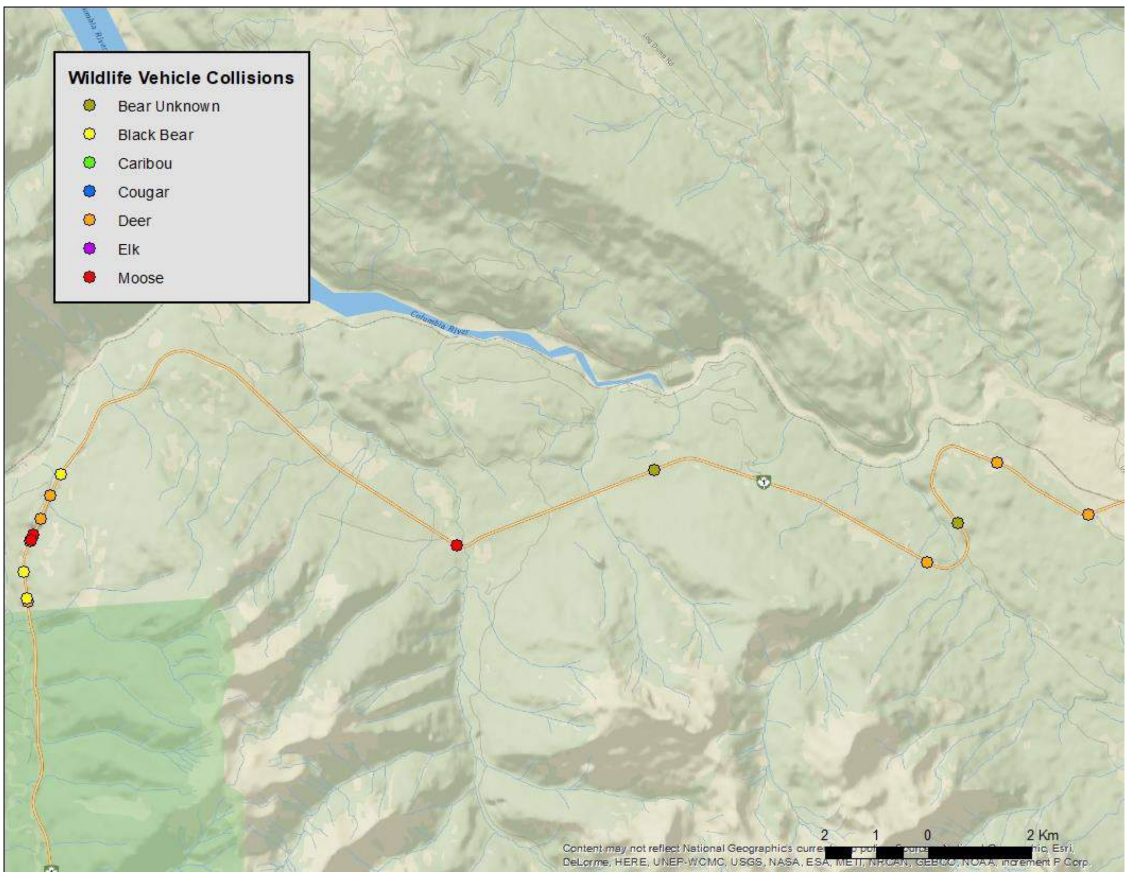

Figure 3-3: Road-caused mortalities of wildlife on the Trans-Canada Highway (TCH), Central Area of study area between East boundary of Glacier National Park and Donald Bridge, B.C.

East – Donald Bridge to Golden

The East section of the mitigation project runs from Donald Bridge to the west entrance to town of Golden, B.C. In the WARS and Parks Canada's mortality databases we found 30 total WVCs in this section including 24 deer, 2 unknown bear, 1 black bear, 1 cougar, 1 elk, and 1 moose (Figure 3.4). Deer mortalities were clustered in 3 spots: with the largest cluster just north of Moberly Road (N=4) and 2 smaller clusters (N=3) near the town of Golden. Black bear and unknown bear WVCs were spread out and not clustered in this section. The only moose mortality in this section was found east of Donald Bridge. The only cougar mortality that we found in the databases occurred in April 2017 near a cluster of deer kills and was located in the east of this section, near Golden. We found no caribou, grizzly bear (maybe unknown), mountain goat, wolf, lynx, or wolverine WVCs along this section of highway. The two most significant road mortality hot spots in this section are located just east of the east boundary of Revelstoke NP where a moose and 3 deer were killed and near west entrance to Golden (some WVCs have the same UTMs so not all are displayed below).

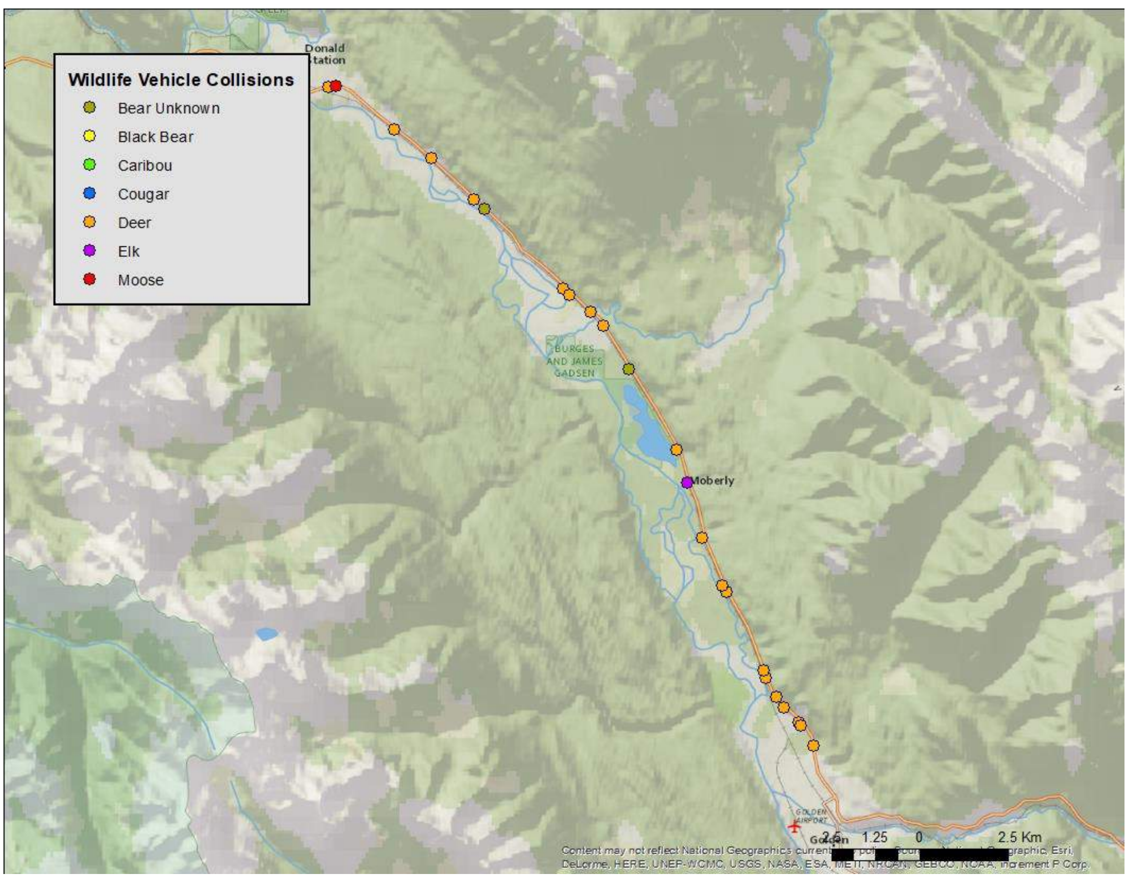

Figure 3-4: Road-caused mortalities of wildlife on the Trans-Canada Highway in TCH-East Area of study area between Donald Bridge and west entrance to Golden, BC.

4. Connectivity Modeling

Introduction

Connectivity allows individuals and populations to move across a fragmented landscape. Modelling animal movements helps to identify important areas for maintaining and restoring demographic (Sawaya et al. 2013) and genetic connectivity (Sawaya et al. 2014) at wildlife crossing structures. Connectivity models can be useful for identifying important habitat linkages and specific areas (i.e. pinch points) for highway mitigation. Previously, Geographic Information System (GIS)-generated habitat models have been used to determine the regionally important locations for wildlife crossing structures (Clevenger et al. 2002; Clevenger and Wierzchowski 2006); however, good habitat does not always translate to movement corridors. Recent attention has focused on the use of landscape resistance models to guide highway mitigation efforts (Landguth et al. 2012). These types of connectivity models that test the landscape by resistance hypothesis to gene flow (McRae 2006) may be particularly well-suited for identifying important crossing locations as they model large, landscape scale processes (i.e. dispersal patterns) that are crucial to long-term population viability.

We used 4 landscape resistance (i.e. connectivity) models, based on published models for black bears (Cushman et al. 2006, Landguth et al. 2012), grizzly bears (Graves et al. 2014, Proctor et al. 2015), moose (Clevenger et al. 2017) and wolverines (Balkenhol 2009, Copeland et al. 2010, McKelvey et al. 2011, Inman 2013) and generalized here, to help identify key areas for highway mitigation in the Trans-Canada Highway (TCH) from Revelstoke to Golden, British Columbia (BC). We did not specifically model ungulate movements other than moose, but based on past experience we feel that our black bear model may be a good surrogate for deer and elk movements. We used black bears to represent *general forest connectivity in low elevations* across the highway (Landguth et al. 2012) and used grizzly bears to represent connectivity at *middle elevations* and wolverines to represent connectivity at *high elevations*. We modeled these species because they are of conservation interest in the region (i.e. grizzly bears, wolverines), have detrimental effects when hit by vehicles (i.e. moose), are good surrogates for other forest-dwelling species (i.e. black bears), and they have been used in other nearby highway mitigation assessments (i.e. black bear, grizzly bear, wolverine). Other species such as caribou were not modeled for this assessment but could be modeled in the future if desired.

By representing the landscape as a resistance or cost-surface, least-cost paths (LCP) can be calculated that represent the route of maximum efficiency between two locations as a function of the distance travelled and the costs traversed. Essentially, a LCP finds the path of least cost (i.e. resistance) through the landscape based on a resistance surface that combines multiple landscape variables that may affect movement in that species. Our specific objective for LCP analysis was to use the generalized forest connectivity models for the 4 species to identify and prioritize important habitat linkages for wildlife across a range of elevational gradients by examining where LCPs cross the TCH in provincial lands between Revelstoke and Golden, B.C.

Methods

For our connectivity models, we focused on black bear, grizzly bear, moose, and wolverine, because they have extensive home ranges, need to cross roads frequently to access habitat patches, disperse long distances, and thus are ideal species for landscape resistance models (Cushman et al. 2006). Further, they may be suitable surrogates for other forest dwelling species (e.g., deer, elk, lynx, wolf). We modelled moose movements as collisions with moose are a public safety concern as they often lead to serious injury or death.

Study Area

We delineated a 28,618 km^2 study area for modeling landscape connectivity that encompassed the TCH and surrounding mountains between Revelstoke and Golden (Figure 4-1). This extensive area was chosen so that the area would be roughly centered in the middle of the extent to allow each least cost path for all 4 wildlife species to gather strength before entering the focal area of interest for highway mitigation; this helps to prevent the issue of biased low strength LCPs on the edges of extent due to fewer possible connections.

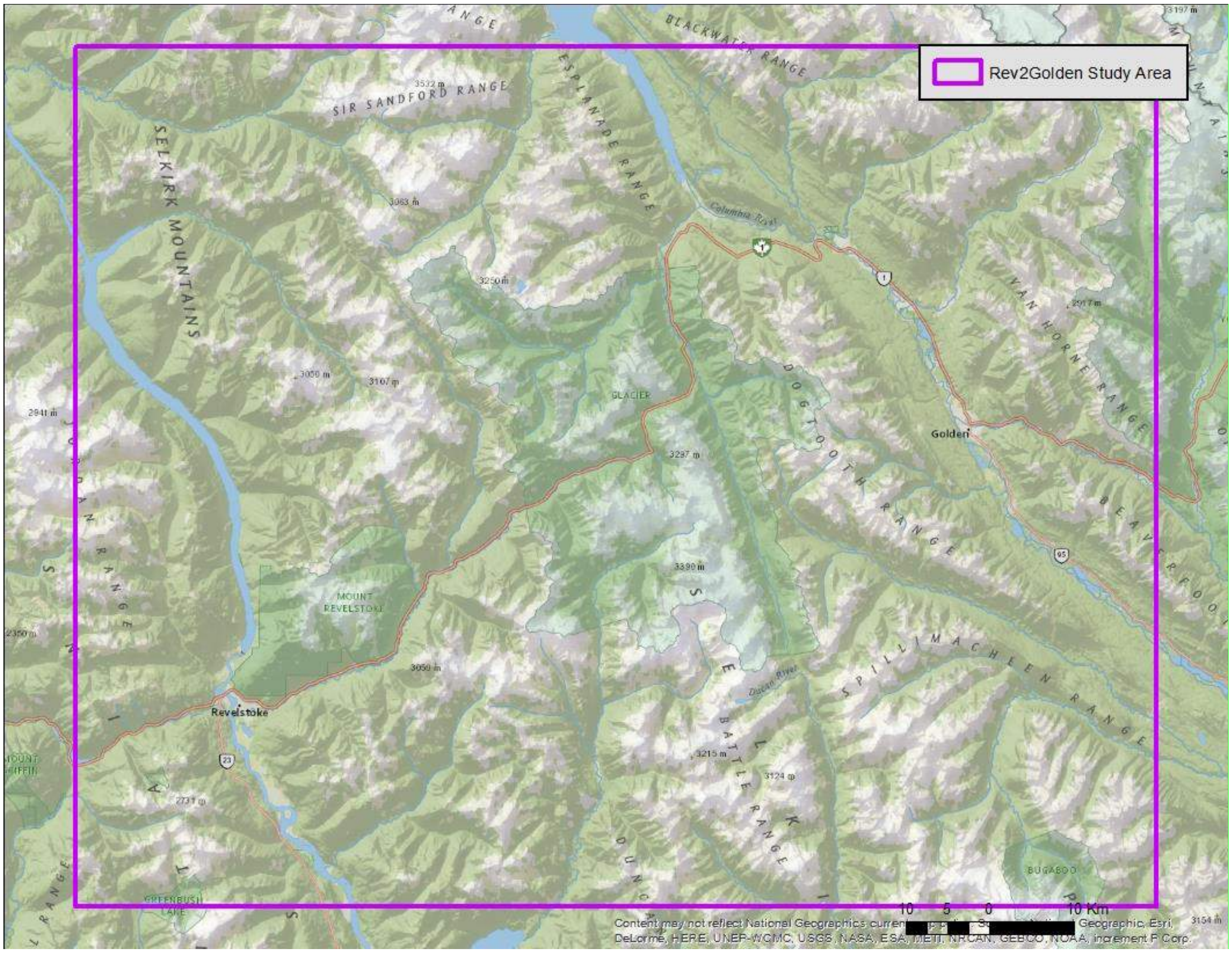

Figure 4-1: Our extensive study (28,618 km^2) for landscape connectivity modeling between Revelstoke and Golden, British Columbia.

Landscape resistance models

We gathered *GIS data* based on published analyses to model resistance to movement for each of the 4 species. We built resistance models from the following landscape variables: elevation, forest cover, non-habitat (e.g., buildings, large water bodies), ruggedness, persistent snow, and protected status. Additionally, we modeled resistance to roads for past projects; however, we did not use the road variable in our final LCP analysis as we wanted to know where the strongest paths occur in the absence of roads and including it did not change the main paths and limited the number of paths that crossed the TCH. Each of the GIS layers was reclassified to resistance values between 1-10 (1=low resistance, 10=high resistance). Reclassified raster layers were then combined together by summing the resistance values to get final landscape resistance surfaces. Details about GIS data layers, landscape resistance methods and results can be found in **Appendix C**.

We used the following expert opinion models to build landscape resistance surfaces based on published analyses and generalized for comparability and to emphasize the elevational gradient across species:

Black Bears (low elevation)
Elevation + Forest Cover + Non-habitat + Protected Areas

Grizzly Bears (medium elevation)
Elevation + Forest Cover + Non-habitat + Protected Areas

Moose (low elevation wetlands and wet forest)
Elevation + Forest Cover + Non-habitat + Protected Areas + Slope + Aspect

Wolverines (high elevation)
Elevation + Forest Cover + Non-habitat + Protected Areas + Ruggedness + Persistent Snow

We converted each of the landscape data to a landscape resistance model following Cushman et al. (2006). We randomly placed 500 points in our extensive study area with a minimum distance of 2 km from each other and selecting against non-habitat surfaces for bears, moose and wolverines (**Appendix C**). Preliminary runs from a previous project explored number of points and point placement with relatively little change in path convergence; we used 500 points with a 2 km spacing as it maximized LCP distribution and density while maintaining computational efficiency. LCP models identify the shortest path of least resistance from point A to point B. We used UNICOR (Landguth et al. 2012) to run LCPs between the 500 starting points and examined areas where the paths crossed the TCH. Our generalized models used landscape variables gleaned from several studies, though our past work compared our expert opinion-based pathways to single published landscape resistance models from other study areas. For black bears, we used the Cushman et al. (2006) black bear resistance model in northern Idaho, which included minimum resistance to medium elevation, high resistance to non-forested areas and roads. For grizzly bears, we used the Graves et al. (2014) resistance model that included habitat type and road density. For wolverines, we used the Balkenhol (2009) resistance model (e. g., Dilkina et al. 2016). These models were highly congruent with our more generalized models in that study; therefore, we do not report the results here.

Results

Our landscape connectivity models were run over an area much larger than the TCH corridor between Revelstoke and Golden as the real extents encompassed all of the surrounding national parks and provincial lands (Figures 4.2, 4.3, 4.4). As mentioned in Methods above, the large area was chosen so the TCH corridor study area would be centered, allowing the LCP for each wildlife species to gather strength before entering our area of interest for highway mitigation.

We identified several important cross-highway linkages and corridors using LCPs from UNICOR and these are shown in more detail in the following section (*Synthesis and Mitigation Development*). As expected, many of the LCPs follow low-mid elevation gradients and contour with major watersheds. In past analyses that used a single highway barrier layer for roads, there was little difference between the LCPs under different hypotheses so we used the elevation and forest cover resistance removing road resistance to identify habitat linkages; this allowed us to identify the best areas for animal movement in the absence of roads.

Three areas of importance to cross-highway movement emerged from this analysis:

1. Mount Revelstoke National Park (MRNP).
2. Glacier National Park (GNP) from Rogers Pass to the Beaver Valley.
3. Columbia Valley from Donald Bridge to Golden.

Our analysis highlighted these 3 areas as regionally important corridors for north-south movement for all four wildlife species.

Black bears

High strength LCPs for black bears were concentrated along the entire length of the valley bottom from Rogers Pass to the town of Revelstoke and the valley bottom from Rogers Pass to the east boundary of GNP. High strength LCPs were also concentrated in the bottom of the Beaver Valley. This pattern reflects the low elevation preference that we modeled for this generalist species. Our analysis highlighted the Beaver River, Columbia River, and confluences with major tributaries as regionally important corridors for north-south movement.

The following areas of importance to cross-highway movement emerged for black bears:

1. Western edge of MRNP to the eastern edge of MRNP.
2. Western edge of GNP to the Beaver Valley.
3. Columbia Valley between Donald Bridge and the town of Golden.

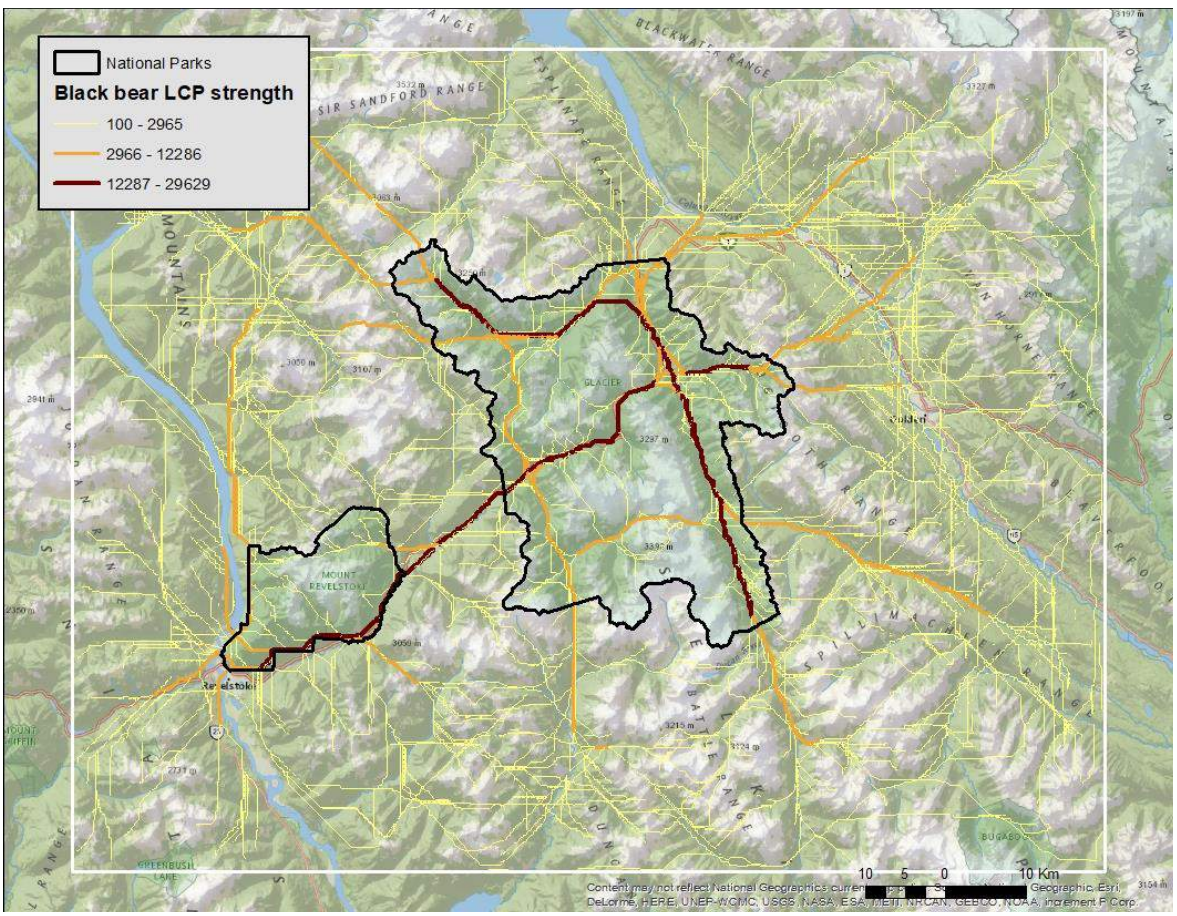

Figure 4-2: Least cost paths (LCP) for black bears within the Trans-Canada Highway study area. LCP signal strength is cumulative strength of pathways at that point, measured in per pixel conductance.

Grizzly bears

High strength LCPs for grizzly bears were more restricted to upper elevations than black bears. This pattern reflects the mid elevation preference that we modeled for this species to reflect their tendency to avoid low elevations which are dominated by humans (Proctor et al. 2015). Our analysis highlighted the MRNP, Rogers Pass and the confluences of the Columbia River with its major tributaries as regionally important corridors for north-south movement.

The following areas of importance to cross-highway movement emerged for grizzly bears:

1. Midway between west and east boundaries of MRNP.
2. Western edge of GNP to Rogers Pass.
3. Rogers Pass to the Beaver Valley.
4. Columbia Valley between Donald Bridge and the town of Golden.

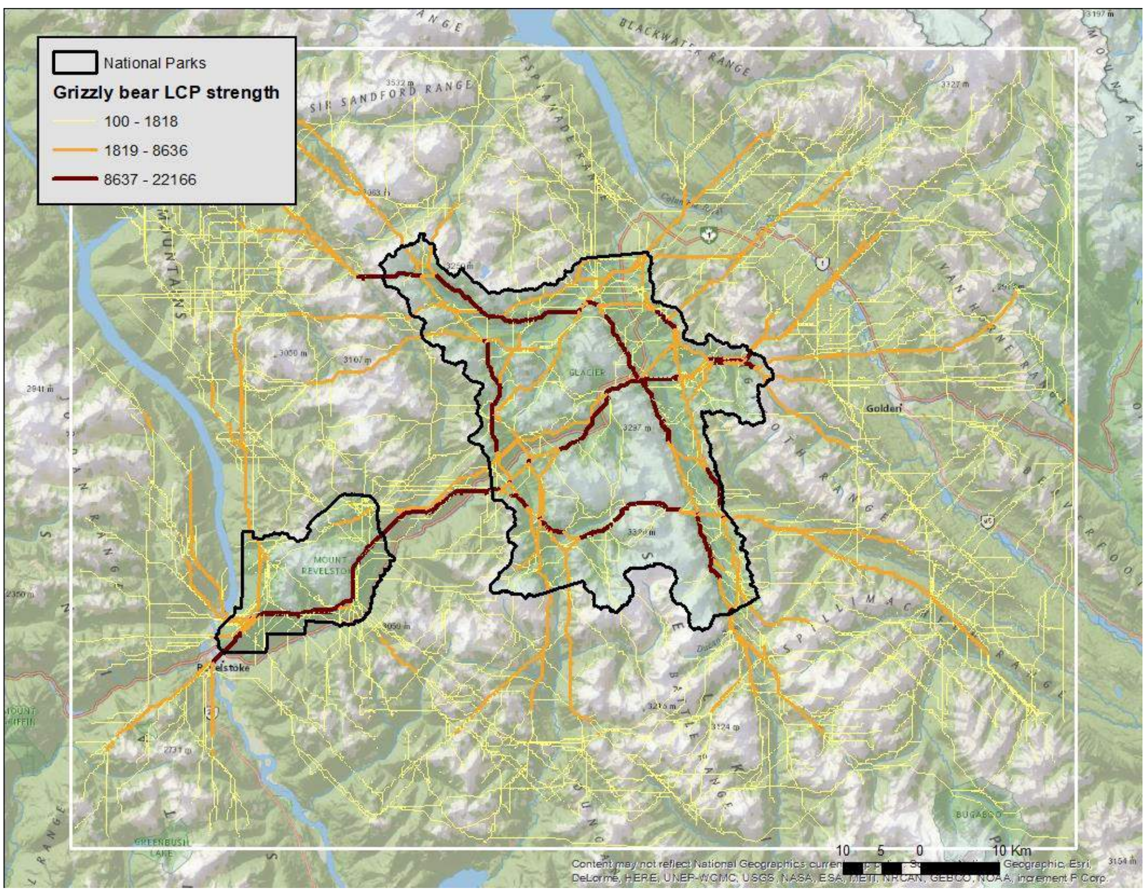

Figure 4-3: Least cost paths (LCP) for grizzly bears within the Trans-Canada Highway study area. LCP signal strength is cumulative strength of pathways at that point, measured in per pixel conductance.

Moose

High strength LCPs for moose were more restricted to lower elevations with wetter habitats than black bears. This pattern reflects the preferences for specific slopes and aspects that we modeled for this species to reflect their tendency to use slopes and aspects which are dominated by wet habitat types (Clevenger et. 2017). Our analysis highlighted Rogers Pass, the Beaver Valley and the confluences of the Beaver River and Columbia Rivers with their major tributaries as regionally important corridors for north-south movement for moose.

The following areas of importance to cross-highway movement emerged for moose:

1. Western edge of MRNP to the eastern edge of MRNP.
2. Western edge of GNP to the Beaver Valley.
3. Columbia Valley between Donald Bridge and the town of Golden.

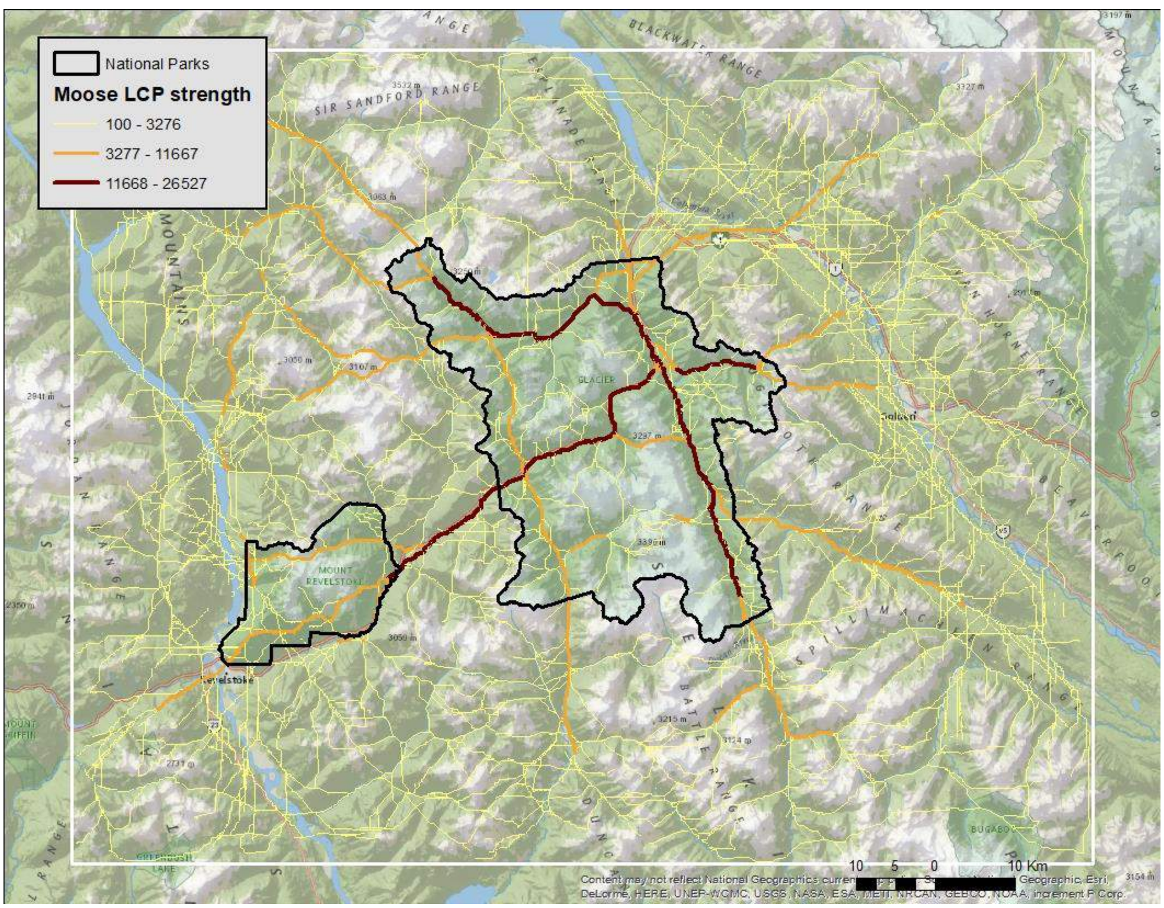

Figure 4-4: Least cost paths (LCP) for moose within the Trans-Canada Highway study area. LCP signal strength is cumulative strength of pathways at that point, measured in per pixel conductance.

Wolverines

High strength wolverine LCPs were concentrated along valley bottoms and ridges. This pattern reflects the high elevation, snow, and ruggedness preferences that we modeled for this species. Our analysis highlighted Mount Revelstoke in MRNP, Rogers Pass in GNP and the Beaver Valley in GNP as regionally important corridors for north-south movement for wolverines.

The following areas of importance to cross-highway movement emerged for wolverines:

1. Western edge of MRNP to eastern edge of MRNP.
2. Western edge of GNP to Rogers Pass.
3. Rogers Pass to the Beaver Valley.
4. Columbia Valley between Donald Bridge and the town of Golden.

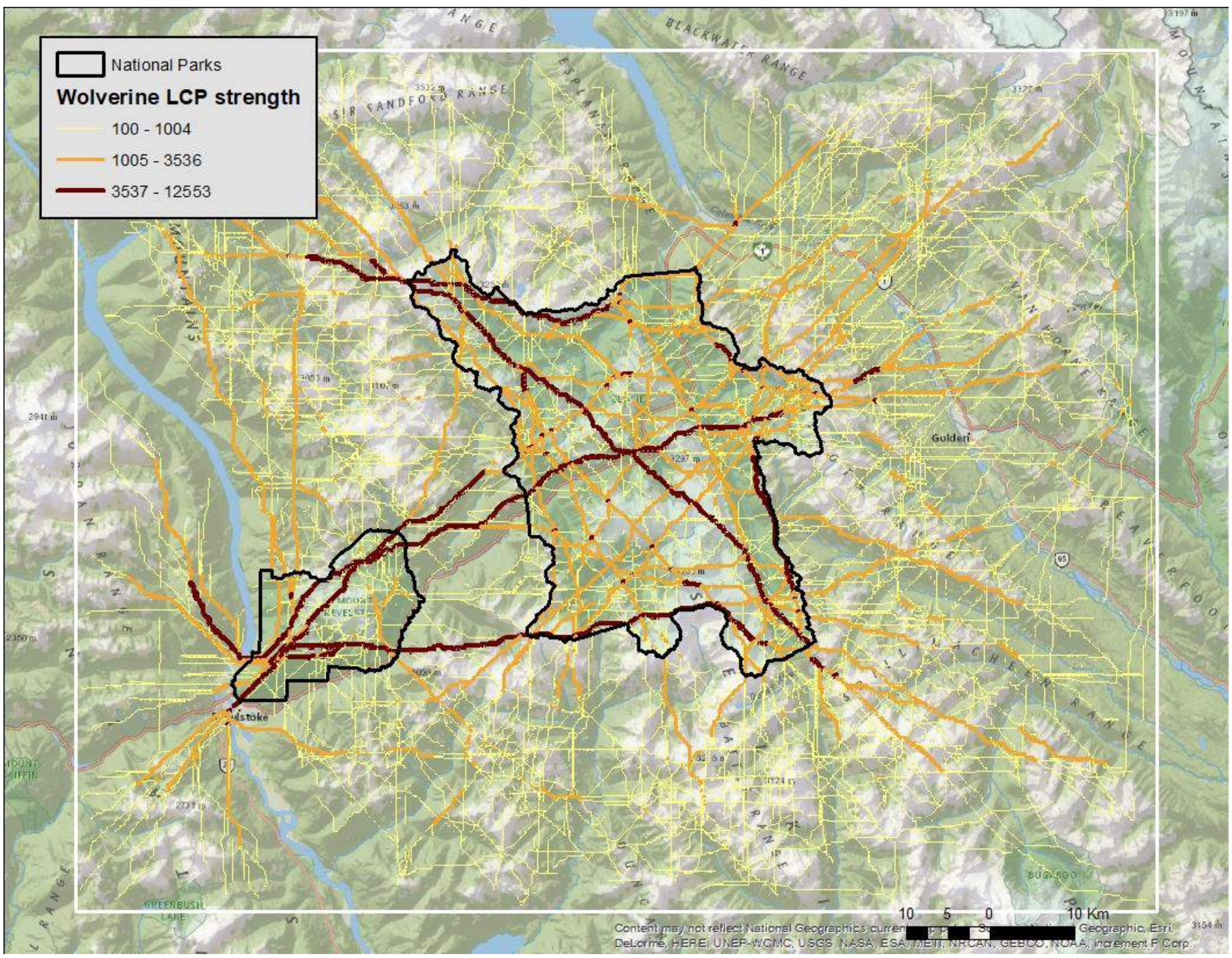

Figure 4-5: Least cost paths (LCP) for wolverines within the Trans-Canada Highway study area. LCP signal strength is cumulative strength of pathways at that point, measured in per pixel conductance.

5. Synthesis and Mitigation Development

In this section of the report we synthesize and integrate the previous data collected on WVCs and Connectivity within a framework that provides site-specific and technical detail regarding key locations for mitigation in the study area.

5.1 Highway Mitigation Design and Prioritization

Identification of Mitigation Emphasis Sites (MES)

We created a valuation matrix of the MES by scoring each in terms of regional connectivity (averaged across species), regional connectivity (averaged across species), mitigation constructability potential, human influence, and mortality risk. These criteria or variations of were used in previous mitigation assessment in the Columbia Mountains (Clevenger et al. 2014) and other projects (Clevenger et al. 2010, Lee et al. 2012, Clevenger and Barrueto 2016, Clevenger et al. 2017). We conducted a site visit at each MES in September 2018 and evaluated each for the 5 criteria listed above. We used these criteria as the basis for developing the recommended mitigation design type. Multiple site visits were made with B. Persello (BC MoTI) during the course of the project to investigate potential mitigation sites and designs.

We assigned each site a score from 1 (low) to 5 (high) on the basis of the following five criteria listed below. The matrix assisted in ranking sites for mitigation priority.

1. *Regional Connectivity Value* - the potential significance of highway mitigation to address regional connectivity concerns for the *combined* four species (averaged values); we modeled connectivity (black bear, grizzly bear, moose, wolverine). These three carnivore species were used as surrogates to represent landscape connectivity in low (black bear), middle (grizzly bear) and high (wolverine) elevations across the highway (Landguth et al. 2011); moose was used to represent low elevation wetlands and wet forest.

2. *Local Connectivity Value* – the value of the highway mitigation to local wildlife conservation regardless of regional significance. This was associated with high quality local habitats, i.e., meadows, creeks, rivers.
3. *Constructability* – the degree or relative ease to which mitigation can be constructed at the site. This is primarily based on site factors such as: existing infrastructure, local topography, proximity to: rivers, lakes, railway lines; assumed water table levels etc.
4. *Human Influence Value* - the potential impact of human infrastructure other than the main highway (built areas, access roads, railway, etc.) and associated disturbance on wildlife occupancy and movement in local area.
5. *Mortality* – the relative rate and composition of WVCs. These criteria defines important areas where motorist safety needs to be addressed. We weighted collision data from moose higher than locations with elk and deer collisions. In addition to motorist safety, mortality data tell us where wildlife are killed on roadways, which is often times a useful indicator where important habitat linkages are located and where animal movement corridors intersect highways.

Once the five criteria were scored we reviewed each MES in terms of the importance of the local area in terms of increasing motorist safety by reducing WVCs and maintaining movement of wildlife across the TCH. The evaluation was made by a local biologist with >20 years of experience studying wildlife in the study area.

- *Local knowledge* – an independent evaluation by a local wildlife expert (Richard Klafki, R.P. Bio., Golden, BC) of the importance of location for reducing highway mortality and maintaining connectivity.

Table 5-1 displays the scores for each criteria for all six criteria for each MES. We recorded scores and comments on Information or Hot Sheets (**Appendix D**) and averaged scores to help prioritize the MES. Sites were assigned as *High Priority* if above the average score for all MES and *Moderate Priority* if below.

Table 5-1. Summary of scoring of 6 criteria used to prioritize mitigation emphasis sites (MES) along Trans-Canada Highway between Revelstoke and Golden, BC. MES from 3 sub-study areas are colour-coded: West (green), Central (grey), East (blue). *High Priority* MES (bold) are based on equal to or higher than average total scores.

MES No.	Regional Connectivity	Local Connectivity	Construct-ability	Human influence	Mortality	Local knowledge	Total score
MES01	1.5	2	1	2	1	2	**9.5**
MES02	1	3	3	3	2	2	**14.0**
MES03	1.5	3	3	3	1	2	**13.5**
MES04	1	3	4	4	1	2	**15.0**
MES05	1.75	3	3	4	4	5	**20.75**
MES06	2	**3**	3	5	1	4	**18.0**
MES07	1	4	**3**	5	2	5	**20.0**
MES08	2.75	3	**4**	4	5	5	**23.75**
MES09	1	3	2	4	2	3	**15.0**
MES10	1.75	4	3	5	1	3	**17.75**
MES11	1	4	4	5	1	5	**20.0**
MES12	1.25	2	2	3	1	2	**11.25**
MES13	3.25	3	3	5	1	3	**18.25**
MES14	2.5	3	3	5	1	3	**17.50**
MES15	1.25	5	5	4	4	5	**24.25**
MES16	1.5	4	3	4	1	4	**17.5**
MES17	1.5	2	3	4	2	3	**15.5**
MES18	1.5	4	2	3	1	2	**13.5**
MES19	2.25	3	3	4	1	3	**16.25**
MES20	2.75	3	3	4	1	3	**16.75**
MES21	2.25	5	5	4	1	4	**21.25**
MES22	2	3	3	3	1	2	**14.0**
MES23	2.5	3	3	3	4	5	**20.5**
MES24	1	3	3	3	3	4	**17.0**
MES25	1.5	4	3	3	3	4	**18.50**
MES26	2.75	2	3	2	5	5	**19.75**

MES27	2.25	3	3	1	5	3	17.25

5.2 Rationale for Design Criteria

Our design guidelines for the three categories of proposed wildlife crossing structures are largely based on long-term research results in nearby Banff National Park that includes the same suite of species found in our B.C. study area (Clevenger and Waltho 2000, 2005; Clevenger and Barrueto 2014).

Categories of Wildlife Crossing Structure Design

We devised three categories of recommended wildlife crossing structures with the following design criteria (Table 5-2). **Primary** wildlife crossing structures consist of wildlife overpasses or large open span bridge underpass. **Secondary** wildlife crossing structures consist of open span bridge or arched culvert underpass. **Tertiary** wildlife crossing structures consist of elliptical multi-plate culverts or concrete box culverts.

Table 5-2. Design type and structural guidelines for three categories of recommended wildlife crossing structures on Trans-Canada Highway, Revelstoke to Golden, BC.

CATEGORY	CROSSING DESIGN TYPE	RECOMMENDED DIMENSIONS
Primary	Overpass Underpass (open span)	Width: 40-50 m Length:[1] Height: 3.5 m Width: 21 m Length: [1]
Secondary	Underpass (open span or arched culvert)	Height: 3 m Width: 11 Length: [1]
Tertiary	Elliptical culvert Concrete pre-fab box culvert	Height: 3 m Width: 7 m Length: [1] Height: 2.6 m Width: 2.8 m Length: [1]

[1] Length will be based on constructed width of highway at location.

The location of the tertiary crossing structures is more flexible than that of the primary and secondary crossing structures. It is important that the primary and secondary crossing structures are built at the recommended locations. However, one or possibly two of the tertiary crossing structures could eventually be eliminated, or a secondary structure moved, if engineering constraints prove their constructability unfeasible at the recommended site.

The TCH corridor has been identified as a source of mortality and fragmentation for wildlife populations in the Columbia and Rocky Mountains: wolverines (Krebs et al. 2004, Clevenger 2013), grizzly bears (Chruszcz et al. 2003, Bertch and Gibeau 2010), wolves (Callaghan et al. 1998), moose (Parks Canada, unpublished data), lynx (Apps 2000) and mountain goats (Parks Canada, unpublished data). As described above, the MES are specific locations within the study area where our connectivity models and empirical data show the best opportunities for improving connectivity throughout the project area. Models and validation data have identified these key linkage areas. The next step and level of detail will consist of conducting site visits at each MES to ascertain the feasibility of construction, most likely making simple locational adjustments to our initial recommendations within this report. Further, this next step provides an opportunity for consultation and input from indigenous communities and elders to communicate the traditional ecological importance of these sites for wildlife and their communities. Other supplementary information (ground and aerial survey data, trapping harvest data etc.) if available, would be of value to strengthen site recommendations.

These types of finer-scale site inspections with engineers are part of the highway mitigation design process prior to starting preliminary design work and have been a part of numerous highway mitigation projects in North America (A.P. Clevenger, personal observation). Such projects include TCH in Yoho National Park; TCH Phase 3B in Banff National Park; Montana US93 (Evaro to Polson); Interstate-90 Snoqualmie Pass East, Washington; SR 260 near Payson, Arizona; US 101 Liberty Canyon in southern California.

5.3 Mitigation Measures

Devising measures that effectively mitigate the impacts of roads with the dual purpose of providing safe passage for motorists and wildlife is the new norm today for transportation agencies (Kociolek et al. 2015). A recent meta-analysis of WVC reduction measures revealed that fencing and wildlife crossing structures led to an 83% reduction in WVCs, compared to a 57% reduction for animal detection systems, and only 1% for reflectors (Rytwinski et al 2016).

To date the most comprehensive evaluation of WVC reduction measures was prepared for a report to the U.S. Congress, commissioned by the Federal Highway Administration (Huijser et al. 2008). The report summarized 36 different animal–vehicle collision mitigation measures currently in use throughout the world. The mitigation measures were grouped into four types:

- Measures that attempt to influence driver behaviour (18).
- Measures that attempt to influence animal behaviour (10).
- Measures that seek to reduce wildlife population size (4).
- Measures that seek to physically separate animals from the roadway (4).

As part of the report to US Congress, a Technical Working Group was convened that included seven national experts in the area of animal–vehicle collisions. One of their tasks was to rank the current animal–vehicle collision mitigation measures into three categories:

1. Measures that are *proven* and should be implemented (where appropriate).
2. Measures that appear *promising* but require further investigation.
3. Measures or practices that are proven *ineffective*.

Selected Trans-Canada Highway (Revelstoke to Golden) mitigation measures

The recommendations for improving motorist safety and wildlife connectivity include a total of five different proven or promising mitigation measures. Information sheets on these measures are found in **Appendix E**, including information on *gates and ramps* that are accessory to fencing and wildlife crossing structures.

We developed recommendations for mitigation measures at each MES. A variety of measures are recommended, from simple to complex. Some require only replacing existing under-sized culverts with larger culverts, while others necessitate major structural work, e.g., widening bridge supports while upgrading existing bridge structures. The recommendations for improving motorist safety and wildlife connectivity for the TCH in the study area include five different proven or promising mitigation measures (Huijser et al. 2007). Table 5-3 includes a list of the measures, their effectiveness in reducing WVCs, the target of the measure (type) and the ranking category as presented in the Huijser et al. (2008) report to Congress.

Table 5-3. Wildlife mitigation measures, their focus and effectiveness.

Mitigation measure	**Effectiveness**	**Type[1]**	**Category[2]**
Animal detection system	87%	Driver	Promising
Fencing	86%	Separate	Proven
Underpass with waterflow	86%	Animal	Proven
Underpass – wildlife	86%	Animal	Proven
Overpass – wildlife	86%	Animal	Proven

[1] *Driver*: Measures that attempt to influence driver behaviour; *Animal*: Measures that attempt to influence animal behaviour; *Size*: Measures that seek to reduce wildlife population size; *Separate*: Measures that physically separate animals from the roadway. From Huijser et al. 2008.
[2] *Proven*: Measures that should be implemented (where appropriate); *Promising*: Measures that appear promising, but require further investigation. From Huijser et al. 2008.

6. Mitigation Recommendations

The 27 MES were divided into our 3 sub-study areas based on habitat and topographic conditions along the highway from Revelstoke to Golden. (Figure 6-1). Sections of the TCH in and between Mount Revelstoke and Glacier National Parks was completed as part of another mitigation assessment (Clevenger et al. 2014).

- **9 sites in West Area** (Revelstoke to west gate of Mt Revelstoke National Park; Figure 6-2)
- **12 sites in Central Area** (East gate of Glacier National Park to Donald Bridge; Figure 6-3)
- **6 sites in East Area** (Donald Bridge to Golden; Figure 6-4)

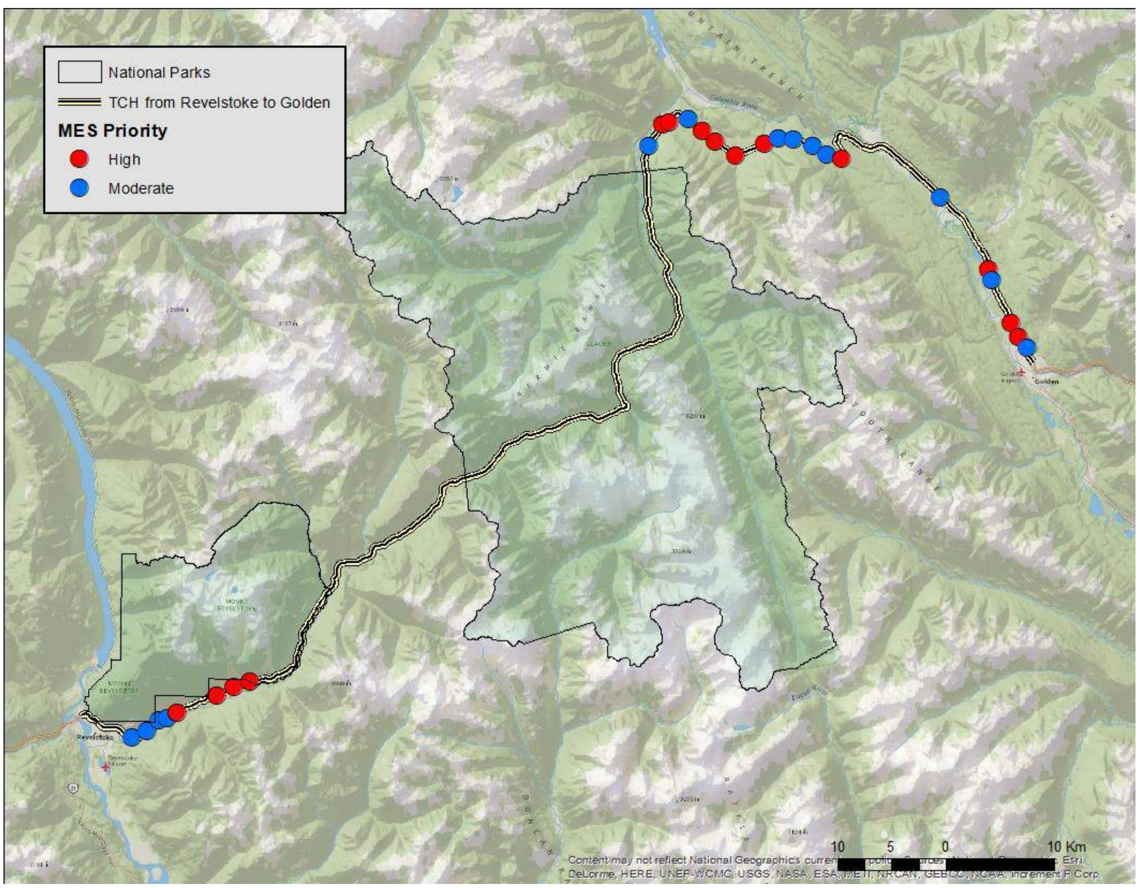

Figure 6-1. Map of overall study area with mitigation emphasis sites shown as *High Priority* (red) and *Moderate Priority* (Blue).

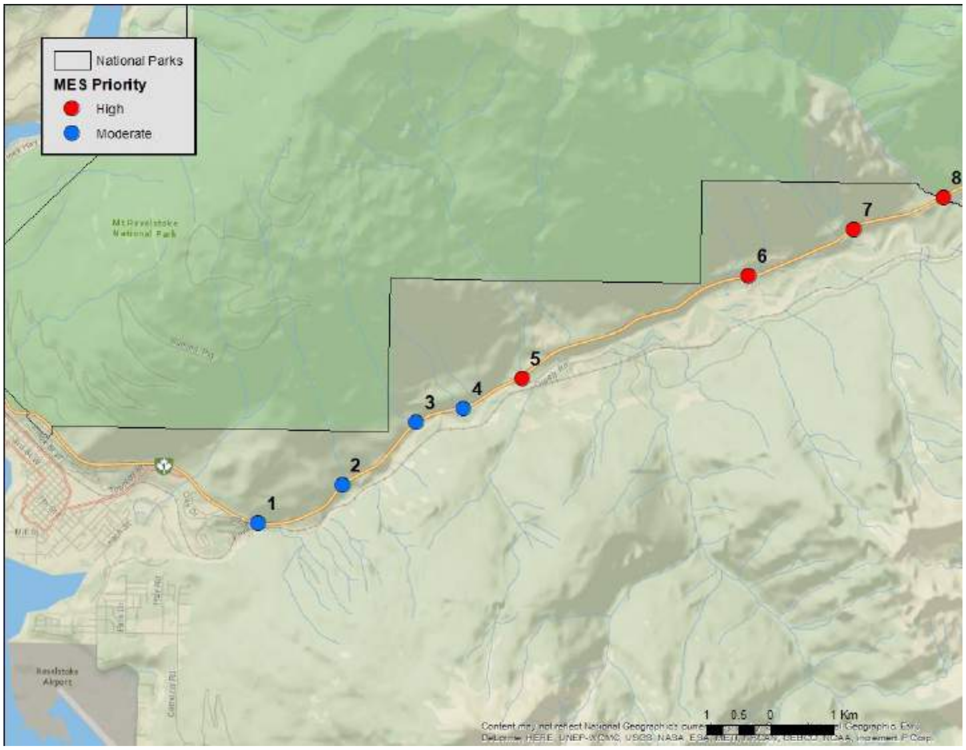

Figure 6-2. Map of West Area (Revelstoke to west gate Mount Revelstoke National Park) with mitigation emphasis sites shown as *High Priority* (red) and *Moderate Priority* (blue).

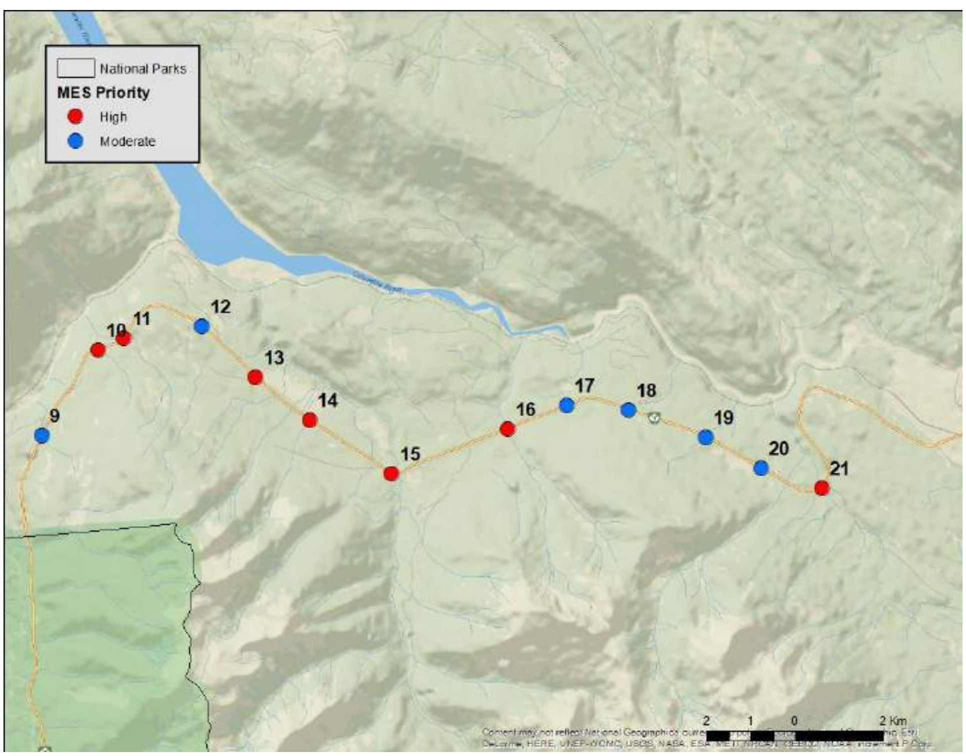

Figure 6-3. Map of Central Area (East gate of Glacier National Park to Donald Bridge) with mitigation emphasis sites shown as *High Priority* (red) and *Moderate Priority* (blue).

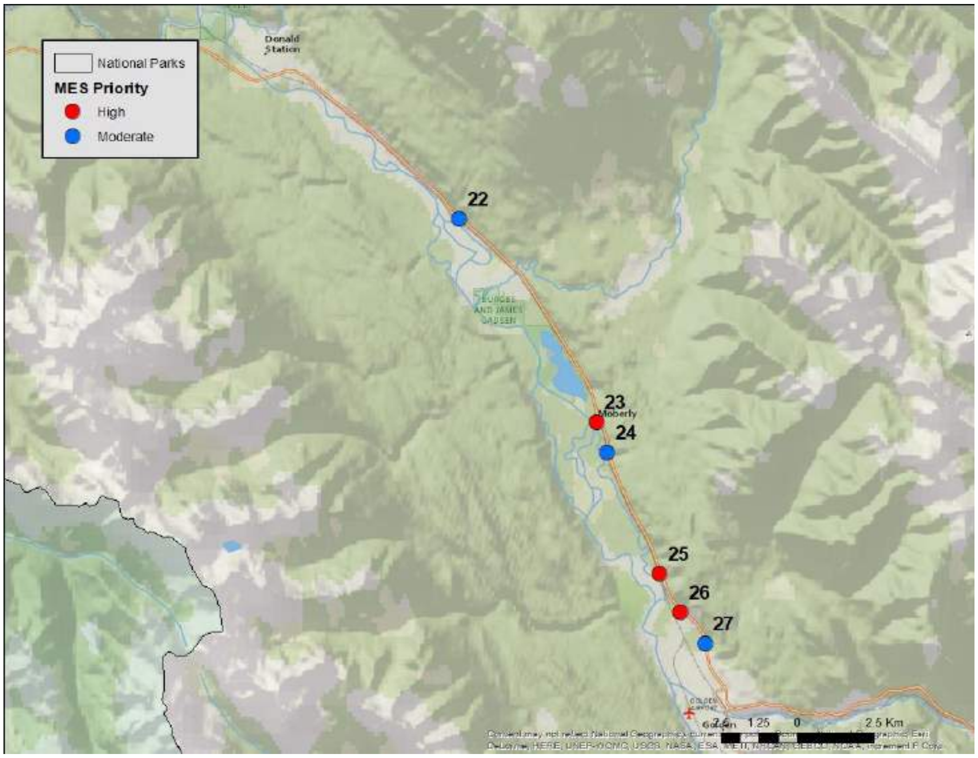

Figure 6-4. Map of East Area (Donald Bridge to Golden) with mitigation emphasis sites shown as *High Priority* (red) and *Moderate Priority* (blue).

A large amount of information has been amassed specific to each MES. Information or "Hot Sheets" (**Appendix D**) were prepared for each site and describe all site-specific information with regard to mitigation importance, target species, wildlife objectives, and recommendations for mitigation measures. The Hot Sheets are a quick and easy reference that summarizes mitigation opportunities at each site.

There are a large number of MES throughout the TCH corridor and recommendations for each site. Instead of reviewing each of the 27 sites in detail in this report, we highlight the most relevant sites primarily with regard to wildlife–vehicle collision reduction and regional conservation and connectivity. To do this, we averaged the values for the 27 sites within the study area. The maximum and minimum score for a site was 24.25 and 9.5, respectively. The average score for the matrix valuation of the 27 sites was 17.26. Fifteen of the 27 sites had scores very near or above the average score. Those sites are listed below in descending order. The 7 highest-ranking sites (>90th percentile) are shown in **bold type** and valuation matrix total scores are in parentheses.

1. **Quartz Creek – MES 15 (24.25)**
2. **Clachnacudainn Creek – MES 08 (23.75)**
3. **Wiseman Curves – MES 21 (21.25)**
4. **Hamilton Creek – MES 05 (20.75)**
5. **Hartley Road – MES 23 (20.50)**
6. **Hanner Lake – MES 07 (20.0)**
7. **Beaver 02 – MES 11 (20.00)**
8. North Anderson – MES 26 (19.75)
9. Quarry North – MES 25 (18.50)
10. West Heather – MES 13 (18.25)
11. West Hanner – MES 06 (18.0)
12. Beaver 01 – MES 10 (17.75)
13. West Quartz Creek – MES 14 (17.50)
14. Wiseman Creek – MES 16 (17.50)
15. West Golden – MES 27 (17.25)

We discuss each of these sites and their mitigation recommendations in light of their respective attributes associated with local and regional conservation values and the safety of motorists traveling the TCH. Below we review the 15 sites in order of high to low ranking, as shown above. Specific mitigation measures are italicized; general descriptions of the five mitigation measures are found in **Appendix E**.

Of interest is 14 of the 15 MES either are located at a creek/river crossing or have a culvert in place. We make recommendations for how these hydrological structures can be retrofitted or adapted during twinning to meet dual needs of hydrology and motorist safety/wildlife passage needs.

1. MES-15 Quartz Creek (Central Area)

The Quartz Creek site **ranked highest of all MES in the study area**. It was rated high (both 5) for Local Conservation Value and Constructability; and moderately high for Human Disturbance (lack of) and Mortality Risk (both 4). There are abundant populations of moose, deer, and black bears in the area and possibly elk and grizzly bears. It had a low score for Regional Conservation Significance (1.25), most likely due to Quartz Creek being a dead-end drainage with high headwalls limiting wildlife movement. However, the Quartz Creek site ranked high (5) in terms of Local Knowledge of the area in terms of the importance of this area for reducing wildlife mortality and maintaining movement across the TCH. The site had a high score for Constructability (5). There is currently a large bridge over Quartz Creek that will be replaced with a new and better aligned bridge in 2020 as part of a TCH twinning project in the Selkirk Mountains.

The new Quartz Creek Bridge will be on a new alignment and the bridge will span over a larger portion of Quartz Creek. The dimensions of the bridge will provide excellent passage for all wildlife in the area. Trails should be cut into slopes on both sides of drainage to facilitate wildlife movement through the area. Quartz is the largest watershed in the area and is an important corridor moving wildlife between high and low elevations.

Wing fencing (200–500 m depending on terrain) will be used to guide wildlife under the bridge. Each mitigation situation is different and will require a site-specific assessment, but as a general rule, fence ends should terminate at a wildlife crossing structure. If a wildlife crossing cannot be installed at the fence ends, then fences should be designed to terminate in the least suitable location or habitat for wildlife movement—i.e., places wildlife are least likely to cross roads. Examples of terminations and fence technical specifications are given in **Appendix E, Sheet B**. *Fencing notes*: Snow is not likely a concern at this location.

Jump-outs: Jump-outs or escape ramps should be located appropriately to allow animals to escape the right-of-way should they gain access within the fenced area. We recommend a pair of jump-outs (one on each side of highway) close to the fence end (<100 m) and another pair 200-300 m from the first pair. Examples and technical specifications are given in **Appendix E, Sheet C**.

2. MES-08 Clachnacudainn Creek (West Area)

The site ranked in the **Top 7 and 2nd overall** and was rated high (5) for Mortality Risk and moderately high (4) for Human Disturbance (lack of). Moose, deer and bears are in the area and pose a safety risk to motorists. Clachnacudainn Creek ranked high for Local Knowledge (5) in terms of the importance of this area for reducing wildlife mortality and maintaining movement across the TCH. It had a moderate score for Regional Conservation Significance (2.75) and Local Conservation Value (3) as modeling of regional connectivity indicated this location was particularly important to black bears (5). The site had a moderate high score for Constructability (4).

Existing infrastructure consists of a >3000m diameter culvert over the Clachnacudainn Creek that has good vertical clearance. The bridge could be rebuilt should the TCH be improved through widening or twinning. If the highway is reconstructed, a new bridge will be added to the existing bridge.

To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended (see *Wildlife Underpass with water flow*, **Appendix E, Sheet A**). Selection of design type is dependent on terrain, engineering and hydrological constraints. All bridge construction or reconstruction must be designed with wildlife movement (and hydrologic flow) in mind. The new bridge should be designed with a span matching existing and allow for dry travel sections (≥3 m wide) above high-water mark.

Wing fencing (200–500 m depending on terrain) will be used to guide wildlife to the underpass. Each mitigation situation is different and will require a site-specific assessment, but as a general rule, fence ends should terminate at a wildlife crossing structure. If a wildlife crossing cannot be installed at the fence ends, then fences should be designed to terminate in the least suitable location or habitat for wildlife movement—i.e., places wildlife are least likely to cross roads. Examples of terminations and fence technical specifications are given in **Appendix E, Sheet B**. *Fencing notes*: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.

Jump-outs: Jump-outs or escape ramps should be located appropriately to allow animals to escape the right-of-way should they gain access within the fenced area. We recommend a pair of jump-outs (one on each side of highway) close to the fence end (<100 m) and another pair 200-300 m from the first pair. Examples and technical specifications are given in **Appendix E, Sheet C**.

3. MES-21 Wiseman Curves (Central Area)

The site ranked high, in the **Top 7 and was 3rd overall** and was rated high (4) for Human Disturbance (lack of) and Local Conservation Value (5). It had moderate high score for Local Knowledge (4) in terms of the importance of this area for reducing wildlife mortality and maintaining movement across the TCH. Score for Regional Conservation Significance as moderately low (2.25). The site had a low score for Mortality Risk (1), however, moose, deer, elk and bears are in the area. The site had a high score for Constructability (5). There is a small culvert of unknown dimensions at the site that would be rebuilt should the TCH be improved through widening or twinning.

To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended (see *Wildlife Underpass with water flow*, **Appendix E, Sheet A**). Selection of design type is dependent on terrain, engineering and hydrological constraints. Recommend replacing culvert during twinning and install open-span preferred design. Minimum dimension for underpass is 11 m wide x 3 m high due to high likelihood of moose, elk and grizzly bear movement through this area. Retrofitting the existing creek culvert to a larger underpass will need to have design that allows for wildlife passage (>3 m path on one side or other) above high water levels to ensure hydrological and wildlife connectivity function at this location.

Wing fencing (200–500 m depending on terrain) will be used to guide wildlife to the underpass. Each mitigation situation is different and will require a site-specific assessment, but as a general rule, fence ends should terminate at a wildlife crossing structure. If a wildlife crossing cannot be installed at the fence ends, then fences should be designed to terminate in the least suitable location or habitat for wildlife movement—i.e., places wildlife are least likely to cross roads. Examples of terminations and fence technical specifications are given in **Appendix E, Sheet B**. *Fencing notes*: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.

Jump-outs: Jump-outs or escape ramps should be located appropriately to allow animals to escape the right-of-way should they gain access within the fenced area. We recommend a pair of jump-outs (one on each side of highway) close to the fence end (<100 m) and another pair 200-300 m from the first pair. Examples and technical specifications are given in **Appendix E, Sheet C**.

4. MES-05 Hamilton Creek (West Area)

The site ranked in the **Top 7 sites, 4th overall** and was rated high (5) for Local Knowledge of the importance of this area for reducing wildlife mortality and maintaining movement across the TCH. It had moderately high scores (4 each) for Mortality Risk and Human Disturbance (lack of). Potential future recreational development in this area (Hamilton Creek) may result in lower human disturbance values. It is an area where WVC can be problematic, primarily with deer and moose. The site had moderate scores for Constructability (3), although there is a 3000 mm culvert at the site for Hamilton Creek and it would be rebuilt should the TCH be improved through widening or twinning.

The area is important in terms of Local Connectivity (3), but less so for Regional Conservation Significance (1.75). Modeling of regional connectivity for black bear, grizzly bear, moose, and wolverine movement indicated this location was not particularly important. Situated at Hamilton Creek, it is a natural travel corridor for wildlife year-round.

To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended (see *Wildlife Underpass with water flow*, **Appendix E, Sheet A**). Selection of design type is dependent on terrain, engineering and hydrological constraints. An open-span design is preferred, however a bottomless arch may be required to accommodate creek/hydrological requirements. Fish values are high in Hamilton Creek and there may be opportunities to capitalize on fish and wildlife passage requirements. Minimum dimension for underpass is 11 m wide x 3 m high due to high likelihood of moose and grizzly bear movement through this area. Retrofitting Hamilton Creek culvert to a larger underpass will need to have design that allows for wildlife passage (>3 m path on one side or other) above high water levels to ensure hydrological and wildlife connectivity function at this location.

Wing fencing (200–500 m depending on terrain) will be used to guide wildlife to the underpass. Each mitigation situation is different and will require a site-specific assessment, but as a general rule, fence ends should terminate at a wildlife crossing structure. If a wildlife crossing cannot be installed at the fence ends, then fences should be designed to terminate in the least suitable location or habitat for wildlife movement—i.e., places wildlife are least likely to cross roads. Examples of terminations and fence technical specifications are given in **Appendix E, Sheet B**. *Fencing notes*: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.

Jump-outs: Jump-outs or escape ramps should be located appropriately to allow animals to escape the right-of-way should they gain access within the fenced area. We recommend a pair of jump-outs (one on each side of highway) close to the fence end (<100 m) and another pair 200-300 m from the first pair. Examples and technical specifications are given in **Appendix E, Sheet C**.

5. MES-23 Hartley Road (East Area)

The site ranked high, in the **Top 7 and was 5th overall** and was rated high (5) for Local Knowledge of the importance of this area for reducing wildlife mortality and maintaining movement across the TCH. It had moderately high score (4) for Mortality Risk and moderate scores for Human Disturbance (lack of), Local Conservation Value, and Regional Conservation Significance. Modeling of regional connectivity for grizzly bear and wolverine movement indicated this location was relatively important for mid and high elevation species. It is an area where WVC can be problematic, primarily with deer, elk, bears and cougars. The site had moderate scores for Constructability (3). Moberly Creek runs year-round through a small 900mm culvert at this site and would be rebuilt should the TCH be improved through widening or twinning.

To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended (see *Wildlife Underpass with water flow*, **Appendix E, Sheet A**). Selection of design type is dependent on terrain, engineering and hydrological constraints. An open-span design is preferred, however a bottomless arch may be required to accommodate creek/hydrological requirements. Minimum desirable dimension for underpass is 11 m wide x 3 m high due to the combined high score for this site and likelihood of significant wildlife movement through this area. Retrofitting Moberly Creek culvert to a larger underpass will have some engineering constraints to obtain sufficient clearance (3 m in addition to cover). Retrofit will need to include design that allows for wildlife passage (>2-3 m path on one side or other) above high water levels to ensure hydrological and wildlife connectivity function at this location. Focal species in area such as deer, elk, black bears, cougars utilize culverts of recommended dimensions.

Wing fencing (200–500 m depending on terrain) will be used to guide wildlife to the underpass. Each mitigation situation is different and will require a site-specific assessment, but as a general rule, fence ends should terminate at a wildlife crossing structure. If a wildlife crossing cannot be installed at the fence ends, then fences should be designed to terminate in the least suitable location or habitat for wildlife movement—i.e., places wildlife are least likely to cross roads. Examples of terminations and fence technical specifications are given in **Appendix E, Sheet B**. *Fencing notes*: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.

Jump-outs: Jump-outs or escape ramps should be located appropriately to allow animals to escape the right-of-way should they gain access within the fenced area. We recommend a pair of jump-outs (one on each side of highway) close to the fence end (<100 m) and another pair 200-300 m from the first pair. Examples and technical specifications are given in **Appendix E, Sheet C**.

6. MES-07 Hanner Lake (West Area)

The site ranked in the **Top 7, being 6th overall** and was rated high (5) for Human Disturbance (lack of), Local Conservation Value (4) and Local Knowledge (5) in terms of the importance of this area for reducing wildlife mortality and maintaining movement across the TCH. It had low score for Regional Conservation Significance (1) as modeling of regional connectivity indicated this location was not particularly important. The site had a moderately low score for Mortality Risk (2), however, moose, deer and bears are in the area. The site had a moderate score for Constructability (3). There is a small culvert of unknown dimensions at the site that would be rebuilt should the TCH be improved through widening or twinning.

To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended (see *Wildlife Underpass,* **Appendix E, Sheet D**). Selection of design type is dependent on terrain, engineering and hydrological constraints. The north side has good amount of fill, while south side is steep but levels off downslope. The culvert in place carries a small volume of water. A wildlife underpass could be situated at either end (west or east ends) of the south side slope embankment as there are shoulder sections that the underpass could tie into and serve as travel ramp to and from underpass. At the east end there is a rock cut that could serve as possible location for wildlife overpass, pending engineering and geotechnical feasibility of the site. Minimum recommended underpass dimension where feasible ca. 3 m high by 11 m wide and minimum recommended overpass dimension is 40 m wide; both dimensions due to high likelihood of moose and grizzly bear movement through this area.

Wing fencing (200–500 m depending on terrain) will be used to guide wildlife to the underpass. Each mitigation situation is different and will require a site-specific assessment, but as a general rule, fence ends should terminate at a wildlife crossing structure. If a wildlife crossing cannot be installed at the fence ends, then fences should be designed to terminate in the least suitable location or habitat for wildlife movement—i.e., places wildlife are least likely to cross roads. Examples of terminations and fence technical specifications are given in **Appendix E, Sheet B**. *Fencing notes*: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.

Jump-outs: Jump-outs or escape ramps should be located appropriately to allow animals to escape the right-of-way should they gain access within the fenced area. We recommend a pair of jump-outs (one on each side of highway) close to the fence end (<100 m) and another pair 200-300 m from the first pair. Examples and technical specifications are given in **Appendix E, Sheet C**.

7. MES-11 Beaver 2 (Central Area)

The site ranked among the Top 10, 7th overall and was rated high (5) for Human Disturbance (lack of) and Local Conservation Value (4) and Local Knowledge (5) in terms of the importance of this area for reducing wildlife mortality and maintaining movement across the TCH. It had low score for Regional Conservation Significance (1) as modeling of regional connectivity indicated this location was not particularly important. The site had a low score for Mortality Risk (1), however, moose and bears are in the area. The site had moderately high score for Constructability (4). There is a small culvert of unknown dimensions at the site that would be rebuilt should the TCH be improved through widening or twinning.

To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended (see *Wildlife Underpass with water flow*, **Appendix E, Sheet A**). Selection of design type is dependent on terrain, engineering and hydrological constraints. The north side has good amount of fill, while south side is steep but levels off downslope. Culvert in place carries small volume of water. Existing culvert could be replaced with a bottomless arch culvert, ca. 3 m high by 7 m wide or open span bridge (2.5-3m high x 11 m wide). Focal species in area such as moose and grizzly bears utilize culverts of recommended dimensions. Retrofitting the existing creek culvert to a larger underpass will need to have design that allows for wildlife passage (>2 m path on one side or other) above high water levels to ensure hydrological and wildlife connectivity function at this location.

Wing fencing (200–500 m depending on terrain) will be used to guide wildlife to the underpass. Each mitigation situation is different and will require a site-specific assessment, but as a general rule, fence ends should terminate at a wildlife crossing structure. If a wildlife crossing cannot be installed at the fence ends, then fences should be designed to terminate in the least suitable location or habitat for wildlife movement—i.e., places wildlife are least likely to cross roads. Examples of terminations and fence technical specifications are given in **Appendix E, Sheet B**. *Fencing notes*: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.

Jump-outs: Jump-outs or escape ramps should be located appropriately to allow animals to escape the right-of-way should they gain access within the fenced area. We recommend a pair of jump-outs (one on each side of highway) close to the fence end (<100 m) and another pair 200-300 m from the first pair. Examples and technical specifications are given in **Appendix E, Sheet C**.

8. MES-27 North Anderson (East Area)

The site was ranked in the Top 10, being 8th overall and was rated high (5) for Local Knowledge in terms of the importance of this area for reducing wildlife mortality and maintaining movement across the TCH. Mortality Risk (5) was also high at the North Anderson site, primarily collisions with deer, elk, cougars and some black bears. Scores were moderately low (both 2), however, for Human Disturbance (lack of) and Local Conservation Value. Regional Conservation Significance of the site was average (2.75). Modeling of regional connectivity for grizzly bear, moose, and wolverine movement indicated this location was relatively important. The site had an average score for Constructability (3). There is a culvert of unknown dimensions at the site that would be rebuilt should the TCH be improved through widening or twinning.

To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended (see *Wildlife Underpass with water flow*, **Appendix E, Sheet A**). Selection of design type is dependent on terrain, engineering and hydrological constraints. Recommend replacing culvert during twinning and install open-span preferred design. Minimum dimension for underpass is 11 m wide x 3 m high due to need of moving common wildlife species through this area. Retrofitting the existing creek culvert to a larger underpass will need to have design that allows for wildlife passage (>3 m path on one side or other) above high water levels to ensure hydrological and wildlife connectivity function at this location.

Wing fencing (200–500 m depending on terrain) will be used to guide wildlife to the underpass. Each mitigation situation is different and will require a site-specific assessment, but as a general rule, fence ends should terminate at a wildlife crossing structure. If a wildlife crossing cannot be installed at the fence ends, then fences should be designed to terminate in the least suitable location or habitat for wildlife movement—i.e., places wildlife are least likely to cross roads. Examples of terminations and fence technical specifications are given in **Appendix E, Sheet B**. *Fencing notes*: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.

Jump-outs: Jump-outs or escape ramps should be located appropriately to allow animals to escape the right-of-way should they gain access within the fenced area. We recommend a pair of jump-outs (one on each side of highway) close to the fence end (<100 m) and another pair 200-300 m from the first pair. Examples and technical specifications are given in **Appendix E, Sheet C**.

9. MES-25 Quarry North (East Area)

The site ranked 9th overall and had overall moderate scores for all criteria. The highest score (4) was for Local Knowledge, indicating that despite the average scores the site is important for mitigating road-kill and loss of connectivity for the main species in the area: deer, elk, cougar and black bear. Quarry North had moderate or average scores for Human Disturbance (lack of), Local Conservation Value (4) and Mortality Risk (3). It had moderately low scores for Regional Conservation Significance (1.5). Modeling of regional connectivity for wolverine movement indicated this location was relatively important for high elevation species. The site had a moderate high score for Constructability (3). There is a small culvert of unknown dimensions at the site that would be rebuilt should the TCH be improved through widening or twinning.

To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended (see *Wildlife Underpass with water flow*, **Appendix E, Sheet A**). Selection of design type is dependent on terrain, engineering and hydrological constraints. Minimum dimension for underpass is 2.6 m wide x 2.8 m high to pass common wildlife species through this area. Retrofitting the existing creek culvert to a larger underpass will need to have design that allows for wildlife passage (>1-2 m path on one side or other) above high water levels to ensure hydrological and wildlife connectivity function at this location.

Wing fencing (200–500 m depending on terrain) will be used to guide wildlife to the underpass. Each mitigation situation is different and will require a site-specific assessment, but as a general rule, fence ends should terminate at a wildlife crossing structure. If a wildlife crossing cannot be installed at the fence ends, then fences should be designed to terminate in the least suitable location or habitat for wildlife movement—i.e., places wildlife are least likely to cross roads. Examples of terminations and fence technical specifications are given in **Appendix E, Sheet B**. *Fencing notes*: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.

Jump-outs: Jump-outs or escape ramps should be located appropriately to allow animals to escape the right-of-way should they gain access within the fenced area. We recommend a pair of jump-outs (one on each side of highway) close to the fence end (<100 m) and another pair 200-300 m from the first pair. Examples and technical specifications are given in **Appendix E, Sheet C**.

10. MES-13 West Heather (Central Area)

The site ranked 10th overall and was rated high (5) for Human Disturbance (lack of). It had moderate scores for Regional Conservation Significance (3.25), Local Conservation Value (3) and Local Knowledge (3) in terms of the importance of this area for reducing wildlife mortality and maintaining movement across the TCH. Modeling of regional connectivity for black bear (3) grizzly bear (4) and wolverine (4) movement indicated this location was particularly important. The site had a low score for Mortality Risk (1), however, moose, deer, elk and bears are in the area. The site had a moderate high score for Constructability (3). There is a small culvert of unknown dimensions at the site that would be rebuilt should the TCH be improved through widening or twinning.

To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended (see *Wildlife Underpass with water flow*, **Appendix E, Sheet A**). Selection of design type is dependent on terrain, engineering and hydrological constraints. There is ample fill on both sides of highway. Minimum dimension for underpass is elliptical culvert 4 m high x 7 m wide. Retrofitting the existing creek culvert to a larger underpass will need to have design that allows for wildlife passage (>2 m path on one side or other) above high water levels to ensure hydrological and wildlife connectivity function at this location. Open span measuring 2.5 m high x 11 m wide should also be considered.

Wing fencing (200–500 m depending on terrain) will be used to guide wildlife to the underpass. Each mitigation situation is different and will require a site-specific assessment, but as a general rule, fence ends should terminate at a wildlife crossing structure. If a wildlife crossing cannot be installed at the fence ends, then fences should be designed to terminate in the least suitable location or habitat for wildlife movement—i.e., places wildlife are least likely to cross roads. Examples of terminations and fence technical specifications are given in **Appendix E, Sheet B**. *Fencing notes*: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.

Jump-outs: Jump-outs or escape ramps should be located appropriately to allow animals to escape the right-of-way should they gain access within the fenced area. We recommend a pair of jump-outs (one on each side of highway) close to the fence end (<100 m) and another pair 200-300 m from the first pair. Examples and technical specifications are given in **Appendix E, Sheet C**.

11. MES-06 West Hanner (West Area)

There are two potential sites for mitigation: MES-06 and MES-06B (see **Appendix D**). The site ranked 11th overall and was rated high (5) for Human Disturbance (lack of) and Local Conservation Value (3) and Local Knowledge (4) in terms of the importance of this area for reducing wildlife mortality and maintaining movement across the TCH. It had low score for Regional Conservation Significance (2) as modeling of regional connectivity indicated this location was not particularly important. The site had a low score for Mortality Risk (1), however, moose, elk and bears are in the area. The site had moderate score for Constructability (3). There is a small culvert of unknown dimensions at the site that would be rebuilt should the TCH be improved through widening or twinning.

To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended (see *Wildlife Underpass with water flow*, **Appendix E, Sheet A**). Selection of design type is dependent on terrain, engineering and hydrological constraints. The north side of TCH has steep slopes, from here a diagonal drainage runs down to the site on TCH. The south side has a moderately steep slope but the highway is on good amount of fill for an underpass. Lots of space from road edge to toe of slope.

An open-span design is preferred, however a bottomless arch may be required to accommodate creek/hydrological requirements. Minimum dimension for underpass is 11 m wide x 3 m high due to high likelihood of moose and grizzly bear movement through this area. Retrofitting the existing creek culvert to a larger underpass will need to have design that allows for wildlife passage (>3 m path on one side or other) above high water levels to ensure hydrological and wildlife connectivity function at this location.

Wing fencing (200–500 m depending on terrain) will be used to guide wildlife to the underpass. Each mitigation situation is different and will require a site-specific assessment, but as a general rule, fence ends should terminate at a wildlife crossing structure. If a wildlife crossing cannot be installed at the fence ends, then fences should be designed to terminate in the least suitable location or habitat for wildlife movement—i.e., places wildlife are least likely to cross roads. Examples of terminations and fence technical specifications are given in **Appendix E, Sheet B**. *Fencing notes*: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.

Jump-outs: Jump-outs or escape ramps should be located appropriately to allow animals to escape the right-of-way should they gain access within the fenced area. We recommend a pair of jump-outs (one on each side of highway) close to the fence end (<100 m) and another pair 200-300 m from the first pair. Examples and technical specifications are given in **Appendix E, Sheet C**.

12. MES-10 Beaver 1 (Central Area)

The site ranked 12th overall and was rated high (5) for Human Disturbance (lack of) and Local Conservation Value (4). It had a moderate score for Local Knowledge (3) in terms of the importance of this area for reducing wildlife mortality and maintaining movement across the

TCH. It had low score for Regional Conservation Significance (1.75) though modeling of regional connectivity indicated this location was moderately important for wolverine connectivity (3). The site also had a low score for Mortality Risk (1), however, moose, deer and bears are in the area. The site had a moderate score for Constructability (3). There is no existing infrastructure at the site.

To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended (see *Wildlife Underpass*, **Appendix E, Sheet D**). Selection of design type is dependent on terrain, engineering and hydrological constraints. There is ample fill on both sides of highway. Minimum dimension for underpass is elliptical culvert 4 m high x 7 m wide. Open span measuring 2.5 m high x 11 m wide should also be considered.

Wing fencing (200–500 m depending on terrain) will be used to guide wildlife to the underpass. Each mitigation situation is different and will require a site-specific assessment, but as a general rule, fence ends should terminate at a wildlife crossing structure. If a wildlife crossing cannot be installed at the fence ends, then fences should be designed to terminate in the least suitable location or habitat for wildlife movement—i.e., places wildlife are least likely to cross roads. Examples of terminations and fence technical specifications are given in **Appendix E, Sheet B**. *Fencing notes*: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.

Jump-outs: Jump-outs or escape ramps should be located appropriately to allow animals to escape the right-of-way should they gain access within the fenced area. We recommend a pair of jump-outs (one on each side of highway) close to the fence end (<100 m) and another pair 200-300 m from the first pair. Examples and technical specifications are given in **Appendix E, Sheet C**.

13. MES-14 West Quartz Creek (Central Area)

The site similar to MES-13 in site conditions and scoring. MES-14 ranked 13th overall and was rated high (5) for Human Disturbance (lack of). It had moderate scores for Regional Conservation Significance (2.5), Local Conservation Value (3) and Local Knowledge (3) in terms of the importance of this area for reducing wildlife mortality and maintaining movement across the TCH. Modeling of regional connectivity for black bear (4) and moose (4) movement indicated this location was particularly important for low elevation species. The black bear modeling indicated this was a particularly good location for cross-highway connectivity. Being adjacent to Quartz Creek this location (similar to MES-16) may receive lateral movement within the Quartz Creek drainage. The site had a low score for Mortality Risk (1), however, moose, deer, elk and bears are in the area. The site had a moderate high score for Constructability (3). There is a small culvert of unknown dimensions at the site that would be rebuilt should the TCH be improved through widening or twinning.

To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended (see *Wildlife Underpass with water flow*, **Appendix E, Sheet A**). Selection of design type is dependent on terrain, engineering and hydrological constraints. There is ample fill on both sides of highway. Minimum dimension for underpass is elliptical culvert 4 m high x 7 m wide. Open span measuring 2.5 m high x 11 m wide should also be considered. Retrofitting the existing creek culvert to a larger underpass will need to have design that allows for wildlife passage (>2 m path on one side or other) above high water levels to ensure hydrological and wildlife connectivity function at this location.

Wing fencing (200–500 m depending on terrain) will be used to guide wildlife to the underpass. Each mitigation situation is different and will require a site-specific assessment, but as a general rule, fence ends should terminate at a wildlife crossing structure. If a wildlife crossing cannot be installed at the fence ends, then fences should be designed to terminate in the least suitable location or habitat for wildlife movement—i.e., places wildlife are least likely to cross roads. Examples of terminations and fence technical specifications are given in **Appendix E, Sheet B**.

Fencing notes: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.

Jump-outs: Jump-outs or escape ramps should be located appropriately to allow animals to escape the right-of-way should they gain access within the fenced area. We recommend a pair of jump-outs (one on each side of highway) close to the fence end (<100 m) and another pair 200-300 m from the first pair. Examples and technical specifications are given in **Appendix E, Sheet C**.

14. MES-16 Wiseman Creek (Central Area)

The site ranked 14th overall and was rated moderately high (4) for Human Disturbance (lack of), Local Conservation Value (4) and Local Knowledge (4). It had low scores for Regional Conservation Significance (1.5), in terms of the importance of this area for reducing wildlife mortality and maintaining movement across the TCH. The site also had a low score for Mortality Risk (1), however, moose, deer, elk and bears are in the area. The site had a moderate score for Constructability (3). There is a large culvert of unknown dimensions at the site. that would be rebuilt should the TCH be improved through widening or twinning.

To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of a large *underpass* is recommended (see *Wildlife Underpass with water flow* and *Large span bridge* **Appendix E, Sheet A & E**). Selection of design type is dependent on terrain, engineering and hydrological constraints. There is good moose habitat on both sides of highway and moose travel across the TCH to access these wetland and upland habitats. Selection of design type is dependent on terrain and engineering constraints; a large span bridge built in place of fill on causeway is the preferred design. A large span bridge underpass is preferred at this location due to moose and grizzly bear movement through this area. Whatever passage structure is built here it will need to have design that allows for wildlife passage (>3 m path on one side or other) above high water levels to ensure hydrological and wildlife connectivity function at this location.

Wing fencing (200–500 m depending on terrain) will be used to guide wildlife to the underpass. Each mitigation situation is different and will require a site-specific assessment, but as a general rule, fence ends should terminate at a wildlife crossing structure. If a wildlife crossing cannot be installed at the fence ends, then fences should be designed to terminate in the least suitable location or habitat for wildlife movement—i.e., places wildlife are least likely to cross roads. Examples of terminations and fence technical specifications are given in **Appendix E, Sheet B**. *Fencing notes*: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.

Jump-outs: Jump-outs or escape ramps should be located appropriately to allow animals to escape the right-of-way should they gain access within the fenced area. We recommend a pair of jump-outs (one on each side of highway) close to the fence end (<100 m) and another pair 200-300 m from the first pair. Examples and technical specifications are given in **Appendix E, Sheet C**.

15. MES-28 West Golden (East Area)

The site ranked 15th overall and was rated high (5) for Mortality Risk, primarily white-tailed and mule deer at this location. The site had average scores for Local Conservation Value (3) and Local Knowledge (3) in terms of the importance of this area for reducing wildlife mortality and maintaining movement across the TCH. It had moderately low score for Regional Conservation Significance (2.25) as modeling of regional connectivity indicated this location was relatively important for black bears (3) and grizzly bears (3). The site had a low score for Mortality Risk (1), however, moose and bears are in the area. The site had moderate score for Constructability (3). There is no culvert at this location.

To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended (see *Wildlife Underpass*, **Appendix E, Sheet D**). Selection of design type is dependent on terrain, engineering and hydrological constraints. Both sides of the highway have a good amount of fill. The underpass should run diagonally across TCH to connect best habitats on both sides. Minimum recommended dimension where feasible for underpass is 3 m wide x 3 m high due to importance of location for moving wildlife, primarily deer, through this area. Focal species in area such as white-tailed and mule deer, and cougars utilize culverts of recommended dimensions. There are opportunities to use fill from project to create noise and light attenuating berms at entrances to underpass.

Wing fencing (200–500 m depending on terrain) will be used to guide wildlife to the underpass. Each mitigation situation is different and will require a site-specific assessment. East end fencing would run below but next to the frontage road on the east side of TCH, while on the west side fencing would follow the edge of the wetland terminate close to the commercial lands (e.g., Tim Horton's parking lot). As a general rule, fence ends should terminate at a wildlife crossing structure. If a wildlife crossing cannot be installed at the fence ends, then fences should be designed to terminate in the least suitable location or habitat for wildlife movement—i.e., places wildlife are least likely to cross roads. Examples of terminations and fence technical specifications are given in **Appendix E, Sheet B**.
Fencing notes: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.

Jump-outs: Jump-outs or escape ramps should be located appropriately to allow animals to escape the right-of-way should they gain access within the fenced area. We recommend a pair of jump-outs (one on each side of highway) close to the fence end (<100 m) and another pair 200-300 m from the first pair. Examples and technical specifications are given in **Appendix E, Sheet C**.

7. Wildlife Crossing Design Types

7.1. Wildlife Underpass Designs

All sites covered in this report are of underpass design. There are roughly a half dozen underpass design types used worldwide (Clevenger and Huijser 2011). Specific design and maintenance details for each can be found in **Appendix E**. Here we summarize briefly key technical design and planning details for wildlife underpasses and their placement along highways.

1. *Large span bridge*—The largest of underpass structures for wildlife use, but usually not built exclusively for wildlife movement. The large span and vertical clearance allows for use by a wide range of wildlife. Structures can be adapted for amphibian and reptiles, semi-aquatic and semi-arboreal species. – **Will be designed for MES-15 Quartz Creek and possibly MES-16 Wiseman Creek.**

2. *Large mammal underpass*—Not as large as most large span bridges, but the largest of underpass structures designed specifically for wildlife use. Designed for large mammals but small- and medium-sized mammals use readily as well. – **Will be the most commonly installed underpass design in the 3 areas of the project.**

3. *Multi-use underpass*—Design similar to large mammal underpass, however management objective is co-use between wildlife and humans. Design is generally smaller than a large mammal underpass because of type of wildlife using the structures along with human use. These structures may not be adequate for all wildlife, but usually results in use by generalist species common in human-dominated environments (e.g., urban or peri-urban habitats). Large structures may be constructed to accommodate the need for more physical space for humans and habitat generalist species. – **This design is not included in our recommendations given the lack of human use in study area where underpasses will be installed.**

4. *Underpass with waterflow*—An underpass structure designed to accommodate the needs of moving water and wildlife. These underpass structures are frequently used by some large mammal species, but their use depends largely on how it is adapted for their specific crossing needs. Small- and medium-sized mammals generally utilize these structures, particularly if riparian habitat or cover is retained within the underpass. – **The majority of underpasses of this type are found in the 3 areas of the project. Creek bridges will need to be constructed that have adequate room on sides to provide a travel path for wildlife.**

7.2. Spacing Intervals for Crossing Structures

The spacing of wildlife crossings on a given section of highway will depend largely on the variability of landscape, terrain, population densities, the juxtaposition of critical wildlife habitat that intersects the roadway and the connectivity requirements for different species. Wildlife crossings are permanent structures embedded within a dynamic landscape. With the lifespan of wildlife crossing structures around 70–80 years, the location and design of the crossings need to accommodate the changing dynamics of habitat and climatic conditions and their wildlife populations over time. Environmental change is inevitable and will occur during the lifespan of the crossing structures. Some basic principles that management needs to consider:

- *Topographic features:* Wildlife crossings should be placed where movement corridors for the focal species are associated with dominant topographic features (riparian areas, ridgelines, etc). Sections of roadway can be ignored where terrain (steep slopes) and land cover (built areas) are unsuitable for wildlife and their movement.
- *Multiple species:* Crossings should be designed and managed to accommodate multiple species and variable home range sizes. A range of wildlife crossing types and sizes should be provided at frequent intervals along with necessary microhabitat elements that enhance movement, e.g., root crowns for cover. Unlike the physical structure of wildlife

crossings, microhabitat elements are movable and can be modified over time as conditions and species distributions change.

- *Adjacent land management:* How well a wildlife crossing structure performs is partly dependent upon the land management that surrounds them. Transportation and land management agencies need to coordinate in the short and long term to ensure that tracts of suitable habitat adjacent to the crossings facilitate movement to designated wildlife crossings.
- *Larger corridor network:* Wildlife crossings must connect to, and form an integral part of, a larger regional corridor network. They should not lead to "ecological dead-ends." The integrity and persistence of the larger corridor network is not the responsibility of the transportation agency, but that of neighboring land management agencies and municipalities.

These basic principles help guide the determination of how many wildlife crossings may be necessary along the TCH and how to locate them in order to get the greatest long-term value in motorist safety and wildlife conservation. There is no simple formula to determine the recommended distance between wildlife crossings, as mentioned earlier each site is different. Planning will largely be landscape- and species-specific.

The spacing interval of some wildlife crossing projects designed for large mammals are found in Table 7-1. Listed are several large-scale mitigation projects in North America (existing and planned). The spacing interval varies from one wildlife crossing per 0.9 mi (1.5 km) to one crossing per 3.8 miles (6.0 km). The projects listed indicate that wildlife crossings are variably spaced but on average about 1.2 mi (1.9 km) apart.

Table 7-1: Average spacing interval per mile between wildlife crossings designed for large mammals at existing and planned transportation projects (Clevenger and Huijser 2011).

Number of crossings	Road length km	Average Spacing/km	Location (Reference)
17	27	1 / 1.6	SR 260, Arizona USA (Dodd et al. 2007)

24	45	1 /1.9	Trans-Canada Highway,[a] Banff, Alberta Canada (Clevenger et al. 2002)
8	12	1 / 1.5	Trans-Canada Highway,[b] Banff, Alberta Canada (Parks Canada, unpubl. data)
32	51	1 / 1.6	Interstate 75, Florida USA (Foster and Humphries 1995)
42	90	1 / 2.14	US 93, Montana USA (Marshik et al. 2001)
16	24	1 / 1.5	Interstate 90, Washington USA (Wagner 2005)
4	24	1 / 6.0	US 93 Arizona USA (McKinney and Smith 2007)
82	72	1 / 0.9	A-52, Zamora Spain (Mata et al. 2005)

[a] Phase 1, 2 and 3A reconstruction.
[b] Phase 3B reconstruction.

7.3 General Guidelines for *Large Mammal Underpass* Construction

- Being generally smaller than a large span bridge, the ability to restore habitat underneath will be limited. Open designs that 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 highway near structure should not be directed toward the underpass.
- Maximize continuity of native soils adjacent to and within the underpass. Avoid importation of soils from outside the project area.

7.4. Suggested design details

Crossing structure

- Structures should be designed to meet the movement needs of the widest range of species possible 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 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 underpass is of native soils. If construction type has closed bottom (e.g., concrete box culvert), a soil substrate $\geq$ 6 in (15 cm) deep must be applied to interior.
- Revegetation is possible in areas of underpass closest to the entrance. Light conditions tend to be poor in the center of the structure.
- Design 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 either baiting or cutting trails leading to structure, if appropriate.

- Avoid building 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.
- Underpass must be within cross-highway 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 underpass. Long-range planning must ensure that adjacent lands will not be developed and the wildlife corridor network is functional.

For more information on the design and maintenance of specific mitigation measures see **Appendix E**.

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APPENDICES

APPENDIX A

Appendix A

Mitigation Emphasis Site Summaries (B1 – B5)

Highway 1 - Trans-Canada Highway between Mount Revelstoke and Glacier National Parks

Mitigation emphasis sites (MES) were identified on the provincial section of the Trans-Canada Highway (TCH) between Mount Revelstoke and Glacier National Parks as part of a contract with Parks Canada[1]. This section of TCH lies between sections we cover in this report, therefore are included to present a complete set of measures recommended for the provincial section of TCH between Revelstoke and Golden, B.C.

Informational summary sheets were prepared for each MES and describe all site-specific information with regard to mitigation importance, target species, wildlife objectives, and transportation mitigation recommendations. The Summary Information Sheets are a quick and easy reference that summarizes mitigation opportunities at each MES. Italicized text is mitigation measures that are explained in detail in **Appendix E**.

2

[2] Clevenger, A.P., M.A. Sawaya, E.L. Landguth, and B.P. Dorsey. 2014. Mitigating multi-species mortality and fragmentation on the Trans-Canada Highway through Mount Revelstoke and Glacier National Parks, British Columbia. Final report to Parks Canada Agency, Revelstoke, British Columbia.

ZONE B MAP

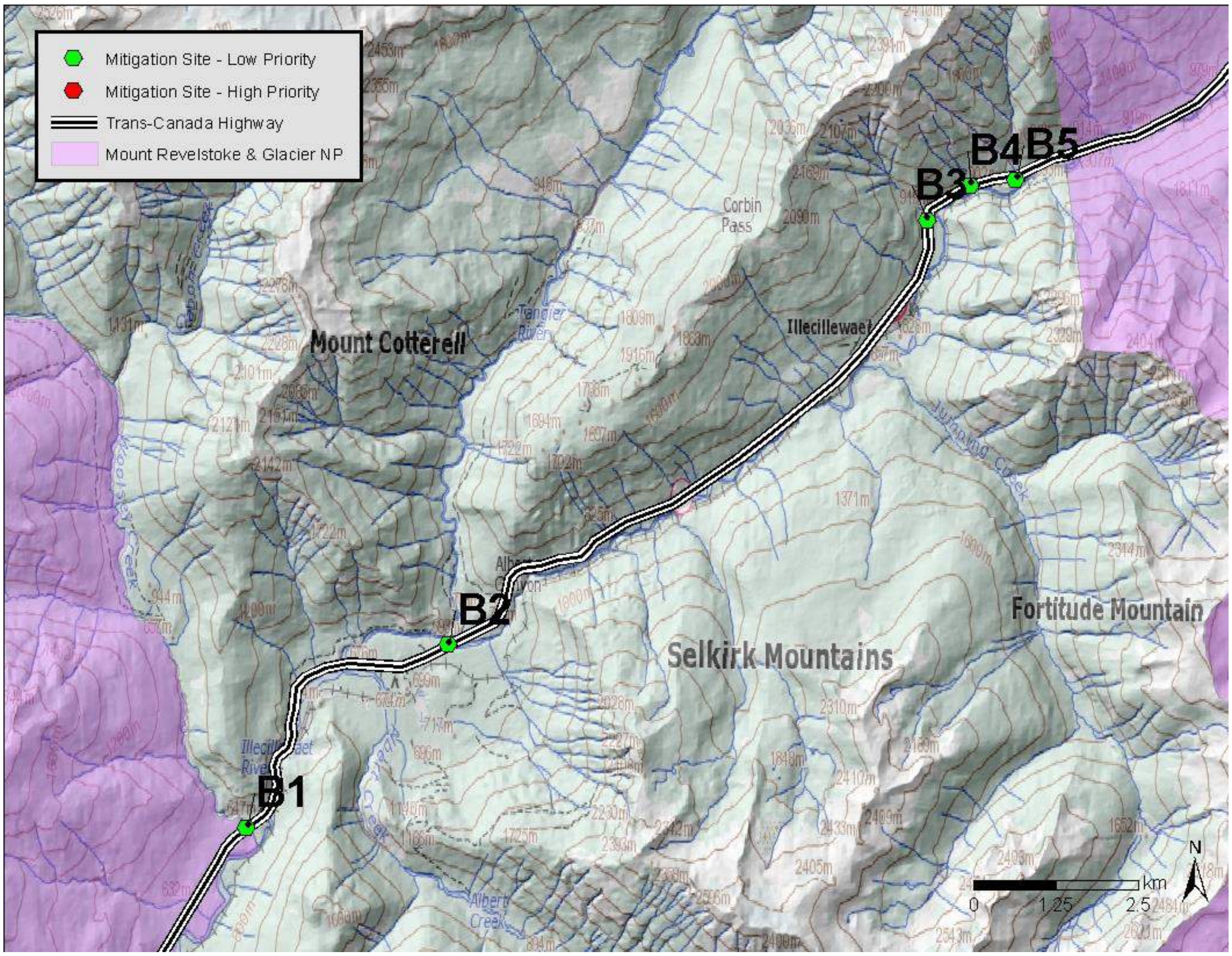

Figure B: Map showing Highway Mitigation Emphasis Zone B in Mount Revelstoke and Glacier National Parks, British Columbia.

Zone B, Site 1 Summary – Provincial (Woolsey Creek)	
Description	
LKI: 975-30.55 km	
Location: UTM: 437548, 5663159	
Species: Multi-species: Deer, moose, bears.	
Mortality risk: N/A – Provincial section of highway.	
Local conservation value: 2	
Regional conservation significance: 3	
Transportation mitigation opportunities: 5	
Wildlife objectives	
• Reduce current levels of wildlife–vehicle collisions in this section of highway, primarily deer, moose and bears. • Provide safe movement for all wildlife species across highway, primarily deer and bears.	
Existing infrastructure	
• Woolsey Creek Bridge	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily.	
Transportation mitigation opportunities	
Score: 5	
Currently the Woolsey Creek Bridge has sufficient space on both sides to allow for wildlife passage. If the highway is reconstructed, a new bridge will be added and to the existing bridge. All bridge construction or reconstruction must be designed with wildlife movement (and hydrologic flow) in mind. The new bridge should be designed with a span matching existing, allowing dry travel sections (≥5 m wide) above high-water mark. Wing *fencing* (200–500 m depending on terrain) should be installed to funnel movements to the crossing structure. Fencing notes: Snow is a concern at this location due to high annual snowfall.	

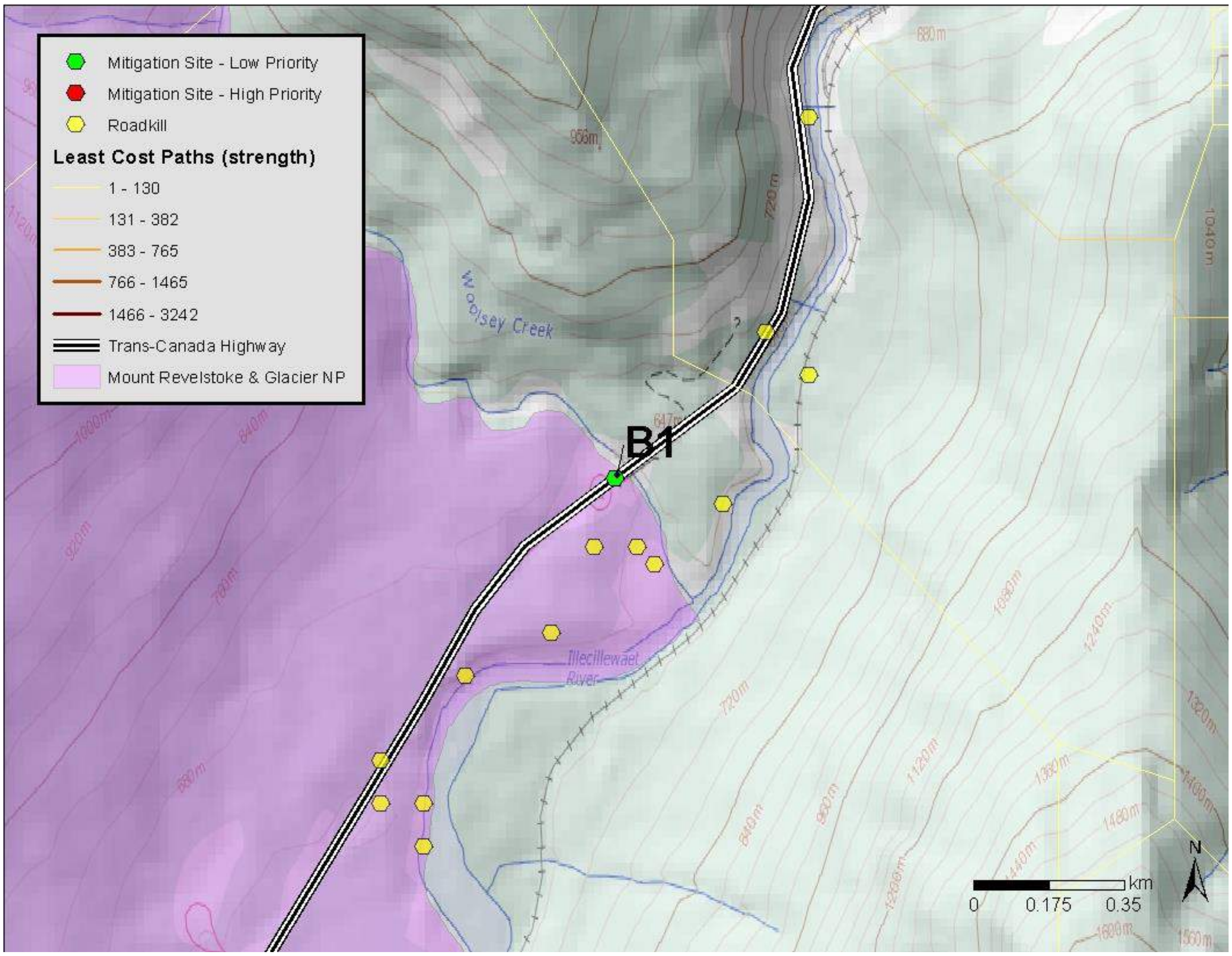

Figure B1: Map showing Highway Mitigation Emphasis Site B1 in Mount Revelstoke and Glacier National Parks, British Columbia.

Zone B, Site 2 Summary – Provincial (Tangier River)	
Description	
LKI: 975-35.47 km	
Location: UTM: 440618, 5665941	
Species: Multi-species: Deer, bears.	
Mortality risk: N/A – Provincial section of highway.	
Local conservation value: 2	
Regional conservation significance: 2	
Transportation mitigation opportunities: 5	
Wildlife objectives	
• Reduce current levels of wildlife–vehicle collisions in this section of highway, primarily deer, moose and bears. • Provide safe movement for all wildlife species across highway, primarily deer and bears.	
Existing infrastructure	
• Tangier River Bridge	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily.	
Transportation mitigation opportunities	
Score: 5	
Currently the Tangier River Bridge has sufficient space on both sides to allow for wildlife passage. If the highway is reconstructed, a new bridge will be added and to the existing bridge. All bridge construction or reconstruction must be designed with wildlife movement (and hydrologic flow) in mind. The new bridge should be designed with a span matching existing, allowing dry travel sections ($\geq$5 m wide) above high-water mark. Wing *fencing* (200–500 m depending on terrain) should be installed to funnel movements to the crossing structure. Fencing notes: Snow could be a concern at this location due to high annual snowfall.	

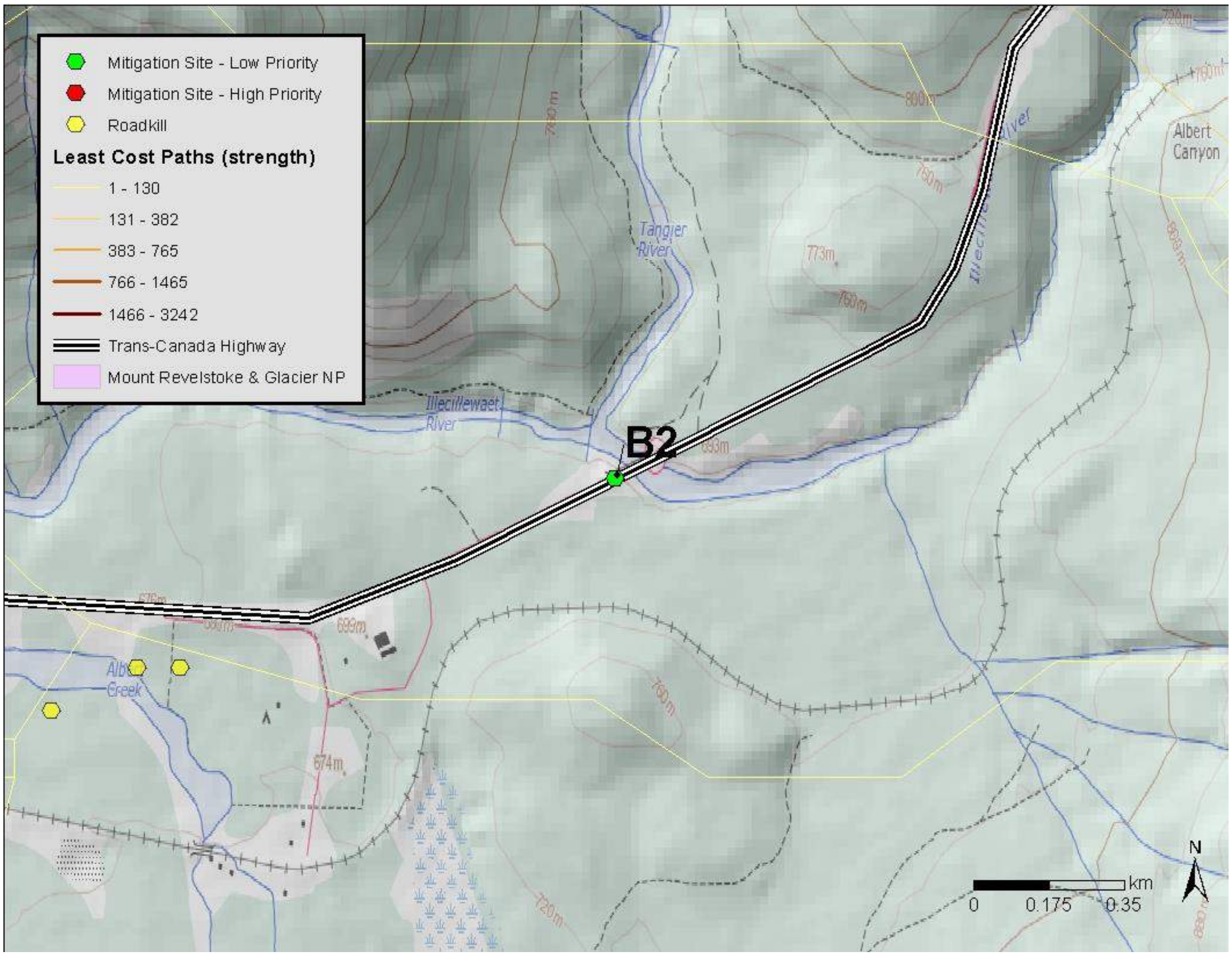

Figure B2: Map showing Highway Mitigation Emphasis Site B2 in Mount Revelstoke and Glacier National Parks, British Columbia.

Zone B, Site 3 Summary – Provincial (Snow Sheds: McDonald)	
Description	
LKI: 975-45.92 km	
Location: UTM: 447920, 5672403	
Species: Multi-species: Mountain goats, grizzly bears, wolverines, lynx, black bears.	
Mortality risk: N/A. – Provincial section of highway.	
Local conservation value: 1	
Regional conservation significance: 5	
Transportation mitigation opportunities: 5	
Wildlife objectives	
• Reduce current levels of wildlife–vehicle collisions in this section of highway, primarily mountain goats. • Provide safe movement for all wildlife species across highway, primarily grizzly bears, wolverines, lynx, black bears and mountain goats.	
Existing infrastructure	
• Snow shed.	
Target species for mitigation planning	
WVC reduction: Mountain goats primarily, but also bears. Mitigation consists of techniques to keep wildlife off the highway and effectively warn motorists of wildlife on the highway or in the show shed tunnel. **Regional conservation and connectivity**: Primarily grizzly bears, wolverines, lynx, black bears and mountain goats. Mitigation should focus on using the snow shed roof as wildlife overpass by providing access to and from roof by a "block step walkway" (see Chapter 6).	
Transportation mitigation opportunities	
Score: 5	
Mitigation strategy consists of keeping mountain goats off the highway and reducing mortality from collisions with vehicles within the snow shed tunnel and outside tunnel entrances. In the short term mitigation to reduce collisions should consist of the following measures: • *Salt diversion*. As part of pilot project prior to implementing salt diversion at snow sheds, evaluate this method of diverting goats from highway salt to areas where salt are manually dispersed in areas adjacent to escape terrain and habitats they occupy. The method has been used successfully in the Okanagan to divert goats from areas of road salt (Andrew Walker, BC Ministry of Forests, Lands, Natural Resource Operations, Penticton, BC, personal communication). • *Animal-detection system*. A radar-based animal detection system placed at tunnel entrances to warn motorists when goats and other wildlife are on the highway near tunnel entrances. The same radar-based animal detection systems placed inside tunnel will detect wildlife inside tunnel and warn motorists approaching tunnel. • *Create barrier*. Block off exterior wall of snow shed where there are existing gaps in wall that allow wildlife, primarily goats, to access tunnel interior. Make the outside wall as impermeable as possible. • *Block step walkway*. Build 1-2 structures along length of tunnel, consisting of interlocking precast concrete 'lego' blocks, that allow for wildlife (goats and bears primarily) to ascend and descend from show shed roofs. Fencing notes: High snow levels and frequent avalanche activity is a concern at this location, therefore fencing is not recommended for any mitigation.	

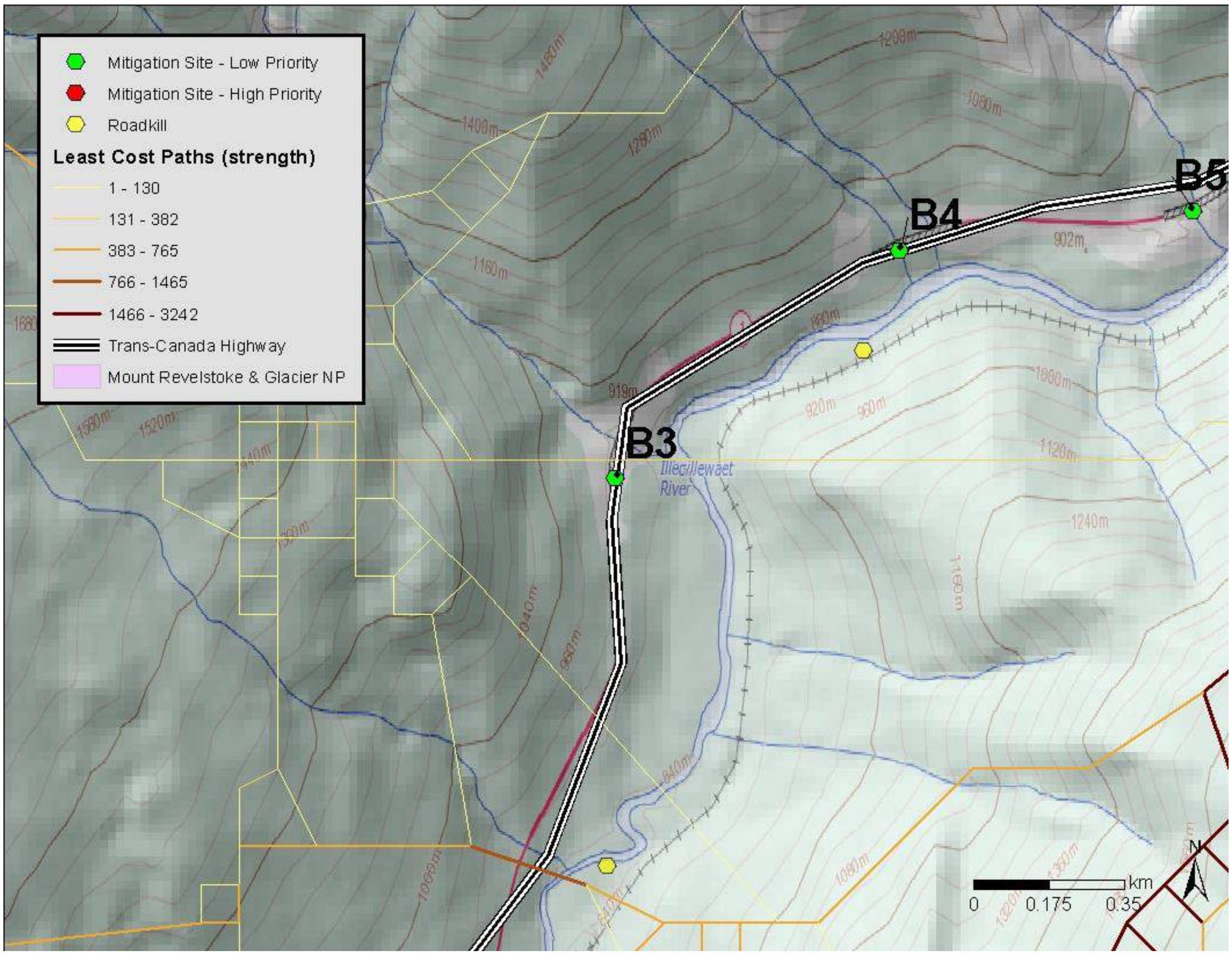

Figure B3: Map showing Highway Mitigation Emphasis Site B3 in Mount Revelstoke and Glacier National Parks, British Columbia.

Zone B, Site 4 Summary – Provincial (Snow Sheds: Twin)	
Description	
LKI: 975-46.75 km	
Location: UTM: 448583, 5672934	
Species: Multi-species: Mountain goats, grizzly bears, wolverines, lynx, black bears.	
Mortality risk: N/A. – Provincial section of highway.	
Local conservation value: 1	
Regional conservation significance: 2	
Transportation mitigation opportunities: 5	
Wildlife objectives	
• Reduce current levels of wildlife–vehicle collisions in this section of highway, primarily mountain goats. • Provide safe movement for all wildlife species across highway, primarily grizzly bears, wolverines, lynx, black bears and mountain goats.	
Existing infrastructure	
• Snow shed.	
Target species for mitigation planning	
WVC reduction: Mountain goats primarily, but also bears. Mitigation consists of techniques to keep wildlife off the highway and effectively warn motorists of wildlife on the highway or in the show shed tunnel. **Regional conservation and connectivity**: Primarily grizzly bears, wolverines, lynx, black bears and mountain goats. Mitigation should focus on using the snow shed roof as wildlife overpass by providing access to and from roof by a “block step walkway” (see Chapter 6).	
Transportation mitigation opportunities	
Score: 5	
Mitigation strategy consists of keeping mountain goats off the highway and reducing mortality from collisions with vehicles within the snow shed tunnel and outside tunnel entrances. In the short term mitigation to reduce collisions should consist of the following measures: • *Salt diversion*. As part of pilot project prior to implementing salt diversion at snow sheds, evaluate this method of diverting goats from highway salt to areas where salt are manually dispersed in areas adjacent to escape terrain and habitats they occupy. The method has been used successfully in the Okanagan to divert goats from areas of road salt (Andrew Walker, BC Ministry of Forests, Lands, Natural Resource Operations, Penticton, BC, personal communication). • *Animal-detection system*. A radar-based animal detection system placed at tunnel entrances to warn motorists when goats and other wildlife are on the highway near tunnel entrances. The same radar-based animal detection systems placed inside tunnel will detect wildlife inside tunnel and warn motorists approaching tunnel. • *Create barrier*. Block off exterior wall of snow shed where there are existing gaps in wall that allow wildlife, primarily goats, to access tunnel interior. Make the outside wall as impermeable as possible. • *Block step walkway*. Build 1-2 structures along length of tunnel, consisting of interlocking precast concrete ‘lego’ blocks, that allow for wildlife (goats and bears primarily) to ascend and descend from show shed roofs. Fencing notes: High snow levels and frequent avalanche activity is a concern at this location, therefore fencing is not recommended for any mitigation.	

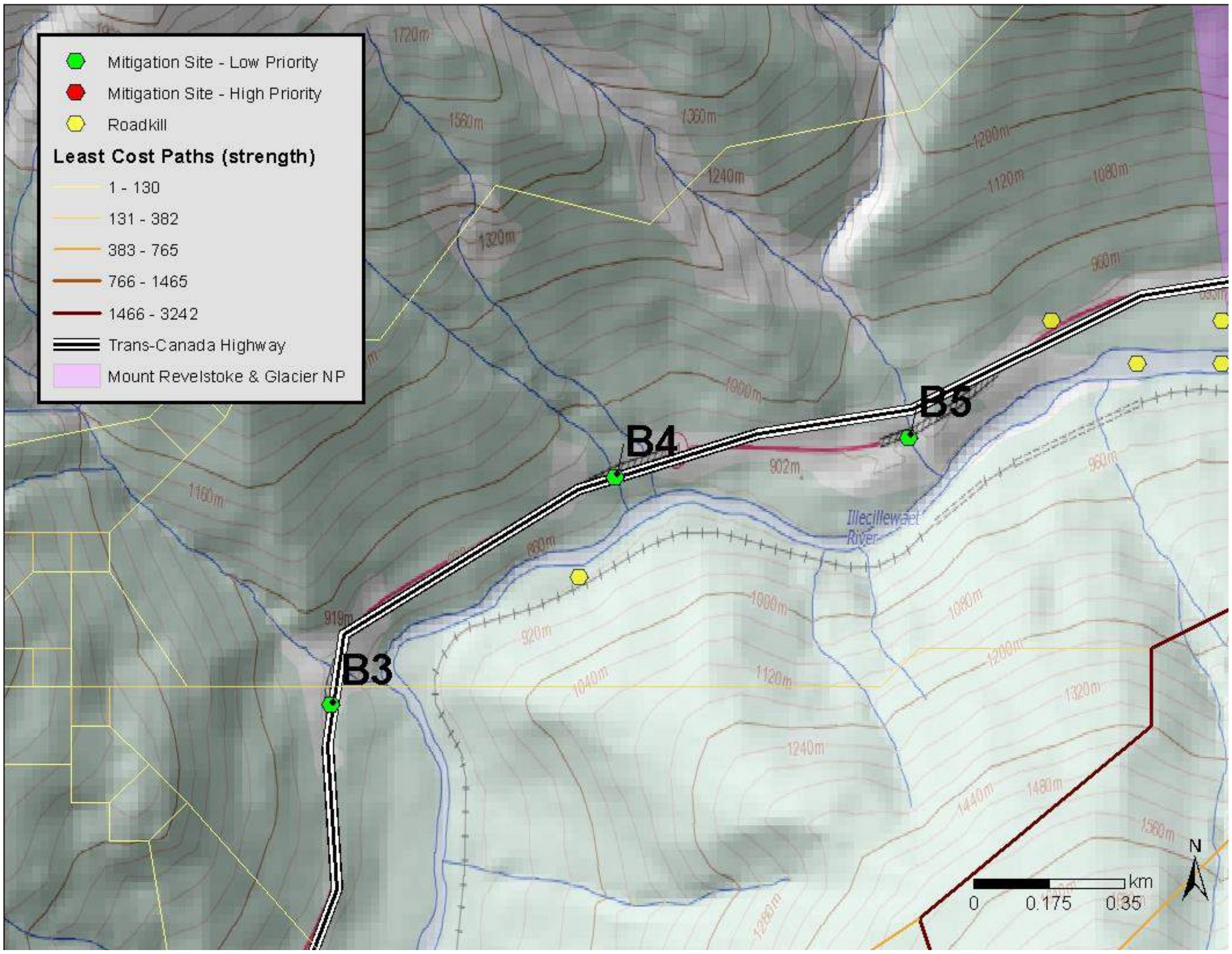

Figure B4: Map showing Highway Mitigation Emphasis Site B4 in Mount Revelstoke and Glacier National Parks, British Columbia.

Zone B, Site 5 Summary – Provincial (Snow Sheds: Lanark)	
Description	
LKI: 975-47.45 km	
Location: UTM: 449268, 5673027	
Species: Multi-species: Mountain goats, grizzly bears, wolverines, lynx, black bears.	
Mortality risk: N/A. – Provincial section of highway.	
Local conservation value: 1	
Regional conservation significance: 2	
Transportation mitigation opportunities: 5	
Wildlife objectives	
• Reduce current levels of wildlife–vehicle collisions in this section of highway, primarily mountain goats. • Provide safe movement for all wildlife species across highway, primarily grizzly bears, wolverines, lynx, black bears and mountain goats.	
Existing infrastructure	
• Snow shed.	
Target species for mitigation planning	
WVC reduction: Mountain goats primarily, but also bears. Mitigation consists of techniques to keep wildlife off the highway and effectively warn motorists of wildlife on the highway or in the show shed tunnel. **Regional conservation and connectivity**: Primarily grizzly bears, wolverines, lynx, black bears and mountain goats. Mitigation should focus on using the snow shed roof as wildlife overpass by providing access to and from roof by a "block step walkway" (see Chapter 6).	
Transportation mitigation opportunities	
Score: 5	
Mitigation strategy consists of keeping mountain goats off the highway and reducing mortality from collisions with vehicles within the snow shed tunnel and outside tunnel entrances. In the short term mitigation to reduce collisions should consist of the following measures: • *Salt diversion*. As part of pilot project prior to implementing salt diversion at snow sheds, evaluate this method of diverting goats from highway salt to areas where salt are manually dispersed in areas adjacent to escape terrain and habitats they occupy. The method has been used successfully in the Okanagan to divert goats from areas of road salt (Andrew Walker, BC Ministry of Forests, Lands, Natural Resource Operations, Penticton, BC, personal communication). • *Animal-detection system*. A radar-based animal detection system placed at tunnel entrances to warn motorists when goats and other wildlife are on the highway near tunnel entrances. The same radar-based animal detection systems placed inside tunnel will detect wildlife inside tunnel and warn motorists approaching tunnel. • *Create barrier*. Block off exterior wall of snow shed where there are existing gaps in wall that allow wildlife, primarily goats, to access tunnel interior. Make the outside wall as impermeable as possible.	

• *Block step walkway*. Build 1-2 structures along length of tunnel, consisting of interlocking precast concrete 'lego' blocks, that allow for wildlife (goats and bears primarily) to ascend and descend from show shed roofs. Fencing notes: High snow levels and frequent avalanche activity is a concern at this location, therefore fencing is not recommended for any mitigation.	

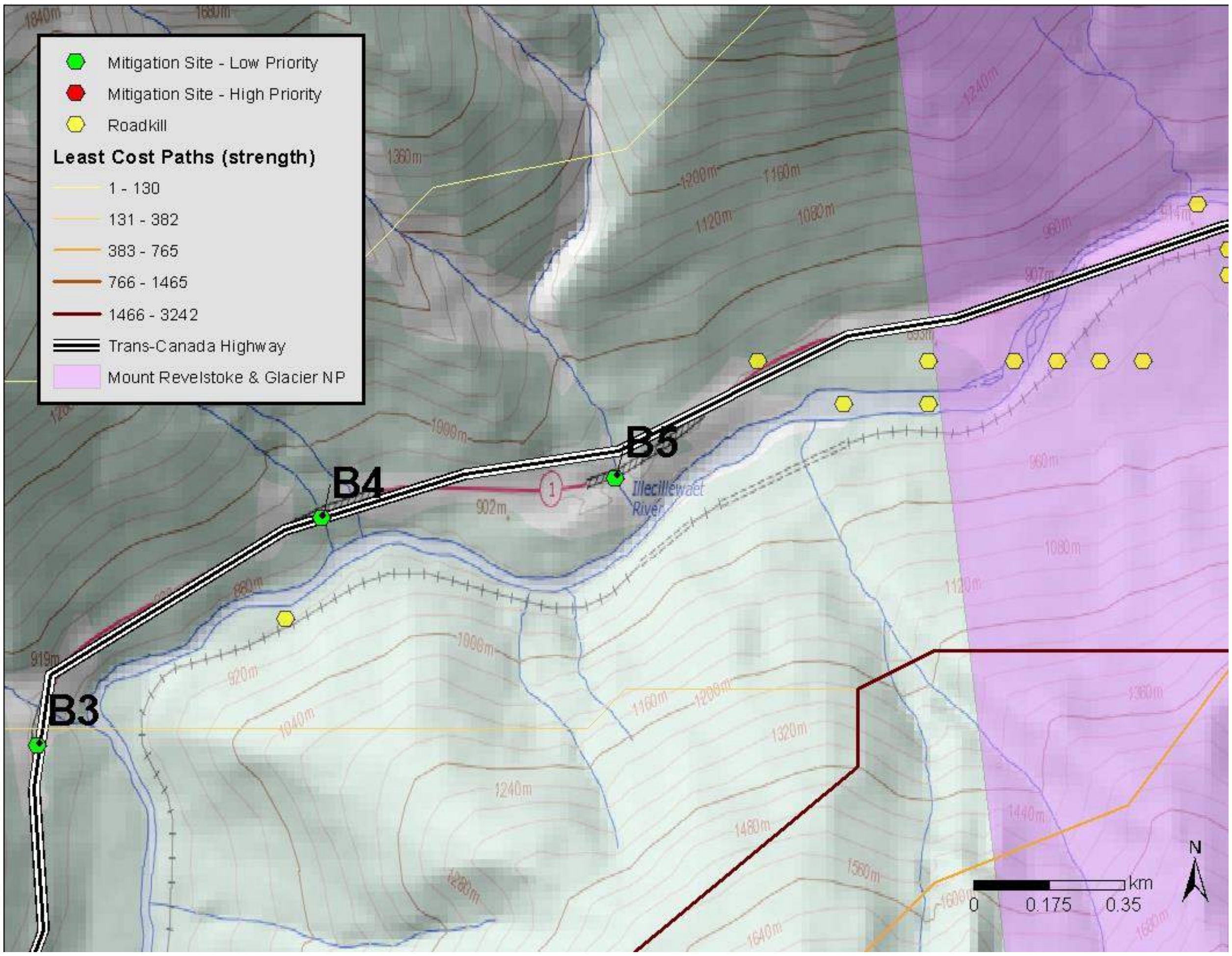

Figure B5: Map showing Highway Mitigation Emphasis Site B5 in Mount Revelstoke and Glacier National Parks, British Columbia.

APPENDIX B

Appendix B

British Columbia Ministry of Transportation and Infrastructure, Annual Day of Week Traffic Volume Summary for 2018.

BC Ministry of Transportation and Infrastructure

Annual Day of Week Summary for 2018

Site Names: Twin Slides P-37-4EW - NY
County: N/A
Funct. Class:
Location: Route 1, 47.0 km east of Revelstoke

Seasonal Factro Group: Highly Seas
Daily Factor Group: Highly Seas
Axle Factor Group:
Growth Factor Group: Highly Seas

	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	MADT	MAWDT	MAWET	% POS
Jan	3,101	3,041	3,572	3,282	3,387	3,316	2,689	3,198	3,321	2,895	51
Feb	3,135	3,647	3,242	3,141	2,993	3,419	3,134	3,244	3,256	3,135	49
Mar	4,075	3,818	3,647	4,182	4,661	4,434	3,476	4,042	4,077	3,776	48
Apr	5,295	5,324	4,403	4,602	5,049	5,092	4,041	4,829	4,844	4,668	51
May	6,181	7,693	5,905	5,773	6,905	7,735	4,883	6,439	6,569	5,532	51
Jun	7,327	7,364	6,705	7,237	8,604	9,553	6,609	7,628	7,477	6,968	48
Jul	11,410	12,019	9,696	9,797	11,148	12,138	11,104	11,045	10,665	11,257	50
Aug	12,526	12,643	10,220	10,318	11,644	13,579	12,527	11,922	11,206	12,526	52
Sep	7,558	8,460	6,963	6,847	7,376	7,499	6,503	7,315	7,411	7,031	52
Oct	4,518	5,661	4,293	4,441	5,374	5,943	4,166	4,914	4,942	4,342	49
Nov	3,300	3,563	3,384	3,408	3,744	3,783	2,960	3,449	3,525	3,130	49
Dec	4,012	3,134	2,730	3,967	4,090	4,721	3,852	3,787	3,480	3,932	48

	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	AADT	AAWDT	AAWET	% POS
2018	6,037	6,364	5,397	5,583	6,248	6,768	5,495	5,984	5,898	5,766	50
2017	6,286	6,450	5,463	5,566	6,294	6,981	5,317	6,051	5,943	5,802	50
2016	6,723	6,500	5,574	5,742	6,791	7,114	5,706	6,307	6,152	6,214	50
2015	6,348	6,350	5,344	5,424	6,202	6,791	5,487	5,992	5,830	5,917	49
2014	5,820	5,986	5,022	4,927	5,742	6,317	5,079	5,556	5,419	5,449	50
2013											
2012	5,529	5,961	4,828	4,800	5,798	6,265	4,926	5,444	5,347	5,227	50
2011	4,988	5,032	4,376	4,251	5,251	5,373	4,135	4,772	4,728	4,562	52
2010	5,435	5,349	4,425	4,566	5,292	5,680	4,490	5,034	4,908	4,963	50
2009	5,015	4,878	4,167	4,104	4,717	5,213	4,130	4,603	4,466	4,572	52

APPENDIX C

Connectivity Modeling

For our connectivity models, we focused on *black bears, grizzly bears, moose, and wolverines*, because they have huge home ranges so they need to cross roads frequently to access habitat patches, they disperse long distances so they are good species for landscape resistance models (Cushman et al. 2006), they may be suitable surrogates for other forest dwelling species (e.g., ungulates, cougars, wolves) and they are large-bodied so their WVCs pose a risk to public safety. We gathered *landscape data* to hypothesize resistance to movement for each species: an iterative approach allowed us to test the interactions and relative strengths of each additional environmental variable on the effects on connectivity in this area.

As described in the Connectivity Section, we created *landscape resistance models* hypothesizing resistance to movement for black bears, grizzly bears, moose, and wolverines. We converted the landscape data to a landscape resistance model following Cushman et al. (2006). We randomly placed 500 points in our study area. Preliminary runs explored number of points and point placement with relatively little change in path convergence. Least cost path models identify the shortest path of least resistance from point A to point B. We used UNICOR (Landguth et al. 2012) to run least cost paths between the 500 starting points and examined areas where the paths crossed the TCH.

Isolation-by-landscape resistance

We produced dozens of landscape-resistance surfaces representing the factorial combinations of 9 landscape factors: aspect, elevation, forest cover, non-habitat, protected areas, roads, ruggedness, slope, and snow cover (Table S1.1). These factors are the landscape features to which black bears, grizzly bears, moose, and wolverines respond most strongly (Cushman et al. 2006, Graves et al 2014, Clevenger et al. 2017, and Balkenhol et al 2009, respectively). Elevation is the most informative measure of physiography, which is why we chose to model across 3 elevation gradients; roads and land cover have well established relationships to habitat quality and movement for a wide range of organisms and for grizzly bears in particular (Proctor et al 2015).

Table S1.1: Metadata for all layers used in the analysis.

Coverage	Description	Source
Aspect	Degree of aspect	Derived from 30-m DEM
Elevation	Digital elevation model meters	Derived from 30-m DEM
Non-habitat	A combined layer that includes features of known impermeability	Geogratis and LLYK Field Unit GIS data
Roads	Road layer including Trans-Canada Highway (TCH), Highways 93 and 95, and other roads	Geogratis and LLYK Field Unit GIS data
Forests	Tree cover percentage classified into forest/non forest areas	Hansen et al. 2013.
Protected Areas	National and Provincial Parks	Geogratis and LLYK Field Unit GIS data
Ruggedness	Topographic Position Index	Derived from 30-m DEM
Slope	Degree of slope	Derived from 30-m DEM
Snow Cover	Persistent snow layer following Copeland	Ben Dorsey, MRG Field Unit

Note: All coverages were resampled to raster grids with 180-m cell size and projection UTM NAD 1983 Z11 system.

Resistance of these factors to gene flow was modeled across 4 levels for elevation, 2 levels for forest cover, 2 levels for non-habitat, 2 levels for protected areas, 3 levels for roads, 2 levels for ruggedness, and 2 levels for snow cover (Table S1.2). We specified a range of levels for each factor, allowing the relative importance of each factor to be expressed in a multifactor model. In this approach, models are most sensitive to the relative magnitude of the factors, not their specific values. Thus, the levels were chosen to cover the range of each factor on the landscape, and all factors were scaled between 1 and 10, allowing each factor to speak with equal weight. The resistance maps corresponding to each factor were combined into the 3 landscape resistance models by addition. After addition, the minimum value on the combined grids was 9, reflecting the sum of the minimum values of the original nine factors. These connectivity models were represented by GIS raster maps whose cell values were equal to the hypothetical resistance of each cell to gene flow. Before analysis, the base maps were resampled to 90-m pixel size and projected to the UTM NAD 1983 Z11 system (Table S1.1).

Table S1.2: Description of factors and levels combined to create our landscape-resistance connectivity models.

Factor and level	**Code**	**Description**
Elevation:		
High elevation	EH	Minimum resistance at high elevation
Middle elevation	EM	Minimum resistance at medium elevation
Low elevation	EL	Minimum resistance at low elevation
Null	EN	No relationship with elevation
Slope:		
	GH	High resistance to high gradient areas
	GN	No resistance to slope/gradient
Aspect:		
	AH	High resistance to specific aspects
	AN	No resistance to aspect
Non-habitat:		
High non-habitat	HH	High resistance to non-habitat areas
Null	HN	No resistance to non-habitat areas
Roads:		
High roads without crossings	XH_0	High resistance to roads that do not include crossing structures
High roads with crossings	XH_1	High resistance to roads with low resistance areas for wildlife crossing structures
Null	XN	No resistance to roads
Forest cover:		
High non-forests	FH	High resistance to non-forested areas
Null	FN	No resistance to non-forested areas
Protected areas:		
High protected areas	PH	High resistance in non-protected areas
Null	PN	No resistance to non-protected areas
Ruggedness:		
High ruggedness	RH	High resistance to low ruggedness
Null	RN	No resistance to ruggedness
Snow cover:		
High snow	SH	High resistance to low persistent snow areas
Null	SN	No resistance to persistent snow

Elevation

Elevation in the study area ranges from 580 m – 3514 m with a 1924 m mean and 483 m standard deviation. Landscape resistance due to elevation was modeled at four levels, including a null model. Resistance was modeled as an inverted Gaussian function as Cushman et al (2006), and parameterized with a minimum of 1 and a maximum approaching an asymptote of 10. The standard deviation of the curve was 483 m. The levels differed only in the elevation at which the function reached its minimum value. The three levels of elevation had resistance minima at 976 (mean minus 2 times the standard deviation), 1924 (mean), and 2908 (mean plus 2 times the standard deviation) m, respectively (Fig. S1.1, S1.2). These three levels reflect a range of potential relationships between resistance to movement and elevation, with increasing resistance to gene flow at elevation higher and lower than the minima, with a maximum resistance of 10 times that of the minima achieved at the asymptote. The null model predicted resistance of 1 at all elevations (i.e., isolation-by-distance).

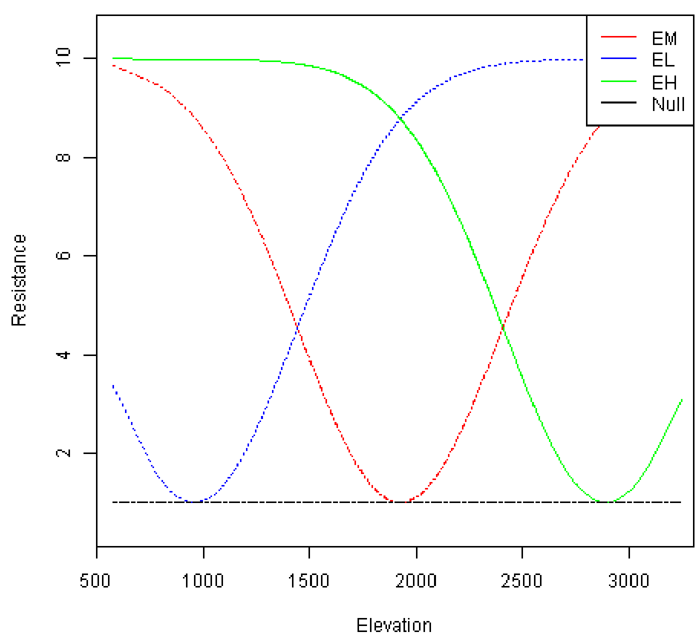

Figure S1.1: Functions used to develop hypotheses regarding resistance due to elevation. The four levels include three Gaussian function of resistance with respect to elevation and one null model. The three Gaussian levels each have a standard deviation of 483 m, minima of 1, and a maximum of 10. They differ only in the elevation at which the minimum resistance is achieved:

976 m for EL, 1924 m for EM, 2908 m for EH (see table 1 for abbreviations). The null model predicts a resistance of 1 for all elevations.

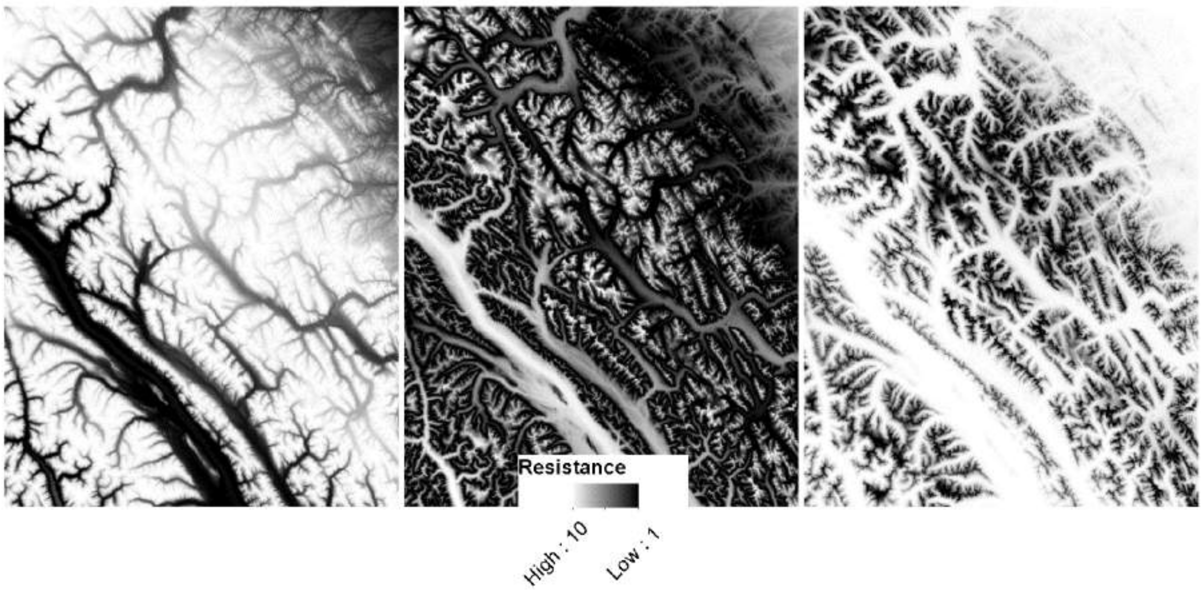

Figure S1.2: The three levels of elevation resistance reclassified based on the Gaussian functions.

Non-habitat

We created a layer for black and grizzly bears, a layer for moose, and a layer for wolverines that combines features of known impermeability for the different species. This included major lakes and buildings for moose; major lakes, permanent snow and ice, and buildings for bears; and everything except the snow/ice layer to build the non-habitat layer for wolverines. We calculated a 500m buffer around the features in the building layer using a 500m radius (Proctor et al 2015); however, the eastern end of the study area had many buildings which blocked paths with that buffer so we ended up using a 50m buffer to allow more LCPs to penetrate this area. Non-habitat except permanent snow and ice was generally classified as “no data” to create pixels impervious to movement, everything else was classified with a resistance value of 1 (see Fig. S1.3). Permanent snow and ice for bears was classified with a resistance value of 10 as bears are known, on occasion, to move through those inhospitable habitats.

Landcover

We obtained percent tree cover from https://storage.googleapis.com/earthenginepartners-hansen/GFC2015/Hansen_GFC2015_treecover2000_60N_120W.tif (Hansen et al. 2013) as a proxy for forested and non-forested areas. Percentages greater than 30 were given a resistance value of 1 and 10 elsewhere (see Fig. S1.4).

Protected areas

Protected areas were used to define three levels of high to low resistance: (1) National parks were given a resistance value of 1, (2) All other protected areas such as provincial parks were given a resistance of 5, and (3) outside of protected areas were given values of 10 (see Fig. S1.5).

Ruggedness

We used the Topography Tools extension in ArcGIS to calculate Topographic Position Index (TPI) from a Digital Elevation Model. We defined terrain ruggedness resistance by reclassifying TPI to values between 1 and 10 (1=low resistance, 10=high resistance) (Fig. S.1.6).

Snow cover

We created a persistent spring snow cover layer following Copeland et al. (2010). We used Modis Terra data from 14 April to 15 May for the 12-year period, 2000 to 2011, and classified each 500 m pixel by presence or absence of snow (Fig. S.1.7). Pixel values ranged between 0 and 12 with a value of 12 indicating that the pixel contained snow during the one-month period in all 12 years. We reclassified snow cover to resistance as follows (resist values in parentheses): snow 0-3 (10), 4 (9), 5 (8), 6 (7), 7 (6), 8 (5), 9 (4), 10 (3), 11 (2), 12 (1).

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APPENDIX D

Appendix D

Mitigation Emphasis Site Summaries (1–27)

Informational summary sheets were prepared for each mitigation emphasis site (MES) and describe all site-specific information with regard to mitigation importance, target species, wildlife objectives, and transportation mitigation recommendations. The Summary Information Sheets are a quick and easy reference that summarizes mitigation opportunities at each MES. Red shading highlights the **Top 15 priority mitigation sites**. Italicized text is mitigation measures that are explained in detail in **Appendix E**.

West

Revelstoke to West Gate of
Mount Revelstoke National Park

West Area, MES 01 Summary – Revelstoke 1	
Description	
Location (LKI): 975 - 5.58 km	
Location (UTM): 419380.5649537	
Species: Moose, deer, black bear	
SCORING	
Mortality risk: 1	
Local conservation value: 2	
Regional conservation significance: 1.5	
Human disturbance: 2	
Constructability: 1	
TOTAL SCORE: 9.5	
RANK: 27	
Local knowledge: 2	
Wildlife objectives	
• Reduce current high levels of wildlife–vehicle collisions in this section of highway, primarily deer and moose. • Provide safe movement for all wildlife species across highway, primarily deer, moose and bears.	
Existing infrastructure	
• None	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily.	
Transportation mitigation recommendations	
Constructability score: 1	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Selection of design type is dependent on terrain and engineering constraints. Maximum clearance at this site is likely 3m high. Width should be minimum 3-4 m. Wing *fencing* should be installed to funnel movements to the crossing structure. Fence terminus can tie into rock-cut immediately to the west of this site. East section of wing fencing (200-500 m) should be installed to funnel movements to the crossing structure. Fencing notes: Snow is not a concern at this location.	

West Area, MES 02 Summary – Revelstoke 2	
Description	
Location (LKI): 975 – 7.26 km	
Location (UTM): 420707.5650148	
Species: Moose primarily, deer, black bear	
SCORING	
Mortality risk: 2	
Local conservation value: 3	
Regional conservation significance: 1	
Human disturbance: 3	
Constructability: 3	
TOTAL SCORE: 14	
RANK: 22	
Local knowledge: 2	
Wildlife objectives	
• Reduce current high levels of wildlife–vehicle collisions in this section of highway, primarily deer, and moose. • Provide safe movement for all wildlife species across highway, primarily deer, moose and bears.	
Existing infrastructure	
• 600 mm diameter culvert	
Target species for mitigation planning	
WVC reduction: Common species including moose. **Regional conservation and connectivity**: Common species primarily; moose of concern. Site is at major tributary and drainage and in good wildlife habitat.	
Transportation mitigation recommendations	
Constructability score: 3	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Selection of specific design type is dependent on terrain and engineering constraints. North side has good amount of fill, while south side is steep but levels off downslope. Culvert in place carries small volume of water. Existing culvert could be replaced with a bottomless arch culvert. Minimum recommended dimension where feasible is ca. 3 m high by 7 m wide. Focal species in area such as moose utilize culverts of recommended dimensions. Wing *fencing* (200–500 m depending on terrain) should be installed to funnel movements to the crossing structure. Fencing notes: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.	

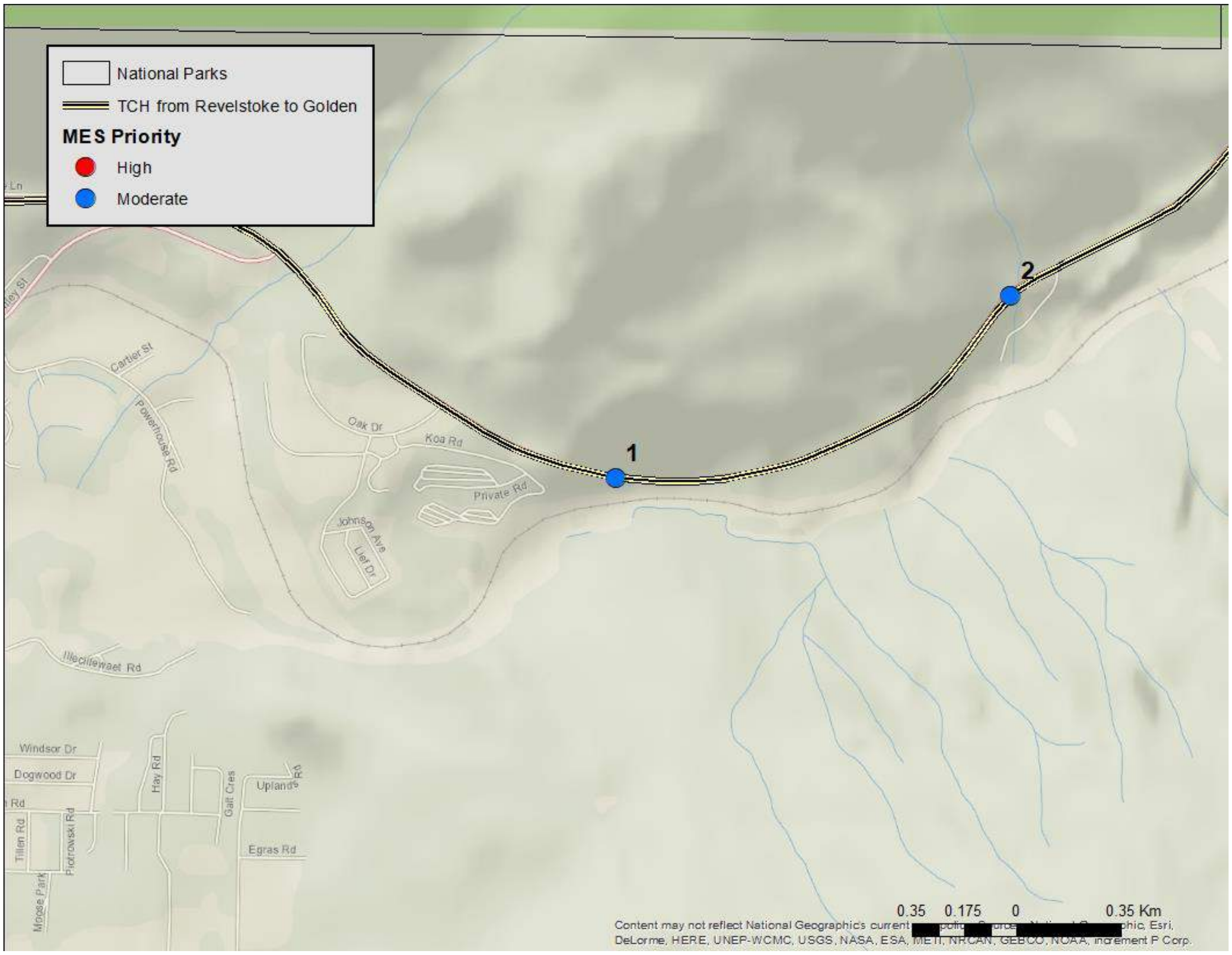

Figure A1: Map showing Highway Mitigation Emphasis Site (MES) 01 (Revelstoke 1) and 02 (Revelstoke 2) in Trans-Canada Highway study area between Revelstoke and Golden, British Columbia.

West Area, MES 03 Summary – Revelstoke 3	
Description	
Location (LKI): 975 – 8.26 km	
Location (UTM): 421873.5651141	
Species: Moose primarily, deer, black bear	
SCORING	
Mortality risk: 1	
Local conservation value: 3	
Regional conservation significance: 1.5	
Human disturbance: 3	
Constructability: 3	
TOTAL SCORE: 13.5	
RANK: 24	
Local knowledge: 2	
Wildlife objectives	
• Reduce current high levels of wildlife–vehicle collisions in this section of highway, primarily deer, and moose. • Provide safe movement for all wildlife species across highway, primarily deer, moose and bears.	
Existing infrastructure	
• Culvert (unknown dimensions)	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily. Cut blocks above site and good moose habitat.	
Transportation mitigation recommendations	
Constructability score: 3	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Selection of specific design type is dependent on terrain and engineering constraints. Culvert in place carries small volume of water. Existing culvert could be replaced with a 3 x 7 m elliptical culvert, large enough to pass moose. There is good amount of fill on the north side and gentle slope on south side. Focal species in area utilize culverts of recommended dimensions. Wing *fencing* (200–500 m depending on terrain) should be installed to funnel movements to the crossing structure. Fencing notes: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.	

West Area, MES 04 Summary – Greely West	
Description	
Location (LKI): 975 – 9.86 km	
Location (UTM): 422621.5651350	
Species: Moose, deer, black bear	
SCORING	
Mortality risk: 1	
Local conservation value: 3	
Regional conservation significance: 1	
Human disturbance: 4	
Constructability: 4	
TOTAL SCORE: 15	
RANK: 20	
Local knowledge: 2	
Wildlife objectives	
• Reduce current high levels of wildlife–vehicle collisions in this section of highway, primarily deer, and moose. • Provide safe movement for all wildlife species across highway, primarily deer, moose and bears.	
Existing infrastructure	
• 600 mm diameter culvert	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily.	
Transportation mitigation recommendations	
Constructability score: 4	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Selection of specific design type is dependent on terrain and engineering constraints. Steep slope on the north side, while moderate slope angle down to river on south side. Culvert in place carries small volume of water. Existing culvert could be replaced with a bottomless arch culvert, minimum recommended dimension where feasible ca. 3 m high by 7 m wide. Focal species in area such as moose utilize culverts of recommended dimensions. Wing *fencing* (200–500 m depending on terrain) should be installed to funnel movements to the crossing structure. Fencing notes: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.	

West Area, MES 05 Summary – Hamilton Creek	
Description	
Location (LKI): 975 – 11.30 km	
Location (UTM): 423548.5651828	
Species: Moose primarily, but also deer, black bear	
SCORING	
Mortality risk: 4	
Local conservation value: 3	
Regional conservation significance: 1.75	
Human disturbance: 4	
Constructability: 3	
TOTAL SCORE: 20.75	
RANK: 4	
Local knowledge: 5	
Wildlife objectives	
• Reduce current high levels of wildlife–vehicle collisions in this section of highway, primarily deer, and moose. • Provide safe movement for all wildlife species across highway, primarily deer, moose and bears.	
Existing infrastructure	
• 3000 mm diameter culvert	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily, including moose and grizzly bears.	
Transportation mitigation recommendations	
Constructability score: 3	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Selection of design type is dependent on terrain and engineering constraints; open-span preferred design. Minimum recommended dimension where feasible is 11 m wide x 3 m high due to high likelihood of grizzly bear movement through this area. Fish values high in Hamilton Creek and can capitalize fish and wildlife passage requirements. Wing *fencing* (200–500 m depending on terrain) should be installed to funnel movements to the crossing structure. Fencing notes: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.	

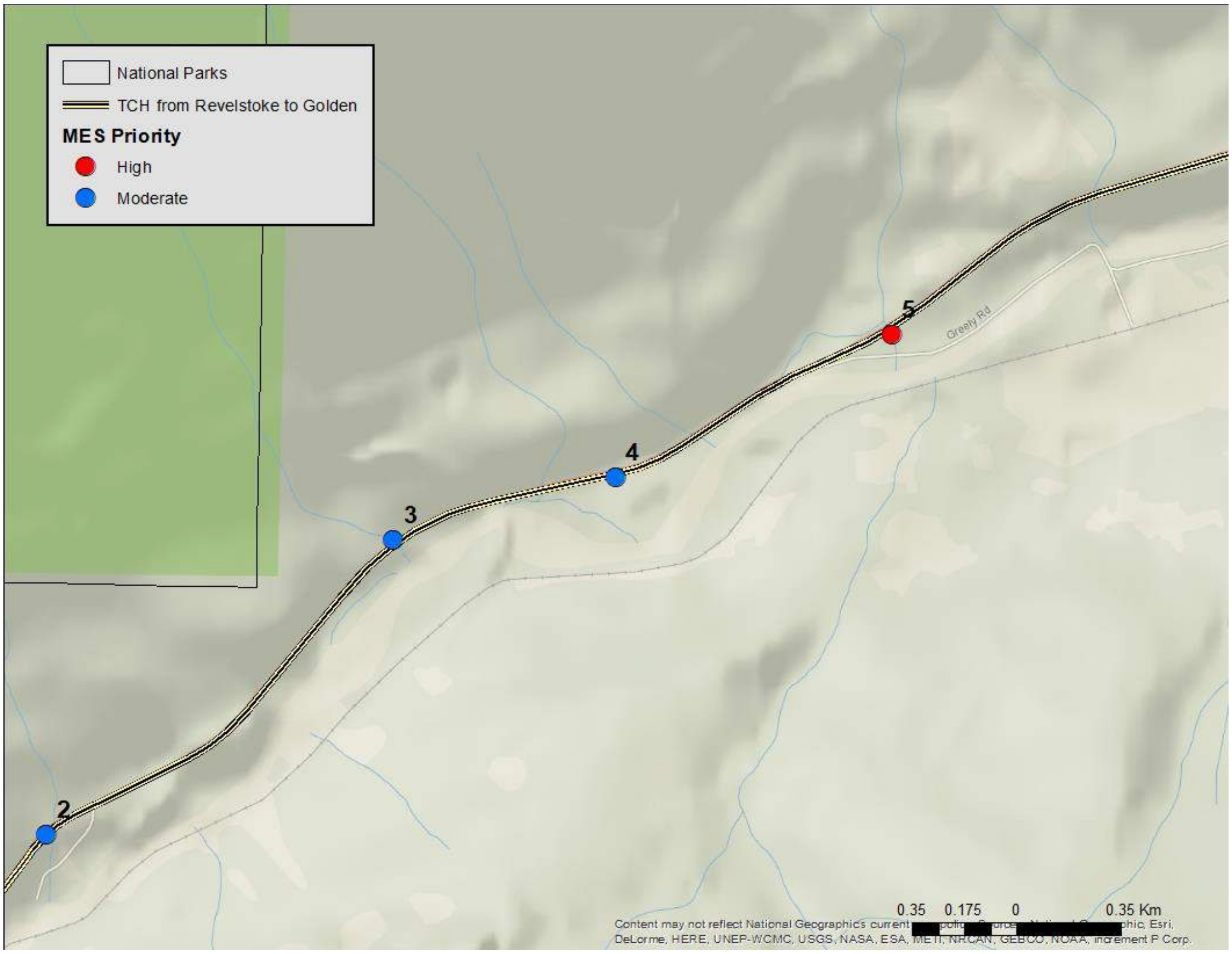

Figure A2: Map showing Highway Mitigation Emphasis Site (MES) 03 (Revelstoke 3), 04 (Greely West) and 05 (Hamilton Creek) in Trans-Canada Highway study area between Revelstoke and Golden, British Columbia.

West Area, MES 06 Summary – West Hanner	
Description	
Location (LKI): 975 – 14.20 km	
Location (UTM): 427122.5653439	
Species: Moose primarily, but also deer and black bear	
SCORING	
Mortality risk: 1	
Local conservation value: 3	
Regional conservation significance: 2	
Human disturbance: 5	
Constructability: 3	
TOTAL SCORE: 18	
RANK: 11	
Local knowledge: 4	
Wildlife objectives	
• Reduce current high levels of wildlife–vehicle collisions in this section of highway, primarily moose. • Provide safe movement for all wildlife species across highway, primarily moose, deer and bears.	
Existing infrastructure	
• Small culvert (unknown dimensions) with flow	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily, including moose and grizzly bears.	
Transportation mitigation recommendations	
Constructability score: 3	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Selection of design type is dependent on terrain and engineering constraints; open-span preferred design. North side has steep slopes. Diagonal drainage runs down to site on TCH. South side is moderately steep slope but highway is on good amount of fill. Lots of space from road edge to toe of slope. Minimum recommended dimension where feasible is 11 m wide x 3 m high due to high likelihood of grizzly bear movement through this area. Wing *fencing* (200–500 m depending on terrain) should be installed to funnel movements to the crossing structure. Fencing notes: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.	

West Area, MES 06B Summary – West Hanner	
Description	
Location (LKI): 975 – 14.35 km	
Location (UTM): 427119.5653434	
Species: Moose primarily, but also deer and black bear	
SCORING	
Mortality risk: 1	
Local conservation value: 3	
Regional conservation significance: 2	
Human disturbance: 5	
Constructability: 3	
TOTAL SCORE: 18	
RANK: 11	
Local knowledge: 4	
Wildlife objectives	
• Reduce current high levels of wildlife–vehicle collisions in this section of highway, primarily moose. • Provide safe movement for all wildlife species across highway, primarily moose, deer and bears.	
Existing infrastructure	
• 600 mm diameter culvert	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily, including moose and grizzly bears.	
Transportation mitigation recommendations	
Constructability score: 3	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Selection of design type is dependent on terrain and engineering constraints; open-span preferred design. North side has steep slopes. Diagonal drainage runs down to site on TCH. South side is moderately steep slope but highway is on good amount of fill. Lots of space from road edge to toe of slope. Minimum recommended dimension where feasible is 11 m wide x 3 m high due to high likelihood of grizzly bear movement through this area. Wing *fencing* (200–500 m depending on terrain) should be installed to funnel movements to the crossing structure. Fencing notes: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.	

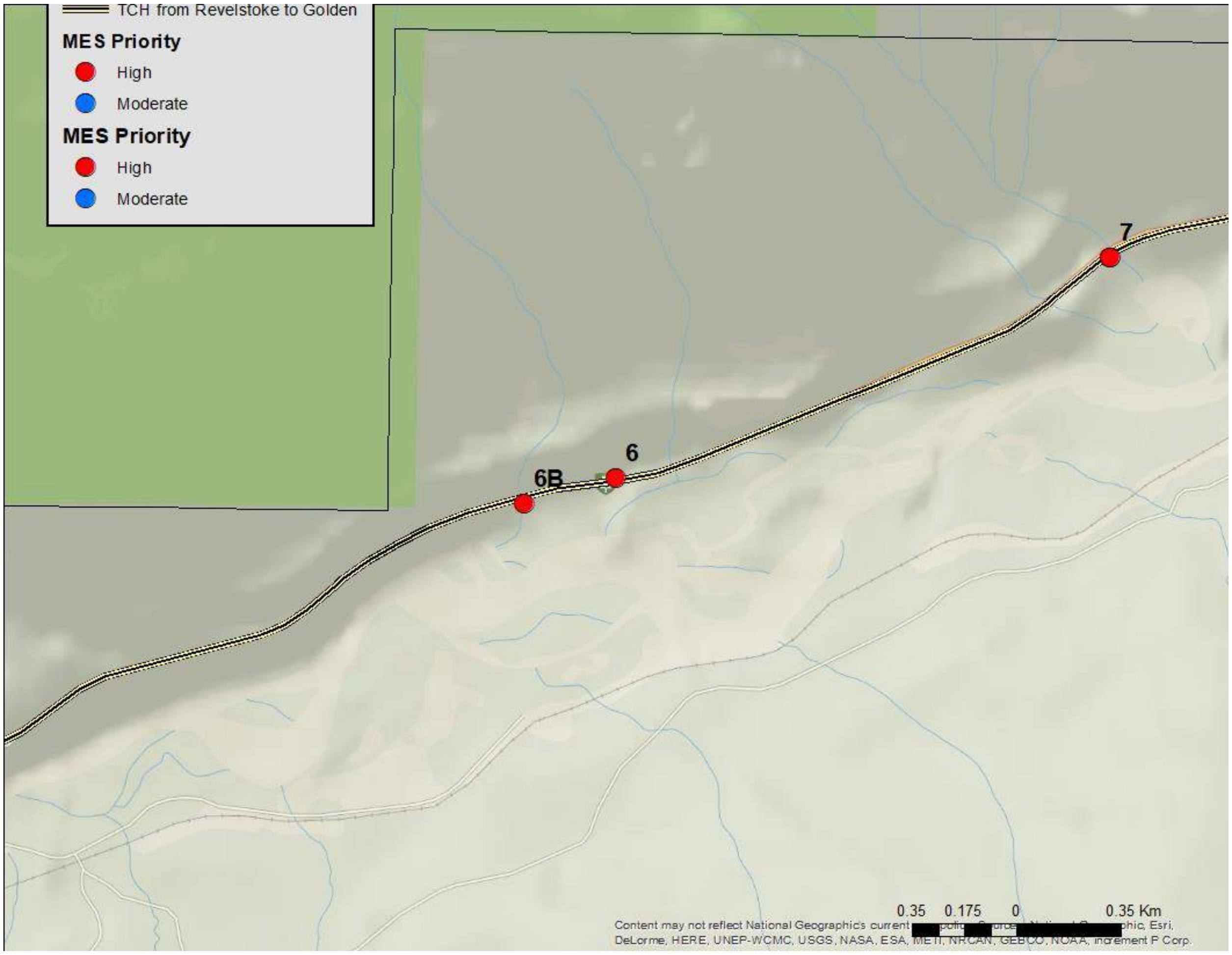

Figure A3: Map showing Highway Mitigation Emphasis Site (MES) 06 (West Hanner) in Trans-Canada Highway study area between Revelstoke and Golden, British Columbia.

West Area, MES 07 Summary – Hanner Lake	
Description	
Location (LKI): 975 – 16.25 km	
Location (UTM): 428783.5654180	
Species: Moose primarily, elk and black bear	
SCORING	
Mortality risk: 2	
Local conservation value: 4	
Regional conservation significance: 1	
Human disturbance: 5	
Constructability: 3	
TOTAL SCORE: 20	
RANK: 6	
Local knowledge: 5	
Wildlife objectives	
• Reduce current high levels of wildlife–vehicle collisions in this section of highway, primarily for moose, elk and bears. • Provide safe movement for all wildlife species across highway, primarily elk, moose and bears.	
Existing infrastructure	
• Culvert (unknown dimensions)	
Target species for mitigation planning	
WVC reduction: Common species, including moose and elk. **Regional conservation and connectivity**: Common species primarily, including moose and grizzly bear.	
Transportation mitigation recommendations	
Constructability score: 3	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* and *overpass* are possible at this location. Selection of specific design type is dependent on terrain and engineering constraints. North side has good amount of fill, while south side is steep but levels off downslope. Culvert in place carries small volume of water. Wildlife underpass could be situated at either end (west or east ends) of the South side slope embankment as there are shoulder sections that the underpass could tie into and serve as travel ramp to and from underpass. At the east end there is a rock cut that could serve as possible location for wildlife overpass, pending engineering and geotechnical feasibility of the site. Minimum recommended underpass dimension where feasible ca. 3 m high by 11 m wide. Minimum recommended overpass dimension is 40m wide. Focal species in area such as moose utilize culverts of recommended dimensions. Wing *fencing* (200–500 m depending on terrain) should be installed to funnel movements to the crossing structure. Fencing notes: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.	

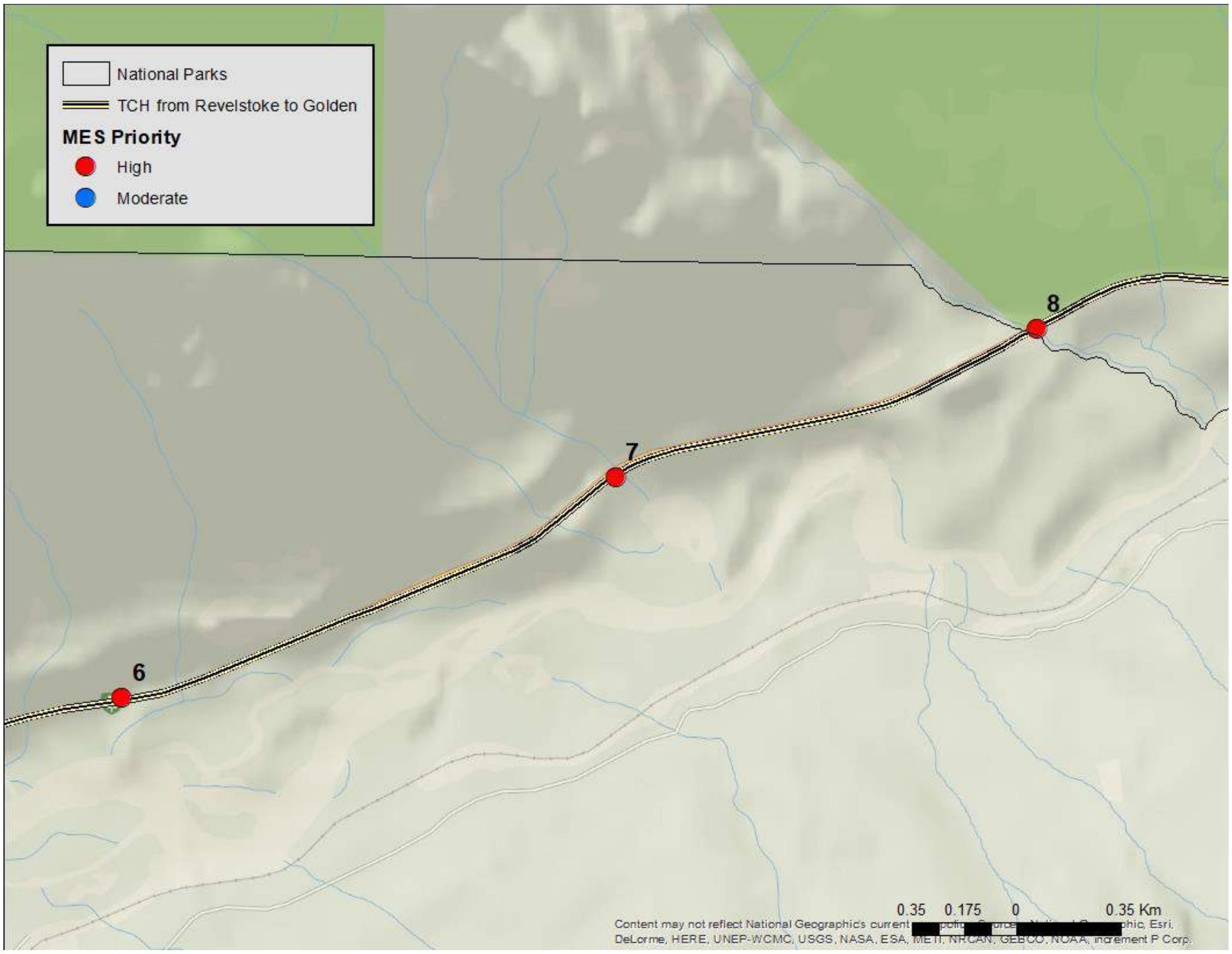

Figure A4: Map showing Highway Mitigation Emphasis Site (MES) 07 (Hanner Lake) in Trans-Canada Highway study area between Revelstoke and Golden, British Columbia.

West Area, MES 08 Summary – Clachnacudainn Creek	
Description	
Location (LKI): 975 – 17.90 km	
Location (UTM): 430199.5654678	
Species: Moose primarily, elk, deer, black bear	
SCORING	
Mortality risk: 5	
Local conservation value: 3	
Regional conservation significance: 2.75	
Human disturbance: 4	
Constructability: 4	
TOTAL SCORE: 23.75	
RANK: 2	
Local knowledge: 5	
Wildlife objectives	
• Reduce wildlife–vehicle collisions in this section of highway, primarily deer, elk and moose. • Provide safe movement for all wildlife species across highway, primarily deer, elk, moose and bears.	
Existing infrastructure	
• >3000 mm diameter multi-plate culvert on Clachnacudainn Creek.	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily.	
Transportation mitigation recommendations	
Constructability score: 4	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and retrofit of the bridge *underpass* is recommended. There is good vertical clearance for wildlife passage on existing bridge. If the highway is reconstructed, a new bridge will be added to the existing bridge. All bridge construction or reconstruction must be designed with wildlife movement (and hydrologic flow) in mind. The new bridge should be designed with a span matching existing, allowing dry travel sections ($\geq$3 m wide) above high-water mark. Wing *fencing* (200–500 m depending on terrain) should be installed to funnel movements to the crossing structure. Fencing notes: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.	

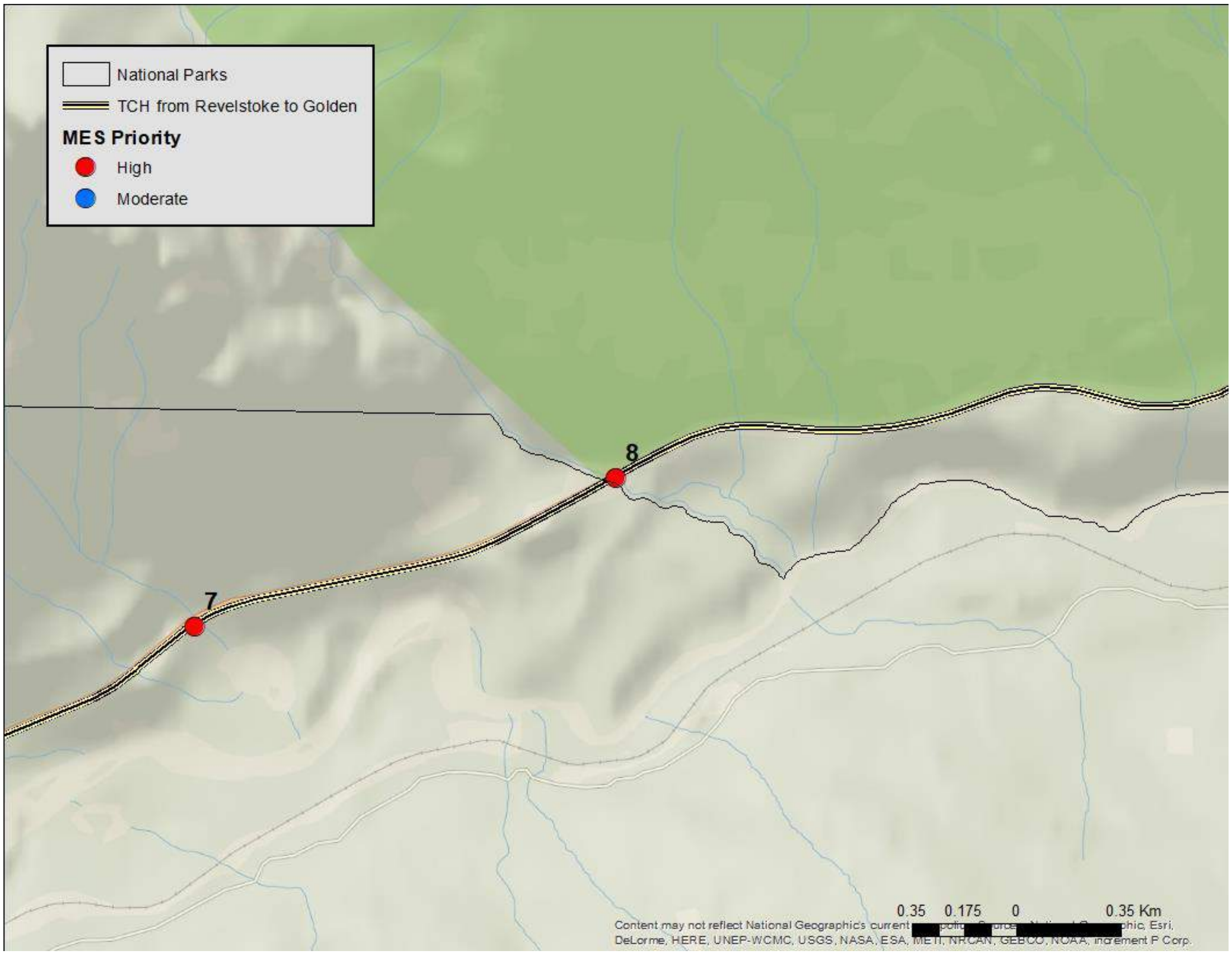

Figure A5: Map showing Highway Mitigation Emphasis Site (MES) 08 (Clachnacudainn Creek) in Trans-Canada Highway study area between Revelstoke and Golden, British Columbia.

Central

East Gate of Glacier National Park to Donald Bridge

Central Area, MES 09 Summary – Rogers Road	
Description	
Location (LKI): 985 – 2.42 km	
Location (UTM): 466970.5703951	
Species: Moose primarily, elk, black bears	
SCORING	
Mortality risk: 2	
Local conservation value: 3	
Regional conservation significance: 1	
Human disturbance: 4	
Constructability: 2	
TOTAL SCORE: 15	
RANK: 21	
Local knowledge: 3	
Wildlife objectives	
• Reduce wildlife–vehicle collisions in this section of highway, primarily black bear, deer, elk and moose. • Provide safe movement for all wildlife species across highway, primarily deer, elk, moose and bears.	
Existing infrastructure	
• None	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily.	
Transportation mitigation recommendations	
Constructability score: 2	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Selection of design type will be dependent on terrain and engineering constraints. Steep slope on west-side might constrain type of underpass. There is limited cover or fill here and likely 3 m vertical clearance is maximum height for culvert. Minimum recommended dimension where feasible is for box culvert (2.6 x 2.8 m). Site will require further engineering assessment to determine culvert size/type feasibility. Wing *fencing* (200–500 m depending on terrain) should be installed to funnel movements to the crossing structure. Fencing notes: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.	

Figure A6: Map showing Highway Mitigation Emphasis Site (MES) 09 (Rogers Road) in Trans-Canada Highway study area between Revelstoke and Golden, British Columbia.

Central Area, MES 10 Summary – Beaver 1	
Description	
Location (LKI): 985 – 4.81 km	
Location (UTM): 468251.5705896	
Species: Moose primarily, elk, deer, bears	
SCORING	
Mortality risk: 1	
Local conservation value: 4	
Regional conservation significance: 1.75	
Human disturbance: 5	
Constructability: 3	
TOTAL SCORE: 17.75	
RANK: 12	
Local knowledge: 3	
Wildlife objectives	
• Reduce wildlife–vehicle collisions in this section of highway, primarily bears, deer, elk and moose. • Provide safe movement for all wildlife species across highway, primarily deer, elk, moose and bears.	
Existing infrastructure	
• None	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily, moose, deer, bears.	
Transportation mitigation recommendations	
Constructability score: 3	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Selection of design type is dependent on terrain and engineering constraints. There is ample fill on both sides of highway. Minimum recommended dimension where feasible is elliptical culvert 4 m high x 7 m wide. Open span measuring 2.5 m high x 11 m wide should also be considered if feasible. Wing *fencing* (200–500 m depending on terrain) should be installed to funnel movements to the crossing structure. Fencing notes: Snow is not a concern at this location.	

Central Area, MES 11 Summary – Beaver 2	
Description	
Location (LKI): 985 – 5.42 km	
Location (UTM): 468829.5706155	
Species: Moose primarily, elk, deer, bears	
SCORING	
Mortality risk: 1	
Local conservation value: 4	
Regional conservation significance: 1	
Human disturbance: 5	
Constructability: 4	
TOTAL SCORE: 20	
RANK: 7	
Local knowledge: 5	
Wildlife objectives	
• Reduce wildlife–vehicle collisions in this section of highway, primarily bears, deer, elk and moose. • Provide safe movement for all wildlife species across highway, primarily deer, elk, moose and bears.	
Existing infrastructure	
• 3000 mm diameter culvert with water flow	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily, bears, elk, moose.	
Transportation mitigation recommendations	
Constructability score: 4	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Selection of specific design type is dependent on terrain and engineering constraints. North side has good amount of fill, while south side is steep but levels off downslope. Culvert in place carries small volume of water. Existing culvert could be replaced with a bottomless arch culvert, minimum recommended dimension where feasible ca. 3 m high by 7 m wide or open span bridge (2.5-3m high x 11 m wide) if feasible. Focal species in area such as moose and grizzly bears utilize culverts of recommended dimensions. Wing *fencing* (200–500 m depending on terrain) should be installed to funnel movements to the crossing structure.	

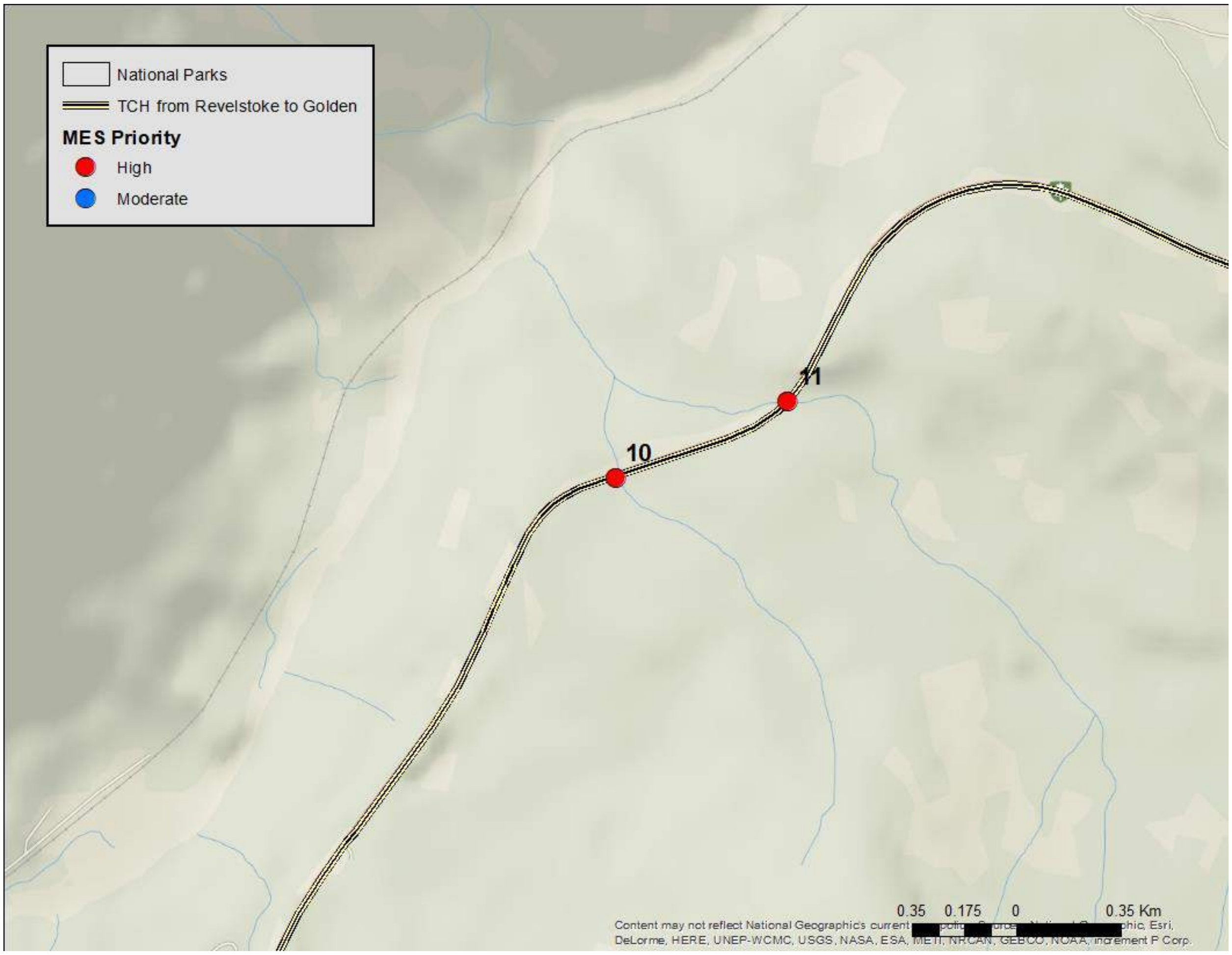

Figure A7: Map showing Highway Mitigation Emphasis Site (MES) 10 (Beaver 01) and 11 (Beaver 02) in Trans-Canada Highway study area between Revelstoke and Golden, British Columbia.

Central Area, MES 12 Summary – Kinbasket Road	
Description	
Location (LKI): 985 – 7.74 km	
Location (UTM): 470607.5706433	
Species: Moose primarily, elk, deer, bears	
SCORING	
Mortality risk: 1	
Local conservation value: 2	
Regional conservation significance: 1.25	
Human disturbance: 3	
Constructability: 2	
TOTAL SCORE: 11.25	
RANK: 26	
Local knowledge: 2	
Wildlife objectives	
• Reduce wildlife–vehicle collisions in this section of highway, primarily black bear, deer, elk and moose. • Provide safe movement for all wildlife species across highway, primarily deer, elk, moose and bears.	
Existing infrastructure	
• Culvert (unknown dimensions)	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily.	
Transportation mitigation recommendations	
Constructability score: 2	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Selection of specific design type is dependent on terrain and engineering constraints. Both sides of highway have good amount of fill. Existing culvert could be replaced with a bottomless arch culvert; minimum recommended dimension where feasible ca. 3 m high by 7 m wide. Focal species in area such as moose utilize culverts of recommended dimensions. Wing *fencing* (200–500 m depending on terrain) should be installed to funnel movements to the crossing structure. Fencing notes: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.	

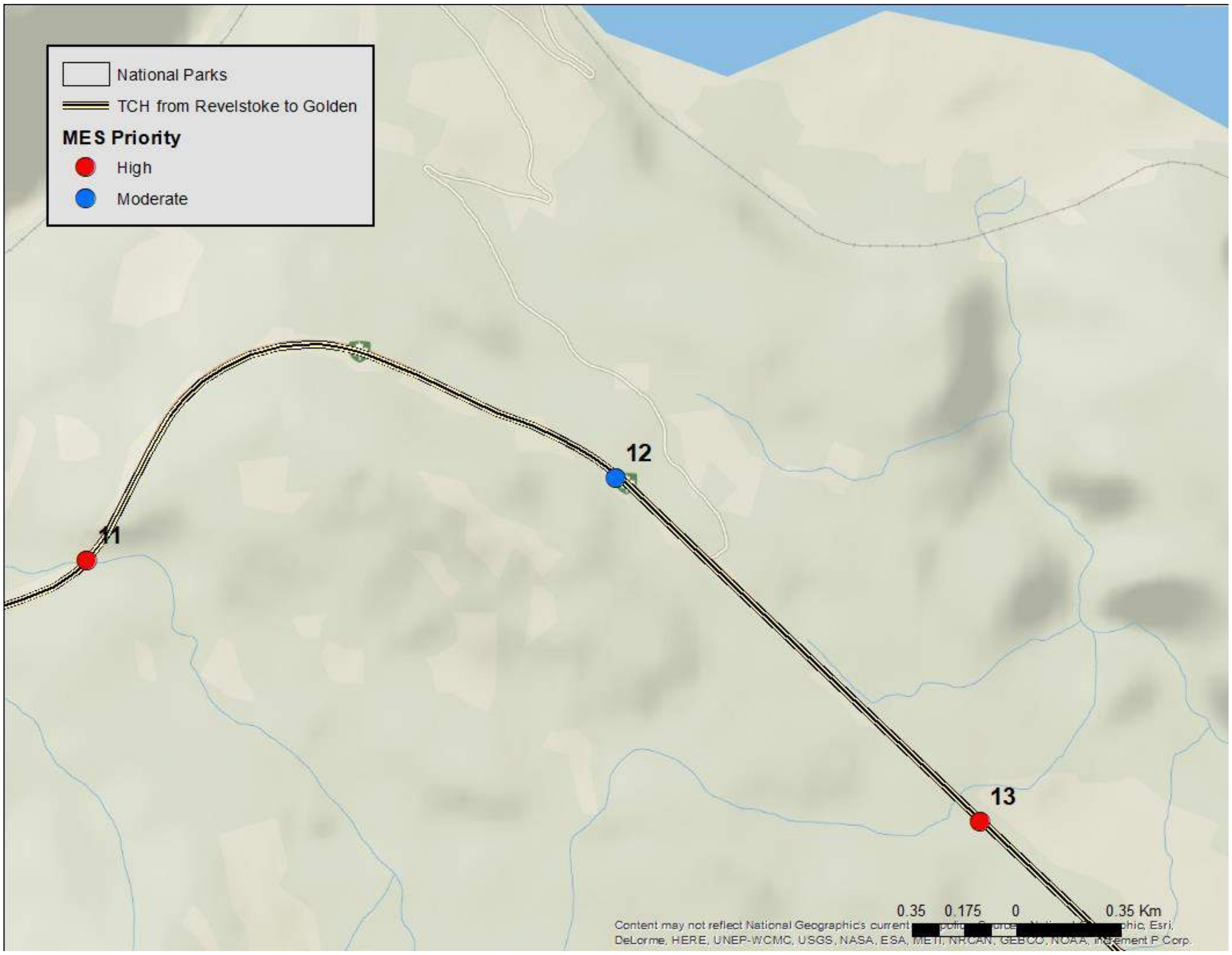

Figure A8: Map showing Highway Mitigation Emphasis Site (MES) 12 (Kinbasket Road) in Trans-Canada Highway study area between Revelstoke and Golden, British Columbia.

Central Area, MES 13 Summary – West Heather	
Description	
Location (LKI): 985 – 9.85 km	
Location (UTM): 471831.5705279	
Species: Moose primarily, elk, deer, bears	
SCORING	
Mortality risk: 1	
Local conservation value: 3	
Regional conservation significance: 3.25	
Human disturbance: 5	
Constructability: 3	
TOTAL SCORE: 18.25	
RANK: 10	
Local knowledge: 3	
Wildlife objectives	
• Reduce wildlife–vehicle collisions in this section of highway, primarily bears, deer, elk and moose. • Provide safe movement for all wildlife species across highway, primarily deer, elk, moose and bears.	
Existing infrastructure	
• Culvert (unknown dimensions)	
Target species for mitigation planning	
WVC reduction: Common species, including moose. **Regional conservation and connectivity**: Common species primarily but also moose and grizzly bear.	
Transportation mitigation recommendations	
Constructability score: 3	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Selection of design type is dependent on terrain and engineering constraints. There is ample fill on both sides of highway. Minimum recommended dimension where feasible is elliptical culvert 4 m high x 7 m wide. Open span measuring 2.5 m high x 11 m wide should also be considered. Wing *fencing* (200–500 m depending on terrain) should be installed to funnel movements to the crossing structure. Fencing notes: Snow is not a concern at this location.	

Central Area, MES 14 Summary – West Quartz Creek	
Description	
Location (LKI): 985 – 12.30 km	
Location (UTM): 473052.5704297	
Species: Moose primarily, elk, deer, bears	
SCORING	
Mortality risk: 1	
Local conservation value: 3	
Regional conservation significance: 2.5	
Human disturbance: 5	
Constructability: 3	
TOTAL SCORE: 17.5	
RANK: 13	
Local knowledge: 3	
Wildlife objectives	
• Reduce wildlife–vehicle collisions in this section of highway, primarily bears, deer, elk and moose. • Provide safe movement for all wildlife species across highway, primarily deer, elk, moose and bears.	
Existing infrastructure	
• Culvert (unknown dimensions)	
Target species for mitigation planning	
WVC reduction: Common species, including moose. **Regional conservation and connectivity**: Common species primarily, but also moose and grizzly bear.	
Transportation mitigation recommendations	
Constructability score: 3	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Selection of design type is dependent on terrain and engineering constraints. There is ample fill on both sides of highway. Minimum recommended dimension where feasible is elliptical culvert 4 m high x 7 m wide. Wing *fencing* (200–500 m depending on terrain) should be installed to funnel movements to the crossing structure. Fencing notes: Snow is not a concern at this location.	

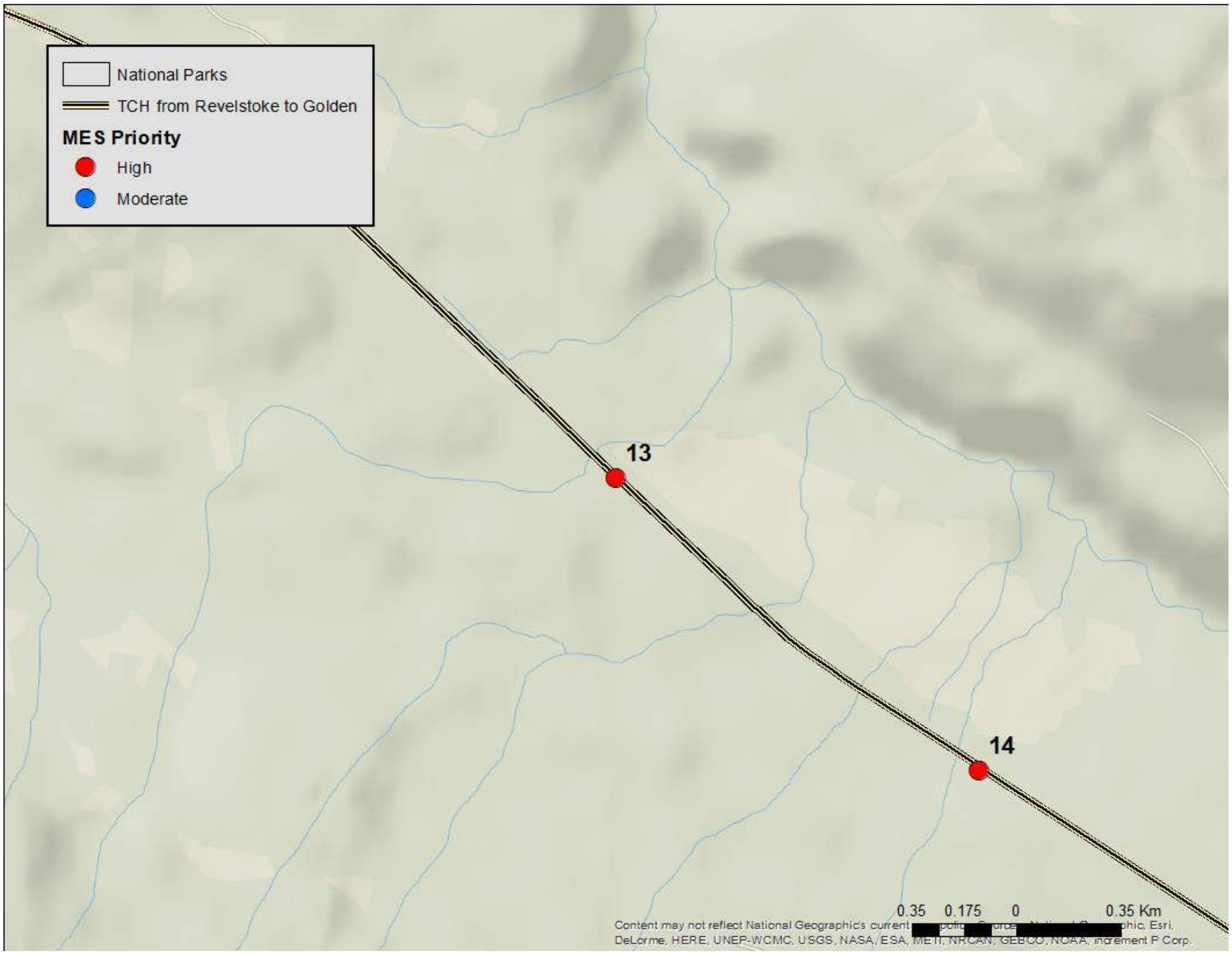

Figure A9: Map showing Highway Mitigation Emphasis Site (MES) 13 (West Heather) and 14 (West Quartz Creek) in Trans-Canada Highway study area between Revelstoke and Golden, British Columbia.

Central Area, MES 15 Summary – Quartz Creek	
Description	
Location (LKI): 985 – 13.30 km	
Location (UTM): 474926.5703087	
Species: All wildlife in area, moose primarily, elk, deer, bears	
SCORING	
Mortality risk: 4	
Local conservation value: 5	
Regional conservation significance: 1.25	
Human disturbance: 4	
Constructability: 5	
TOTAL SCORE: 24.25	
RANK: 1	
Local knowledge: 5	
Wildlife objectives	
• Reduce wildlife–vehicle collisions in this section of highway, primarily moose and black bears. • Provide safe movement for all wildlife species below highway.	
Existing infrastructure	
• Large span bridge that will be replaced in 2020.	
Target species for mitigation planning	
WVC reduction: Moose and black bears. **Regional conservation and connectivity**: Common species primarily but also moose and grizzly bear, wolverine and lynx.	
Transportation mitigation recommendations	
Constructability score: 5	
The new Quartz Creek Bridge will be on a new alignment and the bridge will span over a larger portion of Quartz Creek. The dimensions of the large span bridge will provide excellent passage for all wildlife in the area. Trails should be cut into slopes on both sides of drainage to facilitate wildlife movement through the area. Quartz is the largest watershed in the area and is an important corridor moving wildlife between high and low elevations. Wing *fencing* (200–500 m depending on terrain) should be installed to funnel movements to the trails and passable terrain under the large span bridge. Fencing notes: Snow not likely a concern at this location.	

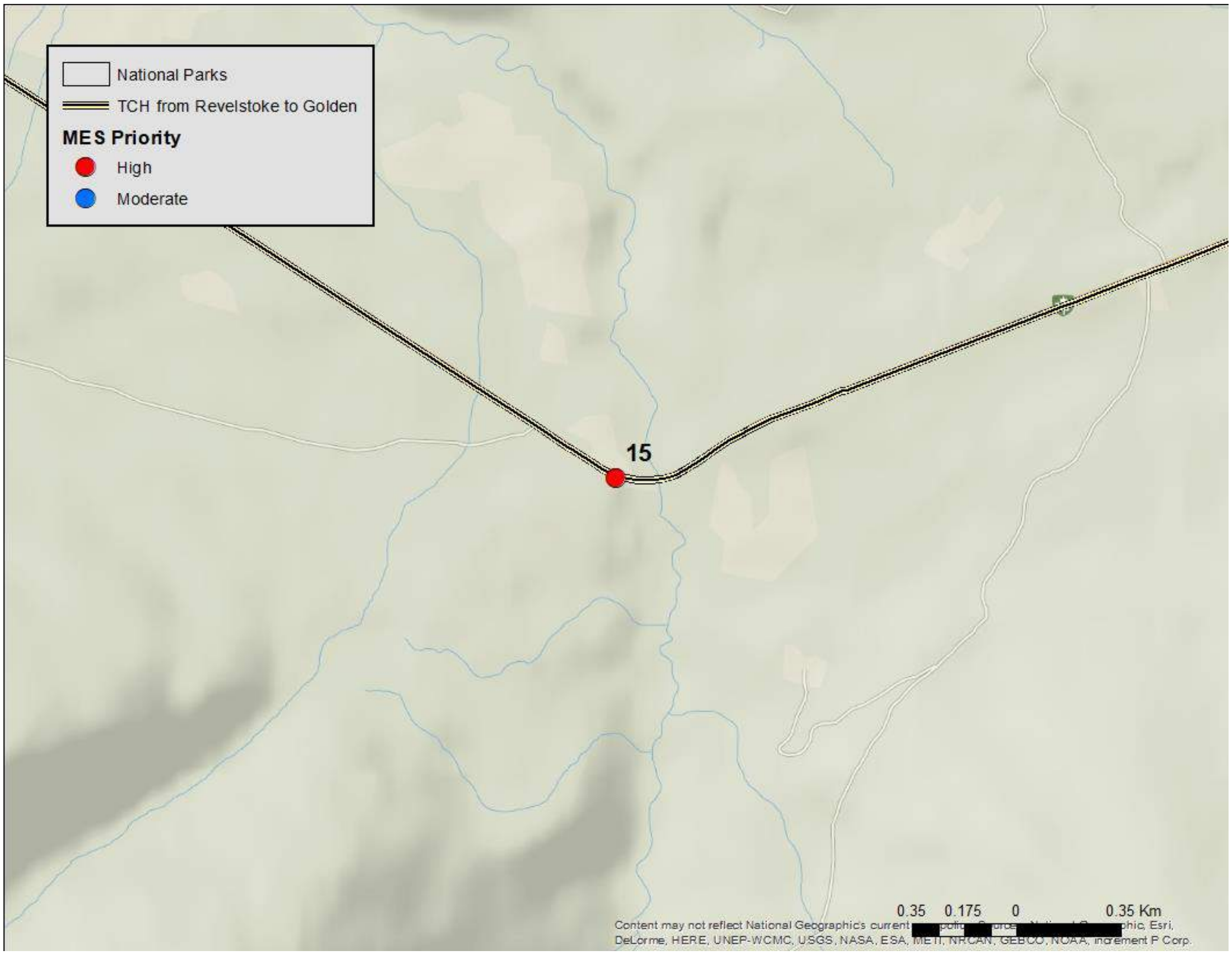

Figure A10: Map showing Highway Mitigation Emphasis Site (MES) 15 (Quartz Creek) in Trans-Canada Highway study area between Revelstoke and Golden, British Columbia.

Central Area, MES 16 Summary – Wiseman Creek	
Description	
Location (LKI): 985 – 16.50 km	
Location (UTM): 477562.5704099	
Species: Moose primarily, elk, bears	
SCORING	
Mortality risk: 1	
Local conservation value: 4	
Regional conservation significance: 1.5	
Human disturbance: 4	
Constructability: 3	
TOTAL SCORE: 17.5	
RANK: 14	
Local knowledge: 4	
Wildlife objectives	
• Reduce wildlife–vehicle collisions in this section of highway, primarily moose, but also elk and bears. • Provide safe movement for all wildlife species across highway, primarily moose to local habitats above and below road, and also elk and bears.	
Existing infrastructure	
• Large diameter culvert (2800 mm).	
Target species for mitigation planning	
WVC reduction: Common species, including moose. **Regional conservation and connectivity**: Common species primarily, but moose is of most concern as wetland habitats are located below highway.	
Transportation mitigation recommendations	
Constructability score: 3	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Selection of design type is dependent on terrain and engineering constraints; open-span preferred design. Minimum recommended dimension where feasible is 11 m wide x 3 m high due to high likelihood of grizzly bear movement through this area. Should highway fill be removed a large span bridge structure would be optimal design and ensure greatest passage for all wildlife species in area. Wing *fencing* (200–500 m depending on terrain) should be installed to funnel movements to the crossing structure. Fencing notes: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.	

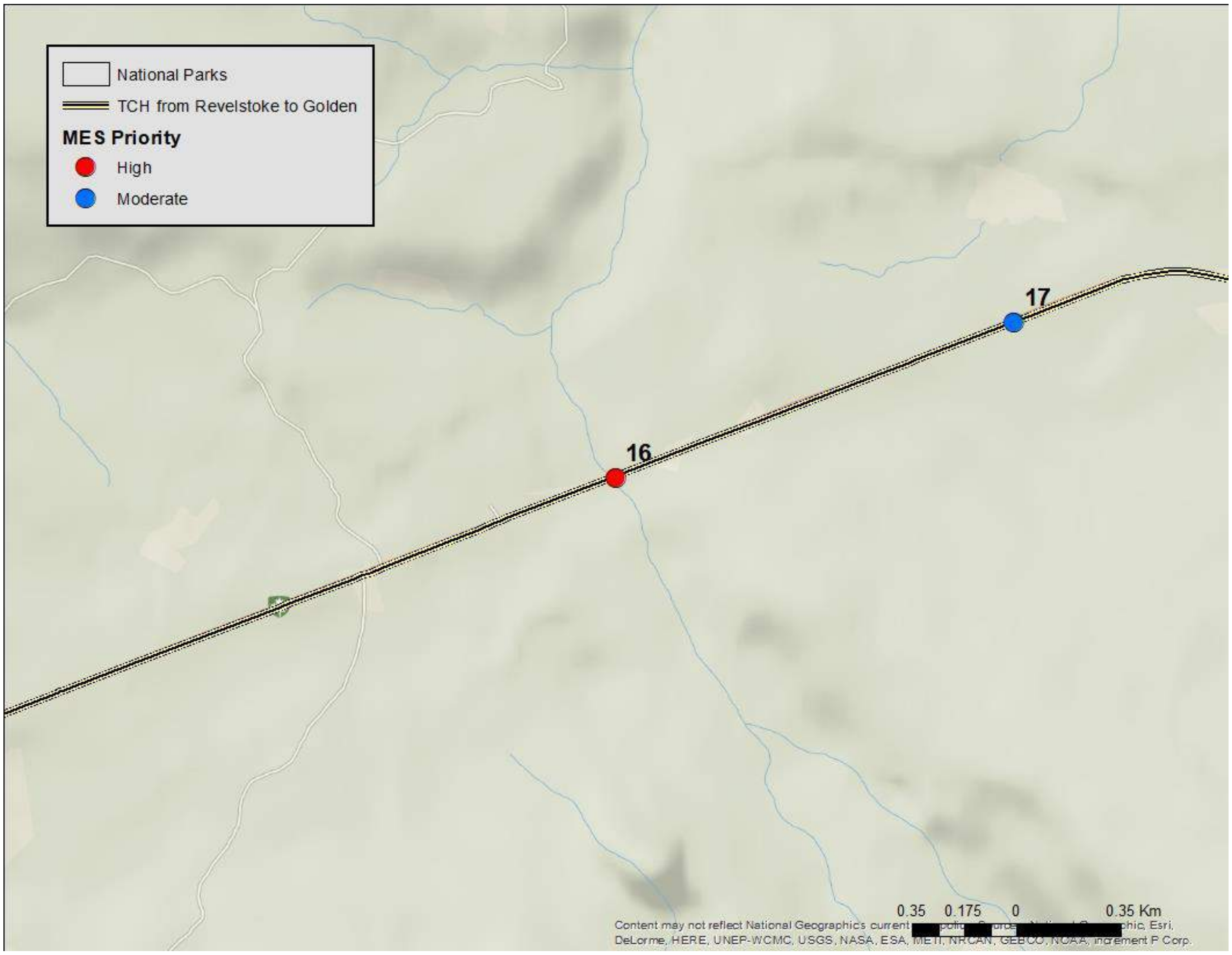

Figure A11: Map showing Highway Mitigation Emphasis Site (MES) 16 (Wiseman Creek) in Trans-Canada Highway study area between Revelstoke and Golden, British Columbia.

Central Area, MES 17 Summary – East Wiseman	
Description	
Location (LKI): 985 – 17.94 km	
Location (UTM): 478901.5704621	
Species: Moose primarily, elk, bears	
SCORING	
Mortality risk: 2	
Local conservation value: 2	
Regional conservation significance: 1.5	
Human disturbance: 4	
Constructability: 3	
TOTAL SCORE: 15.5	
RANK: 19	
Local knowledge: 3	
Wildlife objectives	
• Reduce wildlife–vehicle collisions in this section of highway, primarily moose, elk and bears. • Provide safe movement for all wildlife species across highway, primarily moose, elk, and bears.	
Existing infrastructure	
• Culvert (unknown dimensions).	
Target species for mitigation planning	
WVC reduction: Common species, mostly moose. **Regional conservation and connectivity**: Common species but primarily moose and bears.	
Transportation mitigation recommendations	
Constructability score: 3	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Selection of design type is dependent on terrain and engineering constraints; open-span preferred design. Minimum recommended dimension where feasible is 11 m wide x 3 m high due to high likelihood of grizzly bear movement through this area. Wing *fencing* (200–500 m depending on terrain) should be installed to funnel movements to the crossing structure. Fencing notes: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.	

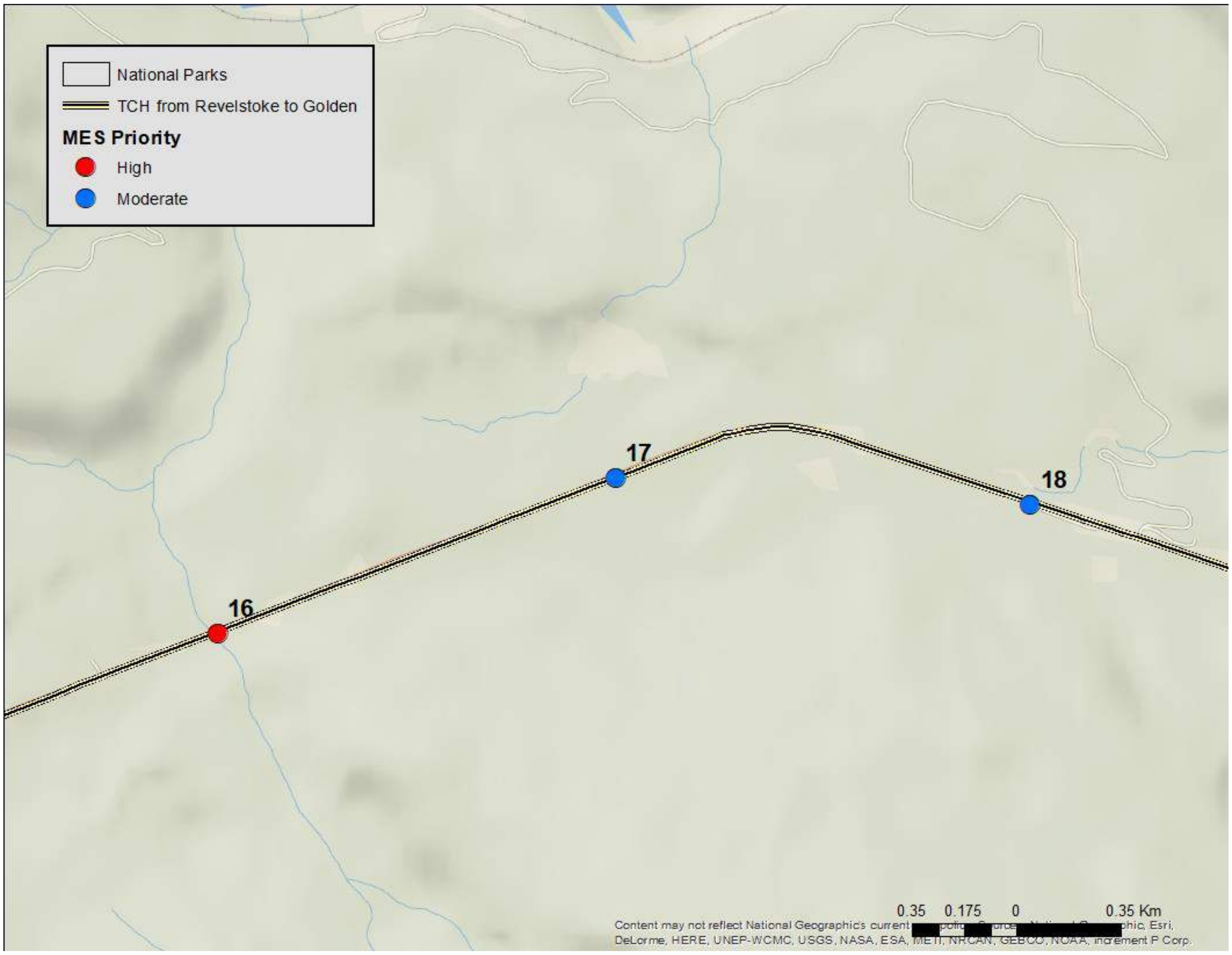

Figure A12: Map showing Highway Mitigation Emphasis Site (MES) 17 (East Wiseman) in Trans-Canada Highway study area between Revelstoke and Golden, British Columbia.

Central Area, MES 18 Summary – Redgrave Rest Area West	
Description	
Location (LKI): 985 – 18.94 km	
Location (UTM): 480295.5704530	
Species: Moose primarily, elk, and bears	
SCORING	
Mortality risk: 1	
Local conservation value: 4	
Regional conservation significance: 1.5	
Human disturbance: 3	
Constructability: 2	
TOTAL SCORE: 13.5	
RANK: 25	
Local knowledge: 2	
Wildlife objectives	
• Reduce wildlife–vehicle collisions in this section of highway, primarily moose, elk and bears. • Provide safe movement for all wildlife species across highway, primarily moose, elk, and bears.	
Existing infrastructure	
• None	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily, including moose. Wetland complex below road (East) and cut blocks provide for good moose habitat.	
Transportation mitigation recommendations	
Constructability score: 2	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Good moose habitat on both sides of highway. Selection of design type is dependent on terrain and engineering constraints; open-span preferred design. Situated on moderate spur ridge coming down to highway, but good fill to construct underpass. Minimum recommended dimension where feasible is 11 m wide x 3 m high due to high likelihood of grizzly bear movement through this area. Wing *fencing* (200–500 m depending on terrain) should be installed to funnel movements to the crossing structure. Fencing notes: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.	

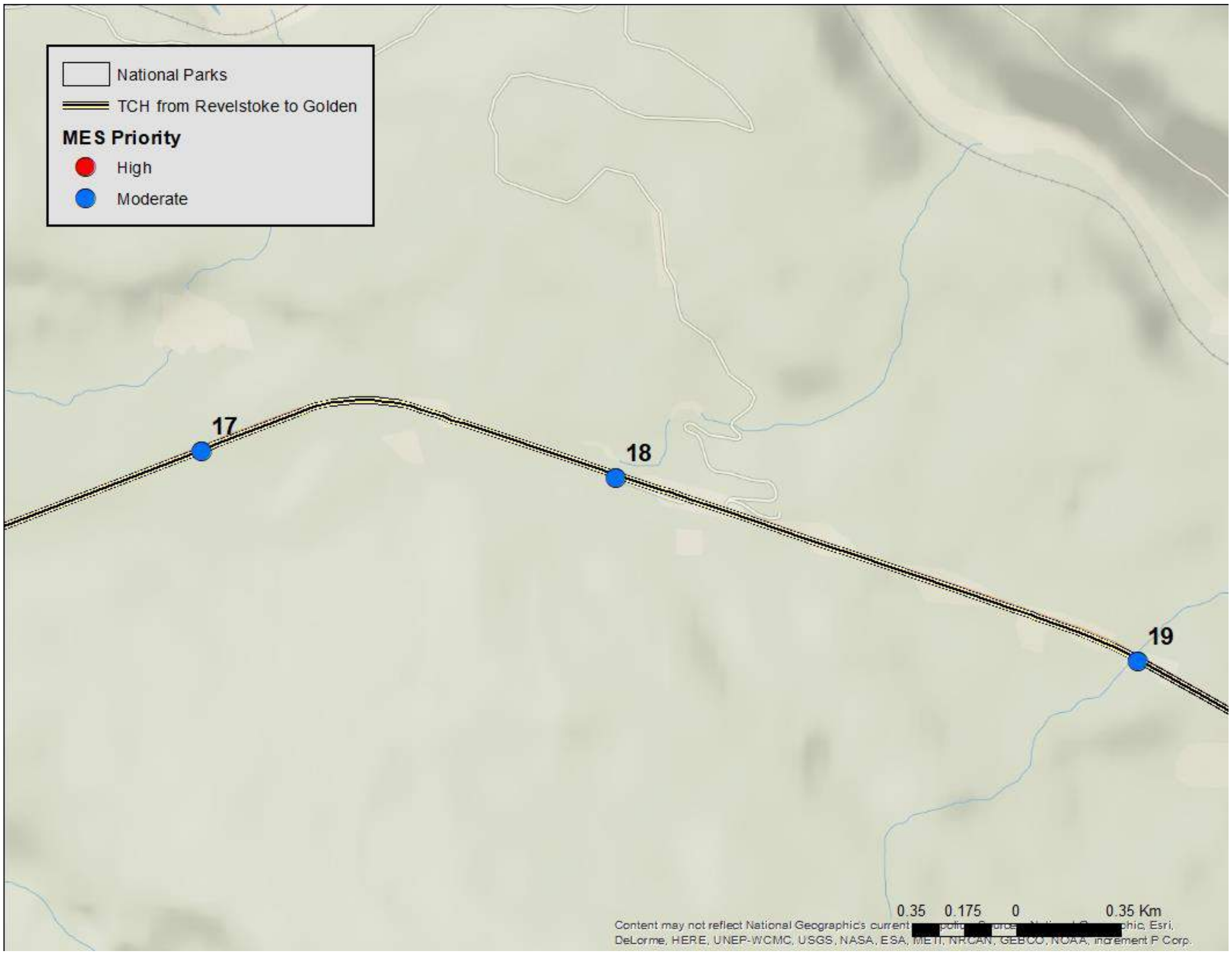

Figure A13: Map showing Highway Mitigation Emphasis Site (MES) 18 (Redgrave Rest Area West) in Trans-Canada Highway study area between Revelstoke and Golden, British Columbia.

Central Area, MES 19 Summary – Redgrave Rest Area East	
Description	
Location (LKI): 985 – 20.84 km	
Location (UTM): 482049.5703914	
Species: Moose primarily, elk, black bears	
SCORING	
Mortality risk: 1	
Local conservation value: 3	
Regional conservation significance: 2.25	
Human disturbance: 4	
Constructability: 3	
TOTAL SCORE: 16.25	
RANK: 18	
Local knowledge: 3	
Wildlife objectives	
• Reduce wildlife–vehicle collisions in this section of highway, primarily black bear, elk and moose. • Provide safe movement for all wildlife species across highway, primarily black bear, elk and moose.	
Existing infrastructure	
• Culvert (unknown dimensions)	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily.	
Transportation mitigation recommendations	
Constructability score: 3	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Good moose habitat on both sides of highway. Causeway type cut and fill at this location. Selection of design type is dependent on terrain and engineering constraints; open-span preferred design. Situated on moderate spur ridge coming down to highway, but good fill to construct underpass. Minimum recommended dimension where feasible is 11 m wide x 3 m high due to high likelihood of grizzly bear movement through this area. Wing *fencing* (200–500 m depending on terrain) should be installed to funnel movements to the crossing structure. Fencing notes: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.	

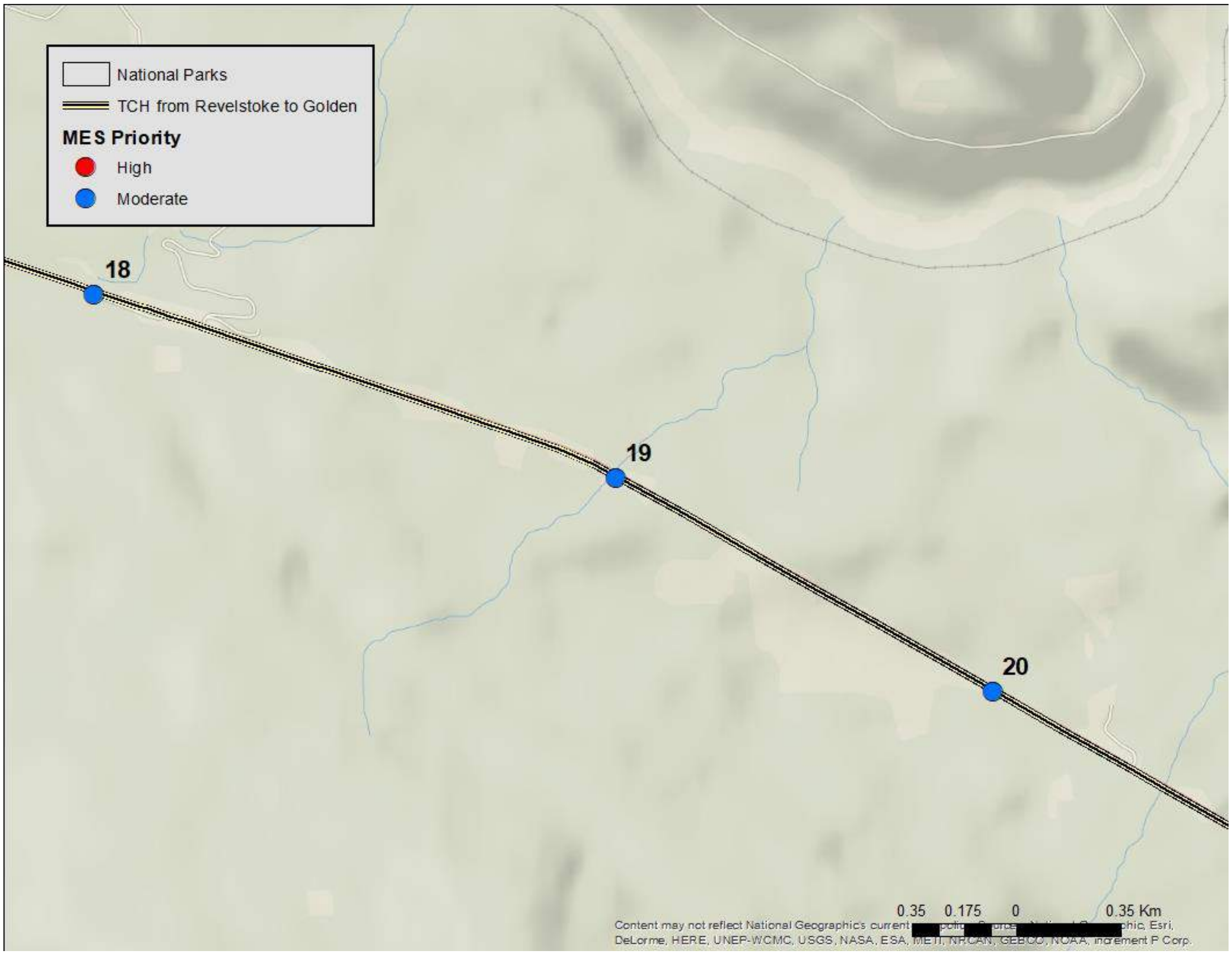

Figure A14: Map showing Highway Mitigation Emphasis Site (MES) 19 (Redgrave Rest Area East) in Trans-Canada Highway study area between Revelstoke and Golden, British Columbia.

Central Area, MES 20 Summary – West Oldman	
Description	
Location (LKI): 985 – 22.65 km	
Location (UTM): 483316.5703197	
Species: Moose primarily, elk, bears	
SCORING	
Mortality risk: 1	
Local conservation value: 3	
Regional conservation significance: 2.75	
Human disturbance: 4	
Constructability: 3	
TOTAL SCORE: 16.75	
RANK: 17	
Local knowledge: 3	
Wildlife objectives	
• Reduce wildlife–vehicle collisions in this section of highway, primarily bears, elk and moose. • Provide safe movement for all wildlife species across highway, primarily deer, elk, moose and bears.	
Existing infrastructure	
• Culvert (unknown dimensions and transverse)	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily.	
Transportation mitigation recommendations	
Constructability score: 3	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Good moose habitat on both sides of highway. Selection of design type is dependent on terrain and engineering constraints; open-span preferred design. Situated on moderate spur ridge coming down to highway, but good fill to construct underpass. Minimum recommended dimension where feasible is 11 m wide x 3 m high due to high likelihood of grizzly bear movement through this area. Wing *fencing* (200–500 m depending on terrain) should be installed to funnel movements to the crossing structure. Fencing notes: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.	

Central Area, MES 21 Summary – Wiseman Curves (Donald FSR)	
Description	
Location (LKI): 985 – 24.00 km	
Location (UTM): 484695.5702756	
Species: Moose primarily, elk, deer, bears	
SCORING	
Mortality risk: 1	
Local conservation value: 5	
Regional conservation significance: 2.25	
Human disturbance: 4	
Constructability: 5	
TOTAL SCORE: 21.25	
RANK: 3	
Local knowledge: 4	
Wildlife objectives	
• Reduce wildlife–vehicle collisions in this section of highway, primarily bears, elk and moose. • Provide safe movement for all wildlife species across highway, primarily elk, moose and bears.	
Existing infrastructure	
• 3000 mm diameter culvert	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily, but also grizzly bears, moose, wolverine and lynx. This is a major watershed in the Selkirk Mountain section and important wildlife corridor.	
Transportation mitigation recommendations	
Constructability score: 5	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Recommend replace culvert during twinning and install open-span preferred design. Minimum recommended dimension where feasible is 11 m wide x 3 m high due to high likelihood of moose and grizzly bear movement through this area. Wing *fencing* (200–500 m depending on terrain) should be installed to funnel movements to the crossing structure. Fencing notes: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.	

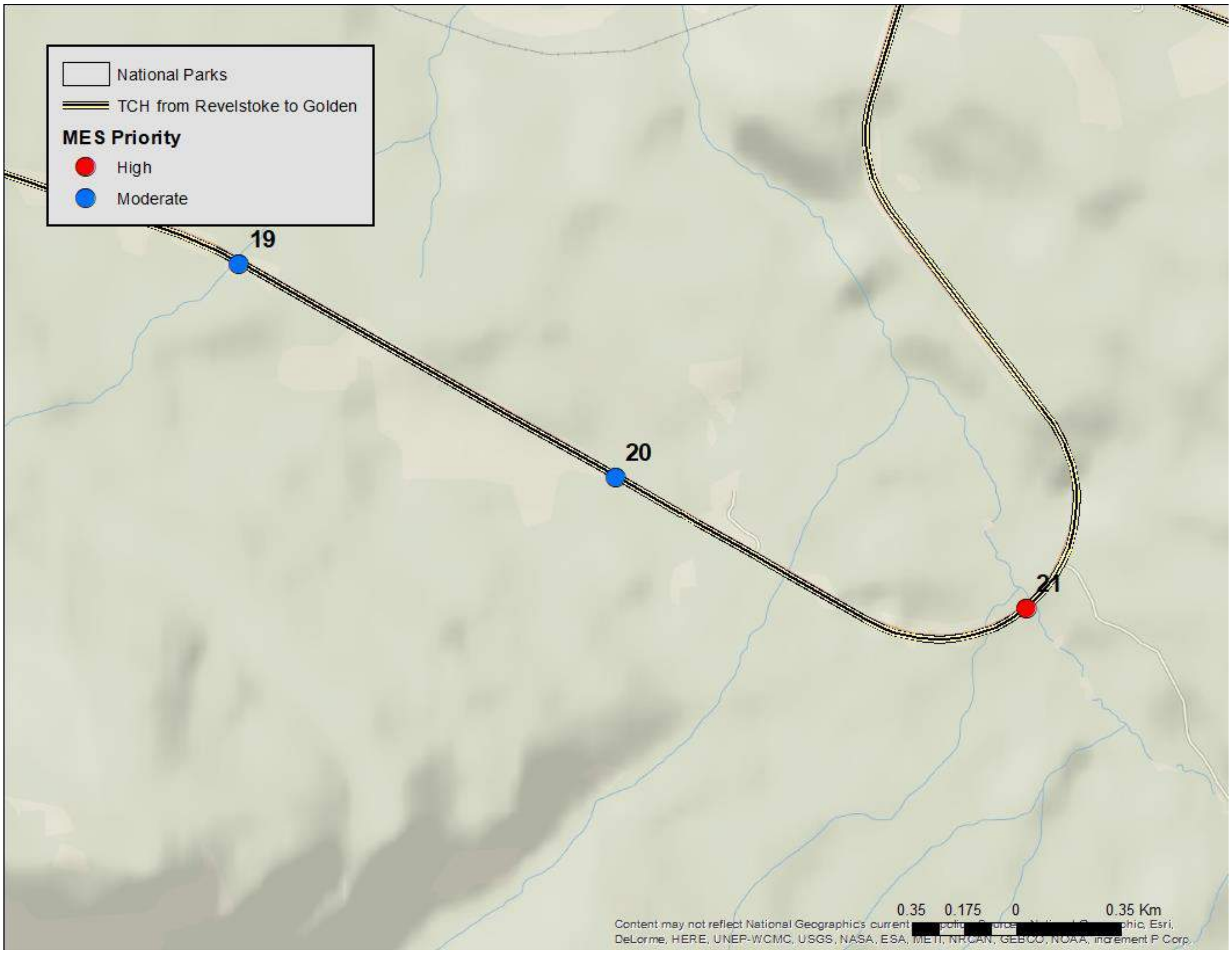

Figure A15: Map showing Highway Mitigation Emphasis Site (MES) 20 (West Oldman) and 21 (Wiseman Curves) in Trans-Canada Highway study area between Revelstoke and Golden, British Columbia.

East

Donald Bridge to Golden

East Area, MES 22 Summary - Doyle	
Description	
Location (LKI): 985 – 38.06985 – 2.42 km	
Location (UTM): 493738.5699241	
Species: Primarily elk, deer, black bears	
SCORING	
Mortality risk: 1	
Local conservation value: 3	
Regional conservation significance: 2	
Human disturbance: 3	
Constructability: 3	
TOTAL SCORE: 14	
RANK: 23	
Local knowledge: 2	
Wildlife objectives	
• Reduce wildlife–vehicle collisions in this section of highway, primarily deer and elk. • Provide safe movement for all wildlife species across highway, primarily deer, elk, cougars and bears.	
Existing infrastructure	
• None	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily, but also elk, deer and bears.	
Transportation mitigation recommendations	
Constructability score: 3	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Selection of design type is dependent on terrain and engineering constraints; however an open-span design is preferred at this location. Minimum recommended dimension where feasible is 11 m wide x 3 m to pass common wildlife species (including elk) through this area. There is ample highway fill allowing for a 3m clearance underpass. Wing *fencing* (200–500 m depending on terrain) should be installed to funnel movements to the crossing structure. Fencing notes: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.	

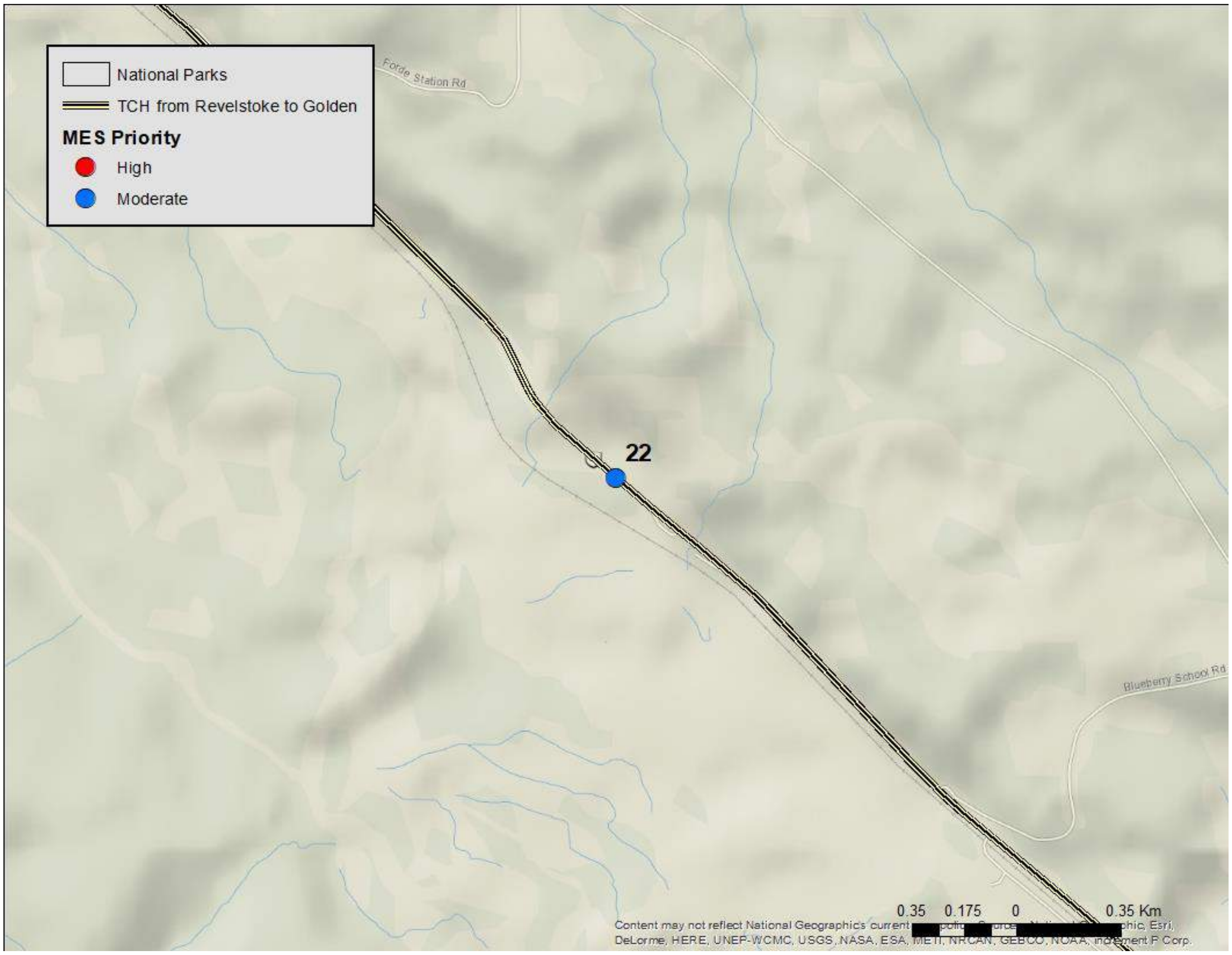

Figure A16: Map showing Highway Mitigation Emphasis Site (MES) 22 (Doyle) in Trans-Canada Highway study area between Revelstoke and Golden, British Columbia.

East Area, MES 23 Summary – Hartley Road	
Description	
Location (LKI): 985 – 46.22 km	
Location (UTM): 498228.5692618	
Species: Primarily, elk, deer, bears, cougars	
SCORING	
Mortality risk: 4	
Local conservation value: 3	
Regional conservation significance: 2.5	
Human disturbance: 3	
Constructability: 3	
TOTAL SCORE: 20.5	
RANK: 5	
Local knowledge: 5	
Wildlife objectives	
• Reduce wildlife–vehicle collisions in this section of highway, primarily deer and elk. • Provide safe movement for all wildlife species across highway, primarily deer, elk, cougars and bears.	
Existing infrastructure	
• 900 mm diameter culvert on Moberly Creek	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily.	
Transportation mitigation recommendations	
Constructability score: 3	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *creek bridge underpass* is recommended. Minimum desirable dimension for underpass is 11 m wide x 3 m high due to the combined high score for this site and likelihood of significant wildlife movement through this area. Retrofitting Moberly Creek culvert to a larger underpass will have some engineering constraints to obtain sufficient clearance (3 m in addition to cover). Retrofit will need to include design that allows for wildlife passage (>2-3 m path on one side or other) above high water levels to ensure hydrological and wildlife connectivity function at this location. Focal species in area such as deer, black bears, cougars utilize culverts of recommended dimensions. Wing *fencing* (200–500 m depending on terrain) should be installed to funnel movements to the crossing structure. Fencing notes: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.	

East Area, MES 24 Summary – Hartley East	
Description	
Location (LKI): 985 – 47.28 km	
Location (UTM): 498571.5691631	
Species: Primarily, elk, deer, bears, cougars	
SCORING	
Mortality risk: 3	
Local conservation value: 3	
Regional conservation significance: 1	
Human disturbance: 3	
Constructability: 3	
TOTAL SCORE: 17	
RANK: 16	
Local knowledge: 4	
Wildlife objectives	
• Reduce wildlife–vehicle collisions in this section of highway, primarily deer and elk. • Provide safe movement for all wildlife species across highway, primarily deer, elk, cougars and bears.	
Existing infrastructure	
• 600 mm diameter culvert	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily.	
Transportation mitigation recommendations	
Constructability score: 3	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Selection of design type is dependent on terrain and engineering constraints. Minimum recommended dimension where feasible is box culvert (2.6 x 2.8 m) or elliptical culvert 3 m high x 7 m wide to pass common wildlife species (including elk) through this area. Wing *fencing* (200–500 m depending on terrain) should be installed to funnel movements to the crossing structure. Fencing notes: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.	

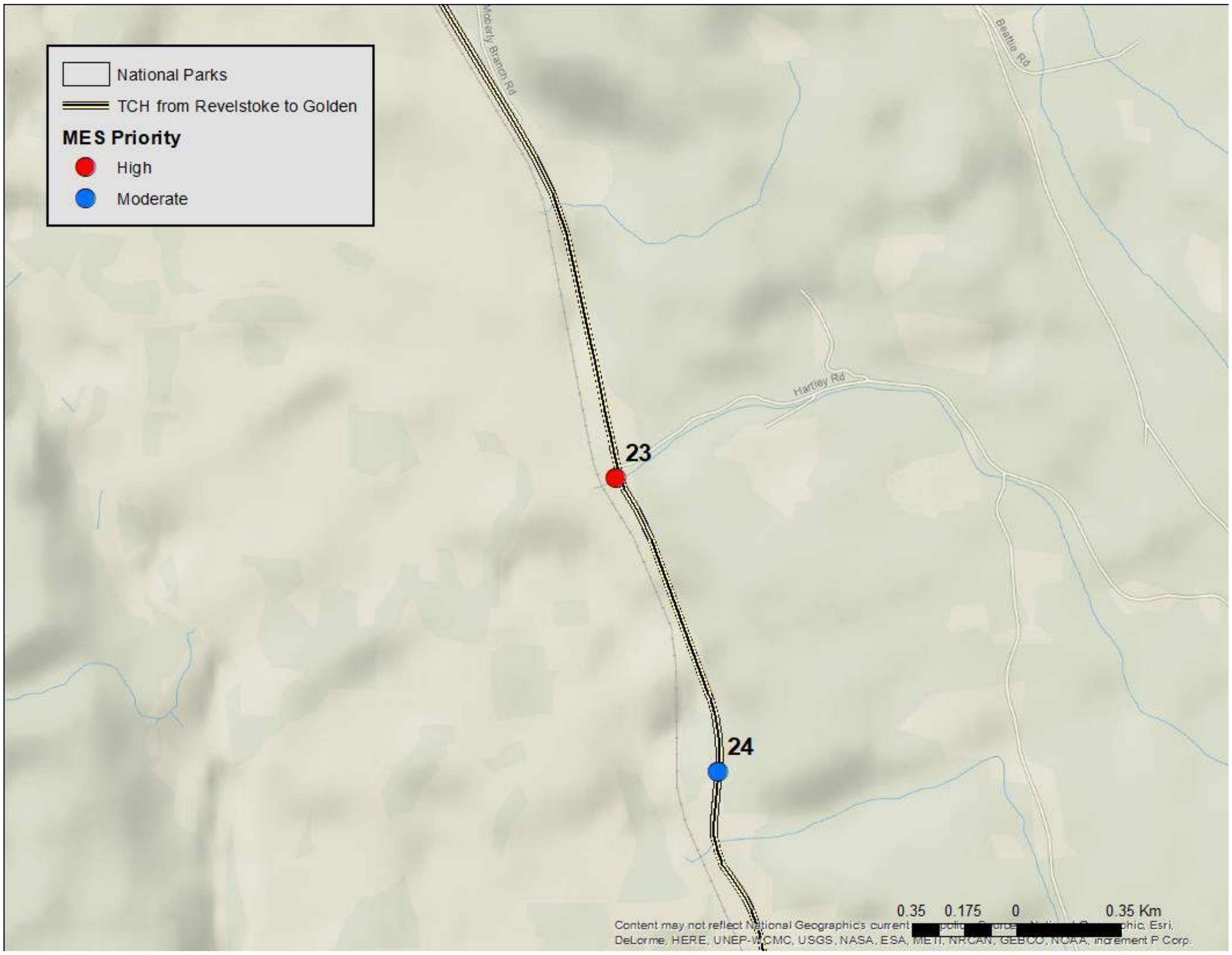

Figure A17: Map showing Highway Mitigation Emphasis Site (MES) 23 (Hartley Road) and 24 (Hartley East) in Trans-Canada Highway study area between Revelstoke and Golden, British Columbia.

East Area, MES 25 Summary – Quarry North	
Description	
Location (LKI): 985 – 51.75 km	
Location (UTM): 500288.5687674	
Species: Primarily, deer, bears, cougars	
SCORING	
Mortality risk: 3	
Local conservation value: 4	
Regional conservation significance: 1.5	
Human disturbance: 3	
Constructability: 3	
TOTAL SCORE: 18.5	
RANK: 9	
Local knowledge: 4	
Wildlife objectives	
• Reduce wildlife–vehicle collisions in this section of highway, primarily deer. • Provide safe movement for all wildlife species across highway, primarily deer, cougars and bears.	
Existing infrastructure	
• 1000 mm diameter culvert	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily.	
Transportation mitigation recommendations	
Constructability score: 3	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Selection of design type is dependent on terrain and engineering constraints. Minimum recommended dimension where feasible is 3m wide x 7 m high to pass common wildlife species through this area. Wing *fencing* (200–500 m depending on terrain) should be installed to funnel movements to the crossing structure. Fencing notes: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.	

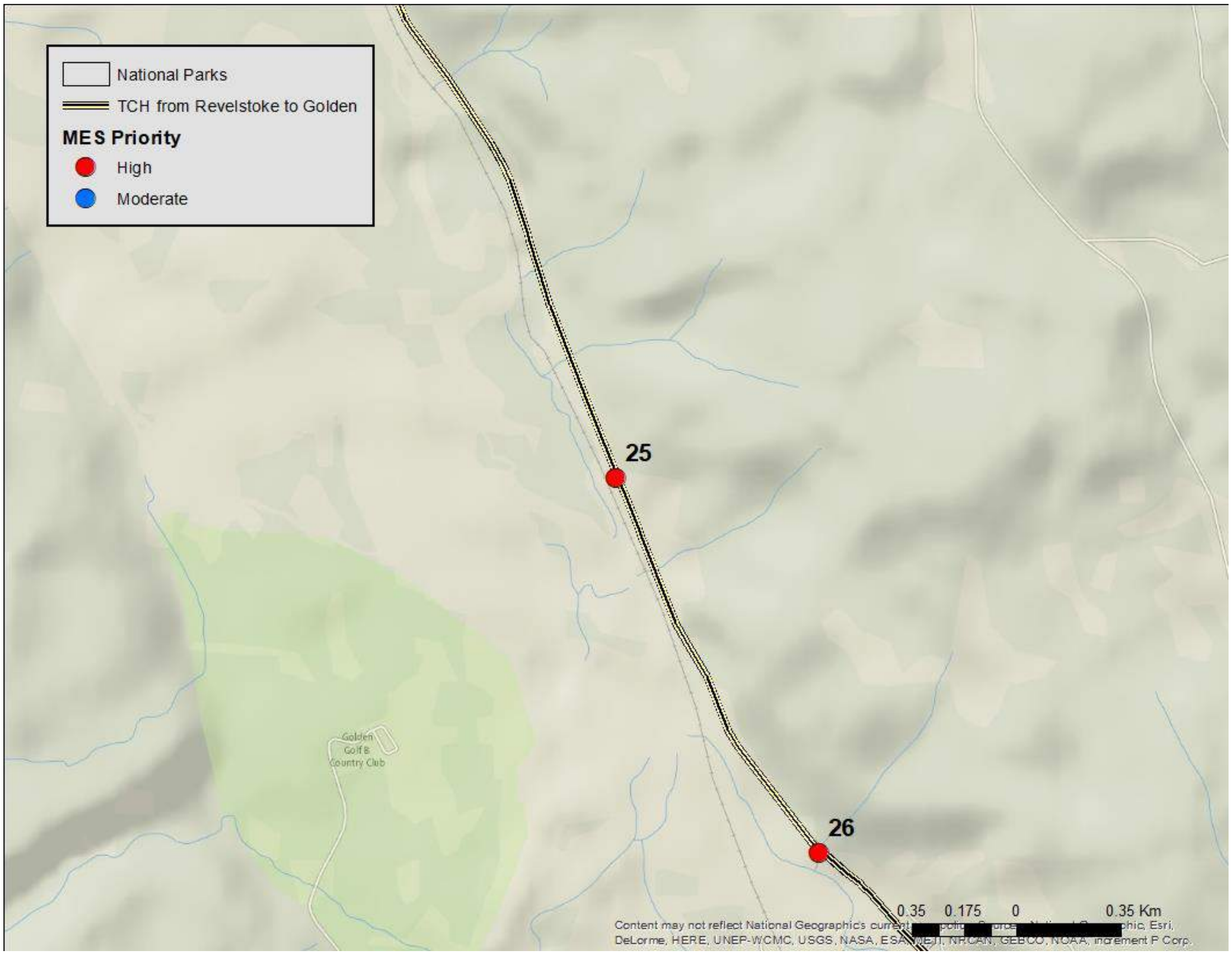

Figure A18: Map showing Highway Mitigation Emphasis Site (MES) 25 (Quarry North) in Trans-Canada Highway study area between Revelstoke and Golden, British Columbia.

East Area, MES 26 Summary – North Anderson	
Description	
Location (LKI): 985 – 52.95 km	
Location (UTM): 500969.5686413	
Species: Primarily deer and cougars	
SCORING	
Mortality risk: 5	
Local conservation value: 2	
Regional conservation significance: 2.75	
Human disturbance: 2	
Constructability: 3	
TOTAL SCORE: 19.75	
RANK: 8	
Local knowledge: 5	
Wildlife objectives	
• Reduce wildlife–vehicle collisions in this section of highway, primarily deer. • Provide safe movement for all wildlife species across highway, primarily deer, cougars, elk and bears.	
Existing infrastructure	
• 1000 mm diameter culvert	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: No species of regional connectivity concerns at this location.	
Transportation mitigation recommendations	
Constructability score: 3	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Selection of design type is dependent on terrain and engineering constraints; open-span preferred design. Minimum recommended dimension where feasible is 11 m wide x 3 m high due to importance of location for moving common wildlife through this area. Wing *fencing* (200–500 m depending on terrain) should be installed to funnel movements to the crossing structure. Fencing notes: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.	

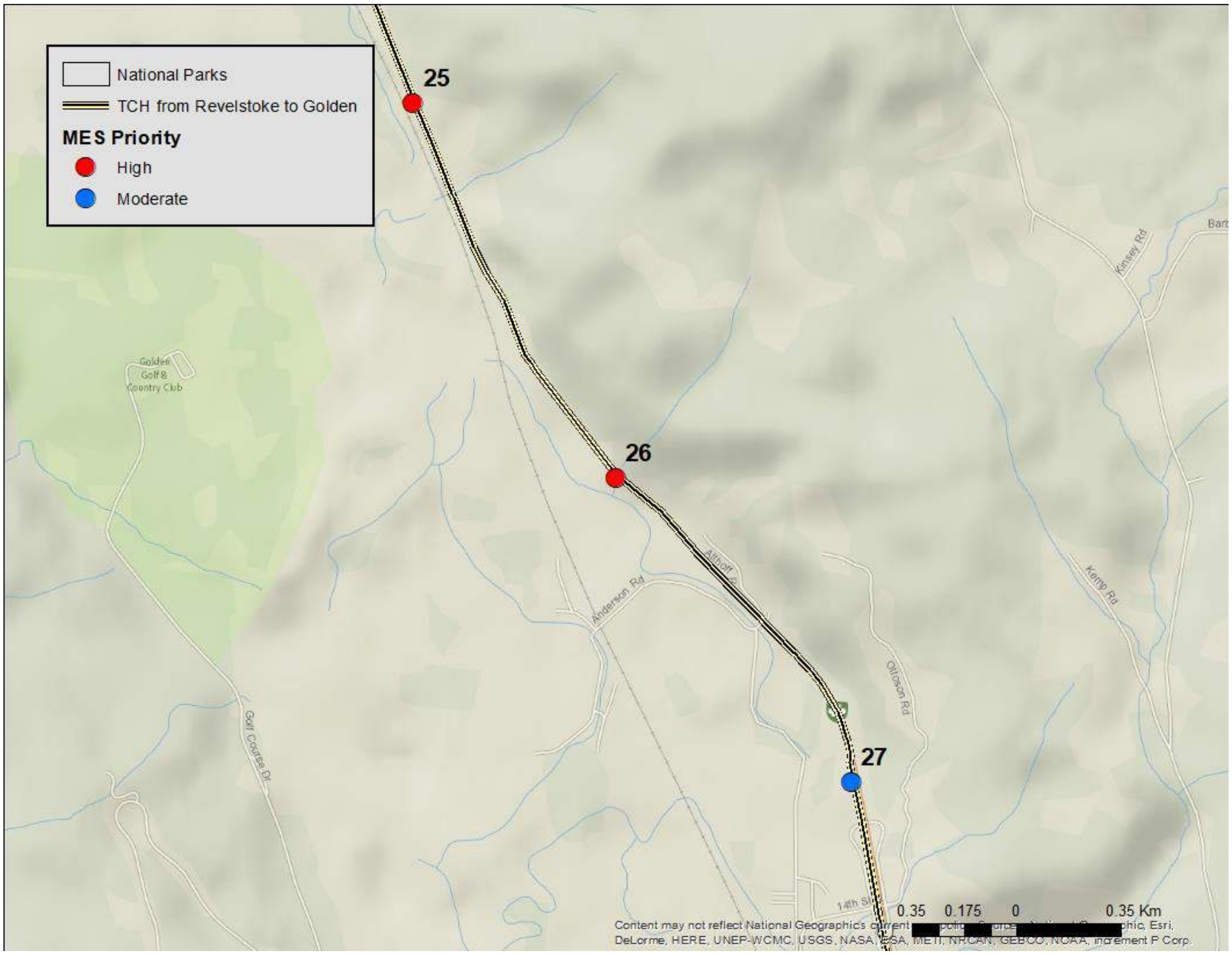

Figure A19: Map showing Highway Mitigation Emphasis Site (MES) 26 (North Anderson) in Trans-Canada Highway study area between Revelstoke and Golden, British Columbia.

East Area, MES 27 Summary – West Golden	
Description	
Location (LKI): 985 – 54.50 km	
Location (UTM): 501760.5685390	
Species: Primarily, deer and cougars	
SCORING	
Mortality risk: 5	
Local conservation value: 3	
Regional conservation significance: 2.25	
Human disturbance: 1	
Constructability: 3	
TOTAL SCORE: 17.25	
RANK: 15	
Local knowledge: 3	
Wildlife objectives	
• Reduce wildlife–vehicle collisions in this section of highway, primarily white tailed deer. • Provide safe movement for all wildlife species across highway, primarily white tailed deer and cougars.	
Existing infrastructure	
• None	
Target species for mitigation planning	
WVC reduction: Common species mostly white tailed deer **Regional conservation and connectivity**: No species of regional connectivity concerns at this location.	
Transportation mitigation recommendations	
Constructability score: 3	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Selection of design type is dependent on terrain and engineering constraints; concrete box culvert or bottomless arch preferred design. Underpass should run diagonally across TCH to connect best habitat on both sides. Minimum recommended dimension where feasible for underpass is 3 m wide x 3 m high due to importance of location for moving wildlife, primarily deer, through this area. Wing *fencing* (200–500 m depending on terrain) should be installed to funnel movements to the crossing structure. On east side of TCH fence can follow frontage road and run uphill anto suitable termination point. On west side of TCH fence should run from underpass out away from highway and frontage road and terminate near Tim Hortons. There are opportunities to use fill from project to create noise and light attenuating berms at entrances to underpass. Fencing notes: Snow is not likely a concern at this location due to lower elevation compared to other parts of study area.	

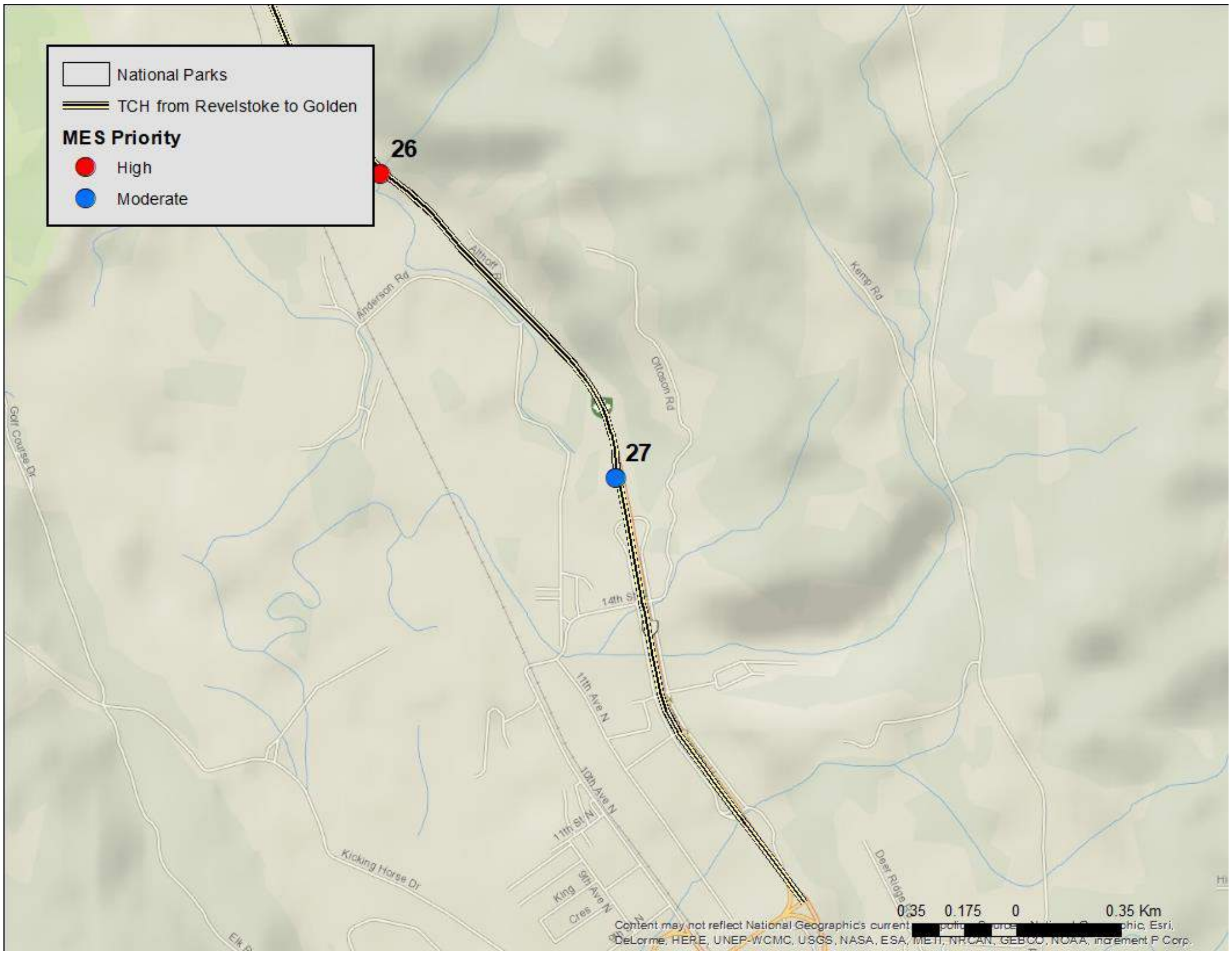

Figure A20: Map showing Highway Mitigation Emphasis Site (MES) 27 (West Golden) in Trans-Canada Highway study area between Revelstoke and Golden, British Columbia.

APPENDIX E

Mitigation Measure Information Sheets (A–E)

Mitigation measure information sheets are based on the *Handbook for Design and Evaluation of Wildlife Crossing Structures in North America* (Clevenger and Huijser 2011).

Sheet A: Wildlife Underpasses with Water Flow

Sheet B: Fencing

Sheet C: Gates and Ramps

Sheet D: Wildlife Underpasses

Sheet E. Large span bridge

Wildlife Underpasses with Water Flow SHEET A

General design

This is an underpass structure designed to accommodate dual needs of moving water and wildlife. Structures are generally located in wildlife movement corridors given their association with riparian habitats; however, some may be only marginally important. Structures aimed at restoring proper function and connection of aquatic and terrestrial habitats should be situated in areas with high landscape permeability, that are known wildlife travel corridors and that experience only minimal human disturbance. These underpass structures are frequently used by several large mammal species, yet use by some large mammals will depend on how it may be adapted for their specific crossing requirements. Small- and medium-sized mammals (including carnivores) generally utilize these structures, particularly if riparian habitat is retained or cover is provided along walls of the underpass by using logs, brush or root wads. These underpass structures can be readily adapted for amphibians, semi-aquatic and semi-arboreal species.

Wildlife underpass designed to accommodate water flow (Photo: Tony Clevenger).

Use of the structure

Exclusively for wildlife, but may have some human use.

General guidelines

- Underpass structure should span the portion of the active channel migration corridor of unconfined streams needed to restore floodplain, channel and riparian functions.
- If underpass structure covers a wide span, support structures should be placed outside the active channel.
- Design underpass structure with minimal clearing widths to reduce impacts on existing vegetation.
- Even with large span structures the ability to restore habitat underneath will be limited. Open designs that provide ample natural lighting will encourage greater development of important native riparian vegetation.
- Maximize the continuity of native soils adjacent to and within the underpass. Avoid importation of soils from outside project area.
- Motor vehicle or all-terrain-vehicle use should be prohibited. Eliminating public or any other human use, activity or potential disturbance at the underpass and adjacent area is recommended for proper function and maximizing wildlife use.
- Underpass should be designed to conform to local topography. Design drainage features so flooding does not occur within underpass. Run-off from highway near structure should not end up in underpass.

Dimensions – General guidelines

Dimensions will vary depending on width of active channel of water flow (creek, stream, river). Guidelines are given below for dimensions of wildlife pathway alongside active channel and height of underpass structure.

Minimum:

Width: 3 m pathway
Height: 3 m

Recommended:

Width: >3 m pathway
Height: >4 m

Types of construction

Concrete bridge span (open-span bridge)
Steel beam span
Concrete bottomless arch

Suggested design details

Crossing structure

- Structures should be designed to meet the movement needs of widest range possible of species that live in the area or might be expected to re-colonize the area—e.g., high- and low-mobility species.

- Attempt to mirror habitat conditions found on both sides of the road and provide continuous riparian habitat adjacent to and within the structure.
- Maximize microhabitat complexity and cover within underpass using salvage materials (logs, root wads, rock piles, etc.) to encourage use by semi-arboreal mammals, small mammals, reptiles and species associated with rocky habitats.
- Preferable that the substrate of underpass is of native soils.
- Revegetation will be possible in areas of underpass closest to the entrance, as light conditions tend to be poor in the center of the structure.
- Design 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 the underpass.
- Wildlife fencing is the most effective and preferred method to guide wildlife to structure and prevent intrusions to the right-of-way. Mechanically stabilized earth walls, if high enough, can substitute for fencing and is not visible to motorists.
- Encourage use of underpass by either baiting or cutting trails leading to structure, if appropriate.
- Avoid building underpass in a 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.
- Underpass must be within cross-highway 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 underpass. Long-range planning must ensure that adjacent lands will not be developed and the wildlife corridor network is functional.

Mechanically stabilized earth (MSE) wall serving as wildlife exclusion "fence" (Photo: Tony Clevenger).

Possible variations

Divided road (two structures)
In-line:

Undivided road (one structure)

Maintenance

- If the wildlife underpass is not being monitored on a regular basis, periodic visits should be made to ensure that there are no obstacles or foreign matter in or near the underpass that might affect wildlife use.
- Fence should be checked, maintained and repaired periodically (minimum once per year, preferably twice per year).

Fencing SHEET B

General purpose

Wildlife exclusion fencing keeps animals away from roadways. However, fencing alone can isolate wildlife populations, thus creating a barrier to movement, interchange and limiting access to important resources for individuals and affecting the long-term survival of the population. Fencing is one part of a two-part mitigation strategy—fencing *and* wildlife crossing structures.

Fences keep wildlife away from the roadway and lead animals to wildlife crossings, thus allowing them to travel safely under or above the highway. Fences need to be impermeable to wildlife movement in order to keep traffic-related mortality to a minimum and ensure that wildlife crossings will be used. Defective or permeable fences result in reduced use of the wildlife crossings and increased risk of wildlife–vehicle collisions. Little research and best management practices exist regarding effective fence designs and other innovative solutions to keep wildlife away from roads.

Wildlife exclusion fencing and culvert design wildlife underpass (Photo: Tony Clevenger).

Configurations

Fencing configuration used to mitigate road impacts will depend on several variables associated with the specific location, primarily adjacent land use and traffic volumes. Both sides of the road must be fenced (not only one side) and fence ends across the road need to be symmetric and not offset or staggered.

- *Continuous fencing* – Most often associated with large tracts of public land with little or no interspersed private property or in-holdings. Advantages: Long stretches of continuous fencing have fewer fence ends and generally few problems of managing wildlife movement ("end-runs") around multiple fence ends, as with discontinuous fencing (below). Disadvantages: Access roads with continuous fencing will need cattle guards, electro-mats, or gates to block animal access to roads (see Sheet C).
- *Partial (discontinuous) fencing* – More common with highway mitigation for wildlife in rural areas characterized by mixed land use (public and private land). Generally installed when private lands cannot be fenced. Partial fencing is recommended in locations like MRG where it is not feasible or there is a need to fence long sections of highway. Advantages: Generally accepted by public stakeholders. Few benefits to wildlife and usually the only alternative when there is mixed land use. Disadvantages: Results in multiple segments of fenced and unfenced sections of road, each fenced section having two fence ends. Additional measures need to be installed and carefully monitored to discourage end-runs at fence ends and hasten wildlife use of new crossing structures (see Terminations below). Earthen ramps or "jump-outs" are also needed in close proximity to fence ends in order to allow animals escape the fenced once inside (see Sheet C).

Interceptions

Fences invariably intersect other linear features that allow for movement of people or transport materials. This can include access roads, but also recreational trails (people) and water (creeks, streams). These breaks or interceptions in the fence require special modifications in order to limit the number of wildlife intrusions into the right-of-way.

Roads

Texas Gates – Transportation and land management agencies commonly install Texas Gates (also called cattleguards or cowcatchers) where fences intersect access roads. Many different designs have been used, but few have been tested for their effectiveness with wildlife. Designs of Texas Gates vary in dimension, grate material (flat or cylindrical steel grates), and grate adaptations for safe passage by pedestrians and cyclists. Recently a grate pattern was developed that was 95 percent effective in blocking Key deer movement and was safe for pedestrians and cyclists. Work by Allen et al. (2013) on fenced sections of US-93 in Montana showed that Texas gates were >85% effective in keeping deer from accessing the road and 93.5% of deer used the crossing structure instead of the adjacent wildlife guard when crossing the road. The gates were less effective in keeping black bear and coyotes from accessing the road (33–55%). However, all black bears and 94.7% of coyotes used the crossing structure instead of the adjacent wildlife guard when crossing the road.

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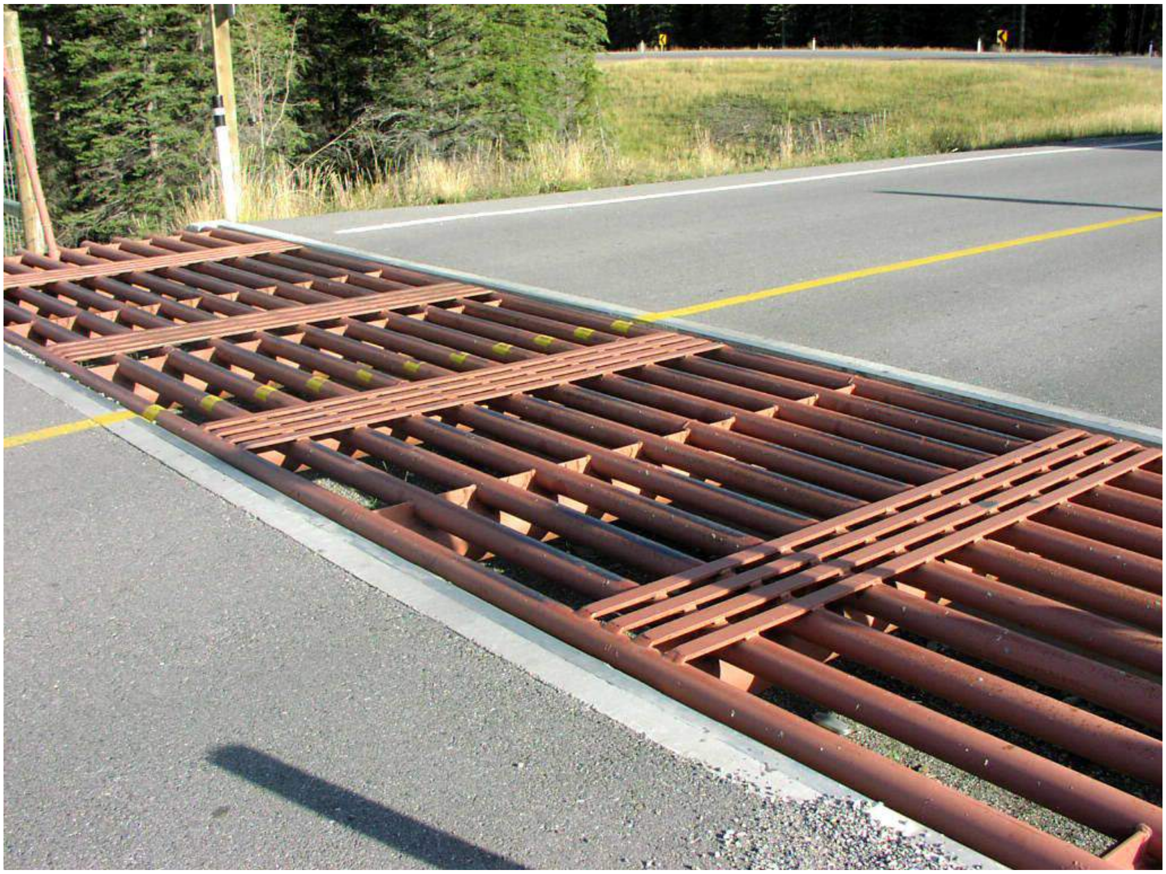


Cattle guard (Texas gate) in road (Photo: Tony Clevenger).

- *Electro-mats* – These electrified mats act like electric Texas Gates to discourage wildlife from crossing at the gap in the fence. Pedestrians wearing shoes and bicyclists can cross the mats safely, but dogs, horses and people without shoes will receive an electric shock. The electro-mats are generally 2-3 m wide, but can be designed to any width, and built into access roads where they breach fences. Cross-Tek® has been the lead company developing the e-mas and have had great success in high snowfall areas (Anchorage, Alaska) and dry areas (Arizona). They are currently designing and testing e-mats in Banff National Park.
- *Painted crosswalks* – Highway crosswalk structures have been used to negotiate ungulates across highways at grade level. White crosswalk lines are painted across the road to emulate a cattle guard. The painted crosswalk serves as a visual cue to guide ungulates directly across the highway. Painted crosswalks have not been tested, but if effective, they would be an inexpensive alternative to the more costly cattle guards. See Lehert and Bissonette 1997 for more details).

Trails

- *Swing gates (for fishermen, hikers)* – Where fences impede public access to popular recreation areas, swing gates can be used to negotiate fences. Gates must have a spring-activated hinge that ensures that even if the gate is left open it will spring back and close.

In areas of high snowfall, gates may be elevated and steps built to keep the bottom of the gate above snow.

Step gate with spring-loaded door situated at trailhead in Banff National Park, Alberta (Photo: Tony Clevenger).

- *Canoe/kayak landings* – There are no known simple gate solutions for transporting canoes/kayaks through fences. The swing gate described above is one solution, although the gate should be slightly wider than normal to allow a wide berth suitable for moving canoes/kayaks. Gates must have a spring-activated hinge that ensures they remain closed after use.

Watercourses

- *Rubber hanging drapes* – Watercourses pose problems for keeping fences impermeable to wildlife movement, as their flow levels tend to fluctuate throughout the year. When water levels are low, gaps may appear under the fence material allowing wildlife to easily pass beneath. Having fencing material well within watercourses will cause flooding problems, as debris being transported will not pass through the fence and can eventually obstruct water flow. A solution to this problem would require having a device on the bottom of the fence that moves up and down with the water levels. This could be done by attaching hinged strips of rubber mat-like material, draping down from the bottom of the fence material into the water. The rubber strips are hinged, so they float on top of the water and move in the direction of flow.

Suggested design details

Mesh type, gauge and size

Fence material may consist of woven-wire (page-wire) or galvanized chain-link fencing. Fence material must be attached to the back (non-highway) side of the posts, so impacts will only take down the fence material and not the fence posts.

- *Woven- or page-wire fencing* – Woven-wire fences consist of smooth horizontal (line) wires held apart by vertical (stay) wires. Spacing between line wires may vary from 8 cm at the bottom for small animals to 15–18 cm at the top for large animals. Wire spacing generally increases with fence height. Mesh wire is made in 11, 12, 12 ½, 14, and 16 gauges and fences are available in different mesh and knot designs. The square-shaped mesh may facilitate climbing by some wildlife, such as bears. If climbing is a concern then use of a smaller mesh is recommended.
  Wildlife fences along the Trans-Canada Highway in Banff National Park consist of 12 ½ gauge line wires with tensile strength of 1390 N/sq. mm. Stay wires have a tensile strength of 850 N/sq. mm. All wires had Class III zinc galvanized coating (see below) at a minimum of 260 gms/sq. m.
- *Chain-link fencing* – Chain-link fence is made of heavy steel wire woven to form a diamond-shaped mesh. It can be used in various industrial, commercial and residential applications. Chain-link was used for highway mitigation fencing along I-75 and SR 29 in Florida. There have been agency and public concerns about the visual aesthetics of chain-link fencing compared to woven-wire as it is less attractive and does not blend into the landscape. Steel posts are always used with chain-link fencing. Chain-link fence fabrics can be galvanized mesh, plastic-coated galvanized mesh or aluminum mesh.
- Most wire sold today for fencing has a coating to protect the wire from rust and corrosion. Galvanizing is the most common protective coating. The degree of protection depends on thickness of galvanizing and is classified into three categories; Classes I, II, and III. Class I has the thinnest coating and the shortest life expectancy. Nine-gage wire with Class I coating will start showing general rusting in 8 to 10 years, while the same wire with Class III coating will show rust in 15 to 20 years.
- *Electrified fencing* – Electric fences are a safe and effective means to deter large wildlife from entering highway right-of-ways, airfields and croplands. The 2-m-high fence will deliver a mild electric shock to animals that touch it, discouraging them from passing through. It is made of several horizontal strands of rope-like material about 1 cm in diameter that can deliver a quick shock that is enough to sting, but not seriously harm

humans. Wildlife respond differently to standard electric fences; high voltage fences are generally required to keep bears away. There are public safety issues of having electrified fencing bordering public roads and highways as there is high likelihood that people will come into contact with the fence (fishermen, hikers, motorists that run into fence).

Post types

- *Wood* – Wood posts are commonly used and can be less expensive than other materials if cut from the farm woodlot or if untreated posts are purchased. Post durability varies with species. For example, osage orange and black locust posts have a lifespan of 20 to 25 years whereas southern pine and yellow poplar rot in a few years if untreated.
- The life expectancy of pressure-treated wooden posts is generally 20 to 30 years depending on the type of wood. Softwoods are the most common wood used for posts when fencing highways. Lodgepole pine and Jack pine are common tree species for fence posts. For Trans-Canada Highway wildlife fences, all round fence posts were pressure treated with a chromate copper arsenate (CCA) wood preservative.
- Wood posts are highly variable in size and shape. For typical 2.4-m-high fencing, non-sharpened wooden posts 3.7 m and 4.2 m long are used. Fence posts are sharpened and then installed by preparing a pilot hole approximately 125 mm in diameter, vibrating the post down to specified post height and backfilling around the post with a compacted non-organic material to ground level. The strength of wood posts increases with top diameter. Post strength is especially important for corner and gate posts, which should have a top diameter of at least 16 cm. Line posts can be as small as 13 cm and should not need to be more than 14 cm on top diameter, although larger diameter posts make fences stronger and more durable.
- *Steel* – Steel posts are used to support fences when crossing rock substrate. They weigh less and last longer than wood posts; the main disadvantage is they are more expensive than wood posts. Steel posts are supplied in 3.7 m lengths and installed in concreted 1000-mm-long sleeves for the 3 m x 8 cm steel posts.
- Tension – Tension between posts can consist of metal tubing on metal posts and reinforced cable on wooden posts.

Reinforcements

- *Unburied fence* – Unburied fences are used in areas where resident wildlife are not likely to dig under the fence. The fence material should be flush with the ground to minimize animals crawling beneath the fence and reaching the right-of-way.
- Buried fence – This is strongly recommended in areas with wildlife capable of digging under the fence (e.g., bears, canids, badgers, wild boar). Buried fence in Banff National Park significantly reduced wildlife intrusions to the right-of-way compared to unburied fence (Clevenger et al. 2002). Buried fence consists of a 1- to 1.2-m-wide section of galvanized chain-link fence spliced to the bottom of unburied fence material. The chain-link section is buried at a 45-degree angle away from the highway and is approximately 1.1 m below ground. Swing gates should have a concrete base to discourage digging under them.
- Cable (protective) – Trees blown onto fences can not only damage fence material but provide openings for wildlife to enter the right-of-way. This is typically a problem during

the initial years after construction, but can continue over time. A high-tensile cable strung on top of fence posts to help break the fall of trees onto the fence material should reduce fence damage, repair costs and maintenance time.

Wildlife exclusion fence with buried apron (Photo: Tony Clevenger).

Concrete base of swing gate to prevent animal digging under wildlife fence (Photo: Tony Clevenger).

High tensile cable designed to break fall of trees onto fence material (Photo: Tony Clevenger).

Terminations

Fence ends are notorious locations for wildlife movements across roads and, thus, for accidents with wildlife. The problem is more acute soon after fence installation as wildlife are confused, unsure where to cross the road, and tend to follow fences to their termination, and then make end-runs across the road or graze inside the fence.

Each mitigation situation is different and will require a site-specific assessment, but as a general rule, fence ends should terminate at a wildlife crossing structure.

If a wildlife crossing cannot be installed at the fence ends, then fences should be designed to terminate in the least suitable location or habitat for wildlife movement—i.e., places wildlife are least likely to cross roads. Some examples are:

- Steep, rugged terrain such as rock-cuts (bighorn sheep and mountain goats excluded).
- Habitats that tend to limit movement, e.g., open areas for forest-dwelling species.
- Human-altered habitats and areas with frequent human activity and disturbance.

Placing animal-detection systems (see Sheet A) at fence ends has been an effective method of alerting motorists of wildlife approaching or crossing roads where at fence terminations. The most rigorous testing of the system took place over a 3-year period in Arizona. Overall, the animal-detection system and associated warning signs met their objective of modifying driver behavior by reducing speeds between 14-18%, (8-10 mph), thereby reducing the risk of collision with wildlife (Gagnon et al. 2010). They encountered few instances when their roadside animal-detection system and signs were inoperable; overall, their "crosswalk" system performed properly on 93% of their test visits. Motorist warning signs activated 98% of the time for both species at some point following the presence of animals in the detection zone. Overall, the system exhibited a relatively minimal amount of false positives or false negatives; following final modifications to the system, the amount of time the system was not operable was negligible (Gagnon et al. 2010).

Dimensions – General guidelines

Highway fencing for large mammals, including most native ungulate species of moose, elk, deer, and bighorn sheep, should be a minimum of 2.4 m high with post separation on average every 4.2 to 5.4 m. In some cases the fence height may not need to be designed for large ungulates. Alternate fence design and specifications will need to reflect not only requirements for species present, but also species that may re-colonize or disperse into the area in the future.
Fencing is an important component of a successful and functional mitigation scheme. However, in high snowfall areas standard fencing guidelines have been modified to address snow-load problems with fence posts and material (mesh type). These issues are a concern throughout many parts of the MRG study area, but less so in lower sections.

For previous work planning mitigation on highways in high snowfall areas we inquired with colleagues working for the Norwegian Directorate of Transportation (Oslo, Norway) and has worked with mitigation fencing for wildlife in areas with high snowfall. Bjørn Iuell prepared some guidelines currently being used in Norway with regard to fence mesh size, poles, distance between poles and fence height. We have included those guidelines as an Appendix to this report. Colleagues working for the Swedish Road Administration and Norwegian Directorate of Transportation (Oslo, Norway) will be able to provide valuable information on fence designs for parts of the Trans-Canada Highway in MRG. Raised mechanically stabilized earth (MSE) walls may be an option in places where the walls function as fences to block animal movement onto the highway and guide animals to crossing structures (see photo of MSE wall in Sheet E).

Maintenance

- Fences are not permanent structures, nor are they indestructible. They are subject to constantly occurring damage from vehicular accidents, falling trees, and vandalism. Natural events also cause damage and threaten the integrity of the fence. Soil erosion, excavation by animals, and flooding can loosen fence posts and collapse portions of fencing.
- Fences must be checked every six months by walking entire fence lines, identifying gaps, breaks and other defects caused by natural and non-natural events.

References

Allen, T., M. Huijser, D. Willey. 2013. Effectiveness of wildlife guards at access roads. Wildlife Society Bulletin 37:402-408.

Clevenger, A.P., Chruszcz, B., Gunson, K., and Wierzchowski, J. 2002. Roads and wildlife in the Canadian Rocky Mountain Parks - Movements, mortality and mitigation. Final Report (October 2002). Report prepared for Parks Canada, Banff, Alta.

Lenhert, M.A. and J.A. Bissonette. 1998. Effectiveness of highway crosswalk structures at reducing deer-vehicle collisions. Wildlife Society Bulletin 25, 809-818.

Gates and Ramps SHEET C

General purpose

If wildlife become trapped inside the fenced area, they need to be able to safely exit the highway area. The most effective means of escape are through a steel swing gate or an earthen ramp or "jump-out". The number, type and location of escape structures will depend on the target species, terrain and habitat adjacent to the highway fence.

Escape ramp (jump-out) for wildlife trapped inside highway right-of-way (Photo: Tony Clevenger).

Application

- *Swing gates* are generally used (with or without ramps) in areas where highways are regularly patrolled by wardens/rangers. As part of their job, if wildlife are found inside the fence, the nearest gates are opened and animals are moved towards the opened gate. Double swing gates are more effective than single swing gates, especially for larger mammals such as elk or moose. Swing gates are used to remove ungulates and large carnivores (e.g., bears). In high snowfall areas swing gates will be rendered ineffective until snow melts and gates can swing open and closed.

Single swing gate in wildlife exclusion fence (Photo: Tony Clevenger).

- *Earthen ramps or jump-outs* allow wildlife (large and small) to safely exit right-of-ways on their own without the aid of wardens or rangers. Typically wildlife find the ramps and exit by jumping down to the opposite side of fence. Deer and elk are the most common users, but moose, bighorn sheep, bears and cougars use these structures as well. The outside walls of the escape ramp must be high enough to discourage wildlife from jumping up onto the ramp and accessing the right-of-way. However, the walls should not be so high they discourage wildlife from jumping off. The landing spot around the outside wall must consist of loose soil or other soft material to prevent injury to animals. The outside walls must be smooth to prevent bears or other animals from climbing up. For best use, escape ramps should be positioned in a setback in the fence, in an area protected with dense vegetative cover, so animals can calm down and look over the situation before deciding to use the jump out or continue walking along the fence. A right-angle jog in the fence is recommended for positioning the escape ramp but not necessary.

  Earthen ramps or jump-outs have an important function at fence terminations. Fence ends are typically problematic as wildlife occasionally perform "end runs", which may lead to having wildlife inside the fenced right-of-way. Fence end problems can be corrected by ensuring that there are at least two jump-outs (one on each side of highway) near each fence end. If wildlife come inside the fenced section of a highway they typically travel close to the fence searching for an exit. By having a jump-out in close proximity to the fence end maximizes the chances that the animal will find the jump-out and exit the right-of-way.

Wildlife"jump-out" escape ramp (Photo: Tony Clevenger).

Maintenance

- Like fences, gates and ramps are not permanent structures, neither are they indestructible. They are subject to constantly occurring damage from vehicular accidents, falling trees, and vandalism. Natural events also can cause damage, obstruct gates and affect how well they perform.
- Like fences, escape structures must be checked every six months to ensure that they are functioning properly and that they perform when needed. Maintenance checks should take place at the same time as fence inspections.

Wildlife Underpasses SHEET D

General design

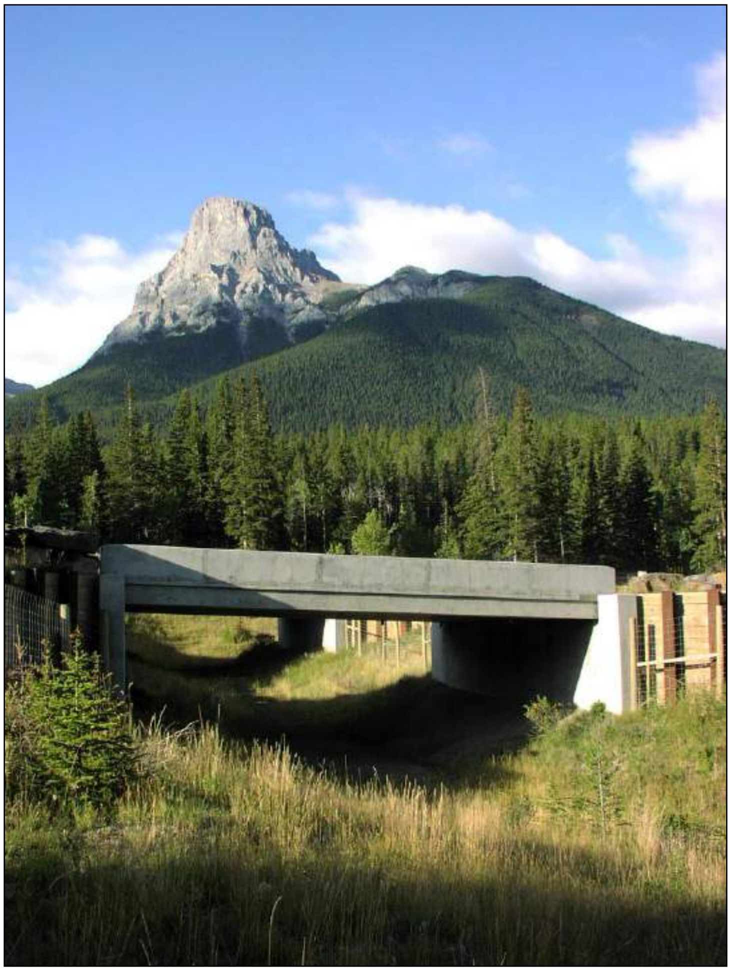
The wildlife underpass is not as large as most large span bridges or viaducts, but is the largest of underpass structures designed specifically for wildlife use. It is primarily designed for large mammals, but use by some large mammals will depend on how it may be adapted for their specific crossing 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.

Use of the structure

The wildlife underpass is designed exclusively for use by wildlife.

General guidelines

- Being generally smaller than a large underpass or viaduct or flyover, the ability to restore habitat underneath will be limited. Open designs that provide ample natural lighting will encourage greater development of native vegetation.
- To ensure performance and function, wildlife underpasses should be situated in areas with high landscape permeability that are known wildlife travel corridors and that experience only 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.
- Underpasses should be designed to conform to local topography. Design drainage features so flooding does not occur within the underpass. Highway runoff near structure should not be directed toward the underpass.
- Maximize continuity of native soils adjacent to and within the underpass. Avoid importation of soils from outside the project area.



Open span wildlife underpass (Photo: Tony Clevenger).

Dimensions – General guidelines

Width:

Minimum: 7 m
Recommended: >12 m

Height:

Minimum: 4 m
Recommended: >4.5 m

Types of construction

Span

Concrete bridge span (open-span bridge)
Steel beam span

Arch

Concrete bottomless arch
Corrugated steel bottomless arch
Elliptical multi-plate corrugated steel culvert

Box culvert
Prefabricated concrete

Suggested design details

Crossing structure

- Structures should be designed to meet the movement needs of the widest range possible of species that live in the area or might be expected to re-colonize 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 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 the underpass is of native soils. If construction type has a closed bottom (e.g., concrete box culvert), a soil substrate $\geq$ 6 in (15 cm) deep must be applied to interior.
- Revegetation is possible in areas of the underpass closest to the entrance. Light conditions tend to be poor in the center of the structure.
- Design 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 the 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 walls, if high enough, can substitute for fencing and are not visible to motorists.
- Encourage use of underpass by either baiting or cutting trails leading to the structure, if appropriate.
- Avoid building underpass in locations where a road runs 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.

Brush and root wads placed along underpass wall to provide cover for mammals (Photo: Nancy Newhouse).

- Underpass must be within cross-highway 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 underpass. Long-range planning must ensure that adjacent lands will not be developed and the wildlife corridor network is functional.

Possible variations

Divided road (two structures)
  In-line
  Off-set:

Undivided road (one structure)

Maintenance

- If wildlife underpass is not being monitored on a regular basis, periodic visits should be made to ensure that there are no obstacles or foreign matter in or near the underpass that might affect wildlife use.
- Fence should be checked, maintained and repaired periodically (minimum once per year, preferably twice per year).

Large Span Bridge SHEET E

General design

The large span bridge or viaduct, is the largest of wildlife underpass structures; however, it is usually not built specifically for wildlife movement. The large span and clearance allows for use by a wide range of wildlife (see Figure A-11). Structures can be adapted for amphibians, semi-aquatic and semi-arboreal species. Large span bridges with support pillars help keep habitats intact and nearly undisturbed. Large span bridges also help restore or maintain hydrological flows and the biological diversity associated with riparian habitats. They are commonly used for crossing wetland habitats. A range of dimensions exist from long structures with low vertical clearance for wetlands to short structures with high clearance spanning deep canyons.

Large span bridge as wildlife underpass (Credit: Ministère des Transports du Québec).

Use of the structure

The large span bridge is intended for wildlife, but may support occasional human use.

General guidelines

- Large span bridges are an alternative to constructing underpasses on cut-and-fill slopes, which tend to limit wildlife movement and reduce habitat connectivity compared to large span bridges.

- Large span bridges minimize the disturbance to habitats, vegetation, and riparian areas during construction. Design should be sufficiently wide enough to conserve riparian habitats and maintain local landform (see Figure A-12).
- Replant with local native vegetation if the area is disturbed during construction.

Large span bridge designed to conserve floodplain (Credit: Tony Clevenger).

Dimensions – General guidelines

Variable dimensions depending on location and terrain.

Types of construction

Concrete bridge span with support structures
Steel beam span

Suggested design details

Crossing structure

- Areas under large span bridges should be restored after construction with same vegetation in adjacent undisturbed areas leading up to the structure (see Figure A-13). Effort should be made to reconstruct the habitat and eventually have continuous vegetation types and structure within and adjacent to the large span bridge.
- Ponds or wetland habitat may be constructed connecting isolated habitats for amphibian species.
- Stringers of brush and root wads can be used to provide cover and microhabitat for cover-dwelling species until native vegetation can be restored to area.

- Drainage is generally not a problem if spanning water courses, however, riparian habitats should be protected as best as possible during and after construction. Pillars should avoid impacting riparian habitats completely, being outside the high-water mark.

Local habitat management

- If wildlife fencing is used below the large span bridge to funnel animals, then fencing should tie into the support structures or be close as possible to side slopes, thus providing the widest area for wildlife passage.
- Human use and any signs of human presence (e.g., storage of materials) should be minimized around large span bridges.

Large span bridge with retention of riparian vegetation (Credit: Tony Clevenger).

Possible Variations

- Road construction and operation should be avoided if at all possible underneath large span bridges that are adapted for wildlife use. If roads are necessary, they should have low traffic volumes and be placed to one side of the large span bridge. Trees, shrubs and other shielding devices should be used to reduce any impacts of vehicle disturbance to wildlife use of the site.
- Some large span bridges spanning wetlands may have sound-attenuating walls to reduce traffic noise or disturbance to adjacent habitat. In these cases, walls should not be transparent. If they are, they should have proper markings to adequately warn birds of their presence. Poles have been used effectively on bridges to deflect terns flying over span bridges.

Maintenance

- Inspections should be made periodically to ensure that there are no obstructions to wildlife movement below large span bridges.
- While restoring native vegetation, periodic checks should be made to ensure that vegetation is properly cared for and there is adequate water or fertilizer for vegetation to grow.
- Sound-attenuating walls should be inspected and repaired as necessary.