
WILDLIFE CROSSING STRUCTURE HANDBOOK

Design and Evaluation in North America

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Administration**



Central Federal Lands Highway Division
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FOREWORD

The Federal Highway Administration (FHWA) encourages programs that protect both wildlife and roadway users when the two groups eventually interact. An ever increasing human population demands safe and efficient access to their facilities, but this often comes with the need to mitigate the compromises to the animal habitats. Safety of drivers and preservation of animals are important components that when they successfully mesh we achieve major program goals for improved safety, enhanced livability, and protection of the environment.

This FHWA report called the *Wildlife Crossing Structure Handbook* offers key background information on defining the overall wildlife-vehicle interaction problem, the needs to be addressed, and offers a multitude of tangible solutions to plan, design, construct, monitor and maintain effective critter crossings. This handbook is for all transportation, environmental, wildlife resource, and stakeholder officials who strive to preserve and reweave safe corridor passages for animals and vehicle travelers.



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16. Abstract This handbook provides numerous solutions to wildlife-vehicle interactions by offering effective and safe wildlife crossing examples. It initially describes the critter crossing problem and justifies the need to solve it. Project and program level considerations are identified for planning, placement and design of wildlife crossing structures. Key design and ecological criteria, construction and maintenance guidelines, and effective monitoring techniques are shown and described in this handbook's practical application examples called Hot Sheets.			
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	25.4	Millimeters	mm
ft	feet	0.305	Meters	m
yd	yards	0.914	Meters	m
mi	miles	1.61	Kilometers	km
AREA				
in ²	square inches	645.2	Square millimeters	mm ²
ft ²	square feet	0.093	Square meters	m ²
yd ²	square yard	0.836	Square meters	m ²
ac	acres	0.405	Hectares	ha
mi ²	square miles	2.59	Square kilometers	km ²
VOLUME				
fl oz	fluid ounces	29.57	Milliliters	mL
gal	gallons	3.785	Liters	L
ft ³	cubic feet	0.028	cubic meters	m ³
yd ³	cubic yards	0.765	cubic meters	m ³
NOTE: volumes greater than 1000 L shall be shown in m ³				
MASS				
oz	ounces	28.35	Grams	g
lb	pounds	0.454	Kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
ILLUMINATION				
fc	foot-candles	10.76	Lux	lx
fl	foot-Lamberts	3.426	candela/m ²	cd/m ²
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	Newtons	N
lbf/in ²	poundforce per square inch	6.89	Kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	Inches	in
m	meters	3.28	Feet	ft
m	meters	1.09	Yards	yd
km	kilometers	0.621	Miles	mi
AREA				
mm ²	square millimeters	0.0016	square inches	in ²
m ²	square meters	10.764	square feet	ft ²
m ²	square meters	1.195	square yards	yd ²
ha	Hectares	2.47	Acres	ac
km ²	square kilometers	0.386	square miles	mi ²
VOLUME				
mL	Milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	Gallons	gal
m ³	cubic meters	35.314	cubic feet	ft ³
m ³	cubic meters	1.307	cubic yards	yd ³
MASS				
g	grams	0.035	Ounces	oz
kg	kilograms	2.202	Pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m ²	candela/m ²	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	Poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in ²

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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CHAPTER 1 – INTRODUCTION

BACKGROUND

The linear nature of surface transportation systems creates a suite of concerns for transportation and natural resource management agencies as they seek to ameliorate the impacts of their projects on environmental resources, as roads divide habitats and hydrological features. To help better understand the interactions between roads and environment the discipline of road ecology has emerged in the last 10 years. Road ecology strives to understand surface transportation infrastructure and its impacts on wildlife and motorist safety, aquatic resources, habitat connectivity, and many other environmental values.

The effects of roads on wildlife populations have been the focus of many studies in the last decade and increasing concern for transportation and natural resource management agencies. Roads affect populations in numerous ways, from habitat loss and fragmentation, to barriers to animal movement, and wildlife mortality. The impact of roads on wildlife populations is a significant and growing problem worldwide. In rural and suburban areas of North America, accidents with wildlife are quickly becoming a major safety concern for motorists as shown in Figure 1.

In parts of North America today, roads are a serious obstacle to maintaining population connectivity and a threat to the long-term survival of some regionally important wildlife populations. Wildlife crossing structures are intended to increase permeability and habitat connectivity across roads and reduce wildlife–vehicle collisions. These are above-grade (wildlife overpasses) or below-grade (wildlife underpasses) structures designed to facilitate movement of animals and connections among populations. Like landscape corridors, the conservation value of wildlife crossing structures are gaining attention as applied measures to help adapt changes in species ranges and animal distributions to climate change. The effect of roads on wildlife and biodiversity in general are a primary reason why the public raises questions about the environmental impacts of roads and vehicles. Calls for implementation of solutions are increasingly heard from environmental scientists, the transportation community, and decision makers.

Over the last decade, federal, state and provincial land management and transportation agencies have become increasingly aware of the effects that roads have on wildlife. Significant advances in our understanding of these impacts have been made; however, the means to adequately mitigate these impacts have been slower in coming. There are examples where wildlife crossing structures and fencing significantly reduce the impacts of roads on wildlife populations and have increased motorist safety. Anticipated population growth and ongoing highway investments in many regions as shown in Figure 2, coupled with the resounding concern for maintaining large-scale landscape connectivity for wildlife populations has generated increasing interest in crossing structures as management tools. Yet currently there is limited knowledge and technical guidance on how best design wildlife crossing systems for the range of wildlife found throughout North America.



Figure 1. Photo. Accidents with wildlife in rural and suburban areas are becoming a major safety concern for motorists and transportation agencies (credit: John Nordgren).

JUSTIFICATION

There is currently an urgent need to provide transportation and other stakeholder agencies with technical guidance and best management practices on the planning and design of wildlife crossing mitigation measures. Research in this area has increased over the years but has not resulted in sufficient rigorously tested practices useful to transportation agencies. As a result, many transportation agencies continue to build costly structures for wildlife connectivity with little evidence-based guidance. Technical guidelines and best management practices have not been articulated and are still much in need for many North American wildlife species and their habitats.

The siting of wildlife crossing structures is equally as important as their design. Identifying the proper location of crossing structures is critical for designing effective mitigation of the barrier effect caused by roads. The number of methods used to determine these key locations on roads has increased in recent years. However, few attempts have been made to critically review the techniques that are currently available to transportation agencies.



Figure 2. Photo. Wildlife crossings are becoming more common in highway expansion projects in North America. An example is the Greenway Landbridge on Interstate 75 in Marion County, Florida (Credit: Google Earth).

Two recent publications help guide transportation agencies in the development of effective wildlife crossing structures. “Safe Passage” (Southern Rockies Ecosystem Project 2007) provides a simplified approach to planning the location and design of wildlife crossings. A comprehensive National Cooperative Highway Research Project 25-27 report provides decision support for issues related to the planning and general design of wildlife crossings. Both reports, however, lack technical guidelines for the design of wildlife crossings and fencing for species and species groups in North America.

Performance evaluations are not a regular part of transportation projects with wildlife crossing structures. Most monitoring efforts have been largely short-term or sporadic. Monitoring typically is aimed at single species; consequently, such programs may not recognize the requirements of other non-target species and populations in the area. Further, monitoring is rarely conducted long enough to meet the adaptation periods (or learning curves) wildlife need to begin using crossings on a regular basis. Guidance is still needed on the increasing number of techniques available for monitoring wildlife crossings, designing sound monitoring programs, and evaluating performance for adaptively managing future transportation projects.

IMPORTANT DATES IN ROAD ECOLOGY HISTORY

- 1955—First wildlife crossing built in United States: Black bear underpass, Florida
- 1974—First wildlife crossing built in Europe: Badger tunnel, The Netherlands
- 1975—First wildlife overpass built in United States: Interstate 15, Utah
- 1982—First wildlife crossing built in Canada: Trans-Canada Highway wildlife underpass, Banff National Park
- 1982—First wildlife overpass built in Europe: Le Hardt, France
- 1990—First wildlife overpass built in Canada: Coquihalla Highway, British Columbia
- 1991—ISTEA: Intermodal Surface Transportation Efficiency Act of 1991**
- 1996—“Transportation and Wildlife: Reducing Wildlife Mortality and Improving Wildlife Passageways Across Transportation Corridors.” First international meeting on wildlife and transportation in Orlando, Florida (30 April to 2 May 1996)
- 1997—National Academies publication “Toward a sustainable future: addressing the long-term effects of motor vehicle transportation on climate and ecology,” National Academy Press, Washington, D.C.
- 1998—TEA-21: Transportation Efficiency Act of the 21st Century**
- 1998—First International Conference on Wildlife Ecology and Transportation (ICOWET) at Fort Meyers, Florida (10–12 February 1998)
- 2001—ICOWET becomes ICOET (International Conference on Ecology and Transportation), Keystone, Colorado
- 2001—Federal Highway Administration (FHWA) European Scan Tour, “Wildlife habitat connectivity across European highways”
- 2002—National Cooperative Highway Research Program (NCHRP) Synthesis paper published, “Interaction between roadways and wildlife ecology: a synthesis of highway practice”
- 2003—“Road Ecology: Science and solutions” published by Island Press. First major publication that outlines, describes and synthesizes available knowledge of the ecological effects of roads and emerging field of road ecology
- 2005—SAFETEA-LU passed (Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users)**
- 2005—National Academies publication “Assessing and Managing the Ecological Impacts of Paved Roads,” National Academy Press, Washington, D.C.
- 2005 – First Transportation Research Board Task Force on Animal–Vehicle Collisions (ANB20(2))
- 2006—First Transportation Research Board (TRB) Standing Committee (ADC30) on Ecology and Transportation
- 2007—Society for Conservation Biology (SCB) has session at the ICOET meeting in Little Rock, Arkansas
- 2008—Western Governors’ Association policy resolution to protect wildlife migration corridors and crucial wildlife habitat in the West
- 2008—FHWA report to U.S. Congress on mitigation measures aimed at reducing wildlife–vehicle collisions
- 2008—FHWA manual provides technical guidance on the design and implementation of mitigation measures that are considered best practice to reduce wildlife-vehicle collisions
- 2010—ARC International Wildlife Crossing Infrastructure Design Competition. First design crossing competition. Launched in 2010, and winners announced at the 2011 Transportation Research Board meeting, Washington, DC.

OBJECTIVES

This handbook provides technical guidelines for the planning, design and evaluation of wildlife crossing structures and their associated measures (fencing, gates) that facilitate the safe movement of wildlife across roads and increase motorist safety. It has been prepared for transportation, natural resource and land management agencies responsible for planning, designing and implementing measures for mitigating the impacts of roads on wildlife populations. Stakeholder and other groups involved in mitigation planning will also find this handbook useful in their discussions with agencies.

This handbook describes how to increase the effectiveness of established designs and recommends ways to design for particular species and species groups in different landscapes. The guidelines can be used for wildlife crossings on new or existing highways, highway expansions (e.g., two-lane to four-lane) and bridge reconstruction projects. The response of particular wildlife species to these measures may vary across North America. Therefore, the design guidelines are intended to be generalized and a starting point for the future development of more regionalized, landscape-specific guidelines based on an adaptive management process.

This handbook is the product of an extensive collection and synthesis of current literature, knowledge, and science-based data with regard to the current practices in wildlife crossing mitigation. This handbook provides a sound scientific basis for effective planning, policy and implementation of mitigation aimed at reducing habitat fragmentation and mortality effects of roads on wildlife populations. Recommended designs once implemented and their performance evaluated through monitoring will serve to advance our understanding of the utility of different wildlife crossing designs across North America.

ORGANIZATION

This handbook is organized to provide assistance to transportation and natural resource management practitioners charged with the planning, design and performance evaluations wildlife crossing mitigation. This handbook was designed so that chapters could be consulted independently, depending on the information or technical guidance needs, or all chapters in a practical sequence of project development.

Chapter 2 – Intersections provides background information on the ecological function of roads and examines the main impacts roads have on wildlife populations. These primary functions are important for understanding the landscape and biological context of mitigating road effects on wildlife.

Chapter 3 - Planning and Placement describes in a stepwise approach the different methods to plan the location of highway mitigation for wildlife movement with wildlife crossings at different spatial scales (project-level or systems/landscape-level) of resolution. Planning resources used to help identify appropriate locations for wildlife crossings are listed and describe how they can be used at the two different scales of application.

Chapter 4 - Design is the core of this handbook material. This chapter addresses the question of how to space wildlife crossings followed by context-sensitive and species-specific considerations

in selecting 11 types of wildlife crossing design, based on habitat quality and topography. The 11 wildlife crossing types consist of over-grade and below-grade crossing structures ranging from landscape bridges to amphibian-reptile tunnels. The specific details of each wildlife crossing type are compiled in “Hot Sheets” at the back of this handbook shown in Appendix C. The latter part of the chapter provides guidelines for planning the dimensions of the 11 types of wildlife crossings, in addition to the suitability of each wildlife crossing type for six species groups and 20 species of North American wildlife.

Chapter 5 - Monitoring outlines the basics of monitoring wildlife crossing structures, including a stepwise approach to testing whether management objectives have been met, how to determine performance targets, what monitoring methods are available, and how to design rigorous studies evaluating performance of built mitigation. The chapter concludes discussing the benefits of monitoring for adaptive management and their direct application to future transportation planning.

Suggested Reading—Rather than provide footnotes or literature citations throughout the document, key literature is cited at the end of each chapter for further reading.

Appendix A consists of a glossary of commonly used terms throughout this handbook.

Appendix B lists all the common and scientific names of wildlife covered in this handbook.

Appendix C lists Hot Sheets 1 -14 for the different wildlife crossings showing their fencing and gate details.

Appendix D provides a framework for designing monitoring studies.

Appendix E lists the current monitoring techniques available.

Appendix F and G list relevant handbooks and professional journals with information on wildlife crossing design, planning and performance.

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CHAPTER 2 – WILDLIFE POPULATIONS AND ROAD CORRIDOR INTERSECTIONS

INTRODUCTION

The massive 4-million-mile (6.2 million-km) system of public roads in the United States is used by more than 200 million vehicles every year. This engineering marvel, largely a product of the post-war economy, permeates and links nearly every urban and rural area in the country as illustrated in Figure 3. Together these paved roads constitute approximately one percent of the land area in the United States, roughly the size of Maine. Richard Forman (Harvard University) took this one percent figure one step further by placing roads in the environmental context in which they occur. Since the environmental impacts of roads extend well beyond their paved edge, he estimated that roads affect roughly 20 percent of the land area of the United States.



Figure 3. Photo. The highway system in the United States is used by more than 200 million vehicles and covers more than 6.2 million km (Credit: Tony Clevenger).

The North American economy and population are expected to grow considerably in the next 25 years. In the United States today, traffic and roads are strongly implicated in many of the major environmental problems: air and water pollution, heavy energy use, fragmented farmland and habitat, wildlife and biodiversity losses, and disruption of ecological communities. In turn, these problems can adversely affect human and ecosystem health and the nation’s overall quality of life.

It comes as little surprise that the ecological effects of roads are gaining more attention among transportation agencies, land managers, local decision makers and the general public. Today road networks continue to expand and there are increasing public and political concerns regarding transport, ecology, quality of life, and local communities.

Understanding how roads affect their surrounding environment and wildlife populations will be important for planning and designing practical applications to properly mitigate their impacts.

THE NEW WEST

In much of the North American West, road networks are extensive and the volume of traffic on rural roads has sharply increased, as wild lands are progressively being developed and suburbanized. This new frontier phenomena results in vast changes in land use patterns and the alteration of natural habitats, leading to increased motorist–wildlife conflicts. In the East, the footprint of road systems is relatively stable compared to the growing New West phenomena. Nevertheless, traffic volumes in the East continue to rise on existing roads; suburban areas are expanding amidst a general trend of increasing deer populations.

THE ECOLOGY OF ROAD CORRIDORS

Historically, roads followed natural landscape contours and ran parallel and adjacent to rivers and streams. But post-war transportation planning and road building diverged from the sinuous, landscape form of roads and became more angular and rectilinear in order to provide efficient travel between population centers and key points of interest. As a result, today many roads and highways cut across landscapes, intersect ecosystems and impact local habitats. In doing so, terrestrial and aquatic flows such as wildlife movements and distributions, subsurface and surface hydrology and wind erosion may be blocked or altered. Roads have five different ecological functions that affect wildlife. Roads function as habitats, sources, sinks, barriers, and conduits. Depending on the road, its location and the number of vehicles traveling on it, some of these functions may have important ecological significance.

- As *habitats*, road corridors may harbor entire populations of plants and animals and may be of conservation importance. If they contain some of the last remaining native or semi-native habitats for a species they may be critically important.
- Road corridors may be *sources*, if wildlife populations thrive in these linear habitats compared to adjacent habitats.
- Road corridors where wildlife populations consistently experience high levels of mortality compared to populations in adjacent habitats are considered *sink populations*.
- When roads disrupt wildlife movements connecting habitats and populations, then road corridors are a *barrier*, blocking or selectively filtering important population movements and interchange of individuals and genes.
- The *conduit* or *corridor function* of road corridors occurs when wildlife move parallel along roads in corridor habitat, linking populations found in otherwise isolated patch habitats.

IMPACTS OF ROADS ON WILDLIFE POPULATIONS

Many studies have documented how roads affect wildlife populations and their ability to persist locally or even at a larger landscape scale. Some of the mechanisms for these impacts range from habitat loss and fragmentation to disrupting animal movement and road-related mortality. Mortality and habitat fragmentation are considered to be the greatest threat by far to maintaining wildlife populations. The many ways that roads alter wildlife habitats and the distribution of wildlife populations are described below.

Change In Habitat

Habitat Loss

Road construction and expansion result in loss of wildlife habitat by transforming natural habitats to pavement, dirt tracks, and cleared roadsides or right-of-ways. Some wildlife are more vulnerable to habitat loss than others. Wildlife that have large area needs, are found in relatively low densities, and have low reproductive rates tend to be the most sensitive to road-induced habitat loss. Wide-ranging carnivores are particularly vulnerable to road impacts for those reasons, and thresholds of road density for some carnivore species are known to limit their distributions. Similar patterns of road densities and population persistence have been documented for some amphibian populations in North America and Europe.

Road construction can increase the amount of edge habitat in a landscape conceptually shown in Figure 4. Because roads tend to be shaped long and thin, a disproportionately large amount of forest edge is created. This may benefit some edge-dwelling species, but can be detrimental to forest interior species as it may decrease in the amount of available habitat.

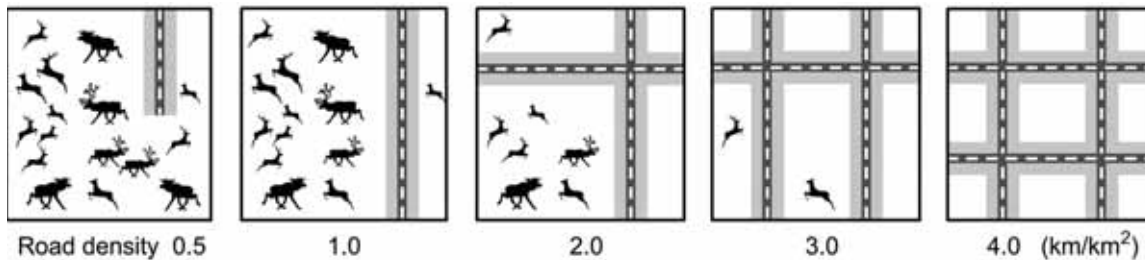


Figure 4. Schematic. Increasing road density fragments habitat into smaller patches and creates a disproportionate amount of edge habitat (from Iuell 2005).

Metapopulation theory suggests that the more mobile species are, the better they are able to manage with habitat loss. Yet mortality of individuals in the areas between the important core habitat patches (i.e., matrix habitat) usually does not figure into metapopulation theory as illustrated in Figure 5. Studies have shown that when mortality is high in the matrix habitat, highly mobile species are actually more vulnerable to habitat loss. Road corridors are one example of many possible matrix habitats in fragmented landscapes.

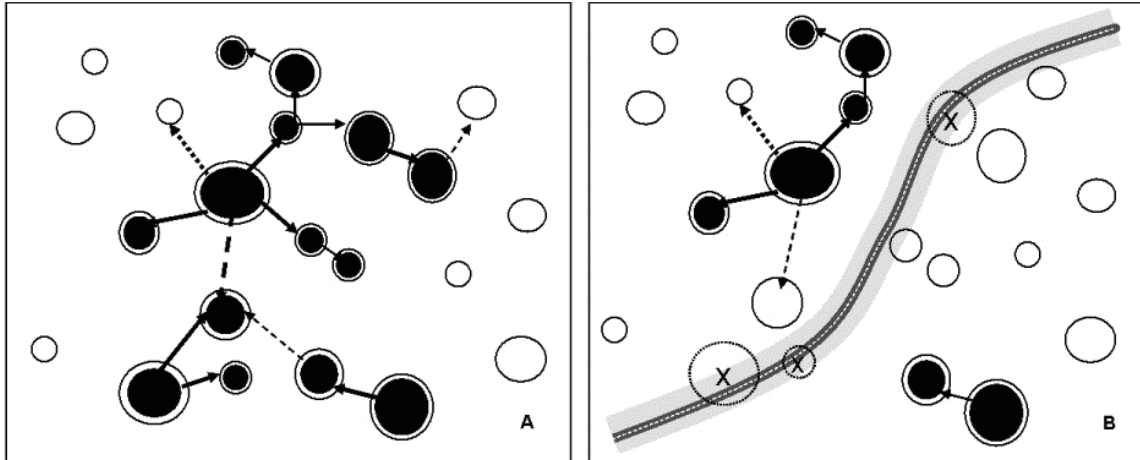


Figure 5. Schematic. Barrier effects on populations. (A) A metapopulation consists of a network of local subpopulations that may vary in size and local dynamics but are linked to each other through dispersal. (B) Road construction causes a disturbance and loss of local populations within the network. In addition, infrastructure imposes a barrier to dispersal that can prevent recolonisation and isolate local subpopulations from the rest of the metapopulation. If important source populations are cut off from the remaining sink populations, the entire metapopulation may be at risk of extinction (from Iuell 2005).

Diminished Habitat Quality

Disturbance from roads can affect wildlife behaviorally and numerically. Behavioral responses of wildlife typically consist of two types:

1. An avoidance response (zone of road avoidance) associated with regular or constant traffic disturbance, and
2. Avoidance due to irregular, less predictable isolated disturbances.

The numerical effect of roads on wildlife may be a decrease in population abundance or density of breeding individuals in habitats adjacent to roads. Should these distributions be strong enough to limit movements across roads, populations can become genetically isolated and the ability to persist over the long term becomes more precarious as graphed in Figure 6.

Improved Habitat Quality

Some wildlife (e.g., snakes) may be attracted to road corridors or the physical surface of roads for a variety of reasons as also shown in Figure 7, but most often the attraction is a result of conditions related to adjacent habitat (nesting, living space) or food found in the right-of-way.

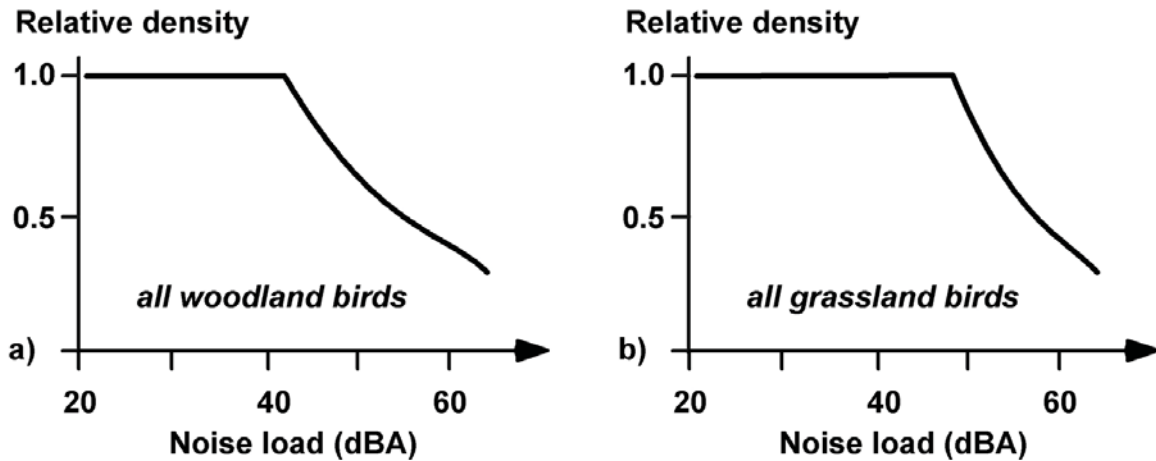


Figure 6. Graph. Results of studies on the impact of traffic noise on breeding bird populations in The Netherlands. When the noise load exceeds a threshold of between 40 and 50 dBA, bird densities were found to drop significantly. The sensitivity to noise and the threshold is different between species and between forested and open habitats (from Reijnen, Veenbaas and Foppen 1995).



Figure 7. Photo. Mountain goats attracted to roadside vegetation along Highway 93 South in Kootenay National Park, British Columbia, Canada (Credit: Tony Clevenger).

Road construction can create high quality habitat where food resources are more abundant compared to adjacent areas. When roads are fenced to keep wildlife out, lush forage along medians and right-of-ways is created and attracts herbivores, from Microtine Rodents to Deer

and Elk. Locally abundant small mammal populations living in these fenced areas become targets for avian and terrestrial predators such as Owls, Hawks, Coyotes and Foxes.

When predators forage in the fenced road corridor close to traffic, collisions with vehicles are inevitable, thus making roadside carrion available and attracting aerial and terrestrial scavengers if not promptly removed by highway maintenance crews.

Change In Wildlife Distribution

Barrier Effects

Landscape connectivity is the degree to which the landscape facilitates animal movement and other ecological flows. High levels of landscape connectivity occur when the area between core habitats in the landscape comprise relatively benign types of habitats without barriers, thus allowing wildlife to move freely through them in meeting their biological needs.

Landscape connectivity is important for two reasons:

1. Many animals regularly move through the landscape to different habitats to meet their daily, seasonal and basic biological needs.
2. Connectivity allows areas to be recolonized, for dispersal, for maintaining regional metapopulations and minimizing risks of inbreeding within populations.

Reduced landscape connectivity and limited movements due to roads may result in higher wildlife mortality, lower reproduction rates, ultimately smaller populations and overall lower population viability. These harmful effects have underscored the need to maintain and restore essential movements of wildlife across roads to maintain within population movements and genetic interchange. This is particularly important on roads with high traffic volumes that can be complete barriers to movement.

The fragmentation effect of roads begins as animals become reluctant to move across roads to access mates or preferred habitats for food and cover. The degree of aversion to roads may vary by age group and gender. The reasons why roads are avoided can generally be attributed to features associated with the road, e.g., traffic volume, road width or major habitat alterations caused by the road.

High-volume and high-speed roads tend to be the greatest barriers and most effective in disrupting animal movements and population interchange. However, some studies have shown that secondary highways and unpaved roads can also impede animal movements.

Corridor Function

Roads can limit movement for some wildlife, but they can also facilitate dispersal and range extensions of others, native and non-native. Depending on the species and the surrounding landscape, the right-of-way can be important habitat and possibly the only remaining functional habitat for some species in highly developed landscapes as shown in Figure 8. Right-of-ways may also serve as travel corridors between patches of important wildlife habitat.



Figure 8. Photo. Right-of-ways can vary considerably between different landscapes and parts of North America. Left: A two-lane highway in Jasper National Park. Dense vegetation of plants, shrubs and trees along roads provide potential nesting sites for birds and screen the road and its traffic from the surrounding landscape. Right: Interstate-65 in Kentucky consisting of a wide right-of-way with little native vegetation. (Credits: Tony Clevenger).

Mortality

The total number of motor vehicle accidents with large wildlife each year has been estimated at one to two million in the United States and at 45,000 in Canada. These numbers have increased even more in the last decade. In the United States alone, these collisions were estimated to cause 211 human fatalities, 29,000 human injuries and over US\$1 billion in property damage annually.

National trends were studied through reviewing several sources of crash data from the United States. From 1990 to 2004, the number of all reported motor vehicle crashes has been relatively steady at slightly above six million per year. By comparison, the number of reported wildlife–vehicle collisions over the same period has grown from less than 200,000 per year to a high of approximately 300,000 per year, a 50 percent increase. Looking at the data another way, wildlife–vehicle collisions now represent approximately 5 percent (or 1 in 20) of all reported motor vehicle collisions. The increase in wildlife-related accidents appears to be associated with an increase in “vehicle miles traveled” and increases in deer population size in most parts of the United States.

Traffic has been shown to be the leading mortality source for some wide-ranging mammals, e.g., Florida Panther, regional Bear and Bighorn Sheep populations. Roads were also shown to be the primary cause of wildlife population declines and habitat fragmentation among many amphibian populations.

ROAD-RELATED MORTALITY VS. BARRIER EFFECTS

Road-related mortality and reduced wildlife movements have the biggest effect on keeping wildlife populations viable over the long term. However, the degree to which these factors depress or threaten populations depends on the level of traffic volume. A conceptual model

shown in Figure 9 describes the effect traffic volume has on (1) animal avoidance of roads, (2) the likelihood of them getting killed while trying to cross, and (3) successful crossing attempts.

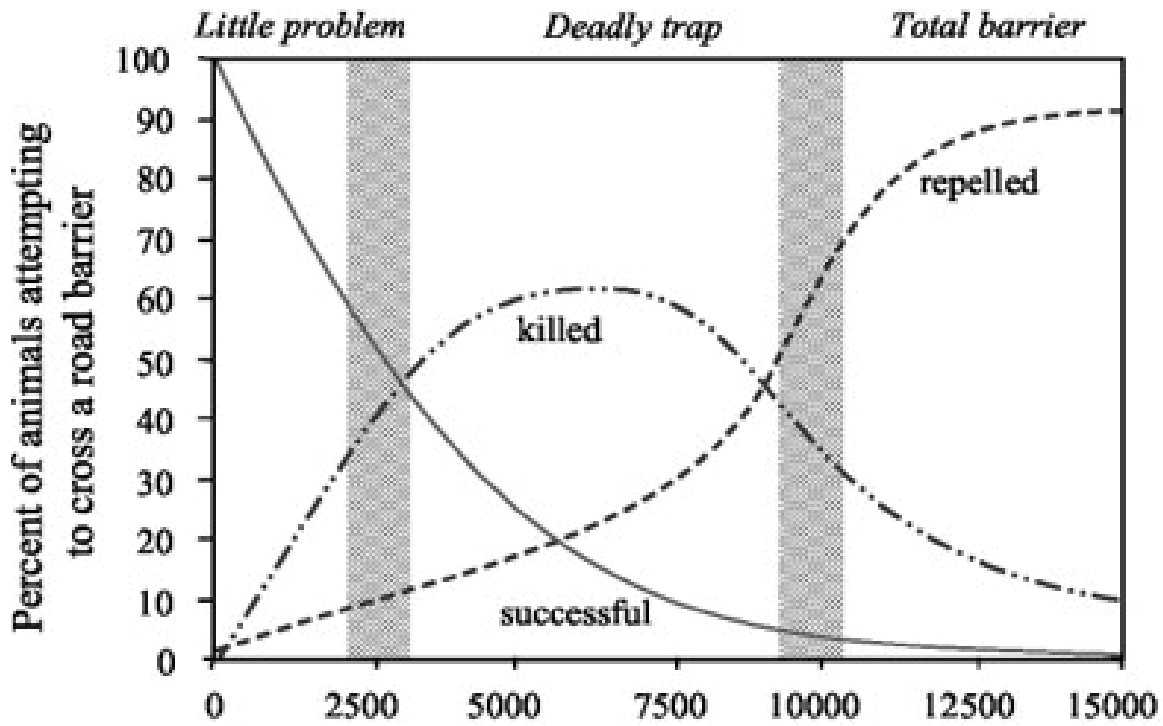


Figure 9. Graph. Conceptual model on the effect of traffic volume on the percentage of animals that successfully cross a road, are repelled by traffic noise and vehicle movement, or get killed as they attempt to cross. The conceptual model indicates that most collisions occur on intermediate roads (from Seiler 2003).

At low traffic volumes (<2500 annual average daily traffic volume (AADT)) the proportion of traffic-related mortalities is generally low, as is the number of animals that may be repelled by the road and traffic disturbance, thus having little or no impact on the population.

As traffic volumes increase to moderate levels (2500–10,000 AADT) mortalities are expected to be high, the number of animals repelled by roads will likely increase, and the proportion of successful crossings should start to decrease dramatically.

At high traffic volumes (>10,000 AADT), only a small proportion of attempted road crossings are expected to be successful. A large proportion of the animals approaching the road are likely repelled due to disturbance and heavy traffic volume, thus traffic-related mortality rarely occurs at all.

The model is particularly useful for understanding how wildlife mortality and cross-highway movements change with varying levels of traffic volume. Low rates of road-related mortality on a busy highway might be interpreted as evidence that impacts are negligible to wildlife, but in actuality the impacts may be that species have become locally extinct or that traffic disturbance

effectively keeps them far from the highway surface. The thresholds and shape of the distribution in the model may be species-specific.

A THRESHOLD FOR TRAFFIC VOLUME AND ROAD EFFECTS?

There has been some thought towards exactly what is the threshold of traffic volume above which roads become a deadly trap, as the model¹ describes, and when there is an urgent need for management intervention. It is unclear whether 2000–3000 vehicles per day is a threshold for transportation agencies to be concerned about. How abundant species are, their behavior and their biological needs will strongly affect what the threshold levels are for different wildlife. Nevertheless, the model provides a basis for further examination of two-lane or low-volume road impacts on mortality and fragmentation of wildlife populations.

¹Andreas Seiler, unpublished data.

Road-related mortality and barrier effects do not impact wildlife populations equally. The effects of road-related mortality on local populations may be seen in one or two generations, while loss of connectivity may take several generations to manifest.

Performance assessments of mitigation measures designed to reduce the impacts of road-related mortality and barrier effects should consider the combined performance of the measures in reducing those two impacts, rather than just one or the other.

Reducing road-related mortality and loss of individuals from populations generally has the greatest positive impact in maintaining populations locally. This is particularly true for medium- and large-sized mammals such as Bears, Cats, Wolves, given their tendency to occur in low densities, their slow rates of reproduction and long generation times.

The design and implementation of functional wildlife crossing structures should promote adequate interchange within the populations affected by roads, allow access to important resources, and ultimately enhance the viability of wildlife populations. However, scientifically understanding how much movement within the population is necessary, and what constitutes a barrier to connectivity, are difficult questions, especially for rare, elusive species such as Wolverine, Grizzly Bear or Lynx as captured in Figure 10. Future research using new methods such as non-invasive genetic sampling of hair or scats, satellite technology using global positioning system (GPS) transmitters, and spatially explicit population viability models may help answer some of these elusive management questions regarding roads, habitat fragmentation and population connectivity.



Figure 10. Photo. Lynx photographed using a wildlife overpass, as part of crossing structure monitoring along the Trans-Canada Highway in Banff National Park, Alberta. Long-term monitoring of the wildlife crossings in Banff has enabled the documentation of the crossings used by locally rare carnivores such as Lynx, and Wolverine (Credit: Tony Clevenger/WTI/Parks Canada).

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CHAPTER 3 – IMPACT IDENTIFICATION, REMEDIATION, PLANNING AND PLACEMENT

INTRODUCTION

When planning, designing and evaluating wildlife crossings, it is important to remember that every mitigation plan will be different, and it is not always possible to extrapolate results or expectations across political boundaries or landscapes. Each mitigation scheme has its own set of wildlife components, population connectivity concerns, transportation objectives, and land management priorities. The requirements for mitigation and plans prepared may be vastly different between adjacent watersheds, municipalities, states/provinces and countries.

These political, management and landscape-related issues should guide the planning process and will play an important role when designing effective mitigation for wildlife populations.

The most common management questions that arise in the planning stage are:

1. Where should wildlife crossing structures go?
2. What should they look like?
3. How will they perform?

In this chapter we will address the first question. The second question will be covered in Chapter 4 and question three will be explored in Chapter 5.

STARTING OUT

Rule of Thumb: Avoid, Mitigate or Compensate

Mitigation is only one of the planning alternatives transportation agencies have to reduce or eliminate impacts of road construction and expansion projects. Transportation projects can (1) have road alignments that *avoid* critical wildlife habitat, (2) *mitigate* affected wildlife populations and habitats, or (3) *compensate* for the loss of wildlife habitat as Figure 11 shows.

Before initiating project planning for wildlife habitat connectivity, the first step in *avoiding* impacts from road construction on wildlife populations and their habitats is to make alignment adjustments to prevent conflicts. The majority of major road construction projects today are expansions or reconstructions, so there may be few opportunities to avoid critical habitats with existing alignments. Some road expansion projects may encroach upon wetland habitats, but chances are based on proximity alone, the existing road has impacted them to some extent.

Road construction or expansion projects may be unable to avoid habitats completely, but road alignments can be planned to minimize impacts to wildlife. Having roadways traverse suboptimal habitat for wildlife can help reduce adverse effects, e.g., alignments on north-facing slopes. Roads that bisect optimal habitat generally have more adverse effects on wildlife compared to those in peripheral, suboptimal habitat illustrated in Figure 12.

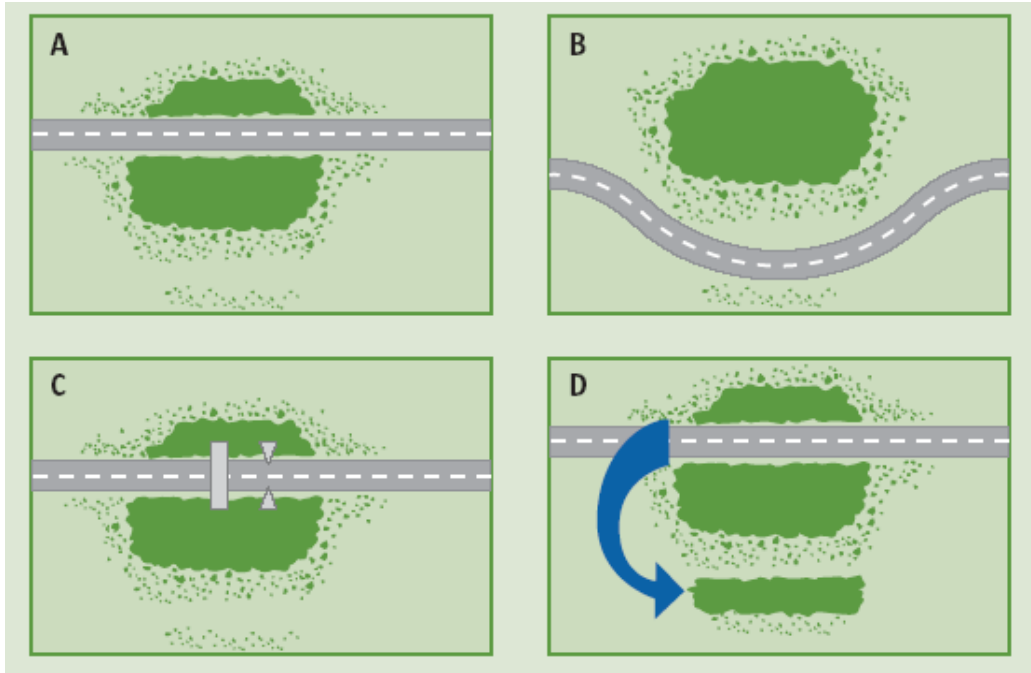


Figure 11. Schematic. Representation of road construction and habitat (A) fragmentation (B) avoidance (C) mitigation by use of under/overpasses, and (D) compensation by creation of replacement habitat nearby (from Iuell et al. 2005).

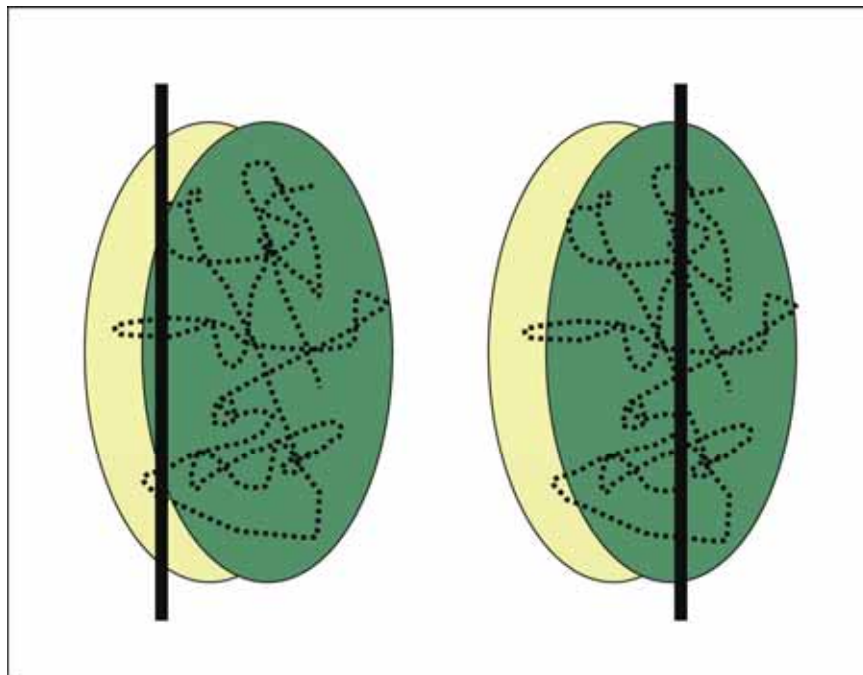


Figure 12. Schematic. Location of alignment of highways with respect to habitat quality may have differential impacts on wildlife movements (dotted line). The impact of a highway alignment located on the periphery in sub-optimal habitat (yellow) would be expected to impact wildlife movements less than if the disturbance equally bisected optimal habitat (green).

If the impacts cannot be avoided, then *mitigation* is an alternative. In North America this is the most common approach when roads impact wildlife habitat. Today there are many examples of mitigation techniques and strategies implemented for wildlife in nearly every North American landscape.

Finally, if projects are unable to avoid or mitigate their impacts then the third option consists of *compensation* measures. The compensation principle holds that for road construction or expansion there is no net loss of habitat, natural processes or biodiversity. This principle is commonly applied in transportation projects throughout North America through the National Environmental Protection Act (NEPA) in the United States and the Canadian Environmental Assessment Act (CEA).

SCALED HABITAT CONNECTIVITY PLANNING

Project-level and systems-level approaches are two different scales of habitat connectivity planning and means of incorporating measures to reduce the effects of roads on wildlife populations. Project-based approaches are most common with transportation agencies, although systems-level approaches that encompass entire states and provinces have become more common in the last few years.

Project-Level Approaches

Mitigating roads for wildlife conservation is most economical during road expansion or upgrade projects. Thus, funding for road mitigation measures such as wildlife crossing structures is most likely to originate from specific transportation projects that address multiple transportation management concerns, one of which may reduce vehicle collisions with wildlife and provide safe passage across busy roadways.

This *project-level approach* is concerned with proximate objectives—i.e., those within the transportation corridor and occasionally lands adjacent to it as mapped in Figure 13. A project-level focus may not necessarily consider how the wildlife crossing structures fit into the larger landscape and regional wildlife corridor network. Wildlife crossings should not lead to ecological “dead-ends” or “cul-de-sacs,” where wildlife have nowhere to go, but must link to a larger regional landscape and habitat complex that allows them to disperse, move freely, and meet their daily and life requisites. This requires not only large spatial-scale considerations but should also incorporate future (or projected) land-use change into the planning process.

Systems-Level or Landscape-Level Approaches

Wildlife crossings may also emerge from a systems-level analysis of transportation management concerns and priorities over a much larger area than transportation corridor projects. Rather than seeking to place a specific crossing structure (± 1 mile), the systems perspective identifies which stretches of highway should require mitigation (± 10 – 100 miles) and how intensive the mitigation should be. Key wildlife crossing areas may also be identified from a regional landscape assessment of wildlife connectivity needs around a state-/province-wide road system or regional transportation corridor.

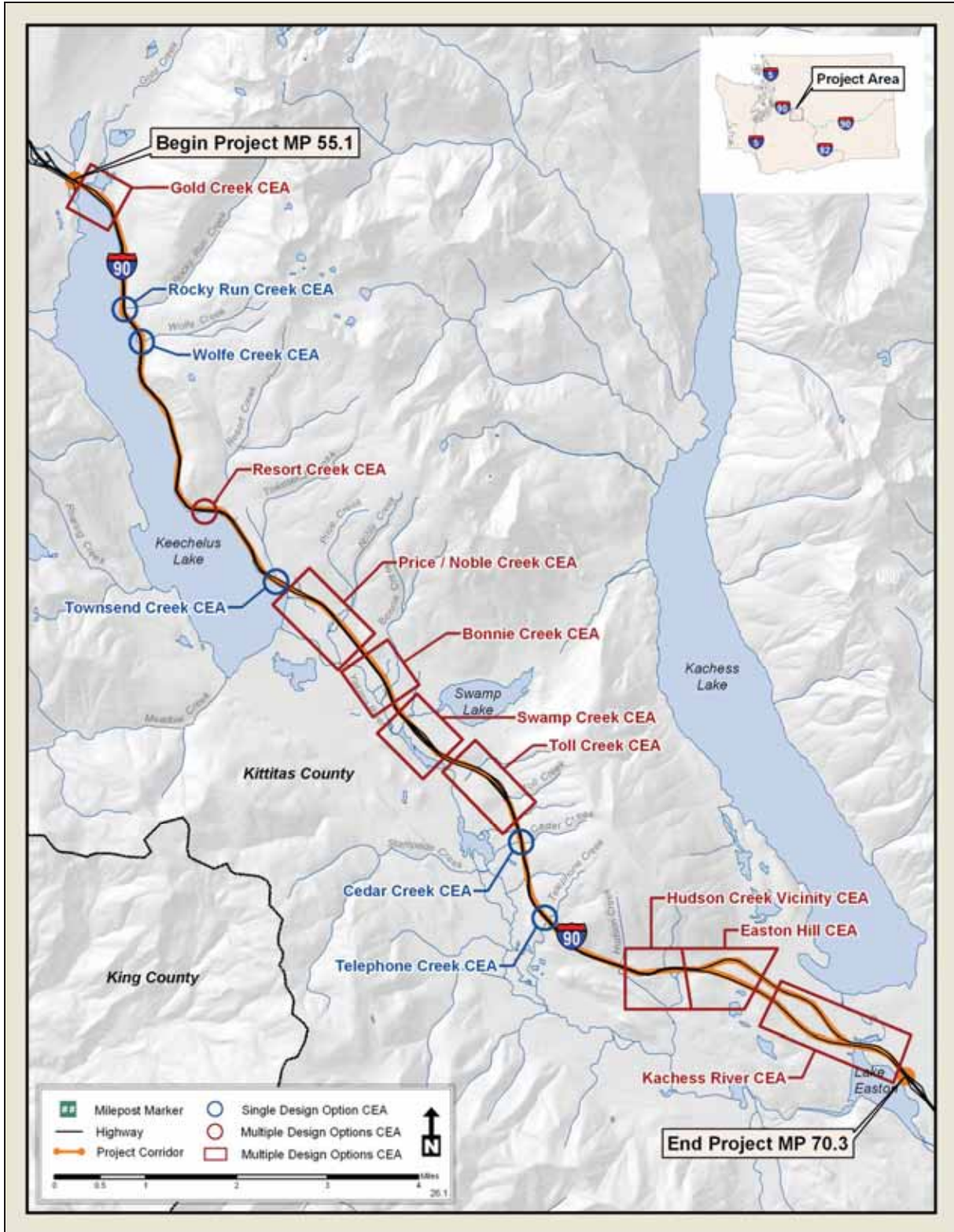


Figure 13. Map. A project-scale analysis of connectivity emphasis areas (CEA) for the Interstate 90 Snoqualmie Pass East project area, Washington State. These are locations where wildlife crossing mitigations are proposed to be installed (Source: Washington State Department of Transportation).

This landscape-focused approach can be viewed as the inverse of the project-level, or corridor-focused approach. With the right information it is possible to identify key habitat linkages or zones of important connectivity for wildlife that are bisected by transportation corridors as the Figure 14 map shows. Linkages and potential wildlife crossing locations can be prioritized based on future transportation investments, scheduling, ecological criteria and changing climate regimes. This helps to strategically plan mitigation schemes at a regional or ecosystem level.

This landscape-level approach, which is institutionalized in most of Europe, is gaining appeal with North American transportation agencies. In the United States, the overlay of two state agency maps—Statewide Transportation Improvement Program (STIP) plans with comprehensive Wildlife Conservation Plans from natural resources agencies—facilitates the integration and coordination of spatially explicit transportation and wildlife habitat conservation plans at the state level. A recent policy by the Western Governors’ Association to “protect wildlife migration corridors and crucial wildlife habitat in the West” sets a management directive to coordinate habitat protection and land use management for wildlife across jurisdictional boundaries. Of particular note was the section of the report produced by the Transportation Infrastructure Working Group, which makes detailed recommendations on ways to integrate future transportation planning with wildlife habitat conservation at the systems level.

Climate change has been inducing range shifts for many species during the last century. The potential impacts of climate change, coupled with an increasingly fragmented North American landscape less permeable for wildlife dispersal, will require conservation planning that enables wildlife to move and adapt to changing climatic conditions. Incorporating climate change scenarios in systems-level planning of transportation infrastructure makes good sense given the importance of crossing structures in allowing species affected by climate change and habitat fragmentation to expand their range into new climatic space.

There are substantial benefits from the systems-level analysis. By establishing a formal, broad-scaled planning process, it is possible to readily address stakeholder concerns, prioritize agency objectives, and incorporate landscape patterns and processes and climate change into the planning and construction process. It also helps ensure that project-level efforts contemplate the larger ecological network in the surrounding region. This results in more streamlined projects that save transportation agencies money over the long term.

ARIZONA'S WILDLIFE LINKAGES

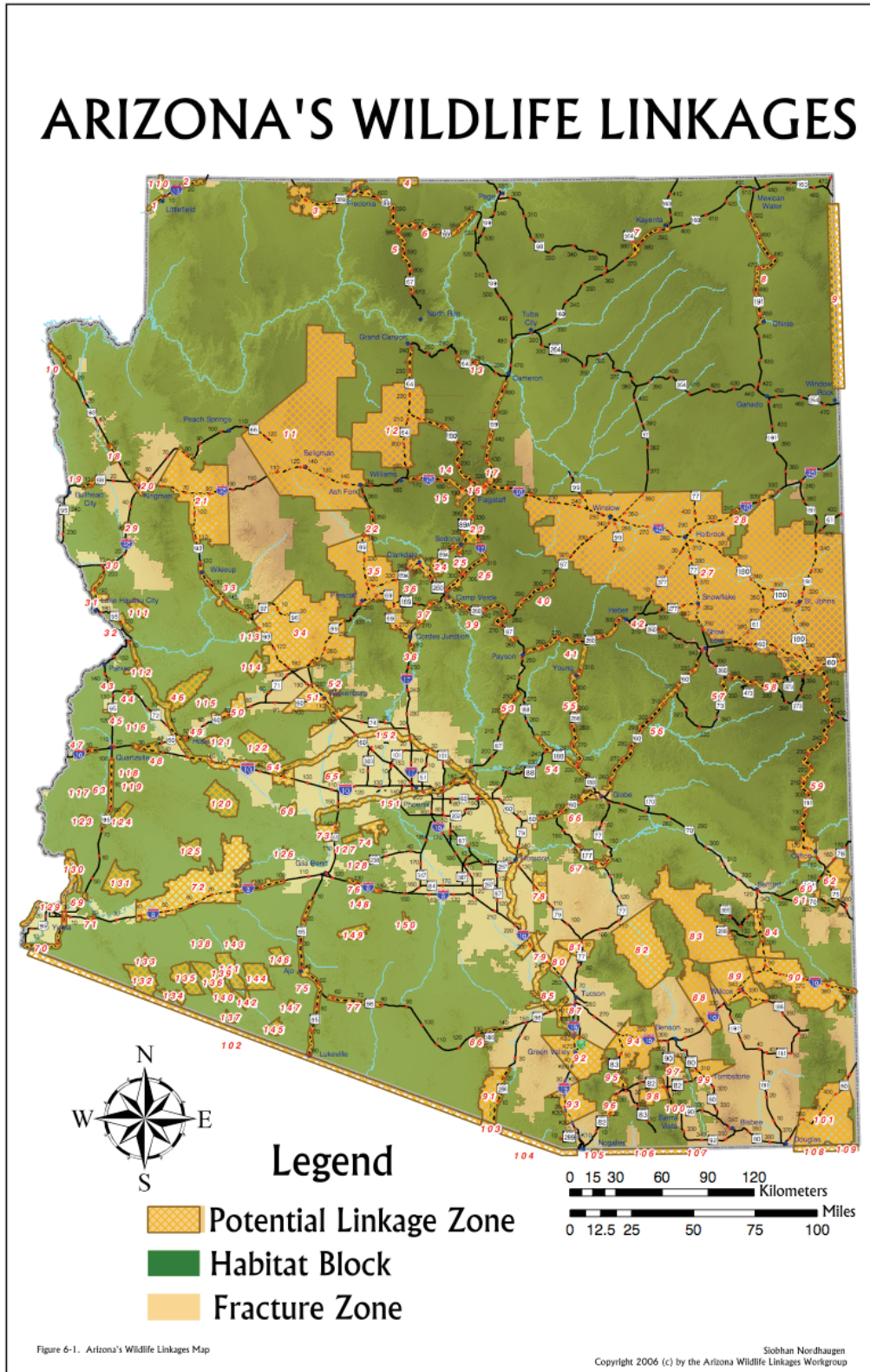


Figure 14. Map. Statewide mapping of highways and fracture zones, blocks of wildlife habitat and connectivity linkage zones for Arizona (Source: Arizona Wildlife Linkages Work Group).

ECO-LOGICAL

Infrastructure consists of the basic facilities—such as transportation and communications systems, utilities, and public institutions—needed for the functioning of a community or society. Sometimes the development of these facilities can negatively impact habitat and ecosystems. Techniques have been developed to better avoid, minimize, and mitigate these impacts, as well as the impacts of past infrastructure projects. However, the avoidance, minimization, and mitigation efforts used may not always provide the greatest environmental benefit, or may do very little to promote ecosystem sustainability. The most important sites for long-term ecological benefits may be “off-site” or outside the project area. This concern, along with a 1995 Memorandum of Understanding to foster the ecosystem approach and the Enlibra Principles, mobilized an interagency Steering Team to collaborate over a three-year period to write *Eco-Logical: An Ecosystem Approach to Developing Infrastructure Projects* (Brown 2006).

Eco-Logical encourages Federal, State, tribal, and local partners involved in infrastructure planning, design, review, and construction to use flexibility in regulatory processes. Specifically, *Eco-Logical* puts forth the conceptual groundwork for integrating plans across agency boundaries, and endorses ecosystem-based mitigation—an innovative approach of mitigating infrastructure impacts that cannot be avoided.

Eco-Logical is a guide to making infrastructure more sensitive to wildlife and ecosystems through greater interagency cooperative conservation. It describes ways for streamlining the processes that advance approvals for infrastructure projects—in compliance with applicable laws—while maintaining safety, environmental health, and effective public involvement. As a way to accomplish this, the guide outlines an approach for the comprehensive management of land, water, and biotic and abiotic resources that equitably promotes conservation and sustainable use. Key components of the approach include integrated planning, the exploration of a variety of mitigation options, and performance measurement.

PLANNING RESOURCES

Deciding where to locate wildlife crossing structures requires adequate tools and resources to identify the most suitable sites for crossing structures at the project and systems level. Listed below are resources that can help define the important wildlife linkages across roads and identify key areas for mitigation.

Maps and Data

Many resources are available today that facilitate the identification of wildlife habitat linkages and movement corridors. Many electronic resources are geographic information system (GIS)-based, readily available from government or non-governmental agencies, and can be downloaded from Internet sites, e.g., state/provincial or national Geospatial Data clearinghouses. Some basic map and data resources for planning wildlife connectivity and crossing mitigation include:

- Aerial photos
- Land cover-vegetation maps
- Topographic maps
- Landownership maps
- Wildlife habitat maps

- Wildlife movement model data
- Wildlife ecology field data
- Wildlife road-kill data
- Road network data

Table 1 describes each resource and how it can be used for project-level and systems-level planning of wildlife habitat connectivity and highway mitigation. Use of these resources in combination with road network and traffic data is an ideal place to start identifying the intersections of high probability habitat linkages and roads. Combining multiple resources will provide greater accuracy in identifying habitat linkages and finalizing site selection for wildlife crossing structures. Most of the resources listed in Table 1 work best at the more localized, project level, however some can be used or adapted for larger, systems-level assessments.

Table 1. Data layers and maps for planning wildlife connectivity and crossing mitigation.

Map/Data Type	Project-level	Landscape-level
Aerial photos	Photos can be used to help identify vegetation types and human developments. Photos come in many scales and image formats (ortho-photos, color infrared, black and white). Some images are high resolution (to 5 m). Readily available from local and state/provincial government agencies.	Typically not practical to use for large landscape-scale assessments of linkage zones. Landsat TM satellite imagery or other remotely sensed imagery are good substitutes for working at a state/provincial scale. Satellite imagery should be available at most local and state/provincial government agencies.
Land cover-vegetation maps	These maps help identify general vegetation types such as deciduous vs coniferous forests, shrublands, grassland/marshes, rock and ice. Land cover maps are more general and include physical (built areas) and biological information. Readily available from local and state/provincial government agencies and their websites.	Maps are available for large-scale habitat and corridor network planning. The scale is much larger and resolution lower, nonetheless important resource to use in large scale planning endeavors. Readily available from local and state/provincial government agencies and their websites.
Topographic map	Information on slopes, ridgelines, valley bottoms, drainages and other main topographic features are valuable for identifying wildlife habitat corridors. Roads, power lines and other human developments are usually found on these maps. Readily available from local and state/provincial government agencies.	Like land cover-vegetation maps above, topo maps are available for state/provincial-wide mapping exercises, however resolution is lower. Readily available from local and state/provincial government agencies.

CHAPTER 3 – IMPACT IDENTIFICATION, REMEDIATION, PLANNING AND PLACEMENT

<p>Landownership map</p>	<p>Coordinating management of lands adjacent to roads is key to successful mitigation. Maps that identify adjacent land use management such as public/crown lands, designated reserves, municipal and private lands are needed for planning corridors and crossings. Readily available from local and state/provincial government agencies.</p>	<p>Also available for large scale planning endeavors. Generalized vegetation and land-use types are provided. Readily available from local and state/provincial government agencies.</p>
<p>Wildlife habitat map</p>	<p>Generally developed from combination of biophysical maps (vegetation maps being one) and models of habitat suitability for certain wildlife species or groups. They identify key habitat types for the species for which they are prepared. Some are very accurate and derived from site-specific studies, while others are less accurate relying on extrapolated information. Readily available from local and state/provincial government agencies and NGOs.</p>	<p>Some states have prepared (or are in preparation) statewide habitat connectivity maps (e.g., FL, WA, CA). In the U.S., state natural resource agencies have prepared “comprehensive wildlife conservation plans” that identify statewide, key habitats for wildlife conservation. These should be readily available from most, if not all, state natural resource agencies today.</p>
<p>Wildlife movement model</p>	<p>Similar to wildlife habitat maps but more specific to where wildlife are most likely to move through the landscape. These are based on either expert opinion or empirical studies that integrate species ecology and landscape suitability. Generally available from wildlife agencies conducting the modeling research.</p>	<p>Generally not available for large-scale exercises unless designed specifically for that purpose. Least-cost path and circuit theory modeling may be promising methods at this scale.</p>
<p>Wildlife ecology field data</p>	<p>Supplemental data in form of telemetry points or population surveys can help guide the location selection for connectivity and crossing structures. Generally available from wildlife agencies conducting research in the project area.</p>	<p>Not generally available for state/provincial-wide work, however, local data can be extrapolated to larger landscapes to aid in habitat corridor planning.</p>

CHAPTER 3 – IMPACT IDENTIFICATION, REMEDIATION, PLANNING AND PLACEMENT

<p>Road-kill data</p>	<p>Many state/provincial transportation agencies collect location-specific data on wildlife species killed on their roads, either through carcass collections or collision reports. These data are primarily collected for large mammals and rarely for small or medium-sized fauna. These data can be used to identify road-kill hotspots, but do not provide information on where wildlife are successfully crossing the roadway.</p>	<p>Data are readily available from state/provincial transportation agencies, usually collected by districts and then stored in a state/provincial-wide database. These data can be used to identify most critical sections of state/provincial highway for accidents with large mammals (primarily elk and deer).</p>
<p>Road network</p>	<p>Municipal and state/provincial governments have digital information on all road types in their jurisdiction.</p>	<p>Road data from state/provincial to national scale can be obtained from the U.S. Census Bureau geospatial database or GeoConnections in Canada.</p>

GIS LAYERS

GIS analysis is widely used in transportation and natural resources management today. Analyses can be done in multiple spatial scales ranging from project to landscapes and regions. Many of the map and data resources listed above are available in digital format and can be overlaid and analyzed in ArcView/GIS® or ArcMap®. Basic GIS layers useful for identifying habitat linkages and siting wildlife crossings at the systems-level include:

- Digital elevation model (DEM; characterizes topography, preferably $\leq 30\text{m}$ resolution)
- Water or hydrology (includes all lakes, ponds, rivers, streams)
- Vegetation or ecological land classification system (general habitat types)
- Wildlife habitat suitability (species-specific habitat map)
- Built areas (areas of human development and activity)
- Roads (network of all paved and unpaved roads)

How To Site Wildlife Crossings

Generally habitat linkage assessments at the systems-level are not suitable for identifying specific locations for wildlife crossings due differences in design considerations, e.g. broad-scale movement patterns of large carnivores versus local topographic and engineering concerns. However, a linkage assessment can help prioritize and identify where wildlife–road conflict areas occur over a large area. Once identified, this is a good starting point for initiating discussions with transportation and regulatory agencies about mitigation plans in the short and long term.

Determining the specific placement or siting of wildlife crossings is generally done at the project-level, or after a thorough field survey as part of a larger systems-level assessment. Regardless of the method, considerations of wildlife crossing placement begin by determining the wildlife species or groups of concern as discussed later in Chapter 4. Once the focal species or group is identified, many of the resources listed above can be used to identify the best locations for wildlife crossing mitigation. Methods to identify those locations are briefly described below. *It is critical to make a field visit and be on the ground at the potential location for any wildlife crossings regardless of the tools or techniques used.*

Below we describe several different approaches used by transportation agencies to location wildlife crossing structures.

FIELD DATA

Physical Data

Road-Kill Data

Intuitively road-kill data would be best suited for determining where wildlife crossings should be placed. However, research suggests that the locations where wildlife are struck by vehicles may have little in common with where they safely cross roads. Many factors associated with roads and adjacent habitats can be the causes of wildlife–vehicle collisions and these factors may not

influence where wildlife safely cross roads. Use of road-kill data alone provides a very limited scope of wildlife movement areas and should be combined with habitat linkage mapping or movement models (see below). If reducing road-kill and increasing habitat connectivity is a project objective, then identifying the location of safe wildlife crossings will be an important consideration in planning crossing structures.

Radio And Satellite Telemetry

Telemetry has been commonly used to describe successful road crossing locations usually through intensive monitoring of wildlife movements. More accurate crossing data are now being obtained using global positioning system (GPS) monitoring devices and satellite-based telemetry captured in Figure 15. Satellite methods allow for more frequent and more accurate relocation data while the animal is collared when compared to radio-based methods.

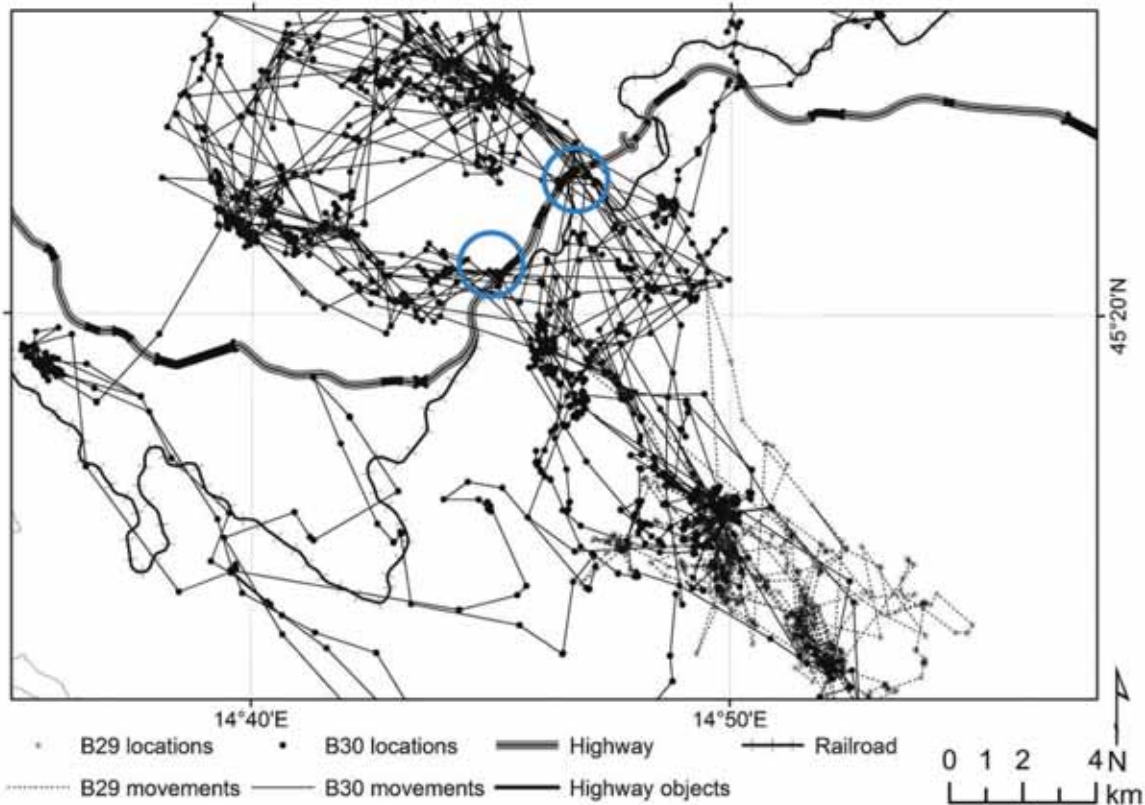


Figure 15. Map. Global position system (GPS) movement data from a male brown bear crossing a major four-lane highway and wildlife crossings (blue circle) in Croatia (Source: D. Huber, Zagreb University).

Capture-Mark-Recapture

By live-trapping and marking individuals and monitoring their movements via translocation or natural movements across roads, the distribution and population density of wildlife can be identified. This approach is most common among smaller fauna, but is becoming less popular as more non-invasive survey methods are being developed.

Road Surveys

In areas that receive regular snowfall, transects adjacent and parallel to the road or road surveys carried out while driving slowly along the road edge are two commonly used techniques to identify animal crossing locations.

Track Beds

Beds of sand or other tracking medium laid out along sections of roadway to intercept animal movements across roads as shown in Figure 16 have been used to estimate the number of animal crossings before road expansion and constructing wildlife crossings. These data can be used to determine the duration of monitoring required to detect a proportional change in crossing rates after construction.

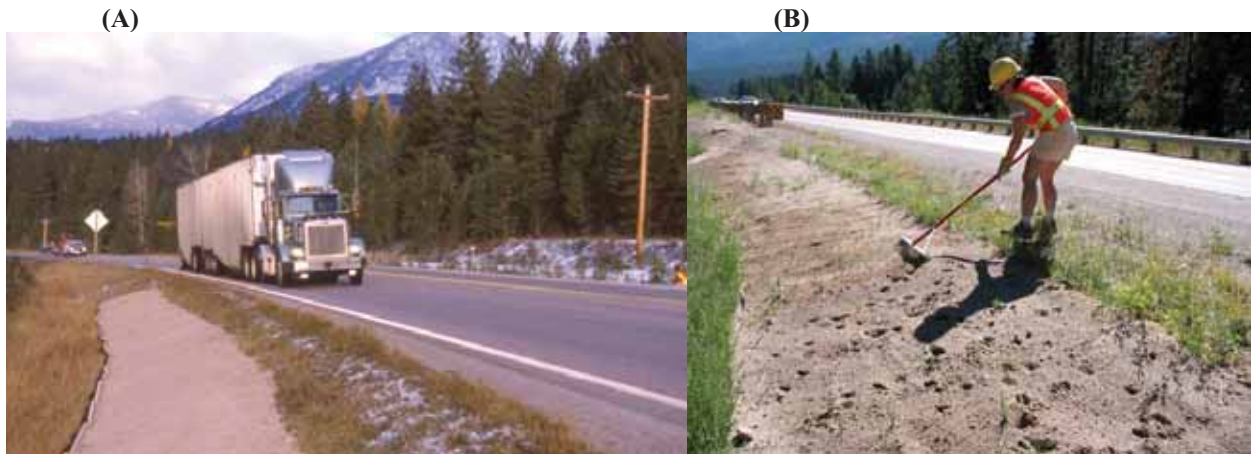


Figure 16. Photo. (A) Use of track beds is one method for obtaining information on wildlife movement across roads and key crossing locations prior to installation of wildlife crossing structures. (B) Raking of track beds along US 93 in Montana to collect pre-mitigation information on wildlife movements in the highway corridor (Credits: M. Huijser).

Camera Detection

Camera systems along roads have their own inherent operating problems and have not proven to be a reliable method of obtaining information on where animals actually cross roads. These problems are related to a camera’s limited range of detection. However, camera data can be used to provide information on wildlife distribution and relative abundance by using camera “traps.” Camera sampling stations can be placed in the study area (road corridor) using a grid or stratified sampling approach that will provide the best results per unit of effort. Animal distributions can be modeled using presence-only data from cameras. Determining relative abundance is more problematic, as it is difficult to identify individual animals detected by cameras.

Genetic Sampling

Similar to camera traps, non-invasive genetic sampling of hair for DNA analysis may be practical if used in a high-density grid pattern and/or focusing efforts at a smaller scale of resolution (e.g., medium-sized mammals). A genetic sampling grid used for obtaining hair samples from bears in Banff National Park, Alberta, is shown in Figure 17. Genetic sampling may only be able to provide general information on the potential location of wildlife crossing structures. Unlike data from camera systems, genetic sampling and DNA analysis can provide minimum estimates of local population size and identify individuals, their gender and genetic relatedness.

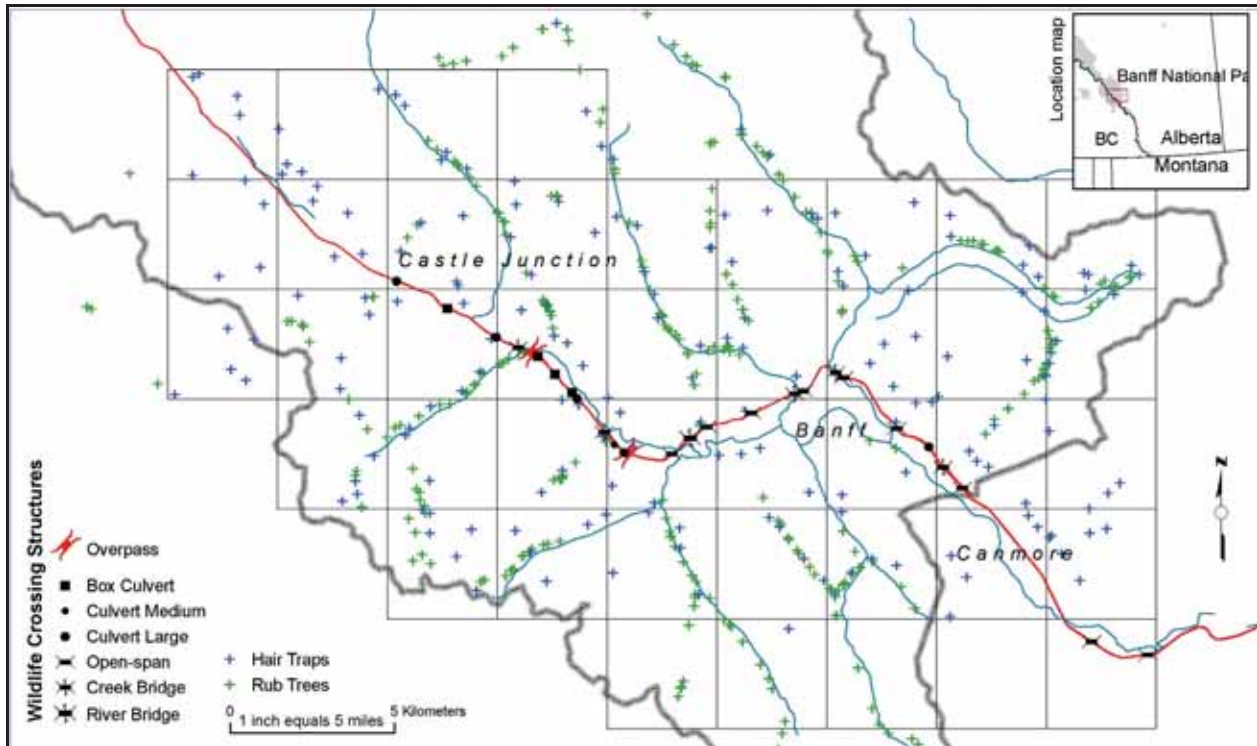


Figure 17. Map. DNA sampling grid in Banff National Park. Hair snag sites and rub tree sites were used to collect population genetic data on individuals in the population and from bears using the wildlife crossings on the Trans-Canada Highway (Source: WTI/Parks Canada).

GIS-Based Movement Model

Landscape-scale GIS-based models have been used to identify key habitat linkages, evaluate habitat fragmentation resulting from human activities, and discover areas where highways are permeable to wildlife movement. Models that simulate movements of wildlife tend to use “resource selection functions” that map habitat quality. The models have rules for simulated movements based on habitat quality and how animals are able to travel through the landscape. The data used to generate a GIS-generated “habitat surface” for these models is based on some type of information on animal distribution, usually obtained by radiotelemetry locations, but can also be derived from other methods to survey animal populations, such as genetic sampling,

sooted track plates, acoustic surveys or scat-detection dogs. Regardless of how the simulated movement or habitat linkage models are developed, the model's ability to predict crossing locations needs to be tested with empirical field data, e.g., road-kill locations, telemetry location data, field observations, transects and survey data, etc.

WHAT IS A RESOURCE SELECTION FUNCTION?

Resource selection functions (RSFs) estimate the relative amount of time an individual animal spends using a resource (e.g., habitat type) as a function of the proportional availability of that resource. The units being selected by animals (e.g., habitat types) are conceived as resources, and predictor variables associated with these resource units may be “resource” variables or covariates of the resources—e.g., elevation, human disturbance. RSF models are similar to methods that have been developed for mapping distributions of animals using species-environment patterns. A RSF model can be considered a form of habitat suitability index (HSI; U.S. Fish and Wildlife Service 1981), but with statistical rigor. RSF models are always estimated directly from data. A RSF usually is estimated from observations of (1) presence/absence (used vs. unused), or (2) presence/available (used vs. available) resource units (Boyce et al. 2002). When linked to a geographic information system (GIS), RSF models can be powerful tools in natural resource management, with applications for cumulative effects assessment, land management planning, and population viability analysis.

No Data

Often transportation and natural resource agencies lack easily accessible field data for planning the location of wildlife crossing structures. Usually decisions regarding design and location need to be made in a few months leaving no time for preconstruction studies. When this is the case, there are several options to consider.

Expert-Based Habitat Model

Expert information can be used to develop simple, predictive, habitat linkage models in a relatively short period of time. Expert information may consist of models based on the opinion of experts or qualitative models based on the best available information obtained from the literature. Several methods have been used to quantitatively analyze expert opinion data, but the analytical hierarchy process (AHP) is popular among environmental biologists. Expert opinion has been successfully used to identify key habitat linkages across roads and site wildlife crossings. The advantages are: (1) it is quick and easy to carry out; (2) legitimacy can be quite high if a consensus-model is employed by participants; (3) the method can be statistically sound and biologically robust for identifying and prioritizing critical habitat linkages; and (4) GIS software to assist in linkage identification is readily available. Software for the AHP is freely available on the Internet, and was designed by AHP authority Thomas L. Saaty. Major limitations of expert-based modeling are that it works best when having a narrow taxonomic focus, and like all models they are best when validated with field data. There are also important considerations for determining who is invited as an expert and how transparent the process is when it comes to finding broader support for the findings of the model. Like all models, it must be validated with field data, like those shown above.

Rapid Assessment

A rapid assessment process has been used that involves gathering experts from the area of concern. This process differs from the expert-based habitat model in that there is no quantitative analysis of expert opinion or modeling. Through consensus participants delineate where they believe key corridors are located on a given section of highway. The advantages are similar to the above model, however they can have a broad taxonomic focus. The main shortcomings are (1) criteria are rarely used for the selection of potential linkage areas, and (2) a lack of decision rules or weighting of factors considered makes it difficult to identify and prioritize the most critical linkages in a biologically robust way. As such, large sections of highway may be deemed “critical” when actually a smaller subset and the most ecologically important linkages are not teased out and identified. Also, rapid assessment results are rarely validated with field data.

Local Knowledge

Historically, local knowledge has been important for wildlife biologists conducting research or managing habitats for wildlife. Long-term residents can provide valuable information about where and how wildlife moves across the land. In landscapes where crossing locations are limited, local knowledge can help guide the planning of wildlife crossings. Local participation in project planning is not only good public relations but also provides stakeholders with input and participation in the project. Local knowledge and public participation have been formalized through citizen-scientist programs. These programs encourage active participation by the local community in wildlife movement and road mortality data collection.

Compatibility Of Adjacent Land Use

The most important part of site selection for wildlife crossing structures is the compatibility of adjacent land use in the present and future. Wildlife crossings will only be as effective as the management strategies developed around them that incorporate all the key landscape elements (humans, terrain, natural resources, transportation). Wildlife crossings are in essence small, narrow, site-specific habitat corridors. Thus, for these measures to fulfill their function as habitat connectors, mitigation strategies must be contemplated at two scales. Site-level or local-scale impacts from development or human disturbance adjacent to crossing structures may impede wildlife use. Similarly, alteration of landscape elements at a broader regional-scale could impede or obstruct movements towards the crossing structures and prevent animals from using them, thus rendering them ineffective. The larger scale concerns must be recognized if the local-scale measures are to be effective.

Coordination between land management and transportation agencies, and in some cases municipal planning organizations, can reconcile the connectivity concerns at both scales. If a transportation agency designs and builds appropriate wildlife crossings, but the land management agency fails to manage adjacent lands, the transportation agency funds will be wasted and the measures likely ineffective. Similarly, if adjacent lands are managed to ensure regional-scale connectivity across a highway, but the transportation agency fails to provide appropriate wildlife crossing structures, then efforts of the land management agency will be of limited value.

In developing recommendations for mitigating with wildlife crossings, it is important to remember the temporal and spatial context of ecosystems. Mitigating highways for wildlife is a long-term process that will last for many decades and affect individuals and populations alike. Thus, highway mitigation strategies developed around land-use planning should not terminate with the construction process. They need to be proactive at both local and regional scales to ensure that crossing structures remain functional over time.

Like bridge structures, the lifespan of wildlife crossing structures is 75–80 years, so mitigation needs to be thought of as long term. The planning of wildlife crossing mitigation requires forecasting, visualization and understanding how to proactively integrate wildlife conservation concerns around a growing infrastructure and a changing landscape.

Long-term planning needs to take into consideration not only change in land use but also range shifts due to climate change. Crossing structures are practical measures that transportation agencies can integrate into state or regional planning exercises to help adapt changes in species ranges and animal distributions to climate change. The potential impacts of climate change, coupled with an increasingly fragmented North American landscape less permeable for wildlife dispersal, will require conservation planning that enables wildlife to move and adapt to changing climatic conditions. Incorporating climate change scenarios in systems-level planning of transportation infrastructure makes good sense given the importance of crossing structures in allowing species affected by climate change and habitat fragmentation to expand their range into new climatic space.

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CHAPTER 4 – DESIGNS, TOOLBOXES, GUIDELINES, AND PRACTICAL APPLICATIONS

INTRODUCTION

Just as important as the correct location of wildlife crossings is to have them properly designed to meet the performance objectives. Questions arise as to the size of the crossing and how species-specific behaviors should be incorporated into the crossing structure design. These concerns are offset by the logistics of the project, which include costs of the structure, available material and expertise, and physical limitations of the site, e.g., soil, terrain, hydrology. Stakeholders involved in the crossing structure design process can then find themselves searching through published and grey literature regarding the design, performance and cost of the project. As project managers attempt to incorporate the designs and lessons from other experiences, several general questions arise:

- What do wildlife crossings look like?
- Where were they built?
- For what species were they designed?
- For what types of roads and highways were they built?
- In what environmental settings were they built (national park/forest, wildland–urban interface, urban, rural agricultural, etc.)?
- Were they successful?

The general questions are followed by many specific questions:

- What documentation is there regarding specific design and construction cost?
- What are the practicalities of each design?
 - Were they over-designed? (They were successful but could have been built more cheaply.)
 - Were they under-designed? (Wildlife used them less than expected and they performed poorly.)

This chapter provides examples of what tools and practical applications are available today for designing wildlife crossings in transportation projects. It is not meant to be a complete list of technical designs or methods used, but describe the most common wildlife crossing structure design types that are currently in use.

FUNCTION OF WILDLIFE CROSSINGS AND ASSOCIATED MEASURES

Wildlife crossing mitigation has two main objectives: 1) to connect habitats and wildlife populations and 2) reduce mortality of wildlife on roads as the Figure 18 chart shows.

<p>Objective Facilitate connections between habitats and wildlife populations</p>	<p>Objective Improve motorist safety and reduce wildlife-vehicle collisions¹</p>			
<p>Wildlife Overpasses</p> <ul style="list-style-type: none"> • Landscape bridge (Sheet 1) • Wildlife overpass (Sheet 2) • Multi-use overpass (Sheet 3) • Canopy crossing (Sheet 4) 	<p>Wildlife Underpasses</p> <ul style="list-style-type: none"> • Viaduct or flyover (Sheet 5) • Large mammal underpass (Sheet 6) • Multi-use underpass (Sheet 7) • Underpass with Waterflow (Sheet 8) • Small to medium-sized mammal underpass (Sheet 9) • Modified culvert (Sheet 10) • Herpetile tunnel (Sheet 11) 	<p>Specific measures</p> <ul style="list-style-type: none"> • Fencing—Large mammals (Sheet 12) • Fencing—Small and medium vertebrates (Sheet 13) • Gates and escape ramps (Sheet 14) • Signage • Animal-vehicle detection systems • Speed reduction • Lighting • Reflectors 	<p>Habitat adaptation</p> <ul style="list-style-type: none"> • Managing habitat and right-of-ways • Intercept feeding 	<p>Infrastructure adaptation</p> <ul style="list-style-type: none"> • Adapting road infrastructure (curbs, drainage grates, Jersey barriers) for wildlife movement • Increasing width of road median

Figure 18. Chart. Types of measures used to reduce the impacts of roads on wildlife (adapted from Iuell 2005).
¹See Huijser et al. (2008).

Objective 1: Facilitate connections between habitats and wildlife populations

To achieve this goal, wildlife crossing structures are designed to allow movement of wildlife above or below road, either exclusively for wildlife use, mixed wildlife–human use, or as part of other infrastructure, e.g., creeks, canals. Wildlife crossing structures come in a variety of shapes and sizes, depending on their specific objective, and can be divided into 11 different design types (see Appendix C, Hot Sheets 1-11).

- Four wildlife crossings are above-grade (over-the-road); seven are designed for below-grade (under-the-road) wildlife movement
- Two of the 11 crossings are designed for both wildlife and human use (multi-use); nine are exclusively for wildlife use
- Unique wildlife crossings include:
 - Canopy crossings for arboreal wildlife
 - Underpasses that accommodate movement of water and wildlife
 - Adapted walkways at canal and creek bridges, and
 - Below-grade tunnels designed for movement of amphibians and reptiles

Objective 2: Improve motorist safety and reduce wildlife–vehicle collisions

Traffic-related mortality of wildlife can significantly impact some wildlife populations; particularly those that are found in low densities, slow reproducing, and need to travel over large areas. Common and abundant species like Deer, Elk and Moose can present serious problems for motorist safety. Many mitigation measures have been designed over the years to reduce collisions with wildlife; but few actually perform well or have been rigorously tested. Mitigation measures can be categorized as three types:

- 1) Specific mitigation measures designed to improve motorist safety and reduce collisions with wildlife
- 2) Mitigation measures that require habitat alterations near roads, and
- 3) Mitigation measures that require modifications to the road infrastructure

Objectives 1 and 2 should work together and can be integrated to provide for safe movements of wildlife across road corridors, by reducing motor vehicle accidents with wildlife. Wildlife crossings generally require one or more types of specific measures designed to improve motorist safety and reduce wildlife–vehicle collisions, e.g., fencing, escape gates and ramps (see Appendix C, Hot Sheets 12-14). Other techniques used to increase motorist safety and reduce collisions with wildlife, such as specific measures (signage and animal detection system) and the adaptation of habitats and road infrastructure, are not within the scope of this work. Detailed descriptions and guidelines for using these types of mitigation measures for wildlife can be found in Huijser et al. (2007a,b) and Iuell (2005).

SPACING OF WILDLIFE CROSSINGS

Landscape connectivity is the degree to which the landscape facilitates wildlife movement and other ecological flows. However, no two landscapes are the same. Terrain, habitat type, levels of human activity and climate are some factors that influence wildlife movements and ecological flows. Therefore the spacing of wildlife crossings on a given section of roadway 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. In landscapes that are highly fragmented with little natural habitat bisected by roadways shown in Figure 19, generally fewer wildlife crossings will be required compared to relatively intact, less fragmented landscapes as Figure 20 shows.

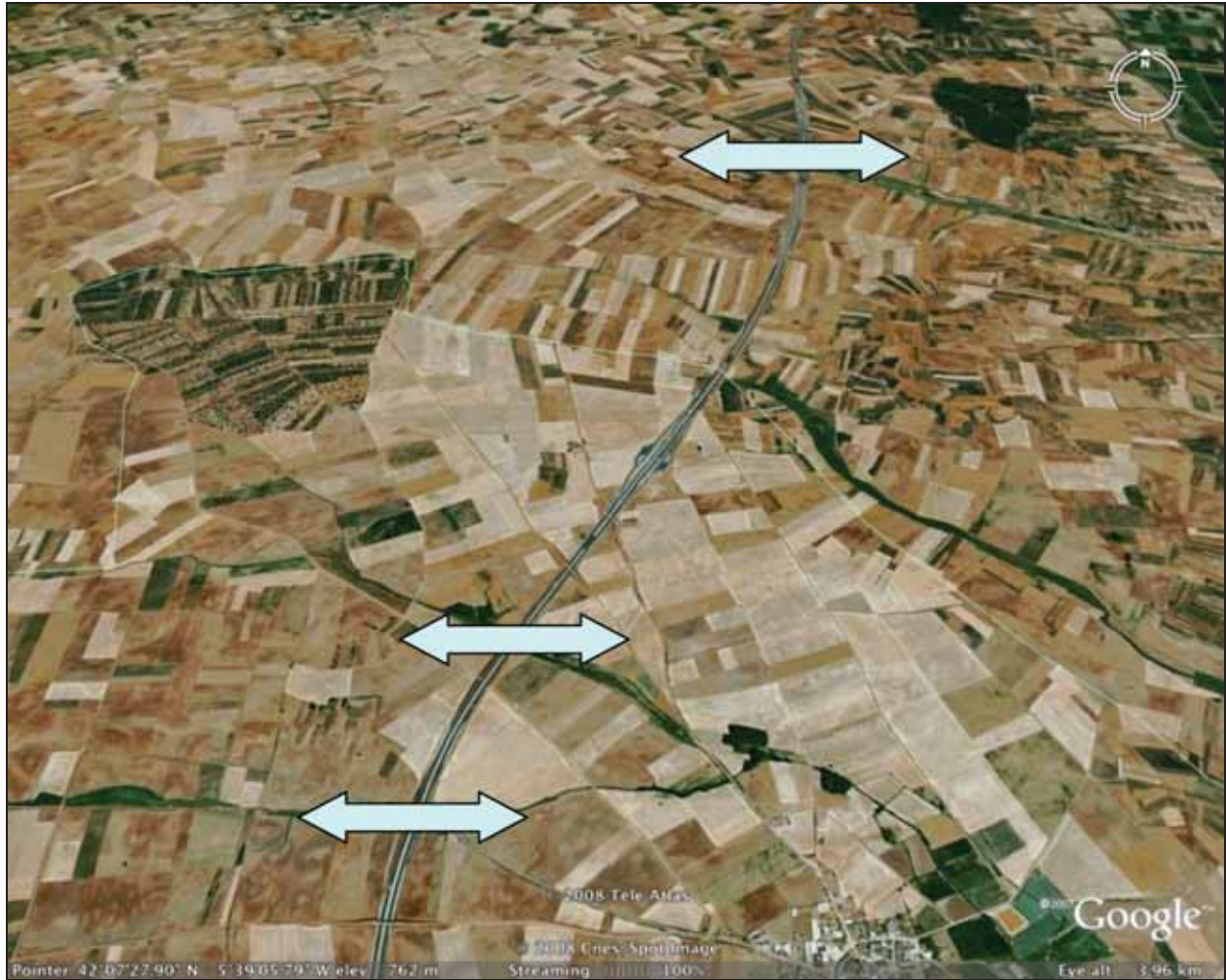


Figure 19. Photo. Benavente, Spain. Highly fragmented landscape (high contrast; adapted from Google Earth).

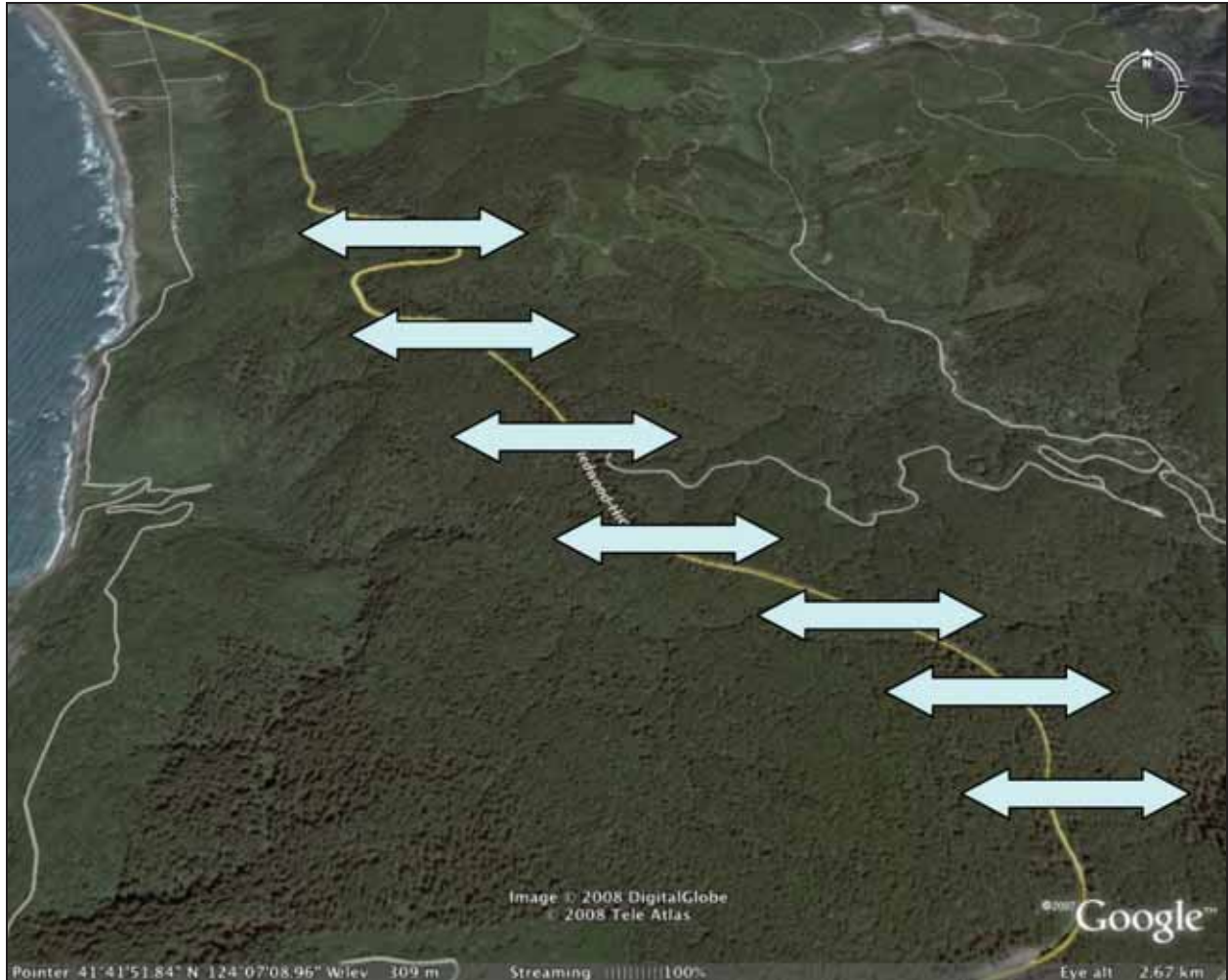


Figure 20. Photo. Hwy 101, Redwood highway, California. Low contrast landscape with low level of habitat fragmentation (adapted from Google Earth).

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. How can we reconcile the dynamic environmental processes of nature with static physical structures on roadways? 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 will help guide the determination of how many wildlife crossings may be necessary and how to locate them in order to get the greatest long-term conservation value. 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 2. 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 2. Average spacing interval per mile between wildlife crossings designed for large mammals at existing and planned transportation projects.

Number of crossings	Road length (km)	Average Spacing/mile (km)	Location (Reference)
17	17 (27)	1 / 1.0 (1 / 1.6)	SR 260, Arizona USA (Dodd et al. 2007)
24	27 (45)	1 / 1.2 (1 / 1.9)	Trans-Canada Highway, ^a Banff, Alberta Canada (Clevenger et al. 2002)
8	7.5 (12)	1 / 0.9 (1 / 1.5)	Trans-Canada Highway, ^b Banff, Alberta Canada (Parks Canada, unpubl. data)
32	32 (51)	1 / 1.0 (1 / 1.6)	Interstate 75, Florida USA (Foster and Humphries 1995)
42	56 (90)	1 / 1.3^c (1 / 2.14)	US 93, Montana USA (Marshik et al. 2001)
16	15 (24)	1 / 0.9 (1 / 1.5)	Interstate 90, Washington USA (Wagner 2005)
4	15 (24)	1 / 3.8 (1 / 6.0)	US 93 Arizona USA (McKinney and Smith 2007)
82	45 (72)	1 / 0.5^c (1 / 0.9)	A-52, Zamora Spain (Mata et al. 2005)

^a Phase 1, 2 and 3A reconstruction.

^b Phase 3B reconstruction.

^c Includes crossings for small and large mammals.

GUIDELINES FOR THE SELECTION OF WILDLIFE CROSSINGS

Earlier, the 11 different wildlife crossing design types were introduced. Their intended use and function are each described below.

Wildlife Crossing Design Types (Appendix C, Hot Sheets 1-11)

Overpass Design

1. *Landscape bridge*—Designed exclusively for wildlife use. Due to their large size they are used by the greatest diversity of wildlife and can be adapted for amphibian and reptile passage.
2. *Wildlife overpass*—Smaller than landscape bridges, these overpass structures are designed exclusively to meet needs of a wide range of wildlife from small to large.
3. *Multi-use overpass*—Generally the smallest of the wildlife overpasses. Designed for mixed wildlife–human use. This wildlife crossing type is best adapted in human disturbed environments and will benefit generalist type species adapted to regular amounts of human activity and disturbance.
4. *Canopy crossing*—Designed exclusively for semi-arboreal and arboreal species that commonly use canopy cover for travel. Meets the needs of species not built for terrestrial travel and generally have difficulties crossing open, non-forested areas.

Underpass Design

5. *Viaduct or flyover*—The largest of underpass structures for wildlife use, but usually not built exclusively for wildlife movement. The large span and vertical clearance of viaducts allow for use by a wide range of wildlife. Structures can be adapted for amphibian and reptiles, semi-aquatic and semi-arboreal species.
6. *Large mammal underpass*—Not as large as most viaducts, 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.
7. *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.
8. *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.
9. *Small- to medium-sized mammal underpass*—One of the smaller wildlife crossing structures. Primarily designed for small- and medium-sized mammals, but species use will depend largely on how it may be adapted for their specific crossing needs.
10. *Modified culvert*—Crossing that is adaptively designed for use by small- and medium-sized wildlife associated with riparian habitats or irrigation canals. Adapted dry platforms or walkways can vary in design and typically constructed on the lateral interior walls of the culvert and above the high-water mark.
11. *Amphibian and reptile tunnels*—Crossing designed specifically for passage by amphibians and reptiles, although other small- and medium-sized vertebrates may use as well. Many different amphibian and reptile designs have been used to meet the specific requirements of each species or taxonomic group.

Determining the type of wildlife crossing structure most suitable for a given location will depend on several criteria. Selection begins by identifying a general wildlife crossing type that conforms to the wildlife habitat connectivity potential for the target species and topography of the site chosen. Figures 21, 22 and 23 can be used to guide the selection of wildlife crossing type based on the two main criteria—quality of wildlife habitat and topographical constraints.

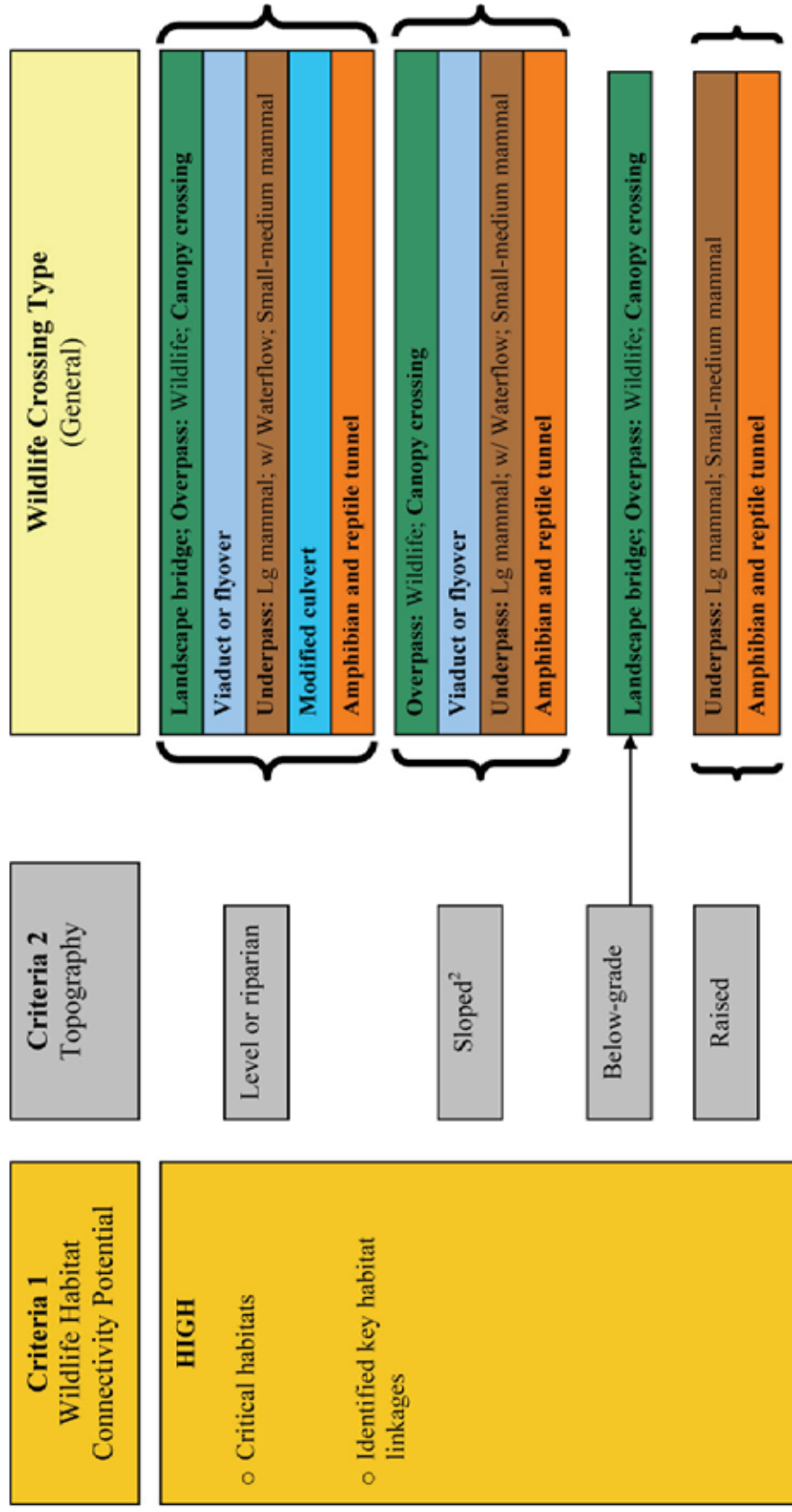


Figure 21. Chart. Criteria for selecting general wildlife crossing type where roads bisect habitats of high conservation value.

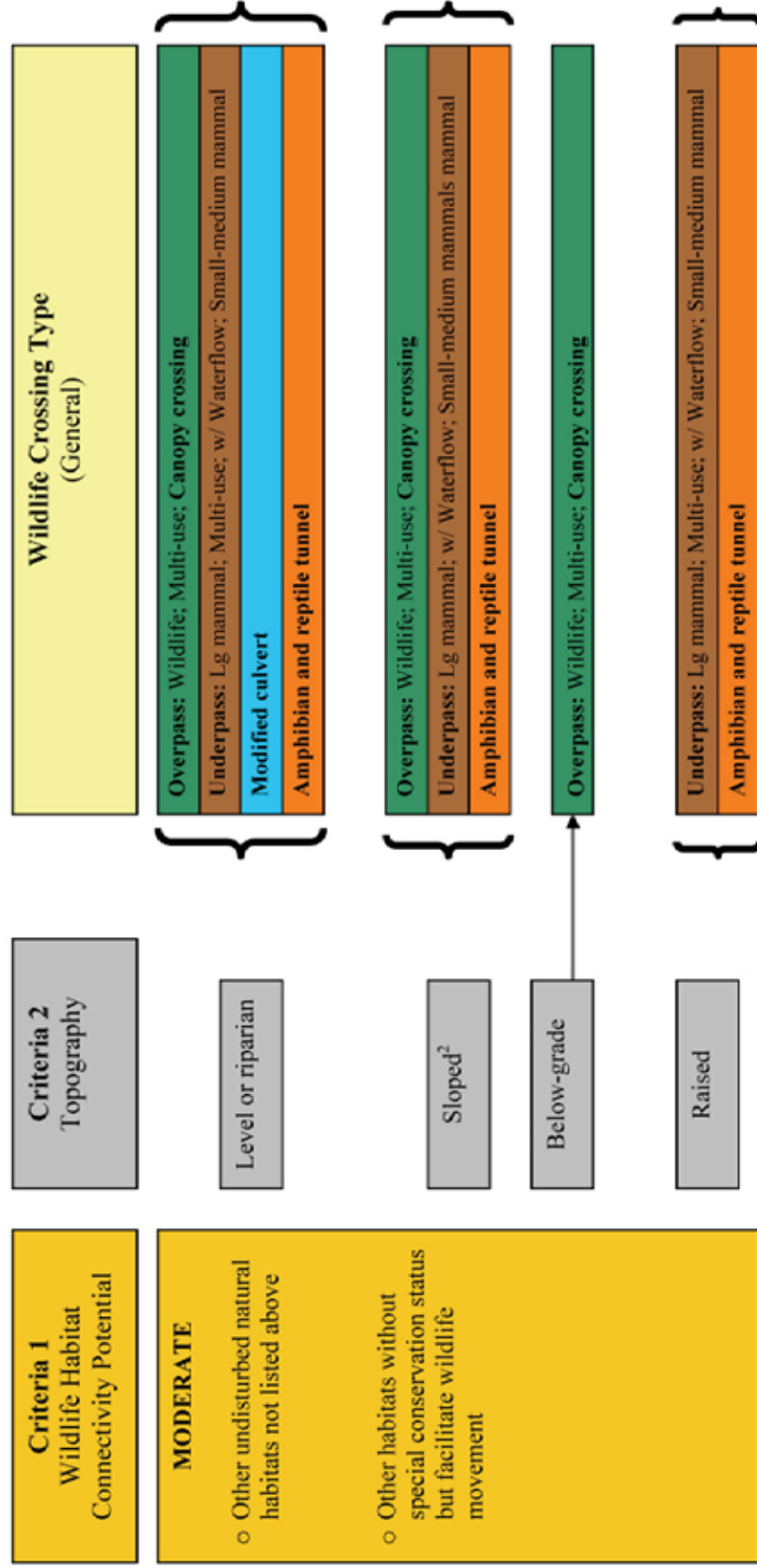


Figure 22. Chart. Criteria for selecting general wildlife crossing type where roads bisect habitats of moderate conservation value.

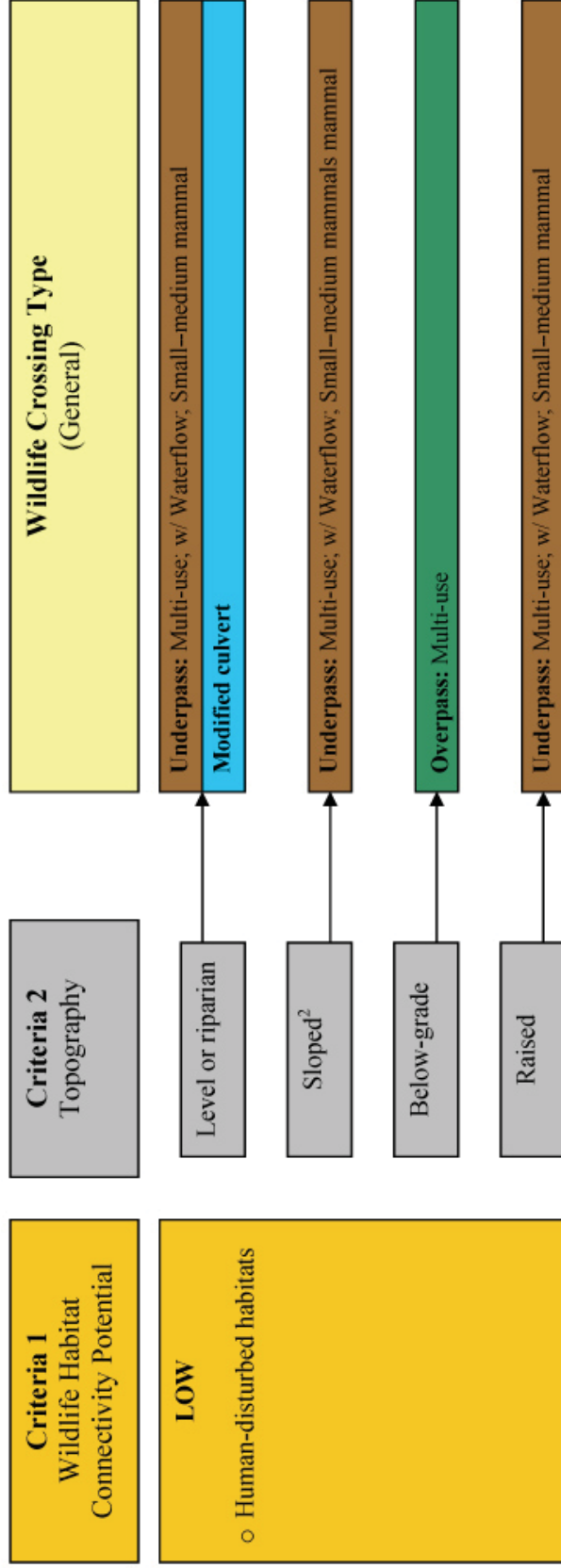


Figure 23. Chart. Criteria for selecting general wildlife crossing type where roads bisect habitats of low conservation value.

Wildlife Habitat Connectivity Potential

Wildlife habitat connectivity potential can be grouped into three categories:

- *High potential*—Sites that occupy high quality or critical habitats for wildlife and/or are identified as key habitat linkages to facilitate movement of wildlife at a local or regional scale.
Associated wildlife crossing types: These are prime areas for wildlife habitat connectivity. Mixed-used (multi-use with humans) wildlife crossings should not be used.
- *Moderate potential*—Relatively intact or undisturbed habitats, but not considered critical wildlife habitat, such as: (a) habitats that lack special conservation value or designation but are suitable for moving wildlife, and (b) habitats that may not be suitable at present but future restoration is planned.
Associated wildlife crossing types: In these areas mixed-use wildlife crossings become an option, but landscape bridges and viaducts or flyovers should not be built.
- *Low potential*—Habitats with human disturbance or regular human activity.
Associated wildlife crossing types: These areas are low potential for wildlife habitat connectivity; overpass structures designed specifically for wildlife are not recommended. However, underpasses adapted for wildlife use (wildlife underpasses with waterflow, modified culverts) and mixed-use and specialized smaller crossing types (small- to medium-sized mammal underpass; amphibian and reptile tunnels) are suggested options.

Topography

Topography strongly influences what type of wildlife crossing can be built at each location. The proximity to water (lakes, ponds, rivers, streams) is another factor, as is the water table at the location, but these factors will not be discussed here. Four general topographies have been identified where wildlife crossings may be constructed on roadways as sketched in Figure 24.

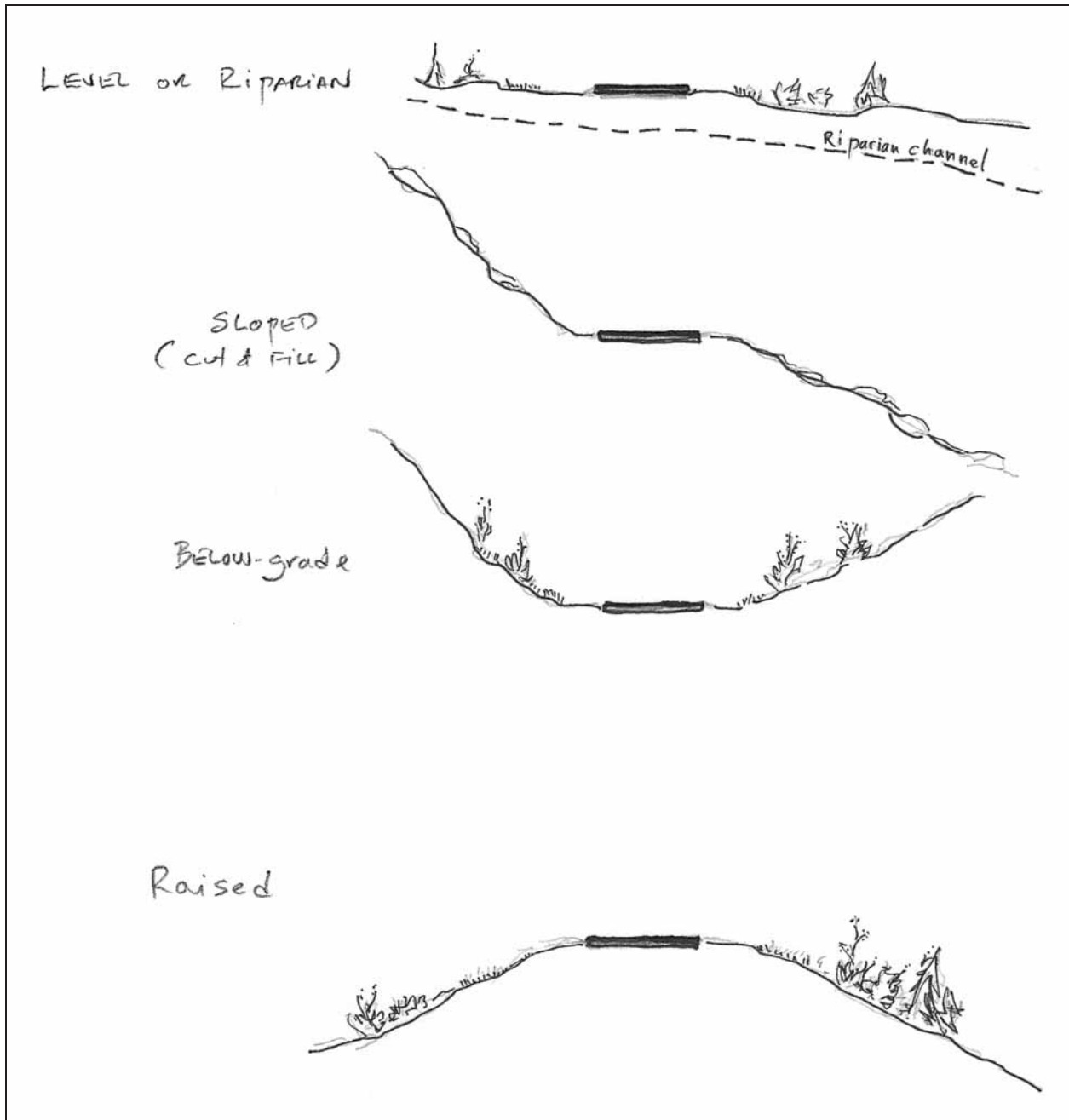


Figure 24. Schematic. Four general types of topography where wildlife crossings may be constructed on roadways (Credit: Tony Clevenger).

- *Level or riparian*—Sections of road and rights-of-way that traverse level terrain or cross over riparian habitats and drainages.
Associated wildlife crossing types: Most wildlife crossing types can be constructed in these areas. Some may require raising the road grade to obtain elevation necessary at the crossing site for underpass or lower the road below grade and excavate to allow the overpass design to fit into the local terrain.
- *Sloped*—Road sections on cut-and-fill slopes.
Associated wildlife crossing types: Road sections on sloped terrain (cut-and-fill) make it difficult to construct overpass designs and canals—adapted design.
- *Below-grade*—Roads that are in cut sections and well below grade level.
Associated wildlife crossing types: These areas are best suited for overpass structures (landscape connectors, overpasses, canopy crossings) given the ease of construction having embankments and natural support on one or both sides of the highway.
- *Raised*—Road sections built on fill and are elevated compared to adjacent terrain including rights-of-way.
Associated wildlife crossing types: Raised sections of road are ideal for all underpass structures. Today, small tunnel-boring machines can perforate roadbeds of two-lane roads making underpasses for small- and medium-sized mammals and amphibian and reptile tunnels an option.

WILDLIFE SPECIES GROUPS AND CROSSING STRUCTURE CLASSIFICATION

Planning and designing wildlife crossings will often be focused on a certain species of conservation interest (e.g., threatened or endangered species), a specific species group (e.g., amphibians) or abundant species that pose a threat to motorist safety (e.g., Deer, Elk).

In this handbook we refer to North American wildlife and species groups when discussing the appropriate wildlife crossing designs. The eight groups mentioned below are general in composition. However, recommendations will be provided, if it is available, for species-specific design requirements (Appendix C, Hot Sheets 1-11). Their ecological requirements and how roads affect them are described along with some sample wildlife species for each group.

1. Large mammals (*ungulates* [Deer, Elk, Moose, Pronghorn], *carnivores* [Bears, Wolves]) – Species with large area requirements and potential migratory behavior; large enough to be a motorist safety concern; traffic-related mortality may cause substantial impacts to local populations; susceptible to habitat fragmentation by roads.

2. High mobility medium-sized mammals (*Bobcat, Fisher, Coyote, Fox*) – Species that range widely; fragmentation effects of roads may impact local populations.
3. Low mobility medium-sized mammals (*Raccoon, Skunk, Hare, Groundhog*) – Species with smaller area requirements; common road-related mortality; relatively abundant populations.
4. Semi-arboreal mammals (*Marten, Red Squirrel, Flying Squirrel*) – Species that are dependent on forested habitats for movement and meeting life requisites; common road-related mortality.
5. Semi-aquatic mammals (*River Otter, Mink, Muskrat*) – Species that are associated with riparian habitats for movement and life requisites; common road-related mortality.
6. Small mammals (*Ground Squirrels, Voles, Mice*) – Species that are common road-related mortality; relatively abundant populations.
7. Amphibians (*Frogs, Toads, Salamanders, Turtles*) – Species with special habitat requirement; relatively abundant populations at the local scale; populations are highly susceptible to road mortality.
8. Reptiles (*Snakes, Lizards*) – Species with special habitat requirement; road environment tends to attract individuals; relatively abundant populations.

DESIGN AND DIMENSIONS

General Design Specifications For Wildlife Species

- As a rule, wildlife crossings should be designed so they allow for movement of the greatest diversity of wildlife species or taxa possible. The diversity of taxa will strongly depend on location and adjacent land use and conservation status. Wildlife species groups and taxa can be associated with different structure types based on general design and dimensions as shown in Tables 3 and 4. Length, width and height of crossings are shown in Figures 25 and 26.

Table 3. General guidelines for minimum and recommended dimensions of wildlife overpass designs.

Type	Usage	Species & Groups	Dimensions Minimum	Dimensions Recommended
Landscape bridge	Wildlife only	All wildlife species Amphibians (if adapted)	W: 230 ft (70 m)	W: >330 ft (>100 m)
Wildlife overpass	Wildlife only	Large mammals High-mobility medium-sized mammals Low mobility medium-sized mammals Small mammals Reptiles Amphibians (if adapted)	W: 130–165 ft (40–50 m)	W: 165–230 ft (50–70 m)
Multi-use overpass	Mixed use: Wildlife & Human activities	Large mammals High-mobility medium-sized mammals Low mobility medium-sized mammals Small mammals Amphibians (if adapted) Reptiles	W: 32 ft (10 m)	W: 50–130 ft (15–40 m)
Canopy crossing	Wildlife only	Semi-arboreal mammals	—	—

Table 4. General guidelines for minimum and recommended dimensions of wildlife underpass designs.

Type	Usage	Species groups	Dimensions: Minimum	Dimensions: Recommended
Viaduct or flyover	Multi-purpose	All wildlife species	<i>There are no minimum dimensions. Structures are generally larger than the largest wildlife underpass structures</i>	<i>There are no recommended dimensions. Structures are generally larger than the largest wildlife underpass structures</i>
Large mammal underpass	Wildlife only	Large mammals High-mobility medium-sized mammals Low mobility medium-sized mammals Semi-arboreal & semi-aquatic mammals (adapted) Small mammals Amphibians (adapted) Reptiles	W: 23 ft (7 m) Ht: 13 ft (4 m)	W: >32 ft (>10 m) Ht: >13 ft (>4 m)
Multi-use underpass	Mixed use: Wildlife & Human activities	Large mammals High-mobility medium-sized mammals Low mobility medium-sized mammals Semi-arboreal & semi-aquatic mammals (adapted) Small mammals Amphibians (adapted) Reptiles	W: 16.5 ft (5 m) Ht: 8.2 ft (2.5 m)	W: >23 ft (>7 m) Ht: >11.5 ft (>3.5 m)

Underpass with waterflow	Wildlife and drainage	Large mammals High-mobility medium-sized mammals Low mobility medium-sized mammals Semi-arboreal mammals (adapted) Semi-aquatic mammals Small mammals & amphibians Semi-arboreal mammals & reptiles (adapted)	W*: 6.5 ft path (2 m) Ht: 10 ft (3 m) <i>*Width will be dependent on width of hydrologic channel in crossing</i>	W*: >10 ft path (>3 m) Ht: >13 ft (>4 m) <i>*Width will be dependent on width of hydrologic channel in crossing</i>
Small to medium-sized mammal underpass	Wildlife and seasonal drainage	High-mobility medium-sized mammals (adapted) Low mobility medium-sized mammals Semi-aquatic mammals (adapted) Small mammals Amphibians (adapted) Reptiles	Same as recommended dimensions <i>Size selection is based on the target species needs or connectivity objective at the site.</i>	W: 1-4 ft (0.3–1.2 m) Ht: 1-4 ft (0.3–1.2 m) OR 1 – 4 ft diameter (0.3–1.2 m)
Modified culvert	Wildlife and drainage	High-mobility medium-sized mammals (adapted) Low mobility medium-sized mammals Semi-aquatic mammals Small mammals Reptiles (adapted) Amphibians	W: 1.5 ft (0.5 m) Clearance: >3 ft (>1 m)	W: >3 ft (>1 m) Clearance: >4 ft (>1.5 m)
Amphibian and reptile tunnel	Wildlife only	Amphibians Low mobility medium-sized mammals (adapted) Semi-aquatic (adapted) Small mammals & reptiles (adapted)	<i>Dimensions vary depending on target species or taxa or local conditions. Tunnels range from 1–3 ft (0.35–1 m) in diameter</i>	<i>Dimensions vary depending on target species or taxa or local conditions. Tunnels range from 1–3 ft (0.35–1 m) in diameter</i>

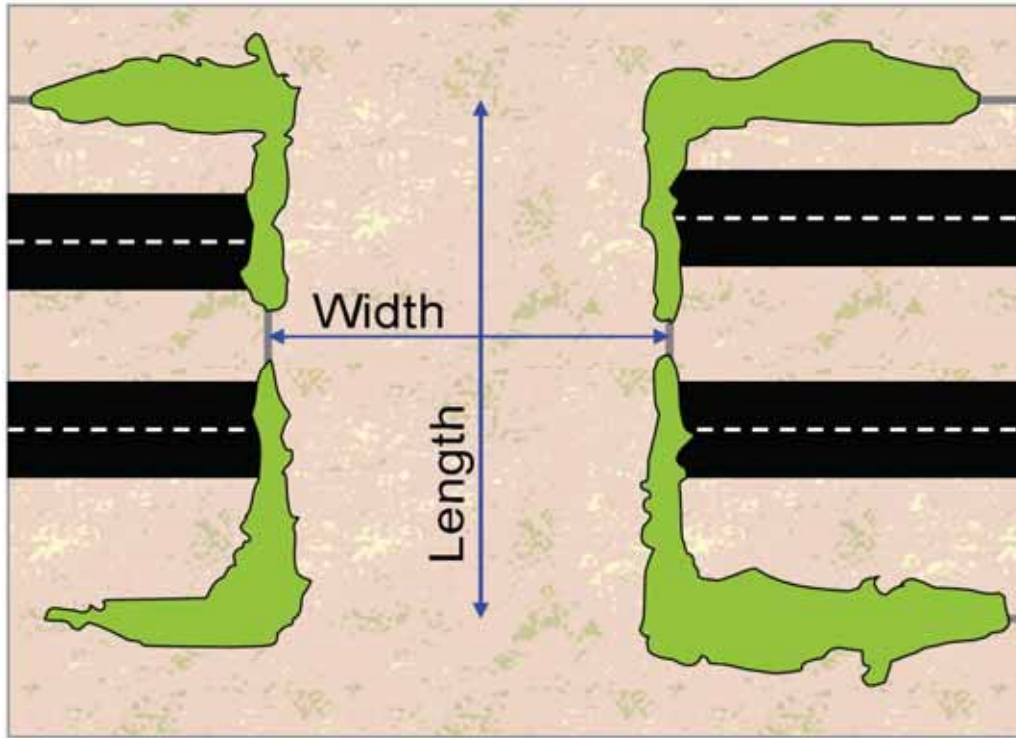


Figure 25. Schematic. Length and width measurements of wildlife overpass (Credit: Tony Clevenger).

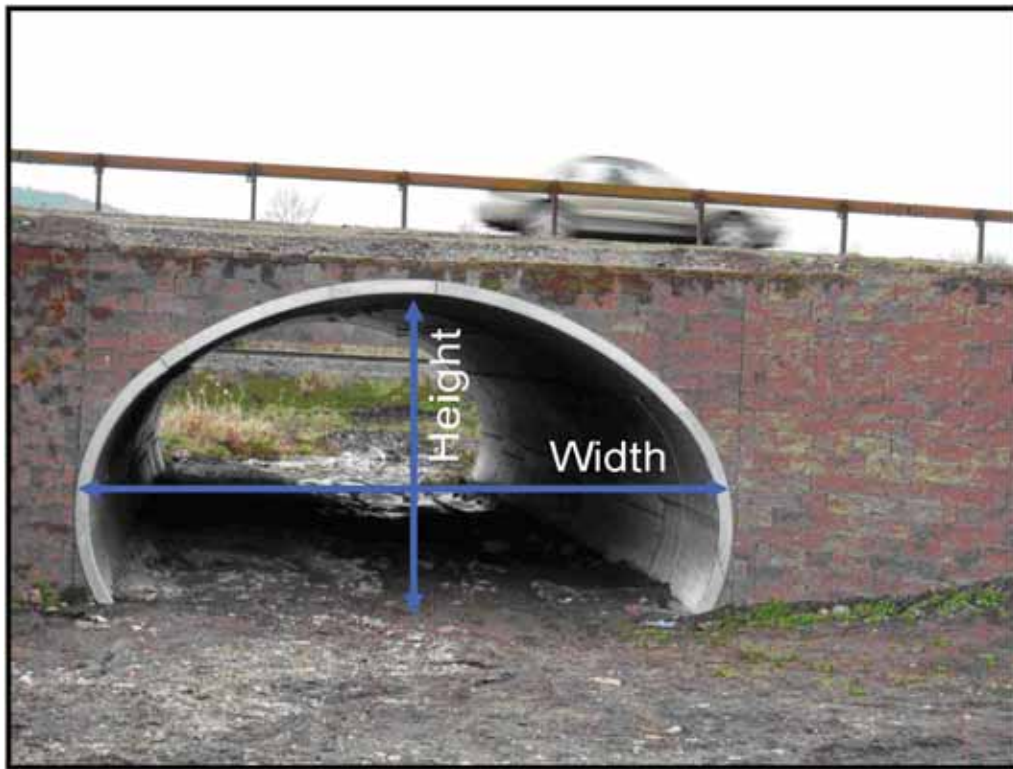


Figure 26. Photo. Width and height measurements of wildlife underpass structure (Credit: Marcel Huijser/WTI).

- Divided vs. undivided highways: Divided highways contain a central median and consist of two separate physical structures; one for each direction of traffic. Undivided highways have traffic lanes bundled and consist of one physical crossing structure. Although crossing structures on undivided highways have less daytime light than those with a central median, the open median generally has higher traffic noise levels. Crossing structures on undivided highways are shorter in length compared to structures on divided highways and have lower noise levels. We recommend that a shorter structure, with less daytime light and lower noise levels will be more effective than crossing structures designed on divided highways. This recommendation is based primarily on structure length and traffic noise levels. The amount of light an underpass receives is not an important factor on which to base crossing structure design when a large part of wildlife movement typically occurs during nighttime hours.
- Normally, wildlife crossings are not be greater than 230–260 ft (70–80 m) in length except in special situations such as spanning ≥ 6 -lane highways or spanning highways in addition to other types of infrastructure, for example, frontage roads and railway line as Figure 27 shows.



Figure 27. Photo. Most wildlife overpasses or landscape bridges are less than 70-80 m long; however, the one shown above near Hilversum, The Netherlands, is 800 m long and spans two roads and a railroad. (Credit: Goois Natuurreservaat, The Netherlands/Photo: W. Metz).

- The recommended and minimum dimensions for each of the 11 wildlife crossing types are provided below. The measurements are for crossing structures designed for 4-lane highways. The guidelines should be followed if the crossings are at minimum to allow for the simplest and most basic connectivity requirement of crossings structures, i.e., the exchange of individuals within populations. Crossings designed for exchange of individuals may not allow for normal demographic processes, thus allowing passage use by few individuals and biased towards male movement. Both genders need to mix freely across the highway for wildlife crossings to perform effectively, and monitoring should be able to document that.
- Follow-up monitoring is discussed in the following chapter, but should determine whether the basic functions of wildlife crossings are being met and provide demographic information on the number of individuals using the crossing structure and their gender. Whether the crossings are functional for local populations affected by a highway will depend largely on how well the structure is planned and designed to integrate species' biological needs with the larger landscape and ecological context in which it is placed.

Specific Design of Wildlife Crossings and Adjacent Habitat

The dimensions shown earlier in Tables 3 and 4 are meant to serve as a general guideline when planning and designing for species groups or taxa. However, oftentimes project objectives are species-specific and design must be customized to their needs.

Our monitoring and research of crossing structures in North America during the last 10 years has yielded valuable information on design needs of a variety of wildlife species. Research results were published in scientific journals and internal agency reports. In Table 5 we synthesized the research results to determine the suitability of the 11 crossing structure types for the most common wildlife species or taxonomic groups in North America. We list 26 wildlife species or taxa and we categorize the suitability of each of the 11 crossing design types for each species as follows:

- Recommended/Optimum solution
- Possible – if adapted to local conditions
- Not recommended
- Unknown – more data are required
- Not applicable

Table 5. Suitability of wildlife crossing design types from Appendix C, Hot Sheets 1-11 for distinct wildlife species and taxa.

	Landscape bridge (Sheet 1)	Wildlife overpass (Sheet 2)	Multi-use overpass (Sheet 3)	Canopy crossing (Sheet 4)	Viaduct or flyover (Sheet 5)	Large mammal underpass (Sheet 6)	Multi-use underpass (Sheet 7)	Underpass with waterflow (Sheet 8)	Small- to medium-sized mammal underpass (Sheet 9)	Modified culvert design (Sheet 10)	Amphibian and reptile tunnel (Sheet 11)
Ungulates											
Moose	●	●	⊗	—	●	●	⊗	●	⊗	⊗	—
Elk	●	●	●	—	●	●	●	●	⊗	⊗	—
Deer sp.	●	●	●	—	●	●	●	●	⊗	⊗	—
Pronghorn	●	●	⊗	—	●	?	⊗	●	⊗	⊗	—
Bighorn sheep	●	●	⊗	—	●	●	⊗	●	⊗	⊗	—
Mountain goat	●	●	⊗	—	●	●	⊗	●	⊗	⊗	—
Carnivores											
Black bear	●	●	⊗	—	●	●	⊗	●	⊗	⊗	—
Grizzly bear	●	●	⊗	—	●	●	⊗	●	⊗	⊗	—
Wolf	●	●	⊗	—	●	●	⊗	●	⊗	⊗	—
Coyote	●	●	●	—	●	●	●	●	●	●	—
Fox1 (<i>V vulpes</i> , <i>Urocyon</i>)	●	●	●	—	●	●	●	●	●	●	—
Fox2 (<i>V macrotis</i> , <i>V velox</i>)	●	●	●	—	●	●	●	●	●	●	—
Cougar	●	●	⊗	—	●	●	⊗	●	⊗	⊗	—
Bobcat	●	●	●	—	●	●	●	●	⊗	●	—
Lynx	●	●	⊗	—	●	?	⊗	?	⊗	⊗	—
Wolverine	●	●	⊗	—	●	?	⊗	?	⊗	⊗	—

OPENNESS?

$$\frac{\text{Height} \times \text{Width}}{\text{Length}}$$

Length

The measure of *openness* was used early on to describe and measure the stimulus of a given underpass to approaching Deer, by calculating the above formula. The thought was that, in theory, an underpass could be so long and confining that it could preclude Deer use¹ and that Deer prefer underpasses with a clear view of the horizon. Since then, openness has been used on many occasions in planning the design of wildlife underpasses and researching their effectiveness. Openness has gained popularity, likely due to its ease and assumed validity based on a simple metric or “magic number.” Engineers, planners and biologists alike tend to aim for the magical openness measure and expect performance without much critical thought of other factors (structural and environmental) that might influence performance. However the relationship between openness and underpass performance may be species-specific and time dependent.

An *openness index* combines underpass width, height, and length. Problems have been identified with its use such as inconsistent use of metric vs. Imperial units, as well as a changing understanding of how openness is measured—as an index, a ratio, or simply a state or concept. Further, underpasses are not always rectilinear, but can be arched, circular or elliptical. There is no guidance regarding how different shaped underpass designs may affect the openness index. As mentioned, the index may be metric or in Imperial measure and can be confused. Some suggested “minimum” openness indices have ranged from 0.6 (metric) for Mule Deer and 0.75 (metric) for Roe Deer and 1.5 (metric) for Red Deer (Elk). Like other roadway geometric design components, designing for the “minimum” is not recommended or appropriate in most cases. However, despite the appeal and popularity of openness indices, there has never been a critical evaluation of the measure for designing wildlife underpasses. There is no recognized guidance on use other than the absolute values that have been bounced around in the grey and published literature.

The validity of using openness as a proven and reliable measure in planning and designing wildlife underpasses is questionable. Openness has been found to be highly correlated to underpass length. Similarly the three main underpass structural measures (length, width, height) exhibit multicollinearity—i.e., they tend to be redundant and highly correlated with one another. We **DO NOT** recommend the use of the openness index in planning and designing wildlife crossings due to the reasons stated above. We **DO** recommend the use of underpass measures (length, width, height) in conjunction with other structural (divided vs. undivided highway configurations) and environmental (habitat quality, target species, etc.) factors when designing wildlife crossing structures.

¹ Reed, D. F., A. L. Ward. 1985. Efficacy of methods advocated to reduce deer–vehicle accidents: research and rationale in the USA. Pages 285–293 in *Routes et faune sauvage*. Service d’Etudes Techniques de Routes et Autoroutes, Bagneaux, France.

Detailed design information for the 26 species and 11 crossing structure types are found in Appendix C, Hot Sheets 1-11.

Hot Sheets 1-11 – Wildlife Crossing Prescriptions (Appendix C)

The Hot Sheets are a guide for the general design, basic building prescriptions, landscaping, possible design variations, and maintenance of each of the 11 crossing structure types. Being a logical endpoint for this chapter, by starting broadly and progressively narrowing the taxonomic focus, the Hot Sheets provide the most detailed design guidelines for the 26 wildlife species and taxa in North America.

Hot Sheets 12-14 – Fencing and Gate Guidelines (Appendix C)

Fencing is a key part of a mitigation plan involving wildlife crossings. Hot Sheets 12-14 provide details on fence configurations, construction specifics, design alternatives and maintenance.

Fences and wildlife crossings have been around many years, however, relatively little is known about effective fence designs and other innovative solutions to keep wildlife away from roads and traffic.

Small- and medium-sized mammals can pass through most fence types for large mammals. Different fencing types and designs are needed to keep these smaller animals from reaching roads (Hot Sheet 13).

When wildlife become trapped inside fenced areas measures need to be in place to allow them to safely exit the right-of-way. Steel swing gates, hinged metal doors or earthen ramps or jump-outs are some commonly used methods (Hot Sheet 14).

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CHAPTER 5 – MONITORING TECHNIQUES, DATA INTERPRETATION, AND EVALUATIONS

CONSERVATION VALUE OF WILDLIFE CROSSINGS

Some basic rules about monitoring the function of wildlife crossings and assessing their conservation value were provided in Forman et al. (2003). The criteria used to measure their function or conservation value, however, will depend on the intended purpose of the wildlife crossings, the taxa of interest and the biological level of organization most relevant to monitoring and research goals.

Monitoring needs to be an integral part of a highway mitigation project, even long after the measures have been in place. Mitigation is costly, generally requiring a large investment of public funds. Post-construction evaluations are not only necessary but also a judicious use of public infrastructure funds and can help agencies save money in future projects (see Adaptive Management below).

Monitoring and research can range from a simple, single-species population within the highway corridor to more complex ecological processes and functions within regional landscapes of conservation importance.

Wildlife crossing structures are, in essence, site-specific movement corridors strategically placed over highways that bisect important wildlife habitat as Figure 28 shows. Like wildlife corridors, crossing structures should allow for the following five biological functions:

1. Reduced mortality and increased movement (genetic interchange) within populations;
2. Meeting biological requirements such as finding food, cover and mates;
3. Dispersal from maternal or natal ranges and recolonization after long absences;
4. Redistribution of populations in response to environmental changes and natural disturbances (e.g., fire, drought); movement or migration during stressful years of low reproduction or survival; and
5. Long term maintenance of metapopulations, community stability, and ecosystem processes.

These functions encompass three levels of biological organization—genes, species/population, community/ecosystem—which form the basis for developing natural resource management and conservation plans.

From these five functions it is possible to set performance objectives, determine best methods to monitor, develop study designs, and resolve the management questions associated with the project objectives.



Figure 28. Photo. Crossing structures are site-specific movement corridors that link wildlife habitat separated by pavement and high-speed vehicles (Credit: Jeff Stetz).

Note that these functions increase both in complexity and in the cost and time required to properly monitor whether they are being facilitated as shown in Table 6. Not all ecological functions may be of management concern for transportation agencies, particularly those at the more complex end of the scale; however, they will be of concern for land and natural resource management agencies.

Simple and low-cost techniques using remote cameras can be used to detect animals using wildlife crossing structures, i.e., level 1 - *genes*. However, information about numbers of distinct individuals, their gender and genetic relationships cannot be reliably obtained using remote cameras.

A non-invasive genetic sampling method was used to assess population-level benefits (level 2 – *species/populations*, Table 6) of 20 wildlife crossings on the Trans-Canada Highway in Banff National Park, Alberta (see Appendix E, Figures 78 and 79; Clevenger and Sawaya 2009).

LEVELS OF BIOLOGICAL ORGANIZATION AND ROAD IMPACTS

A recent U.S. National Academies report on assessing and managing the impacts of roads recommended using the three levels of biological organization as a framework to design future research to assess the ecological effects of paved roads (NRC 2005).

Table 6. Levels of conservation value for wildlife crossing systems as measured by ecosystem function achieved, level of biological organization targeted, type of connectivity potential, and cost and duration of research required to evaluate status.

Level	Ecosystem Function (simple to complex)	Level of Biological Organization ^a	Level of Connectivity ^b	Cost and Duration of Research ^c
1a	Movement within populations and genetic interchange	Genetic	Genetic	Low cost – Short term
1b	Reduced mortality due to roads	Genetic & Species/population	Genetic & Species/population	Low cost – Short term
2	Ensure that the biological requirements of finding food, cover and mates	Species/population	Demographic	Moderate-to-High cost – Long term
3	Dispersal from maternal ranges and recolonization after long absences	Species/population	Functional	Moderate-to-High cost – Long term
4	Populations to move in response to environmental changes and natural disasters;	Ecosystem/community	Functional	High cost – Long term
5	Long term maintenance of metapopulations, community stability, and ecosystem processes	Ecosystem/community	Functional	High cost – Long term

^a See Noss 1990, Redford and Richter 1999.

^b Genetic: Predominantly adult male movement across road barriers; Demographic: Genetic connectivity with confirmed adult female movement across road barriers; Functional: Genetic and demographic connectivity with confirmed dispersal of young females that survive and reproduce.

^c Based on studies of large mammals. Cost and duration will largely be dependent upon area requirements, population densities, and demographics.

AN APPROACH FOR MONITORING IMPACTS

Roads and traffic affect wildlife at multiple levels of biological organization: therefore different management questions require different types of research and mitigation measures. Certain questions can be "big" or general and may require answers from multiple scales and perspectives. However, big picture research is not necessarily general in nature. General principles have to be well founded, and they are often based on thorough studies of the life histories of wildlife species.

This hierarchical approach covers the entire biological spectrum from genes on up to higher levels of communities and ecosystems. It is well suited to answering most transportation and natural resource agency management needs of reducing road impacts on wildlife populations. It can provide guidelines and decision support regarding the monitoring and evaluation of wildlife crossings.

Another value of the hierarchy approach is the recognition that effects of roads and traffic can reverberate through other levels, often in unpredictable ways, as secondary and cumulative effects. Specific indicators can be identified at multiple levels of organization to monitor and assess the performance of mitigation designed to reduce road-related mortality, and restore movements and interchange within populations.

MONITORING AND ASSESSMENT GUIDELINES

The guidelines below are designed for monitoring plans evaluating the conservation value and efficacy of wildlife crossings. This framework can be used to formulate management questions, select methodologies, and design studies to measure performance of wildlife crossings in mitigating road impacts.

1. *Establish goals and objectives.* What are the mitigation goals? Generally the goals are to reduce wildlife–vehicle collisions and/or reduce barrier effects to movement and maintain genetic interchange.
2. *Establish baseline conditions.* Determine the extent, distribution and intensity of road and traffic impacts to wildlife in the area of concern. The impacts may consist of mortality, habitat fragmentation (reduced movements) or some combination thereof. In most cases, the conditions occurring pre-mitigation will comprise the baseline or control.
3. *Identify specific management questions to be answered by monitoring.* These questions will be formulated from the goals and objectives identified in Step 1 and conditions identified in Step 2. Some questions might include:
 - Is road-related mortality increasing or decreasing as a result of the mitigation measures?
 - Is animal movement across the road increasing or decreasing?
 - Are animals able to disperse and are populations able to carry out migratory movements?

Before starting a monitoring program, specific benchmarks and thresholds should be agreed upon that trigger management actions. For example, >50% reduction in road-kill would be acceptable, but <50% reduction would trigger additional management actions to improve mitigation performance. Normally a power analysis is also performed to determine if these reductions can actually be detected (see below).

4. *Select indicators.* Identify indicators at the appropriate level(s) of biological organization (i.e., genes, species/population, and community/ecosystem) that correspond to the specific goals and objectives identified in Step 1 and the questions developed in Step 3. For example:
 - Gene flow and genetic structure may indicate whether exchange of genes (i.e., breeding or movement of individuals) occurs across the highway;
 - Population distribution, abundance and within-population movement data, as well as demographic processes such as dispersal, fecundity, survivorship, and mortality rates, may permit the assessment of species or population-level connectivity; and
 - Herbivory and predation rates may indicate whether exchange across highways contributes to more stable ecosystem processes and community dynamics.
5. *Identify control and treatment areas.* If pre-mitigation data are available, then indicator response in adjacent “control” areas may be compared with treatment areas—i.e., road sections with wildlife crossings. It will be important to control for differences in habitat type and population abundance between treatment and control areas. Therefore controls and treatments should comprise similar habitats, and some means of obtaining population abundance indices to control for confounding effects should be used.
6. *Design and implement a monitoring plan.* Apply principles of experimental design to select sites for monitoring the identified goals and objectives from Step 1 and questions in Step 3. Although treatments and controls should ideally be replicated, this may not always be possible.
7. *Validate relationships between indicators and benchmarks.* Research carried out over the short and long term will be needed to determine whether the selected indicators are meeting the management goals and objectives.

SETTING MONITORING AND PERFORMANCE TARGETS

Developing Performance Targets – Who Defines Them?

Few studies have rigorously monitored and researched the performance of highway mitigation measures using study designs with high inferential strength. For some agencies, monitoring has not been a priority, much less research—if circumstantial evidence suggested that animals appeared to use wildlife crossings, then they were deemed effective.

One of the difficulties in developing performance targets is agreeing on what defines a “reduction” in wildlife–vehicle collisions and an “increase” in landscape connectivity or animal movements across a highway. Transportation agencies tend to have relatively relaxed targets or expectations for how well crossing structures perform. In contrast, resource and land management agencies generally require more science-based evidence that wildlife crossings or

other measures result in positive changes to wildlife movements and regional population connectivity.

Reliably Detecting Change in Target Parameters

A decrease in road-related mortality and an increase in the frequency of highway crossings by focal species may generally be considered performance targets for mitigation efforts. Broad definitions such as these can be used to measure the effectiveness of mitigation measures and whether targets are being met.

However, properly designed monitoring programs with research-specific study designs and predefined performance targets will have the greatest ability to evaluate whether mitigation efforts are meeting their targets (Appendix D).

Developing Consensus-Based Performance Targets

The lead agency and other stakeholders need to know how their mitigation investment dollars are being spent and how the technology can be transferred to future projects. Taxpayers will also want to know whether the measures are effective.

Targets designed to evaluate whether the amount of observed change is acceptable should be determined *a priori* by the transportation agency responsible for the project with the concerns of the natural resource management agency and other project stakeholders in mind.

The agreed-upon targets need to be scientifically defensible. Without specific targets and a means to track performance, transportation and resource management agencies can come under scrutiny for not having objectively defined targets or performance standards.

Because landscape conditions and population dynamics vary over time, short- and long-term monitoring and performance targets should be assessed periodically and readjusted accordingly.

FOCAL SPECIES

All species from a project area cannot be monitored. The selection of focal species should result in monitoring data that will be most relevant to either the greatest number of species in the area, or to those species that are the most sensitive to the process being monitored, e.g., ability to cross highways. Table 7 provides some criteria to help guide the selection of focal species.

Selected focal species are indicators of changes—positive or negative—that result from efforts to mitigate road impacts in the project corridor.

The selected survey methods should permit the collection of data from a large number of species—e.g., most medium and large mammals. Rigorous evaluation of these data will, however, be limited to those species that generate sufficient amounts of data for statistical analyses and inference. In these cases, focal species will not be identified until pre-mitigation population surveys have begun or pilot data is collected in the project area.

Another consideration is how monitoring focal species can translate into direct management benefits and support from outside the project as shown in Table 7. Some wildlife species may resonate with the public and information about them may help generate support for the project. While this is a secondary criterion, it is important to consider in the selection process.

Table 7. Guide to selecting focal species based on monitoring criteria and ecosystem context.

1. Monitoring	
Primary Criteria	
Ecological Attributes	Which focal species will serve as the best indicators of change and maintenance of ecological processes?
Sample Size Requirements	Which focal species will provide large enough datasets to permit sufficiently accurate and precise analyses for the monitoring needs?
Secondary Criteria	
Benefits to Management	Will the information acquired from monitoring the selected focal species provide benefits to (a) local management (e.g., DOT, land management agency) and/or (b) management elsewhere, such that it will have broader research application (e.g., significant contribution to knowledge base and science of road ecology)?
Public Profile and Support	Is at least a subset of the selected focal species high-profile and charismatic such that they resonate with the general public and help to gain public and private support for the project (e.g., cougar, wolverine)?
2. Ecosystem Context	
Taxonomic Diversity	Do the selected focal species represent a diversity of taxonomic groups?
Levels of Biological Organization (see Noss 1990)	Do the selected focal species provide information suitable for addressing questions aimed at the first two levels of biological organization (genes/individuals, species/populations)?

Monitoring information must be of value at the project level, as managers are interested in project-specific applications. However, some results will have management benefits beyond the project area boundaries and have national or international significance in advancing knowledge of wildlife crossing mitigation. Attempts should be made to choose focal species and management questions that have impacts at the project and national or international scale.

After identifying suitable focal species, a second consideration relates to how well the focal species fit within an ecosystem context. For each of the management questions it will be important to maximize the taxonomic diversity represented in the suite of focal species, e.g., amphibians, reptiles, small to large mammals. Road effects on wildlife populations are scale-specific, and such an approach will, therefore, help to ensure that some of the more important scale-related issues (spatial and temporal) of the investigation are adequately addressed.

MONITORING TECHNIQUES

There are a variety of wildlife survey methods available today. These methods range from the relatively simple (reporting of wildlife–vehicle collisions by transportation agency personnel) to the complex (capture and global positioning system [GPS] collaring of individual animals). Whatever the monitoring objective and focal species, the selection of appropriate survey methods is critically important as Table 8 shows.

In some cases multiple methods exist for a given objective–species combination and researchers will have the luxury of balancing cost with specific data requirements and available funding or personnel.

For some methods, most costs occur at the onset of monitoring efforts (e.g., purchase of remote cameras), whereas for others the costs are largely distributed throughout the monitoring period (e.g., snow tracking).

Appendix E describes many methods that can be used to meet a number of basic monitoring objectives. Decisions as to the best methods must be made based on the particular objective, focal species, season, cost, and location.

Table 8. Summary of available monitoring methods, the appropriate time to employ them (pre- or post-construction), potential target species, and cost estimates for conducting wildlife monitoring. See Appendix E for detailed description of each monitoring method (From Clevenger et al. 2008).

Monitoring purpose	Available monitoring methods	Timing	Target species	Check frequency	Area of use	Estimated cost	Cost loading
Assess wildlife-vehicle collision rate							
	Carcass removal by maintenance crews and natural resource agency staff	Pre; post	Elk, deer, black bear and other large species when possible	As occurs	Median/right-of-way	Low	Continuous
	Wildlife-vehicle collision reports by highway patrol	Pre; post	Elk, deer, black bear and other large species when possible	As occurs	Median/right-of-way	Low	Continuous
	Systematic driving surveys	Pre; post	Medium to large mammals	1-7 days	Median/right-of-way	High	Continuous

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Assess use/effectiveness of wildlife crossing structures (existing and proposed)	Remote still cameras or video	Pre; post	Medium to large mammals	Weekly	Wildlife crossings/Culverts	Medium	Front-loaded
	Track beds	Pre; post	Medium to large mammals	1–3 days	Wildlife crossings/Dry culverts	Medium	Continuous
	Unenclosed track plates	Pre; post	Medium to large mammals	1–3 days	Wildlife crossings/Dry culverts	Medium	Continuous
	Enclosed track plates	Pre; post	Smaller mammals	1–3 days	Small dry culverts	Medium	Continuous
	Hair collection devices with DNA methods	Pre; post	Select medium to large mammals	3–5 days	Wildlife crossings/Culverts	Medium to high*	Continuous and end-loaded
	Trap, tag, and recapture/resight	Pre; post	Amphibians, reptiles, small mammals	Select times	Ponds and water bodies within or adjacent to highway	Low	Continuous
	GPS collaring	Pre; post	medium to large mammals	Select times	Within animal home range	High	Front-loaded

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Assess rate of at-grade highway crossings by wildlife									
	Remote still cameras or video (deployed randomly)	Pre**	Medium to large mammals	Weekly	Right-of-way	Medium to high	Front-loaded		
	Remote still cameras or video (deployed at targeted locations)	Pre**	Medium to large mammals	Weekly	Right-of-way	Medium to high	Front-loaded		
	Track beds (deployed randomly)	Pre**	Medium to large mammals	1–3 days	Right-of-way	Medium to high	Continuous		
	Track beds (deployed at targeted locations)	Pre**	Medium to large mammals	1–3 days	Right-of-way	Medium to high	Continuous		
	Snow track transects	Pre**	Medium to large mammals active in winter	3–5 times per winter***	Right-of-way	Medium	Continuous		
	GPS collaring	Pre; post	medium to large mammals	Select times	Within animal home range	High	Front-loaded		

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Monitor wildlife use of locations throughout and adjacent to the project area									
	Remote still cameras or video at scent stations	Pre; post	Medium to large mammals	Weekly	Within 1 mile of highway	Medium	Front-loaded		
	Track plots or track plates at scent stations	Pre; post	Small to large mammals	1–3 days	Within 1 mile of highway	Medium	Continuous		
	Hair collection devices with DNA methods	Pre; post	Small group of targeted species	3 days	Within 1 mile of highway	Low to high*	Continuous and end-loaded		
	Snow tracking	Pre; post	Medium and large mammals active in winter	3–5 times/winter	Within 1 mile of highway	Medium	Continuous		
	Scat detection dogs with DNA methods	Pre; post	3-4 targeted mammals	1 full season	Within 1 mile of highway	Medium to high*	Front-loaded		
	Trap, tag, and recapture/resight	Pre; post	Amphibians, reptiles, small mammals	Select times	Ponds and water bodies within or adjacent to highway	Low	Continuous		
	GPS collaring	Pre; post	medium to large mammals	Select times	Within animal home range	High	Front-loaded		

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Evaluate effectiveness of wildlife fencing									
	Highway maintenance crews report animals inside fencing	Post	Medium to large mammals	As occurs	Median/right-of-way	Medium	Continuous		
	Highway patrol report animals inside fencing	Post	Medium to large mammals	As occurs	Median/right-of-way	Medium	Continuous		
	Systematic checks of fence integrity	Post	Medium to large mammals	Monthly	Fenceline	Medium	Continuous		
	GPS collaring	Pre; post	medium to large mammals	Select times	Within animal home range	High	Front-loaded		
Evaluate effectiveness of jump-outs									
	Remote still cameras or video	Post	Medium to large mammals	Weekly	Jump-outs	Medium	Front-loaded		
	Track beds on top of jump-outs	Post	Medium to large mammals	1–3 days	Jump-outs	Medium	Continuous		

* Cost depends largely on objectives—species-specific identification via DNA methods costs less than individual identification. Both can be cost effective when compared with more labor-intensive methods.
 ** Although these methods can be used to monitor post-construction, it is assumed that wildlife fencing will so dramatically reduce at-grade highway crossing attempts as to make monitoring unnecessary and extremely cost-ineffective.
 *** Will depend on statistical power considerations, number and timing of snow events, and time constraints.

CAMERA VS. TRACK-PAD MONITORING

A recent paper compared the overall efficiency of wildlife monitoring activity using track pads and motion-sensitive cameras, based on the estimated number of detections by each method (Ford et al. 2009). Mammals coyote-sized and larger were used in the analysis. Cameras outperformed track pads by most performance metrics. The only instances where track pads were preferred were at sites where security (e.g., high risk of theft or vandalism) was a concern. One of the most important factors limiting the use of track pads is the frequency of field visits required. Monitoring based on track pads needs to keep the checking intervals short enough to minimize trampling of tracks and loss of data. Increasing the frequency of visits to each site becomes more costly for the project.

ADAPTATION PERIODS

Monitoring of wildlife crossing structures has shown that an adaptation period and learning curve does exist. The few studies that have obtained more than two years of monitoring data showed that animals require an adaptation period that varies in length between ungulates and carnivores. Most monitoring efforts do not sample for sufficient duration to adequately assess how wildlife utilize crossing structures because they don't give them enough time to adapt to the structures and the changes made to the surrounding habitat where they reside. Small sampling windows, typical of one- or two-year monitoring programs, are too brief, can provide spurious results and do not adequately sample the range of variability in a species' wildlife crossing structure use patterns in landscapes with complex wildlife-human interactions.

STUDY DESIGNS TO MEASURE PERFORMANCE

Inferential Strength

Inferential strength in the context of mitigation monitoring is the ability to accurately evaluate whether mitigation efforts have achieved their desired effect. Maximizing inferential strength depends both on the ability to minimize confounding effects and to maximize statistical power.

Monitoring designs with low inferential strength lead to situations where researchers either detect an effect that is not actually there (a Type I error) or fail to detect an effect that is actually present (a Type II error). Minimizing the likelihood of making either type of error is of critical importance to transportation managers and researchers if they are to reliably demonstrate that mitigation measures are effective.

Roedenbeck et al. (2007) addressed this subject by identifying relevant research questions in road ecology today, recommending experimental designs that maximize inferential strength, and giving examples of such experiments for each of five research questions.

Types of Study Design and Resulting Inferential Strength

There are several types of study designs for evaluating how well mitigation measures perform.

BACI Design

One design consists of measuring and comparing impacted areas (I) with non-impacted areas or control sites (C) and assessing how some variable of interest behaves before (B) and after (A) a management intervention such as highway construction or mitigation. In this “BACI” design, if the difference between the control and impact (often referred to as “treatment”) site is greater after intervention than before, then there is strong evidence that intervention has had a causal effect.

To increase inferential strength BACI designs should sample at more than one paired treatment + control site. Locating suitable control sites unaffected by roads can be a challenge, particularly when studying impacts on wide-ranging large mammals.

BA Design

Of lower inferential strength than BACI is the before and after impact (BA) design. This requires sampling one site and evaluating how some environmental variable behaves before and after the impact. The impact could also be some form of management intervention, such as the implementation of mitigation measures. The BA design at one site can demonstrate that the environmental variable changed over time, but it cannot exclude the possibility that change was caused by some reason other than the observed impact.

CI Design

A third approach compares impacted (I) sites with control (C) sites (those that are non-impacted) using a CI design. Data are only collected or made available for the period after intervention or mitigation. The inference is that if the control and impact sites differ in some environmental variable of concern, this difference is, at least in part, due to the intervention. This inference is valid only if control and impact sites would be identical in the absence of intervention.

The study design options described run from high to low inferential strength: BACI, BA, and CI. The key monitoring and research questions identified earlier are found in Appendix D. The table provides a suggested framework for designing studies to evaluate whether the general objectives of highway mitigation are being met.

ADAPTIVE MANAGEMENT

Adaptive management consists of deriving benefits from measured observations from monitoring to inform decision-making with regard to planning and design of subsequent phases of a project. An example of adaptive management would be changing the design of wildlife crossing structures on subsequent phases of highway reconstruction after obtaining empirical data from the use of structures from earlier phases.

- Microhabitat elements within wildlife crossings may require changes if monitoring shows they do not facilitate movement of smaller wildlife.

- Monitoring of fencing may identify deficiencies that lead to revised design or materials used for construction in future phases.
- Pre-construction data on local species occurrence and wildlife movements may lead to changes in the locations and types of wildlife crossing structures (e.g., from small-sized to medium-sized culverts) should monitoring reveal previously undocumented unique populations or important habitat linkages.

Whatever the case may be, monitoring ultimately provides management with sound data for mitigation planning, helps to streamline project planning and saves on project costs.

Regular communication and close coordination between research and management is necessary for adaptive management to be effective. This will allow for timely changes to project design plans that reflect the most current results from monitoring activities.

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 APPENDIX A – GLOSSARY

Words, expressions and terms used in this handbook.

Term	Meaning
Amphibian fencing	A continuous structure erected alongside infrastructure to prevent amphibians from crossing or direct them to a specific crossing point or pitfall trap.
Amphibian tunnel	An enclosed passage structure designed to allow amphibians to move from one side of a roadway to another.
Barrier effect	The combined effect of traffic mortality, physical barriers and avoidance, which together reduce the likelihood and success of wildlife crossing roadways.
Berm	An earth bank constructed to reduce light and noise impacts from traffic.
Biodiversity	The richness among living organisms including terrestrial, marine and freshwater ecosystems. It includes diversity within and between species and ecosystems as well as the processes linking ecosystems and species.
Bottleneck	Defined area (e.g., habitat corridor) which, due to the presence of roadways or other land use, has become a limiting factor to wildlife movement or migration.
Compensation measure	Measure or action taken to compensate for a residual adverse ecological effect that cannot be satisfactorily mitigated. See also “Mitigation.”
Connectivity	The state of structural landscape features being connected, enabling access between places via a continuous route of travel.
Corridor	Physical linkage or connection between habitat patches within a landscape.
Culvert	Box, pipe or channel structure that allows a watercourse or excess water (surface or subsurface) to be removed by passing below road surface.
Dispersal	Process or result of a species movement away from an existing population or away from a parent organism.

Ecoduct	Widely used term in Europe for “wildlife overpass” or “landscape bridge.”
Ecological corridor	Habitat of various sizes and shapes that maintain, establish or enhance connectivity of landscapes, organisms within the landscapes, and environmental processes associated with them.
Ecological network	Regional- or landscape-scale system of ecological corridors (see above) that maintains the connection of core habitats, organisms and environmental processes necessary for conservation of species, communities and ecosystems.
Ecosystem	Complex of plant and animal and micro-organism communities and their physical environments that are dynamic and interact as a functional unit.
Ecotone	Transitional zone between two distinct habitat types.
Edge (effect)	Portion of an ecosystem near its perimeter, where influences of the surroundings prevent the development of interior environmental conditions.
Endemic species	A species confined to a particular region and thought to have originated there.
Environmental Impact Assessment (EIA)	A method and process by which information about potential environmental impacts is collected, assessed and used to inform decision-making.
Escape (refuge) area	A place that provides refuge or shelter.
Fauna	Animal species.
Filter effect	The limiting or selective filtering of movement of certain species or individuals across transportation infrastructure.
Flora	Plant or bacterial life.
Fragmentation	Splitting up or separation of a habitat, landscape or ecosystem into smaller parcels.

Generalist species	A species that is able to thrive in a wide variety of environmental conditions and can make use of a variety of different resources. See Specialist species for opposite.
Habitat	The type of site (vegetation, soils, etc) where an organism or population naturally occurs—including a mosaic of components required for the survival of a species.
Habitat elements	Specific components of natural habitats that make them whole, including habitat structure, vegetative cover and density.
Habitat fragmentation	Subdivision and reduction of the habitat area available to a given species caused directly by habitat loss (e.g., land take) or indirectly by habitat isolation (e.g., barriers preventing movement between habitat patches).
Impact	The immediate response of an organism, species, population or community to an external factor. This response may have an effect on the species that results in wider consequences at the population, species, or community level.
Indicator	Measures of simple environmental variables used to indicate some aspect of the state of the environment, such as the degree of habitat fragmentation.
Indicator species	Species indicative of change from environmental baseline conditions or success of restoration or mitigation actions. Some indicators track changes related to air pollution, environmental contaminants, habitat quality, etc.
Invertebrate	Any animal without a vertebral column or backbone.
Jersey (median) barrier	Tapered concrete barrier used in many narrow highway medians to prevent vehicle crossovers into oncoming traffic.
Keystone species	A species that plays a pivotal role in an ecosystem and upon which a large part of the community depends for survival.
Land cover	Combination of land use and vegetation cover.

Landscape	The total spatial and visual entity of human living space integrating the geological, biological and human-made environment. A heterogeneous land area composed of a cluster of interacting ecosystems that create a specific recognizable pattern.
Landscape bridge	Large wildlife overpass or ecoduct used to connect habitats over transportation infrastructure.
Landscape diversity	The variation and richness of landscapes in a region.
Landscaping	To modify the original landscape by altering the topography and/or vegetative cover—this may include earthmoving and contouring to form new landscape structures.
Linear transport infrastructure	Road, railway or navigable inland waterway.
Matrix	In landscape ecology, the background habitat or land use type separating two patches of core habitat.
Mesic habitat	Pertaining to conditions of moderate moisture or water supply.
Metapopulation	A patchily distributed network of localized subpopulations that cannot survive on their own and are subject to local extinction. Maintenance of the subpopulations depends on the movement of individuals from “source” patches through the metapopulation network.
Migration	The regular, usually seasonal, movement of all or part of an animal population to and from a given area of biological importance.
Mitigation	Action to reduce the severity of an adverse impact.
Monitoring	Combination of observation and measurement used to quantify the performance of a plan, change against a set of predetermined indicators, criteria or policy objectives.
Mosaic	The pattern of patches and corridors embedded in a matrix (referred to within a landscape context). See “Matrix.”

Noise barrier	Measure installed to reduce the emission of traffic-related noise in designated sensitive areas (human-altered and natural areas) typically using walls, fence or screen.
Overpass	Structure that allows passage above transportation infrastructure or obstacle.
Population	Functional group of individuals that interbreed within a given, often arbitrarily chosen area.
Region	A geographical area (usually larger than 100 km ²) consisting of several landscapes and ecosystems that share some environmental features, e.g., topography, wildlife, plant communities, climate, etc.
Restoration	The process of returning something to an historical condition or state. Ecological restoration consists of a series of measures and actions designed to restore a degraded ecosystem, or its components, to their former state.
Right-of-way	Strip of land, often vegetated, beyond road surface and within the road corridor.
Riparian habitat	Habitat associated with or situated adjacent to a watercourse (e.g., creek, stream, river) or other body of water.
Road corridor	Linear surface used by vehicles plus any associated rights-of-way (normally vegetated). Includes the land area immediately influenced by the road and traffic in terms of auditory, visual, hydrological and chemical impacts (typically within 160–330 ft [50–100 m] of road surface edge).
Road network	The interconnected system of roads serving an area.
Root wad	Mass of roots, soil and rocks that remains intact when a tree, shrub, or stump is uprooted. See Stump wall.
Scale	In landscape ecology, the spatial and temporal dimension of patterns and processes.
Semi-aquatic species	Species that are adapted for living and traveling both in water and on land.

Semi-arboreal species	Species that are adapted for living and traveling both on land and in trees.
Site	Defined place, point or locality in a given landscape.
Slope protection	Action or measure to prevent soil erosion on slopes. May consist of seeding or planting vegetation, or structural measures (e.g., retaining walls).
Sink habitats and populations	Areas where populations of a given species have a non-sustaining birth/death ratio and are dependent on immigration from source populations.
Source habitats and populations	Areas where populations of a given species can reach a positive balance between births and deaths, and thus act as a source of emigrating individuals.
Specialist species	A species that can only thrive in a narrow range of environmental conditions and/or have a limited diet. See Generalist species for opposite.
Stepping stone	Ecologically suitable patches where an organism temporarily stops while moving along a heterogeneous path.
Stump wall	Wall of tree stumps generally placed along interior wall of wildlife underpass structure and designed to provide cover for movement of small mammals.
Surface-water drainage	System devised to remove excess water from the surface of the ground (or infrastructure).
Target species	A species that has been identified as the subject of conservation or monitoring actions.
Taxon (plural = taxa)	Category in the Linnaean classification of living organisms, i.e., species that are considered sufficiently distinct from other groups to be treated as a separate unit.
Terrestrial	Pertaining to land or earth.
Topsoil	Top layer of soil that supports vegetation.
Underpass	Structure that allows passage below transportation infrastructure or obstacle.

Vertebrate	Any animal with a vertebral column or backbone.
Viaduct	Long elevated bridge, supported on pillars, that carries infrastructure over a valley or low-lying area.
Wetlands	Land or area with high levels of soil moisture or entirely inundated with water for part of or the entire year.
Wildlife corridor	Generally a linear or elongated area of habitat that facilitates movement of individuals between core habitat patches and provides for connectivity among populations.
Wildlife fence	Fence designed and built to keep animals from accessing right-of-way habitat and road surface, or to funnel animal movement to safe crossing locations (e.g., wildlife crossing structures).
Wildlife overpass	Structure built over road designed to connect habitats and wildlife on either side. Generally layered with topsoil, planted with vegetation and bordered by wall or fence. Fencing of some design is attached to direct animals to structure.
Wildlife underpass	Structure built under road designed to connect habitat and wildlife on either side. Substrate is covered in soil and, at minimum, wing-fencing is attached to direct animals to structure.
Wing fencing	Fencing of short length (generally < 650 ft [200 m]) that extends out from wildlife crossing structure and does not connect with neighboring wildlife crossing structures.
Woody debris	Dead woody material typically consisting of logs, branches and tree stumps.
Xeric habitat	Habitat having very little moisture and characterized by dry conditions.

APPENDIX B – COMMON AND SCIENTIFIC NAMES

MAMMALS

American mink (*Mustela vison*)

Beaver (*Castor canadensis*)

Black bear (*Ursus americanus*)

Bobcat (*Lynx rufus*)

Canada lynx (*Lynx canadensis*)

Coati (*Nasua narica*)

Coyote (*Canis latrans*)

Elk (*Cervus elaphus*)

Fisher (*Martes pennanti*)

Florida panther (*Puma concolor coryi*)

Gray wolf (*Canis lupus*)

Grizzly bear (*Ursus arctos*)

Hoary marmot (*Marmota caligata*)

Key deer (*Odocoileus virginianus clavium*)

Marten (*Martes americana*)

Moose (*Alces alces*)

Mountain goat (*Oreamnos americanus*)

Mountain lion (*Puma concolor*)

Mule deer (*Odocoileus hemionus*)

Muskrat (*Ondatra zibethica*)

Northern flying squirrel (*Glaucomys sabrinus*)

Opossum (*Didelphis virginiana*)

Pika (*Ochotona princeps*)

Porcupine (*Erethizon dorsatum*)

Pronghorn (*Antilocapra americana*)

Raccoon (*Procyon lotor*)

Red fox (*Vulpes vulpes*)

Red squirrel (*Tamiasciurus hudsonicus*)

Ringtail (*Bassariscus astutus*)

River otter (*Lutra canadensis*)

Snowshoe hare (*Lepus americanus*)

Weasel (*Mustela sp.*)

White-tail deer (*Odocoileus virginianus*)

Wolverine (*Gulo gulo*)

Woodchuck/Groundhog (*Marmota monax*)

REPTILES

Desert tortoise (*Gopherus agassizii*)

AMPHIBIANS

Long-toed salamander (*Ambystoma macrodactylum*)

Mole salamanders (family *Ambystomatidae*)

Spotted salamander (*Ambystoma maculatum*)

APPENDIX C – HOT SHEETS

HOT SHEET 1: LANDSCAPE BRIDGE

GENERAL DESIGN

Landscape bridges are the largest wildlife crossing structures that span highways. They are primarily intended to meet the movement needs of a broad spectrum of wildlife from large mammals to reptiles, and even invertebrate taxa as shown in Figure 29. Small mammals, low-mobility medium-sized mammals and reptiles will utilize structures particularly if habitat elements are provided on the overpass. Types of vegetation and placement can be designed to enhance crossings by bats and birds.



Figure 29. Photo. Landscape bridge (Credit: Anonymous).

USE OF THE STRUCTURE

These structures are designed exclusively for the use of wildlife. Prohibiting human use and human-related activities adjacent to structure is highly recommended.

GENERAL GUIDELINES

- Large size enables the restoration of habitats, particularly if designed and integrated so there is habitat continuity from one side to the other.
- To facilitate use by largest number of species, structure should have vegetative composition similar to the vegetation in adjacent habitats.
- To ensure performance and function, landscape bridges should be situated in areas that are known wildlife corridors and have minimal human disturbance.
- Should be closed to public and any other human use/activities as Figure 30 shows.
- Maximize continuity of native soils adjacent to and on landscape bridge. Avoid importation of soils from outside project area.
- Reduce light and noise from vehicles by using earth berms, solid walls, dense vegetation or combination of these on the sides of the structure.



Figure 30. Photo. Closure signage (Credit: Tony Clevenger).

DIMENSIONS – GENERAL GUIDELINES

Bridge Width

Minimum: 230 ft (70 m)
Recommended: >330 ft (>100 m)

Fence/Berm Height

8 ft (2.4 m)

Soil Depth

5–8 ft (1.5–2.0 m)

TYPES OF CONSTRUCTION

Span

Bridge span (steel truss or concrete)

Arch

Pre-fabricated cast-in-place concrete arches
Corrugated steel

SUGGESTED DESIGN DETAILS

Crossing Structure

- Landscape bridges should be a heterogeneous environment, combining open areas with shrubs and trees. Species that are taxonomically close to existing vegetation adjacent to structure should be employed. Site and environmental conditions (climate) may require hardy drought-tolerant species.
- Landscape design should mimic adjacent habitats that the structure intends to connect. Trees and dense shrubs should be planted on edges of structure to provide cover and refuge for small- and medium-sized wildlife. The center section of overpass should be left open with low-lying or herbaceous vegetation. Piles of shrubs, large woody debris or rocks should be placed in stepping-stone fashion to provide refuge for small fauna.
- Soil depth should be sufficient to support 8–12 ft (2.4–3.6 m) trees. Soil must be deep enough for water retention for plant growth. Drainage should slope slightly (at 2–3 percent) from the central longitudinal axis to sides.
- Local topography can be created on surface with slight depressions and mounding of material used for fill.
- Amphibian habitat can be created in a stepping-stone fashion or isolated ponds. Pond habitat may be artificial with impermeable substrates to hold water from rainfall or landscape designed areas for high water retention.
- Earth berms, solid walls, dense vegetation or a combination of these should be installed as sound- and light-attenuating walls on the sides of the structure. The walls should extend

down to approach ramps and curve around to wildlife exclusion fence. The minimum height of walls should be 8 ft (2.4 m).

Local Habitat Management

- Adjacent lands should be acquired, zoned or managed as reserve or protected area into perpetuity.
- Trees and shrubs should be located at the edges of the approach ramps to guide wildlife to the entrance to the structure. The vegetation should integrate with the adjacent habitat.
- Landscape bridges are best situated in areas bordered by elevated terrain, enabling the approach ramps and surface of structure to be at the same level as the adjacent land/grade. If the structure is built on level ground, then approach ramps should have gentle slopes (e.g., 5:1 or less). One or both slopes may be steeper if built in mountainous areas, especially if built on a side slope rather than valley bottom.
- There is a trade-off between slope and retaining vegetative cover on approach ramps. A steep-sloped ramp will retain vegetative cover close to the overpass structure. Gentle slopes (>3:1) generally require more fill, which extends the approach ramp farther out away from the structure and will bury vegetation, including trees.
- Efforts should be made to avoid having roads of any type pass in front of or near the entrance to the landscape bridge, as it will hinder wildlife use of the structure.
- Large boulders can be used to block any vehicle passage on the landscape bridge.
- 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.

POSSIBLE VARIATIONS

- Piles of brush, rocks and isolated large boulders will be important for small fauna (small mammals, reptiles, invertebrates) immediately after construction in order to provide cover and refuge until vegetation takes shape, shown in Figure 31.
- Raised earth berms may be located in the center of the structure (as well as the sides) to allow ungulates greater visibility during use.

MAINTENANCE

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



Figure 31. Photo. Brush piles on wildlife overpass (Credit: Tony Clevenger).

SPECIES-SPECIFIC GUIDELINES

Recommended/Optimum solution for wildlife species/groups

Ungulates

- Moose, Elk, Deer, Pronghorn, Bighorn Sheep, Mountain Goat

Carnivores

- Black Bear, Grizzly Bear, Wolf, Coyote, Fox1, Fox2, Cougar, Bobcat, Lynx, Wolverine, Fisher, Marten, Badger, Weasel

Low-mobility medium-sized mammals

Small mammals

Reptiles

Possible if adapted to local conditions

Semi-arboreal mammals

- Tend to prefer arboreal habitats with structure that provides cover and protection during travel. Providing cover and escape or refuge areas such as piles of brush, stones or large woody debris should help movement across structure.

Semi-aquatic mammals

- Mink, River Otter, Muskrats and other riparian-associated species may be reluctant to use a landscape bridge unless located in or near their preferred habitats. The construction of amphibian habitat, as Figure 32 shows, may facilitate crossings by species associated with those habitat types.

-

Amphibians

- Not likely to use structure unless located in migratory route or during dispersal. Amphibian habitat can be created with series of ponds in a stepping-stone pattern connecting wetland habitats separated by highway.

Not recommended or applicable

None

Unknown – more data are required

None



Figure 32. Photo. Constructed amphibian habitat on edge of wildlife overpass (Credit: Tony Clevenger).

HOT SHEET 2: WILDLIFE OVERPASS

GENERAL DESIGN

Next to a landscape bridge, a wildlife overpass is the largest crossing structure to span highways similar to that shown in Figure 33. It is primarily intended to move large mammals. Small mammals, low-mobility medium-sized mammals and reptiles will utilize these structures if habitat elements are provided on the overpass. Semi-arboreal, semi-aquatic and amphibian species may use the structures if they are adapted for their needs. Types of vegetation and their placement can be designed to encourage crossings by bats and birds.



Figure 33. Photo. Recently completed but unlandscaped wildlife overpass (Credit: Tony Clevenger)

USE OF THE STRUCTURE

Wildlife overpasses are intended for the exclusive use of wildlife. Prohibiting human use and human-related activities adjacent to the structure is highly recommended.

GENERAL GUIDELINES

- Same general design as landscape bridge but not as wide.
- Being narrower in width than landscape bridge, the ability to restore habitats will be limited.
- To ensure performance and function, wildlife overpasses should be situated in areas with high landscape permeability, are known wildlife travel corridors and have minimal human disturbance.
- Maximize continuity of native soils adjacent to and on wildlife overpass. Avoid importation of soils from outside project area.
- Should be closed to public and any other human use/activities as Figure 30 showed.

- Reduce light and noise from vehicles by using earth berms, solid walls, dense vegetation or a combination of these placed on the sides (lateral edges) of the structure as illustrated in Figure 34.



Figure 34. Photo. Berm on wildlife overpass (Credit: Tony Clevenger).

DIMENSIONS – GENERAL GUIDELINES

Overpass Width

Minimum: 130–165 ft (40–50 m)

Recommended: 165–230 ft (50–70 m)

Fence/Berm Height

8 ft (2.4 m)

Soil Depth

5–8 ft (1.5–2.4 m)

TYPES OF CONSTRUCTION

Span

Bridge span (steel truss or concrete)

Arch

Pre-fabricated cast-in-place concrete arches
Corrugated steel

Design will be similar to a landscape bridge. Parabolic arch design overpass creates better opportunities for wildlife to locate approach ramps; however, costs are higher than rectangular or straight-edged constructions as sketch in Figure 35.

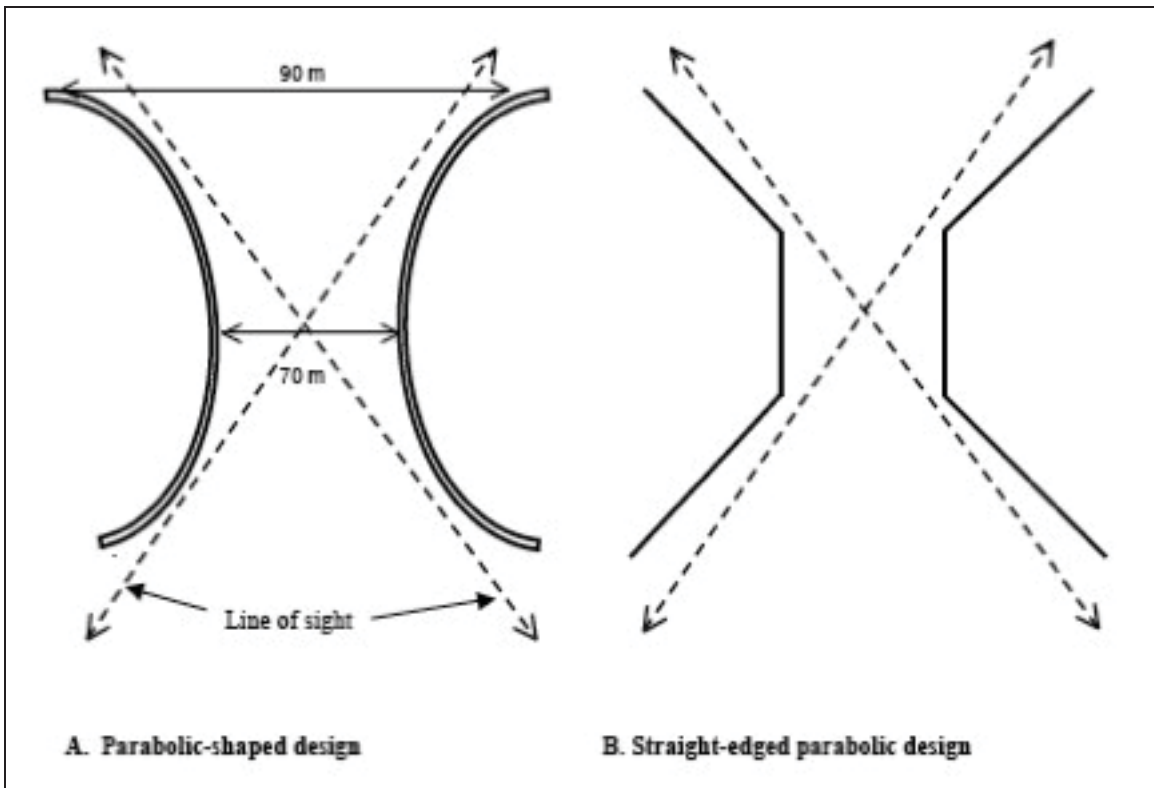


Figure 35. Schematic. (A) Parabolic-shaped design overpass (B) Straight-edged design.

SUGGESTED DESIGN DETAILS**Crossing structure**

- Wildlife overpass should be vegetated with native trees, shrubs and grasses. Species that match or are taxonomically close to existing vegetation adjacent to structure should be employed. Site and environmental conditions (including climate) may require hardy, drought-tolerant species. Composition of trees, shrubs and grasses will vary depending on target species needs.
- Suggested design consists of planting shrubs on edges of overpass providing cover and refuge for small- and medium-sized wildlife. The center section of overpass should be left open with low-lying or herbaceous vegetation. Place piles of shrubs, woody debris (logs) or rock piles in stepping-stone fashion to provide microhabitat and refuge for small, cover-associated fauna as Figure 30 showed. In arid areas, more piles of woody debris and rocks should be used to provide cover for small and medium-sized fauna.

- Soil depth should be sufficient to support 8–12 ft (2.4–3.6 m) trees. Structure should generally be vegetated with grasses and shrubs of varying height. Soil must be deep enough for water retention for plant growth. Structure must have adequate drainage.
- Local topography can be created on surface with slight depressions and mounding of material used for fill.
- Amphibian habitat can be created in a stepping-stone fashion or isolated ponds. Pond habitat may be artificial with impermeable substrates to hold water from rainfall or landscape designed areas for high water retention.
- Earth berms, solid walls, dense vegetation or a combination of these should be installed as sound- and light-attenuating walls on the sides of the structure shown earlier in Figure 34. The walls should extend down to approach ramps and curve around to wildlife exclusion fence. The minimum height of walls should be 8 ft (2.4 m).

Local habitat management

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

POSSIBLE VARIATIONS

- Vegetation for screening and fence
- Berms on approach ramps
- Berm in middle of overpass

MAINTENANCE

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

SPECIES-SPECIFIC GUIDELINES

Recommended/Optimum solution for wildlife species/groups

Ungulates

- Moose, Elk, Deer, Pronghorn, Bighorn Sheep, Mountain Goat

Carnivores

- Black Bear, Grizzly Bear, Wolf, Coyote, Fox1, Fox2, Cougar, Bobcat, Lynx, Wolverine, Fisher, Marten, Badger, Weasel

Low-mobility medium-sized mammals

Small mammals

Reptiles

Possible if adapted to local conditions

Semi-arboreal mammals

- Tend to prefer arboreal habitats with structure that provides cover and protection during travel. Providing cover and escape or refuge areas such as piles of brush, stones or large woody debris should help movement across structure.

Semi-aquatic mammals

- Mink, River Otter, Muskrats and other riparian-associated species may be reluctant to use wildlife overpass unless located in or near their preferred habitats. The construction of amphibian habitat may facilitate crossings by species associated with those habitat types.

Amphibians

- Not likely to use structure unless located in migratory route or during dispersal. Amphibian habitat can be created with series of ponds in a stepping-stone pattern connecting wetland habitats separated by highway.

Not recommended or applicable

None

Unknown – more data are required

None

HOT SHEET 3: MULTI-USE OVERPASS

GENERAL DESIGN

Design of the structure is similar to a wildlife overpass, however the management objective is to allow co-use between wildlife and humans. Design is generally narrower than a wildlife overpass because of mixed use. It may be adequate for movement of some large mammals. Small- and medium-sized mammals will utilize these structures, particularly generalist species common in human-dominated environments. Structures may be adapted for semi-arboreal species. Semi-aquatic and amphibian species may use them if they are located within their preferred habitats.

USE OF THE STRUCTURE

The multi-use overpass is intended for mixed wildlife and human use (recreational, agricultural, etc.).

GENERAL GUIDELINES

- Not as wide as wildlife overpass, but mixes needs of wildlife and human use.
- Human use (e.g., paths, riding trails) should be confined to one side, leaving greater space for wildlife use. Vegetation can be used to shield human use from wildlife as noted in Figure 36.
- May be located in prime wildlife habitat, but are generally near human use areas.
- Bridges can be adapted easily for wildlife use if they have low traffic (e.g., rural, agricultural-related) and human disturbance.
- Modifications consist of designating a section(s) of bridge as a pathway, one on each side, installing a soil substrate and, if possible, vegetation.
- Maximize continuity of native soils adjacent to and on multi-use overpass. Avoid importation of soils from outside the project area.
- Reduce light and noise from vehicles by using earth berms, walls, vegetation or a combination of these.
- Soil depth: not as deep as for wildlife overpass, as less need for deep-rooted trees/shrubs, generally vegetated with grasses and low-lying shrubs.



Figure 36. Photo. Human use lane and vegetated strip on multi-use overpass (Credit: Marcel Huijser).

DIMENSIONS – GENERAL GUIDELINES

Width:

Minimum: 32ft (10 m)
Recommended: 50–82 ft (15–25 m)

Fence/berm height:

8 ft (2.4 m)

Soil depth:

1.6–3.2 ft (0.5–1.0 m)

TYPES OF CONSTRUCTION

Span

Bridge span (steel truss or concrete)

Arch

Pre-fabricated cast-in-place concrete arches
Corrugated steel

SUGGESTED DESIGN DETAILS

Crossing structure

- If the structure has a one-lane road, the lane may be paved or gravel, but sides vegetated with grasses or shrubs. The same is true if the lane is a trail for hiking or horseback riding.
- Borders or other separations (e.g., curbs) should not be installed at interface between human-use lane and wildlife pathway. The interface between the two should be as natural as possible and without obstacles of any kind.
- Plant species that match or are taxonomically close to existing vegetation adjacent to the structure should be employed. Site and environmental conditions (including climate) may require hardy, drought-tolerant species. Composition of trees, shrubs and grasses will vary depending on target species needs.
- In arid areas it may be difficult to keep vegetation alive unless drought-resistant species are used. Piles of woody debris and rocks should be used in these situations to provide cover for small and medium-sized mammals.
- A solid wall or fence should be constructed as a sound- and light-attenuating wall on the sides of the structure. The minimum height of walls should be 8 ft (2.5 m).
-

Local habitat management

- Trees and shrubs should be located at the edges of approach ramps to guide wildlife to the entrance to the structure. The vegetation should integrate with the adjacent habitat as best as possible.
- Multi-use overpasses are best situated in areas bordered by elevated terrain, enabling the approach ramps and surface of structure to be at the same level as the adjacent land. If the structure is built on level ground, then approach ramps should have gentle slopes (e.g., 5:1 or less). One or both slopes may be steeper if built in mountainous areas.
- Large boulders can be used to block any vehicle passage on the overpass.
- Wildlife fencing is the most effective and preferred method to guide wildlife to the structure and prevent intrusions onto the right-of-way.

MAINTENANCE

- Relatively low maintenance. Walls and any fences may need to be checked and repaired if necessary.
- During the first few years it may be necessary to irrigate vegetation on the structure, particularly if there are extended periods with little rainfall. Sufficient watering (assisted or rainfall) will allow vegetation to settle and take root.

SPECIES-SPECIFIC GUIDELINES

Recommended/Optimum solution for wildlife species/groups

Ungulates

- Elk, Deer,

Carnivores

- Coyote, Fox1, Fox2, Bobcat, Fisher, Marten, Badger, Weasel

Low-mobility medium-sized mammals

Small mammals

Reptiles

Possible if adapted to local conditions

Semi-arboreal mammals

- Tend to prefer arboreal habitats with structure that provides cover and protection during travel. Providing cover and escape or refuge areas such as piles of brush, stone or large woody debris should help movement across structure.

Semi-aquatic mammals

- Mink, River Otter, Muskrats and other riparian-associated species are not likely to use a multi-use overpass unless they are located in or near their preferred habitats

Amphibians

- Not likely to use structure unless located in migratory route or during dispersal.

Not recommended or applicable

Ungulates

- Moose – Tend to prefer large, open structures with good visibility and vertical clearance in areas with little human disturbance. Recommended dimensions are likely not sufficient to ensure regular use by individuals of all gender and age classes. Regular human use would deter moose use of overpass.
- Pronghorn – Like moose they tend to prefer large, open structures in areas with little human activity.
- Bighorn Sheep, Mountain Goat – Like Moose, tend to prefer large, open structures with good visibility and minimal human activity.

Carnivores

- Black Bear, Grizzly Bear, Wolf, Cougar, Lynx, Wolverine – Not recommended for these species because of their need for large structures and/or preference for areas in close proximity to humans.

Unknown – more data are required

None

HOT SHEET 4: CANOPY CROSSING

GENERAL DESIGN

Canopy crossings are above-grade crossing structures designed to link forested habitats separated by roads. They are designed for semi-arboreal and arboreal species whose movements are strongly impacted by roads, limiting movements and potentially fragmenting habitat. Canopy crossings allow for movements between forests over many road types and widths. Structures can be designed to meet the needs of particular focal species. Relatively few canopy crossings have been constructed to date.

USE OF THE STRUCTURE

Canopy crossings are intended exclusively for the use of wildlife.

GENERAL GUIDELINES

- Specific crossing structure designed to reduce road-related mortality and increase movements between forested habitats separated by roads.
- The design and materials selected will be site- and species-dependent.
- Structure consists of anchoring thick ropes or cables to trees or permanent fixtures (signage beams, light posts, etc) allowing animals to move between tree canopies situated on opposite sides of the road.
- Over small roads (or railways) ropes or cables can be installed between trees. For multilane highways and roads with wide clearance where there is a greater distance between trees, more permanent and stable fixtures such as that in Figure 37 will be required for anchoring the crossing.
- Permanent fixtures such as signage beams may have wooden platforms or trough-like runways built into them, ropes then extend out to adjacent tree canopies as Figure 38 shows. These trough-like runways shield animals from lights of traffic while using the canopy crossing.

•

DIMENSIONS – GENERAL GUIDELINES

- Ropes at least 3 in (8 cm) diameter.
- Wooden platforms at least 1 ft (30 cm) wide.
- Two steel cables parallel to one another, separated by 8–12 in (20–30 cm) with a nylon net fabric between the cables. In areas receiving snowfall, mesh should be large enough to filter and not accumulate snow.



Figure 37. Photo. Canopy crossing installed in permanent signage fixture (Credit: Tony Clevenger).



Figure 38. Photo. Ropes extending out from canopy crossing to forest canopy (Credit: Tony Clevenger).

SUGGESTED DESIGN DETAILS

Crossing structure

- To ensure performance and function, canopy crossings should be situated in areas with high landscape permeability for target species, that are known corridors for cross-highway population connections, and that experience minimal human disturbance.
- If crossing structure consists of signage beam, ≥ 3 ropes should extend out from end of beam into nearest canopy to allow for animal access.
- For Flying Squirrels, trees in central median or landing post may be sufficient to allow travel across some highways without a canopy crossing structure.

Local habitat management

- Ensure that habitat around canopy crossing is managed for target species populations and their connectivity needs. Maintain continuity of habitat and canopy to allow target species to move throughout the area and access canopy crossing structure.

TYPES OF CONSTRUCTION

Diverse types of construction (rope, steel cable, wood platforms).

POSSIBLE VARIATIONS

- To minimize avian predation and provide greater protection for prey species using the canopy crossing an additional rope or cable can be placed above the devices used for travel.

MAINTENANCE

- Regular inspection and maintenance to avoid deterioration and wear of materials used for the canopy crossing (ropes, cables, attachments, wooden runways) and replacement of any components in poor condition.

SPECIES-SPECIFIC GUIDELINES

Recommended/Optimum solution for wildlife species/groups

Semi-arboreal mammals

- Species include: Tree Squirrels, Flying Squirrels, Fishers, Martens, Raccoons, Ringtails, Coatis and Opossums.

Possible if adapted to local conditions

Small mammals

- Some species with arboreal habits may use canopy crossings.

Not recommended or applicable

Ungulates

Carnivores (other than those listed above)

Low-mobility medium-sized mammals (other than those listed above)

Semi-aquatic mammals

Amphibians

Reptiles

Unknown – more data are required

None

HOT SHEET 5: VIADUCT OR FLYOVER**GENERAL DESIGN**

The viaduct, or flyover, is the largest of wildlife underpass structures; however, it is usually not built specifically for wildlife movement. The large span and clearance of viaducts shown in Figure 39 allow for use by a wide range of wildlife. Structures can be adapted for amphibians, semi-aquatic and semi-arboreal species. Viaducts with support pillars help keep habitats intact and nearly undisturbed. Viaducts 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.



Figure 39. Photo. Viaduct as wildlife underpass (Credit: Ministère des Transports du Québec).

USE OF THE STRUCTURE

The viaduct is intended for wildlife, but may support occasional human use.

GENERAL GUIDELINES

- Viaducts are an alternative to constructing underpasses on cut-and-fill slopes, which tend to limit wildlife movement and reduce habitat connectivity compared to viaducts.
- Viaducts 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 as in the Figure 40 example.
- Replant with local native vegetation if the area is disturbed during construction.



Figure 40. Photo. Wide span viaduct 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 viaduct should be restored after construction with same vegetation in adjacent undisturbed areas leading up to the structure as shown in Figure 41. Effort should be made to reconstruct the habitat and eventually have continuous vegetation types and structure within and adjacent to the viaduct.



Figure 41. Photo. Viaduct with retention of riparian vegetation (Credit: Tony Clevenger).

- 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 viaduct 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 viaducts.

POSSIBLE VARIATIONS

- Road construction and operation should be avoided if at all possible underneath viaducts that are adapted for wildlife use. If roads are necessary, they should have low traffic volumes and be placed to one side of the viaduct. Trees, shrubs and other shielding devices should be used to reduce any impacts of vehicle disturbance to wildlife use of the site.
- Some viaducts 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 a viaduct.

MAINTENANCE

- Inspections should be made periodically to ensure that there are no obstructions to wildlife movement below the viaduct.
- 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.

SPECIES-SPECIFIC GUIDELINES

Recommended/Optimum solution for wildlife species/groups

Ungulates

- Species will vary based on structure dimensions

Carnivores

- Species will vary based on structure dimensions
- Fisher, Marten, Badger, Weasel

Low-mobility medium-sized mammals

Small mammals

Reptiles

Possible if adapted to local conditions

Semi-arboreal mammals

- Tend to prefer arboreal habitats with structure that provides cover and protection during travel. Providing cover and escape or refuge areas such as piles of brush, stones or large woody debris should help movement under structure and between preferred habitats.

Semi-aquatic mammals

- Mink, River Otter, Muskrats and other riparian-associated species will use if riparian habitat is present or nearby.

Amphibians

- Not likely to use structure unless located within or adjacent to their preferred habitats, in a migratory route, or during dispersal. Amphibian habitat can be created with series of ponds in a stepping-stone pattern connecting wetland habitats separated by highway. Figure 42 provides an example of this pattern on a wildlife overpass.



Figure 42. Photo. "Stepping stone" ponds on wildlife overpass used to assist amphibian movement (Credit: Tony Clevenger).

Not recommended or applicable

None

Unknown – more data are required

None

HOT SHEET 6: LARGE MAMMAL UNDERPASS

GENERAL DESIGN

The large mammal underpass is not as large as most 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 largely on how it may be adapted for their specific crossing requirements. Small- and medium-sized mammals (including carnivores) generally utilize these structures, particularly if cover is provided along walls of the underpass by using brush or root wads. These underpass structures can be readily adapted for amphibians, semi-aquatic and semi-arboreal species.

USE OF THE STRUCTURE

The large mammal underpass is designed exclusively for use by wildlife.

GENERAL GUIDELINES

- Being generally smaller than a 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 as shown in Figure 43.
- 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 as Figure 44 shows. 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.

DIMENSIONS – GENERAL GUIDELINES

Width:

Minimum: 20 ft (7 m)

Recommended: >40 ft (>12 m)

Height:

Minimum: 10 ft (4 m)

Recommended: >15 ft (>4.5 m)

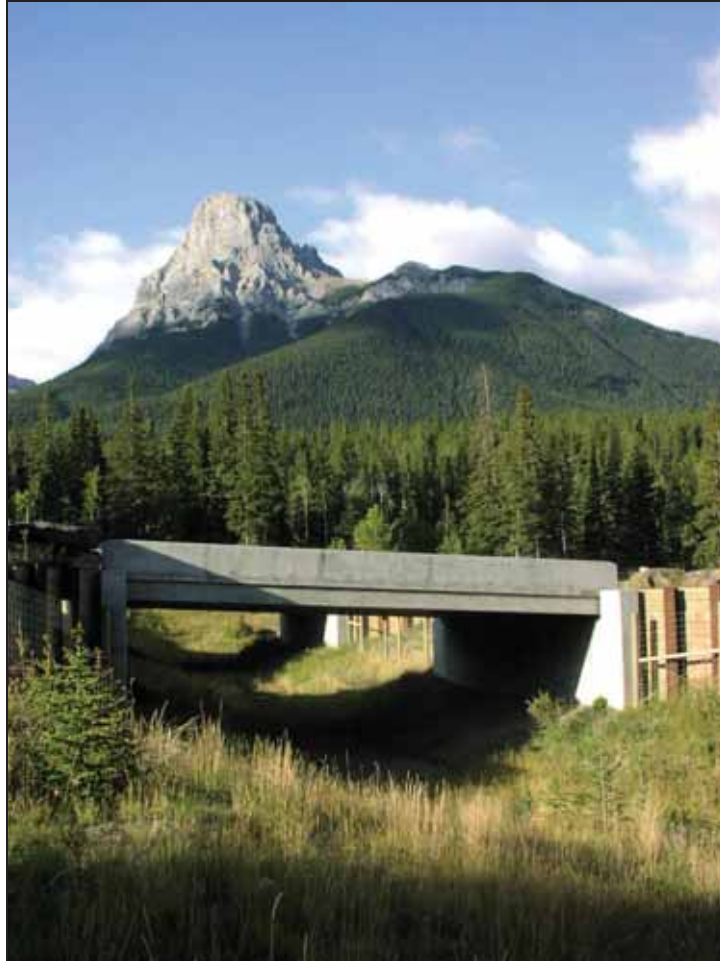


Figure 43. Photo. Open span wildlife underpass (Credit: Tony Clevenger).

TYPES OF CONSTRUCTION

Span

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

Arch

- Concrete bottomless arch
- Corrugated steel bottomless (footed?) arch
- Elliptical multi-plate corrugated steel culvert

Box culvert

- Prefabricated concrete



Figure 44. Photo. Brush and root wads placed along underpass wall to provide cover for mammals (Credit: Nancy Newhouse).

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 as Figure 44 showed.
- 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 ≥ 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.

POSSIBLE VARIATIONS

Divided road (two structures)

In-line:

Off-set:

Undivided road (one structure)

MAINTENANCE

- If wildlife underpass is not being monitored on 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).

SPECIES-SPECIFIC GUIDELINES

Recommended/Optimum solution for wildlife species/groups

Ungulates

- Elk, Deer

Carnivores

- Black bear, Coyote, Fox, Cougar, Bobcat

Low-mobility medium-sized mammals

- For maximum use, cover and protection should be provided in form of rocks, logs, brush or root wads placed along one or both walls. Cover should be continuous within and adjacent to underpass.

Small mammals

- Same as for *low-mobility medium-sized mammals*

Reptiles

- Same as above for *low-mobility medium-sized mammals*

Possible if adapted

Ungulates

- Moose – Tend to prefer large, open structures with good visibility and vertical clearance. Recommended dimensions may not be sufficient to ensure regular use by individuals of all gender and age classes. Recommend minimum 40 ft (12 m) width and 15 ft (4.5 m) height.
- Bighorn Sheep, Mountain Goat – Like Moose, tend to prefer large, open structures with good visibility. Recommended dimensions may not be sufficient to ensure regular use by individuals of all gender and age classes. Recommend minimum 40 ft (12 m) width and 15 ft (4.5 m) height.

Carnivores

- Grizzly Bear, Wolf – Tend to prefer large, open structures with good visibility, such as landscape bridges, wildlife overpasses or viaducts. Recommended dimensions may not be sufficient to ensure regular use by individuals of all gender and age classes. Recommend minimum 40 ft (12 m) width and 15 ft (4.5 m) height.
- Fox2 – Species adapted to arid, open grassland habitats that generally experience high levels of mortality from roads and larger predators (e.g., Coyotes). Few documented cases of Swift/Kit Foxes using wildlife crossings, suggesting they avoid them and prefer to cross at grade-level. To encourage Fox use of structures they should be designed for their body size. Small- and medium-sized mammals, particularly prey species, tend to use passages of a size that allow for their movement, but may limit movement of their larger predators. Hinged iron gates can be placed on underpass entrance. A 6 in x 6 in (15 x 15 cm) mesh spacing on gates will allow foxes to pass through but not the larger predators. In larger structures (e.g., 4 ft x 4 ft (1.2 x 1.2 m) culvert), artificial dens should be installed within structures and near entrances to provide escape cover for Swift/Kit Foxes.
- Fisher, Marten – Forest-dwelling species that tend to prefer structures with ample vegetative cover or form of protection while traveling. Recommended to place brush or root wads along underpass wall (one wall is sufficient; two is preferred but will depend on width of structures) to ensure regular use by individuals of all gender and age classes. In large underpasses, culvert or pipes can be placed to provide cover.
- Badger, Weasel sp. – Species adapted to open habitats and require subterranean burrows for protection. Recommended to place brush or root wads along underpass wall (one wall is sufficient; two is preferred but will depend on width of structures) to ensure regular use

by individuals of all gender and age classes. In large underpasses, culvert or pipes can be placed to provide cover.

Semi-arboreal mammals

- Tend to prefer arboreal habitats with structure that provides cover and protection during travel. Providing cover and escape or refuge areas such as piles of brush, stone or large woody debris should help movement under structure and between preferred habitats.

Semi-aquatic mammals

- Mink, River Otter, Muskrats and other riparian-associated species may be reluctant to use a wildlife underpass unless riparian habitat is present or nearby. The construction of amphibian habitat may facilitate crossings by species associated with those habitat types. See Figure 32 shown earlier for an example of amphibian habitat constructed on a wildlife overpass.

Amphibians

- Not likely to use structure unless located in migratory route or during dispersal. Amphibian habitat can be created with series of ponds in a stepping-stone pattern connecting wetland habitats separated by highway. See Figure 42 shown earlier for an example of this pattern on a wildlife overpass.

Not recommended or applicable

None

Unknown – more data are required

Pronghorn

- Little information available on wildlife crossing design needs of this species. Most reports indicate that good visibility is critical and overpass structures are preferred. However, recently this species has been detected using a large span underpass structure in California.

Lynx

- Similar to Pronghorn, scarce data exist on what type of crossings Lynx will use. Monitoring of wildlife crossings on the Trans-Canada Highway in Banff National Park and adjacent provincial lands have detected Canada Lynx using a range of structure types on the Trans-Canada Highway: 165 ft (50-m) wide overpass, open span bridge underpass (40 ft [12 m] wide x 13 ft [4 m] high).

Wolverine

- The only data at time of writing on Wolverine use of wildlife crossing structures comes from Banff National Park and adjacent Bow Valley Provincial Park. Wolverine have been documented using the following:

- Underpass with Waterflow – Open span bridge with creek
Width: 37 ft (11.5 m)
Height: 8.2 ft (2.5 m)
Usage: 3 detections

- Large Mammal Underpass – Open span bridge
Width: 42.5 ft (13 m)
Height: 16.5 ft (5.0 m)
Usage: 1 detection

- Large Mammal Underpass – Multi-plate elliptical culvert
Width: 24 ft (7.2 m)
Height: 3 ft (4 m)
Usage: 1 detection

HOT SHEET 7: MULTI-USE UNDERPASS

GENERAL DESIGN

A multi-use underpass is similar in design to a large mammal underpass, however the management objective is to allow co-use between wildlife and humans. These structures can be retrofit bridges for wildlife passage or designed specifically for co-use as Figure 45 illustrates. They may be adequate for movement of some large mammals, but not all wildlife. Small- and medium-sized mammals will utilize the structures, particularly generalist species common in human-dominated environments (e.g., urban habitats). Structures may be able to be adapted for semi-arboreal species. Semi-aquatic and amphibian species may use them if they are located within their habitats.



Figure 45. Photo. Multi-use underpass in The Netherlands retrofitted for human use and wildlife passage (Credit: Marcel Huijser).

USE OF THE STRUCTURE

Multi-use underpasses are designed for mixed wildlife and human use (recreational, agricultural, etc.).

GENERAL GUIDELINES

- Being generally smaller than a viaduct or large mammal underpass, the ability to restore habitat underneath will be limited. Open designs that provide ample natural lighting will encourage greater development of native vegetation.
- May be located in prime wildlife habitat, but generally are near human use areas.

- If the structure is > 40 ft (>12 m) wide, human use (e.g., paths, riding trails) should be confined to one side, leaving greater space for wildlife use. Vegetation can be used to shield human use from wildlife.
- Frequent motor vehicle or all-terrain vehicle (ATV) use of underpass should be discouraged. High levels of disturbance from ATVs or other motorized vehicles at the underpass and adjacent area will likely disturb most wildlife in the area and negatively affect the ability of wildlife to use underpass for cross-road movements.
- Low-level vehicular traffic is acceptable through the underpass, e.g., rural or agricultural use. Keep the road unpaved and its margin vegetated providing continuity through the underpass and adjacent habitats.
- 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.

DIMENSIONS – GENERAL GUIDELINES

Width:

Minimum: 16.5 ft (5 m)

Recommended: >23 ft (>7 m)

Height:

Minimum: 8.2 ft (2.5 m)

Recommended: >11.5 ft (>3.5 m)

TYPES OF CONSTRUCTION

Concrete bottomless arch

Concrete bridge span (open span bridge)

Steel beam span

Elliptical multi-plate metal culvert

Prefabricated concrete box culvert

SUGGESTED DESIGN DETAILS

Crossing structure

- Attempt to mirror habitat conditions found on both sides of the road and provide continuous habitat adjacent to and within the structure.
- Revegetation is possible in areas of the underpass closest to entrances, as light conditions tend to be better than in the center of the structure.

- Design underpass to minimize the intensity of noise and light coming from the road and traffic.
- Maximize microhabitat complexity and cover within the underpass using salvage materials (logs, root wads, rocks, 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 the design has a closed bottom (e.g., concrete box culvert), a soil substrate ≥ 6 in (15 cm) deep must be applied to the underpass interior.
- If rural traffic uses the underpass, do not install curbs or elevated margins of road that separate areas of vehicular use from wildlife use. The transition between the two areas should be natural and not present obstacles.
- Depending on the width of the underpass with vehicular traffic, wildlife paths could run along both sides (of a wide underpass) or along one side (of a narrow underpass); regardless of configuration, the wildlife paths should be > 8 ft (2.4 m) wide.
-

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.
- Discourage building underpass in location with a road running parallel and adjacent to the 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.

POSSIBLE VARIATIONS

Divided road (2 structures)

In-line:

Off-set:

Undivided road (1 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).

SPECIES-SPECIFIC GUIDELINES**Recommended/Optimum solution for wildlife species/groups***Ungulates*

- Elk, Deer

Carnivores

- Coyote, Fox1, Bobcat, Fisher, Marten, Weasel, Badger

*Low-mobility medium-sized mammals**Small mammals**Reptiles***Possible if adapted***Carnivores*

- Fox2 – Species adapted to arid, open grassland habitats that generally experience high levels of mortality from roads and larger predators (e.g., Coyotes). Few documented cases of Swift/Kit Foxes using wildlife crossings, suggesting they avoid them and prefer to cross at grade-level. To encourage Fox use of structures they should be designed for their body size. Small- and medium-sized mammals, particularly prey species, tend to use passages of a size that allow for their movement but may limit movement of their larger predators. Hinged iron gates can be placed on underpass entrance. A 6 in x 6 in (15 x 15 cm) mesh spacing on gates will allow Foxes to pass through but not the larger predators. In larger structures (e.g., a 4 ft x 4 ft [1.2 x 1.2 m] culvert) artificial dens should be installed within structures and near entrances to provide escape cover for Swift/Kit Foxes.

Semi-arboreal mammals

- Tend to prefer arboreal habitats with structure that provides cover and protection during travel. Providing cover and escape or refuge areas such as piles of brush, stone or large woody debris should help movement under structure and between preferred habitats.

Semi-aquatic mammals

- Mink, River Otter, Muskrats and other riparian-associated species may be reluctant to use a wildlife underpass unless riparian habitat is present or nearby. The construction of amphibian habitat may facilitate crossings by species associated with those habitat types.

Amphibians

- Not likely to use structure unless located in migratory route or during dispersal. Amphibian habitat can be created with series of ponds in a stepping-stone pattern connecting wetland habitats separated by highway.

Not recommended or applicable

Ungulates

- Moose, Pronghorn, Bighorn Sheep, Mountain Goat

Carnivores

- Black Bear, Grizzly Bear, Wolf, Cougar, Lynx, Wolverine

Unknown – more data are required

None

HOT SHEET 8: UNDERPASS WITH WATERFLOW

GENERAL DESIGN

Underpass structures like those in Figure 46 can be 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 maybe 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, are known wildlife travel corridors and have minimal human disturbance. These underpass structures are frequently used by several large mammal species, yet use by some large mammals will depend largely on how it may be adapted for their specific crossing requirements. Small- and medium-sized mammals (including carnivores) generally utilize these structures, particularly if 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.



Figure 46. Photo. Wildlife underpass designed to accommodate waterflow (Credit: 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 waterflow (creek, stream, river). Guidelines are given below for dimensions of wildlife pathway alongside active channel and height of underpass structure.

Minimum:

Width: 6.5 ft (2 m) pathway

Height: 10 ft (3 m)

Recommended:

Width: >10 ft (>3 m) pathway

Height: >13 ft (>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 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 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 underpass.
- Wildlife fencing is most effective and preferred method to guide wildlife to structure and prevent intrusions to the right-of-way. Mechanically stabilized earth (MSE) walls like the one in Figure 47, 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 connects 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 (2 structures)

In-line:

Undivided road (1 structure)



Figure 47. Photo. Mechanically stabilized earth (MSE) wall serving as wildlife exclusion “fence” (Credit: Tony Clevenger).

MAINTENANCE

- If wildlife underpass is not being monitored on 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).

SPECIES-SPECIFIC GUIDELINES

Recommended/Optimum solution for wildlife species/groups

Ungulates

- Elk, Deer

Carnivores

- Black Bear, Coyote, Fox, Cougar, Bobcat

Low mobility medium-sized mammals

- Providing cover within underpass by using salvage materials (logs, root wads, rocks, etc.) will encourage use by these species.

Semi-aquatic mammals

- Mink, River Otter, Muskrats and other riparian-associated species may be reluctant to use a wildlife underpass unless riparian habitat is present or nearby. Recommended maintaining riparian vegetation through the wildlife underpass to ensure use and regular movement by these species.

Small mammals

- Providing cover within underpass by using salvage materials (logs, root wads, rocks, etc.) will encourage use by these species.

Possible if adapted

Ungulates

- Moose – Tend to prefer large, open structures with good visibility and vertical clearance. The dimensions of some smaller underpasses may not be sufficient to ensure regular use by individuals of all sex and age classes. Recommend minimum 40 ft (12 m) width and 15 ft (4.5 m) height.
- Pronghorn, Bighorn Sheep, Mountain Goat – Like Moose, these species tend to prefer large, open structures with good visibility. Dimensions of some underpasses may not be sufficient to ensure regular use by individuals of all gender and age classes. Recommend minimum 40 ft (12 m) width and 15 ft (4.5 m) height for Bighorn Sheep and Mountain Goat; Recommended minimum 65 ft (20 m) width and 15 ft (4.5 m) height for Pronghorn.

Carnivores

- Grizzly Bear, Wolf - Tend to prefer large, open structures with good visibility, such as landscape bridges, wildlife overpasses and viaducts. Recommended dimensions may not be sufficient to ensure regular use by individuals of all gender and age classes. Recommend minimum 40 ft (12 m) width and 15 ft (4.5 m) height.
- Fox2 - Species adapted to arid, open grassland habitats that generally experience high levels of mortality from roads and larger predators (e.g., Coyotes). Few documented cases of Swift/Kit Foxes using wildlife crossings, suggesting they avoid them and prefer to cross at grade-level. To encourage Fox use of structures they should be designed for their body size, to limit predation risks associated with the crossings. It is unlikely these structures be designed specifically for Swift/Kit Fox use, thus wide and high underpasses with good visibility for prey species would be the most effective. In larger structures artificial dens should be installed within structures and near entrances to provide escape cover for Swift/Kit Foxes.
- Fisher, Marten – Forest-dwelling species that tend to prefer structures with ample riparian habitat, vegetative cover or form of protection while traveling. Recommended to place brush or root wads along underpass wall (one wall is sufficient; two is preferred, but will

depend on width of structure) to ensure regular use by individuals of all gender and age classes. In large underpasses, culvert or pipes can be placed to provide cover.

- Badger, Weasel sp. – Species adapted to open habitats and require subterranean burrows for protection. Recommended to place brush, root wads along underpass wall (one wall is sufficient; two is preferred, but will depend on width of structure) to ensure regular use by individuals of all gender and age classes. In large underpasses, culvert or pipes can be placed to provide cover as Figure 48 shows.



Figure 48. Photo. Pipes placed in culverts to provide cover for small mammal movement (Credit: Tony Clevenger).

Semi-arboreal mammals

- Tend to prefer arboreal habitats with structure that provides cover and protection during travel. Providing cover and escape or refuge areas such as piles of brush, stone or large woody debris should help movement under structure and between preferred habitats.

Amphibians

- Not likely to use structure unless located in migratory route or during dispersal. Amphibian habitat can be created with series of ponds in a stepping-stone pattern connecting wetland habitat separated by highway shown previously in Figure 42 as an example for wildlife overpass. Recommended maintaining riparian vegetation, soil

moisture and natural light conditions throughout the wildlife underpass to ensure use and regular movement by the species of concern.

Not recommended or applicable

None

Unknown – more data are required

Lynx

Similar to Pronghorn, scarce data exist on what type of crossings Canada Lynx will use. Monitoring of wildlife crossings on the Trans-Canada Highway in Banff National Park and adjacent provincial lands have detected Canada Lynx using a range of structure types on the Trans-Canada Highway: 165 ft (50-m) wide overpass, open span bridge underpass (40 ft [12 m] wide x 13 ft [4 m] high). For this species, recommendations are to design large structures but more importantly provide cover in form of logs, brush or root wads within the underpass. Siting the crossing within suitable Lynx habitat will be critical for successful design and use by Lynx.

Wolverine

The only data on Wolverine use of a wildlife crossing comes from Banff National Park and adjacent Bow Valley Provincial Park. Wolverine have been documented using the following:

- Underpass with Waterflow – Open span bridge with creek
Width: 37 ft (11.5 m)
Height: 8.2 ft (2.5 m)
Usage: 3 detections

- Large Mammal Underpass – Open span bridge
Width: 42.5 ft (13 m)
Height: 16.5 ft (5.0 m)
Usage: 1 detection

- Large Mammal Underpass – Multi-plate elliptical culvert
Width: 24 ft (7.2 m)
Height: 3 ft (4 m)
Usage: 1 detection

For this species, recommendations are to design large structures but more importantly provide cover in form of logs, brush or root wads within the underpass. Similar to Canada Lynx, siting the crossing within suitable Wolverine habitat will be critical for successful design and use by this species.

HOT SHEET 9: SMALL-TO-MEDIUM-SIZED MAMMAL UNDERPASS

GENERAL DESIGN

One of the smallest wildlife crossing structures. Primarily designed for small- and medium-sized mammals, but use by most species will depend largely on how it may be adapted for their specific crossing requirements and cover needs as Figure 49 shows. Small- and medium-sized mammals (including carnivores) generally utilize these structures, particularly if they provide sufficient cover and protection. These underpass structures can be of value to semi-aquatic mammals and amphibians if underpass structure is located in or near the habitat of these species.

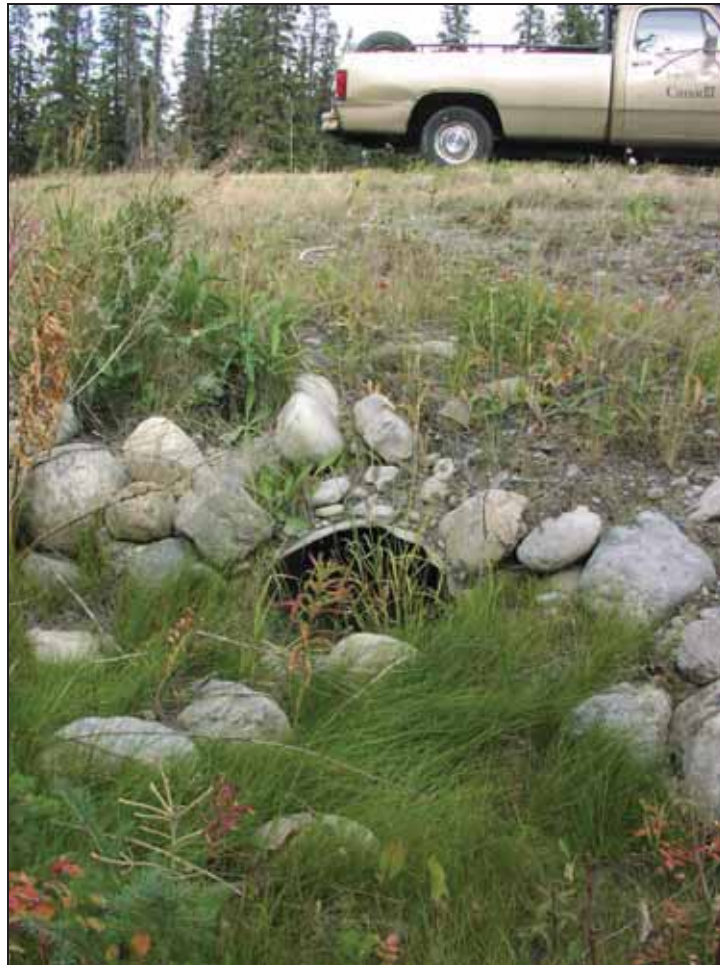


Figure 49. Photo. Small- to medium-sized mammal underpass (Credit: Tony Clevenger).

USE OF THE STRUCTURE

Exclusively for wildlife

GENERAL GUIDELINES

- To ensure performance and function, small to medium-sized mammal underpasses should be situated in areas with high landscape permeability, are known wildlife travel corridors and have minimal human disturbance.
- 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 the target species. Structures generally range from 1 ft to 4 ft (0.4-1.2 m) diameter culverts or underpass structures.

TYPES OF CONSTRUCTION

Concrete bottomless arch

Circular multi-plate metal culvert

Prefabricated concrete box culvert

SUGGESTED DESIGN DETAILS

Crossing structure

- Structures should be designed to meet the movement needs of widest range of species possible that live in the area or might be expected to recolonize area, e.g., high and low mobility species.
- Maximize microhabitat complexity and cover within underpass using salvage materials (logs, root wads, rock piles, etc.) for sustained use by semi-arboreal mammals, small mammals, reptiles and species associated with rocky habitats.
- Preferable that the substrate of larger underpasses is of native soils. If construction type has closed bottom (e.g., concrete box culvert), a soil substrate ≥ 6 in (15 cm) deep must be applied to interior.
- Design underpass to minimize the intensity of noise and light coming from the road and traffic.
- On divided highways, underpass structure should be continuous, below-grade and not open up in the central median as the example in Figure 50 shows.



Figure 50. Photo. Continuous wildlife underpass on divided highway (Credit: Tony Clevenger).

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 larger wildlife crossing structures that may be built during project.
- Attempt to provide continuous habitat leading to and adjacent to the structure.
- Encourage use of structure by using fencing, rock walls, or other barriers along road to direct wildlife into underpass. Use topography and natural features as much as possible.
- Encourage use of underpass by baiting and/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.

Possible Variations

Divided road (2 structures)

In-line:

Off-set:

Undivided road (1 structure)

MAINTENANCE

- If wildlife underpass/culvert is not being monitored on 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).

SPECIES-SPECIFIC GUIDELINES

Recommended/Optimum solution for wildlife species/groups

Carnivores

- Coyote, Fox1 – Generalist species' that occupy a variety of habitat types. Will typically use underpass or culvert designs sufficiently large enough so they can move through them.
- Fisher, Marten – Forest-dwelling species that tend to prefer structures that provide or have cover elements incorporated. Marten are known to readily use drainage culverts to cross 2- and 4-lane roads as captured in Figure 51. There is only anecdotal information on Fishers using drainage culverts. Design of culverts for these mustelid species should be slightly larger than their body size (ca. 2-3 ft diameter), thus providing cover and protection needed for travel. Larger size underpass structures should have continuous cover throughout to ensure regular use by individuals of all gender and age classes.
- Badger, Weasel – Species generally found in open areas and have been documented using drainage culverts to cross roads. Like Martens, Weasels readily use drainage culverts, particularly smaller ones (ca. 2 ft diameter). Badger tunnels have been designed in many countries and shown to be successful mitigation measures as shown in Figure 52. Design of tunnels or culverts for these species should be slightly larger than their body size (badgers, 2-3 ft (0.6-0.9 m) diameter; weasels, 1-2 ft (0.3-0.6 m) diameter), thus providing cover and protection needed for travel. Larger size underpass structures will not likely be sufficient to ensure regular use by individuals of all gender and age classes unless cover is added to them.



Figure 51. Photo. American marten using a drainage culvert to cross the Trans-Canada Highway, Banff National Park, Alberta (Credit: Tony Clevenger).



Figure 52. Photo. Badger tunnel in The Netherlands (Credit: Tony Clevenger).

Low mobility medium-sized mammals

- To encourage use from these species, structures should be designed for their body size. Small- and medium-sized mammals, particularly prey species, tend to use passages of a size that allow for their movement but may limit movement of their larger predators. In larger culverts (e.g., >4 ft (1.2 m) diameter circular or 4 ft x 4 ft [1.2 x 1.2 m] box culverts) the cover requirements of smaller fauna maybe met by placing pipes of varying diameter in the culvert that span the entire length.

Small mammals – (same as above for Low mobility medium-sized mammals)

Reptiles – (same as above for Low mobility medium-sized mammals)

Possible if adapted

Carnivores

- Fox2 – Species adapted to arid, open grassland habitats that generally experience high levels of mortality from roads and larger predators (e.g., Coyotes). Few documented cases of Foxes using a range of wildlife crossing sizes, but generally avoid them preferring to cross at grade-level. Design of culverts for these species should follow guidelines for *Low mobility medium-sized mammals* above. In larger structures (ca. 4 ft x 4 ft [1.2 x 1.2 m] culvert) artificial dens should be installed within structures and near entrances to provide escape cover for Swift/Kit Foxes generally shown in Figure 53.

Semi-aquatic mammals

- Mink, River Otter, Muskrats and other riparian-associated species may be reluctant to use a wildlife underpass unless riparian habitat is present or nearby. Efforts should be made to site underpass structure in most suitable habitat for these species.

Amphibians

- Not likely to use crossing structure unless located in migratory route or in general area where dispersal may occur. Efforts should be made to site underpass structure in known routes of seasonal migration, dispersal or other movement events for the target species.

Not recommended or applicable

Ungulates

- Moose, Elk, Deer, Pronghorn, Bighorn Sheep, Mountain Goat

Carnivores

- Black Bear, Grizzly Bear, Wolf, Cougar, Bobcat, Lynx, Wolverine

***Semi-arboreal mammals* – all species.**

Unknown – more data are required

None

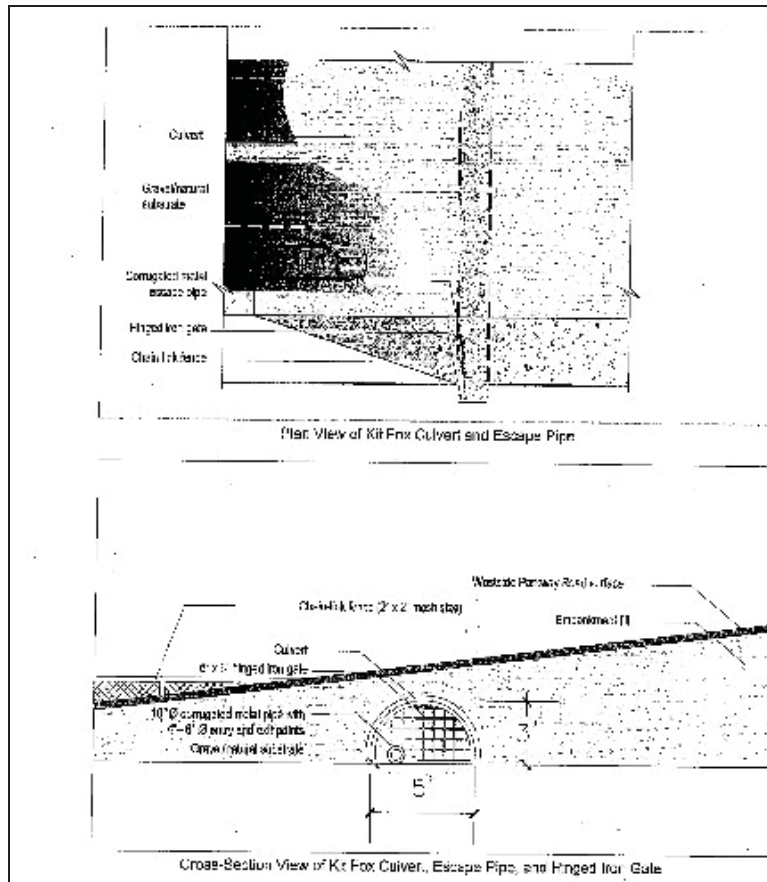


Figure 53. Schematic. Technical design plan for artificial kit fox den in culvert (Credit: US Fish and Wildlife Service).

HOT SHEET 10: MODIFIED CULVERT

GENERAL DESIGN

A crossing that is adaptively designed for use primarily by small and medium-sized wildlife associated with riparian habitats or irrigation canals. Designs to adapt canal bridges for wildlife crossings can take many forms. Dry platforms or walkways are typically constructed on the lateral interior walls of the bridge and above the high-water mark illustrated in Figure 54. Ramps from adjacent habitat and dry ground lead to the dry, elevated walkways inside the drainage structure.

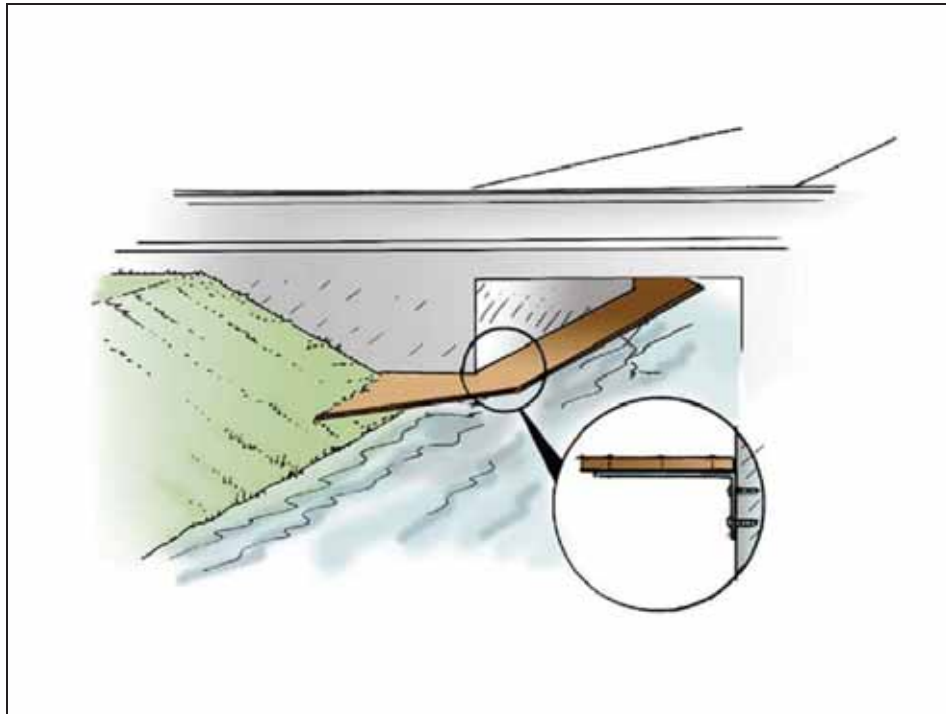


Figure 54. Schematic. Modified culvert (Reprinted with permission from Kruidering et al. 2005).

USE OF THE STRUCTURE

Movement of water and wildlife

GENERAL GUIDELINES

- Adapting drainages and canals for wildlife use is a cost-effective means to provide wildlife passage associated with wetlands and other habitats that are inundated year-round or seasonally.
- There is generally little human activity in these areas; nonetheless, to ensure performance and function a modified culvert should have minimal human disturbance.
- Little modifications are needed to adapt canal bridges for wildlife passage. Platforms made of sturdy materials (corrugated metal is not recommended) such as galvanized steel,

concrete or wooden boards (“2 x 10s”) work well. It is important to keep the walkway platforms dry, above the high-water mark and accessible from adjacent dry habitat.

- Any work to adapt a bridge structure for wildlife passage should not impede or reduce the bridges hydrologic capacity or function.

DIMENSIONS - GENERAL GUIDELINES

- The dimensions of bridges for carrying water are a function of the hydrologic condition and needs of the area.
- Design and dimensions of walkways for wildlife will vary depending on the target species.
- Walkways: Recommended minimum > 1.5 ft (0.5 m) wide.
- Access ramps: Recommended ≤ 30 degrees slope.

TYPES OF CONSTRUCTION

- Concrete bottomless arch
- Prefabricated concrete box culvert
- Circular multi-plate metal culvert (these are least recommended, but can be adapted for wildlife passage using pre-fabricated metal shelves with service ramps (see Foresman 2003).

SUGGESTED DESIGN DETAILS

Crossing structure

- Structures should be designed to meet the movement needs of widest range of riparian-associated species that live in the area or might be expected to recolonize area.
- Wildlife walkways should run along both sides of the canal bridge. Walkways can be placed on only one side of the bridge interior in situations where wildlife habitat was primarily on one side of the bridge.

Local habitat management

- Attempt to provide continuous habitat leading to an adjacent to the structure. Re-vegetation of area may be needed after construction to restore habitat conditions.
- Encourage use of structure by using fencing, rock walls, or other barriers along road to direct wildlife into the modified culvert. Use topography and natural features as much as possible.
- If traffic volume is high on the road above the modified culvert it is recommended that sound attenuating walls be place above the entrance to reduce noise and light disturbance from passing vehicles.

POSSIBLE VARIATIONS

- Concrete platforms or walkways as an integral part of canal bridge structure.
- Platforms made of 2 in x 10 in wooden boards anchored to the interior wall of the structure.
- Pre-fabricated galvanized steel or metal shelves with service ramps installed in existing drainage culverts and bridges.

MAINTENANCE

- Periodic visits should be made to ensure that there is proper access, there are no material defects, or any obstacles in or near the underpass that might affect wildlife use. Checks should be made regularly but also after heavy rain events.
- Fences or other materials used to guide wildlife to the crossing should be checked, maintained and repaired periodically.

SPECIES-SPECIFIC GUIDELINES

Recommended/Optimum solution for wildlife species/groups

Carnivores

- Fisher, Marten, Weasel sp. – Species adaptable in habitat use and associated with a mix of habitat types, including riparian habitats (especially Fisher). Use of modified culverts is likely if located in or near riparian habitats where they reside.

Low mobility medium-sized mammals

- To encourage use from these species, structures should be placed in or near habitats where they are found.

Semi-aquatic mammals

- Mink, River Otter, Muskrats and other riparian-associated species are ideal species for use of a modified culvert, particularly if situated in or near riparian habitat.

Small mammals – (same as above for *Low mobility medium-sized mammals*)

Amphibians

- Efforts should be made to site underpass structure in known routes of seasonal migration, dispersal or other movement events for the target species. Not likely to use structure unless located in migratory route or in general area where dispersal may occur.

Reptiles – (same as above for *Low mobility medium-sized mammals*)

Possible if adapted

Carnivores

- Coyote, Fox1, Bobcat – Species adapted to range of habitat types, including riparian and wetlands. Modified culverts should be designed to provide for wide walkways for these species when located in or near habitats they are found.
- Fox2 – Species adapted to arid, open and agricultural habitats, occasionally with irrigation canals. Few documented cases of Swift/Kit Foxes using a range of wildlife crossing sizes, but generally avoid them preferring to cross at grade-level. Artificial dens should be installed near entrances to provide escape cover for Swift/Kit Foxes.

Not recommended or applicable

Ungulates

- Moose, Elk, Deer, Pronghorn, Bighorn Sheep, Mountain Goat

Carnivores

- Black Bear, Grizzly Bear, Wolf, Cougar, Lynx, Wolverine, Badger

Semi-arboreal mammals – all species.

Unknown – more data are required

None

HOT SHEET 11: AMPHIBIAN/REPTILE TUNNEL**GENERAL DESIGN**

Crossing designed specifically for passage by amphibians, although other small- and medium-sized vertebrates may use as well. One of these is shown in Figure 55. There are many different amphibian/reptile tunnel designs to meet the specific requirements of each species or taxonomic group. Amphibian walls or drift fences are required to guide amphibians and reptiles to location of crossing structure.



Figure 55. Photo. Construction and placement of amphibian tunnel in Waterton National Park, Alberta (Credit: Parks Canada).

USE OF THE STRUCTURE

Exclusively wildlife, primarily amphibians and reptiles

GENERAL GUIDELINES

- To ensure performance and function, amphibian/reptile tunnels should be situated in areas that are known amphibian migration routes and areas of reptile movements.
- Amphibians and reptiles have special requirements for wildlife crossing design since they are unable to orient their movements to locate tunnel entrances. Walls or fences play a critical function in intercepting amphibian and reptile movements and directing them to the crossing structure as Figure 56 shows.



Figure 56. Photo. Drift fence for amphibians and reptiles (Credit: Tony Clevenger).

- Main conflicts with amphibians are where roads intercept periodic migration routes to breeding areas (ponds, lakes, streams or other aquatic habitats). For some species the migration to these critical areas, including the dispersal of juveniles to upland habitats, is synchronized each year. This large movement event results in a massive migration of individuals in a specific direction during a short period of time. Amphibian/reptile tunnels should be located in these key sections of road that intercept their movements year after year. Without tunnels to provide safe passage over the road, huge concentrations of amphibians are run over by vehicles, in some cases causing dangerous driving conditions similar to “black ice.”
- Large tunnels provide greater airflow and natural light conditions; however, smaller tunnels with grated slots for ambient light and moisture can be effective as Figure 57 shows. Grated tunnels are placed flush with the road surface. Distance between tunnels should be 150 ft (45 m) or less.



Figure 57. Photo. Grated slots on amphibian tunnels allows light and conservers ambient temperatures and humidity (Credit: Anonymous).

- Maximize continuity of native soils adjacent to and within the tunnel, if possible. Avoid importation of soils from outside project area.
- Tunnel should be designed to conform to local topography. Design drainage features' so flooding does not occur within amphibian/reptile tunnels. Run-off from highway near structure should not end up in tunnel.

DIMENSIONS - GENERAL GUIDELINES

- The width of amphibian/reptile tunnel will increase with tunnel length.
- The following recommended dimensions were adapted from Ministerio de Medio Ambiente (2006), Kruidering et al. (2005) and Jackson (2003).

Construction design	Tunnel length (ft)				
	<65	65-100	100-130	130-165	165-200
Rectangular	3.2 x 2.5	5.0 x 3.2	5.75 x 4.0	6.5 x 5.0	7.5 x 5.75
Circular (diameter)	3.2	4.5	5.25	6.5	8.0

- Maximum distance between tunnels: 150 ft (45 m), but a 200 ft (60 m) distance could be used if guiding walls/fences are funnel-shaped to guide amphibians to tunnel.
- Minimum height of guiding wall/fence: 1.25 ft (0.4 m); 2.0 ft (0.6 m) for some jumping species.

TYPES OF CONSTRUCTION

- Rectangular and square/box (prefabricated concrete). This design is preferred because vertical walls facilitate movement of amphibians and reptiles through tunnel.
- Circular (prefabricated concrete, metal corrugated, steel, PVC piping, polymer surface product). Steel is not desirable because of its high conductivity and coldness during spring migratory periods.
- Open grated tunnels allow for more natural light and conditions of humidity inside tunnels.

SUGGESTED DESIGN DETAILS

Crossing structure

- Requirements for tunnel design and microhabitat differ among amphibian taxa (see Lesbarrères et al. 2003). Hesitancy and repeated unsuccessful entry attempts at tunnels is believed due to changes in microclimatic conditions, particularly temperature, light and humidity, that animals perceive as localized climate degradation. Larger tunnels (ca. 3 ft diameter) permit greater airflow and increased natural light at tunnel exits. Smaller tunnels can be effective if they are open-grated on top, increasing natural light and moisture. Sandy soil (sandy loam) should be used to cover the bottom of the tunnel to provide a more natural substrate for travel.
- Amphibians have been documented using tunnels that range in length from 22 ft (6.7 m) (Spotted salamanders, Massachusetts) to 125 ft (40 m) (Lausanne, Switzerland). The effectiveness of long tunnels spanning four-lane highways has not been tested.
- Tunnels should be situated at the base of the slope coming off the road grade. The shorter the length of tunnel the better for amphibian and reptile movement.
- Tunnels should be completely level, without slope of any kind at the entrances or within the tunnel.
- On divided highways, tunnels should be continuous, below-grade and not open up in the central median.
- Tunnels should have good drainage to avoid the flooding found in Figure 58. Amphibians are associated with mesic microhabitats but do not move through flooded tunnels.



Figure 58. Photo. Flooding in front of tunnel due to improper drainage design (Credit: Tony Clevenger).

Guiding wall/fence

- Wing walls should angle out from each end of the tunnel at approximately 45 degrees.
- Guiding wall/fence will be 1.25 ft (0.4 m) high and made of concrete, treated wood or other opaque material. Guiding walls/fences made of translucent material or wire mesh are not recommended because some amphibians try to climb over them instead of moving towards the tunnel.
- Bottom section of guiding wall/fence will be secured to ground, not leaving any gaps. Guiding wall/fence will tie into the tunnel entrance, avoiding any surface irregularities that might impede or distract movement towards the tunnel entrance. Any small gaps or defects at the base of the guiding wall will lead to individuals getting onto the road and reducing the efficacy and performance of the tunnel.
- Vertical walls/fences are preferred as bowed or curved walls are more difficult to mow grass and can obstruct the travel of some amphibians moving towards tunnel.
- Walls/fencing should extend out from the tunnel and flare out away from the road at terminal points to orient animals that move away from the tunnel towards natural environment.
- In Waterton National Park, Alberta, curbs were modified into ramps to allow Long-toed Salamanders to cross a road during their annual migration as Figure 59 shows. Without the ramp, salamanders were blocked at the curb and run-over by vehicles.



Figure 59. Photo. Construction of amphibian ramp to replace curb and allow cross-road movement of long-toed salamanders (Credit: Parks Canada).

Local habitat management

- Attempt to provide continuous habitat or vegetative cover leading to an adjacent to the structure. Re-vegetation of area may be needed after construction to restore habitat conditions and provide important cover during migrations and other movement events.
- If an open-grated tunnel, adapt substrate of tunnel to soil conditions and type located adjacent to tunnel.

POSSIBLE VARIATIONS

- Some experts suggest that natural light entering the tunnel from above will facilitate use by amphibians, thus recommending that a grill-type or grated cover be placed on tunnels shown earlier in Figure 57. There are no conclusive studies that demonstrate grates have a positive effect on movements of amphibians and reptiles.

Drift fences and translocations

- Due to the seasonality of amphibian movements across roads an option to a wildlife crossing structure consists of installing temporary system of amphibian protection that prevents animals from reaching the roadway. The system consists of constructing a temporary barrier or drift fence, made of a smooth and opaque fabric, staked down, for a predetermined length that impedes the movement of the majority of migrating amphibians towards the road as Figure 60 shows. The drift fence directs the amphibian to collection buckets where they are protected before being picked up and transported across the road. These systems are labor intensive and require collaboration from many people, usually

agency and non-governmental organizations. Without citizen support these relatively inexpensive mitigation measures would usually not be possible.



Figure 60. Photo. Barrier or drift fence for amphibians and reptiles (Credit: Tony Clevenger).

- Drift fence material must be entirely opaque, of smooth fabric (rigid plastic, polythene, canvas) and a minimum height of 1.25 ft (0.3 m) to keep amphibians and reptiles from climbing or jumping over. Stakes should be placed on the road-side of the drift fence and not the opposite, which would obstruct amphibian movement. If target species is a burrower, such as a Mole Salamanders, steps should be taken to prevent animals from burrowing under the fence. Burying the bottom 2–4 in (5–10 cm) should discourage burrowing under the fence. To prevent breaching by climbing amphibians and reptiles, fence designs that curve inwards or create an overhang or lip have been used successfully. Overhanging vegetation close to the fence has resulted in animals climbing over the fence onto the road. Fencing should be clear of obstructions and vegetation.
- Collection buckets should be placed right up against the drift fence to maximize the “capture” of migrating amphibians into the buckets as documented in Figure 61. Buckets should be a minimum depth of 12–16 in (30–40 cm), buried, with tops of buckets at ground level. The distance between collection buckets should be approximately 30 ft (9

m) apart. A bucket at each end of the drift fence will keep amphibians from reaching the roadway.

- During the migration periods, buckets are checked, amphibians collected and transported across the road every 8 to 24 hours. The interval between checks will depend on the intensity of the movement event. During mass movements or migrations, buckets may need to be checked on an hourly basis.



Figure 61. Photo. Drift fence and collection buckets (Credit: Tony Clevenger).

MAINTENANCE

- Periodic visits should be made to ensure that there is proper access, there are no material defects, or any obstacles in or near the tunnel that might affect amphibian use. Checks should be made regularly but also after heavy rain events.
- Guiding walls/fences or other materials used to guide wildlife to the crossing should be checked, maintained and repaired periodically.
- Grass should be mowed within 2 ft (0.6 m) of the guiding wall/fence on the side that amphibians will travel. This task is important during the migratory period, which will

vary among species and environmental conditions. Herpetologists or local naturalists will be able to recommend the best time for mowing for each particular situation.

SPECIES-SPECIFIC GUIDELINES

Recommended/Optimum solution for wildlife species/groups

Amphibians

- Ideal crossing structure for this taxa. Requirements for tunnel design and microhabitat differ among amphibian taxa. Design of tunnel should meet the requirements of target species. Efforts should be made to site tunnel in known routes of seasonal migration, dispersal or other movement events for the target species. Not likely to use structure unless located in migratory route, within preferred habitat or in general area where dispersal events may occur.

Reptiles

- Ideal crossing structure for this taxa. Requirements for tunnel design and microhabitat differ among reptile taxa. Design of tunnel should meet the requirements of target species. Efforts should be made to site tunnel in known routes of seasonal movements, dispersal or other movement events for the target species. Not likely to use structure unless located in movement area, within preferred habitat or in general area where dispersal events may occur.

Possible if adapted

Low mobility medium-sized mammals

- To encourage use from these species, structures should be placed in or near habitats where they are found. Placement of cover near entrances and leading to adjacent habitat will increase the likelihood of use. If the tunnel is large, cover placed along inside walls will encourage use by these species.

Semi-aquatic mammals

- Their association with wetlands and aquatic habitat components will increase probability of tunnel use by these species, if located in or near habitats where they reside. Placement of adequate cover near entrances and leading to adjacent habitat will increase the likelihood of use by these species.

Small mammals – (same as above for *Low mobility medium-sized mammals*)

Not recommended or applicable

Ungulates – all species.

Carnivores – all species.

Semi-arboreal mammals – all species.

Unknown – more data are required

None

HOT SHEET 12: FENCING – LARGE MAMMALS

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 long-term survival of the population. Fencing like that in Figure 62, is one part of a two-part mitigation strategy—fencing *and* wildlife crossing structures. Fences keep wildlife away from the roadway, 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 may 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.



Figure 62. Photo. Wildlife exclusion fencing and culvert design wildlife underpass (Credit: 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 needs 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 fence 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 (see Hot Sheet 14) or gates to block animal access to roads.

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.

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).

INTERCEPTIONS

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

Roads

- *Cattle guards* – Transportation and land management agencies commonly install cattle guards (“Texas gates” in Canada) shown by Figure 63, where fences intersect access roads. Many different designs have been used, but few if any have been tested. Designs of cattle guards 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% effective in blocking Key deer movement and was safe for

pedestrians and cyclists (Peterson et al. 2003). A cattle guard roughly 6-8 ft (1.8-2.4 m) long and covering 2 lanes of traffic costs approximately \$40,000 (Terry McGuire, Parks Canada, personal communication).



Figure 63. Photo. Cattle guard (Texas gate) in road (Credit: Tony Clevenger).

- *Electric cattle guards* – These electrified mats act like electric cattle guards to discourage wildlife from crossing 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 4 feet (1.2 m) wide and built into access roads where they breach fences. ElectroBraid™ and GapZapper® are two companies that currently design and sell electric cattle guards.
- *Painted crosswalks* – Highway crosswalk structures have been used to negotiate ungulates across highways at grade level (Lenhert and Bissonette 1997). 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.

Trails

- *Swing gates (fisherman, 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 as Figure 64 shows.



Figure 64. Photo. Step gate with spring-loaded door situated at trailhead in Banff National Park, Alberta (Credit: Tony Clevenger).

- *Canoe/Kayak landings* – There are no known simple gate solutions for transporting canoes/kayaks through fences. Swing gate described above is one solution, although the gate should be slightly wider than normal to allow wide berth while moving canoe/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 float on top of the water and move in direction of flow.

SUGGESTED DESIGN DETAILS

Mesh type, gauge & size

Fence material may consist of woven-wire (page-wire) or galvanized chain-link fencing. Fence material must be attached to the back-side (non-highway) 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 3 in (8 cm) at the bottom for small animals to 6-7 in (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. Higher gauge wire mesh is more durable and will last longer than smaller gauge mesh. Wildlife fences along the Trans-Canada Highway in Banff National Park consisted of line wires with tensile strength of 1390 N/sq. mm and 12 ½ gauge. Stay wires had tensile strength of 850 N/sq. mm. All wires were Class 111 zinc galvanized coating 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. They can be made into fences and used in various applications, primarily industrial, commercial and residential. 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-gauge 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 7 ft (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 a ½ in (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 20–30 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 12 ft (3.7 m) and 13.7 ft (4.2 m) long, non-sharpened wooden posts are supplied. Fence posts are sharpened and then installed by preparing a pilot hole approximately 5 in. (125 mm) in diameter, vibrating the post down to specified post height and backfilling with a compacted non-organic material around post to level of existing ground. 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 6.5 in (16 cm). Line posts can be as small as 5 in (13 cm) and should not need to be more than 6.5 in 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 12 ft (3.7 m) lengths and installed in concreted 3.2 ft (1000 mm) long sleeves for the 12 ft x 3 in. 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

Strongly recommended in areas with wildlife capable of digging under the fence (e.g., bears, canids, badgers, wild boar). As illustrated in Figure 65, 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 consist of a 4-5 ft (1-1.2 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 3.5 ft (1.1 m) below ground. Swing gates should have a concrete base to discourage digging under them as shown in Figure 66.



Figure 65. Photo. Wildlife exclusion fence with buried apron (Credit: Tony Clevenger).



Figure 66. Photo. Concrete base of swing gate to prevent animal digging under wildlife fence (Credit: Tony Clevenger).

Cable (protective)

Trees blown onto fences can not only damage fence material but provide openings for wildlife to enter the right-of-way. Typically a problem the initial years after construction, but can continue over time. A high-tensile cable shown in Figure 67 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.



Figure 67. Photo. High tensile cable designed to break fall of trees onto fence material (Credit: Tony Clevenger).

TERMINATIONS

Fence ends are notorious locations for wildlife movements across roads and 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.
- Areas with regular human activity and disturbance.

Another consideration is motorist visibility and speed at fence ends. Fences should end on straight sections of highway with good motorist visibility. Lighting at fence ends may improve motorist visibility and actually enhance road crossings by ungulate species; however, it may deter movement by wary carnivore species. Regardless of the situation, proper signage as Figure 68 shows must be installed to warn motorists of potential wildlife activity and crossings at fence ends.



Figure 68. Photo. Warning signage at end of wildlife exclusion fence (Credit: Tony Clevenger).

Because fence ends create a hazardous situation for motorist and wildlife, it is important to discourage wildlife movement towards fence ends. Having wildlife locate and use wildlife crossings as soon as possible after construction is the best recommendation to discourage end-runs. Cutting trails to wildlife crossings, baiting or use of attractants should help direct wildlife to crossings and hasten the adaptation process.

DIMENSIONS - GENERAL GUIDELINES

Highway fencing for large mammals, including most native ungulate species of Moose, Elk, Deer, Bighorn Sheep, should be a minimum of 8.0 ft (2.4 m) high with post separation on average every 14-18 ft (4.2-5.4 m). In some cases the fence height may not need to be designed for large ungulates. Alternate fence design and specifications will need to consider not only fence requirements for species present, but also species that may potentially recolonize or disperse into the area in the future.

POSSIBLE VARIATIONS

Boulders/terrain

Boulders as a substitute for wildlife fencing has not proved to be effective; however, boulder fields or aprons have been used to effectively discourage wildlife entering the highway right-of-way at fence ends. The boulder apron is positioned on both road shoulders and at the ends of fence (and median for four-lane highway) and can range from 165-325 ft (50-100 m) long (along roadway). The shoulder aprons vary in width from about 25-65 ft (8-20 m), depending on how close the fence is positioned to the roadway - the boulders must extend right from the edge of pavement up to the fence to preclude any path for wildlife to skirt the boulders. Boulder aprons are made of subangular, quarried rock, ranging in size from 10-25 in (20-60 cm), however most should be larger than 12 in (30 cm). The boulder apron, at a depth of about 16-20 in (40-50 cm), is installed on geofabric on sub-excavated smoothed ground. The boulders project about 10-12 in (20-30 cm) above local ground surface as shown in Figure 69.

Reduced fence height

Lower than average fence height may be prescribed where there are commercial or residential concerns of visual effects and aesthetics of fencing. Reducing the fence height (e.g., 6 ft [1.8 m]) with respect to the adjacent area by running the fence through a lowered or depressed area will make the fence appear lower and less obtrusive. Planting shrubs and low trees in front of the fence will also help the fence blend into the landscape.

Outriggers/overhangs

Although never formally tested, outriggers or fence overhangs could potentially discourage wildlife (bears, cat species) from climbing fences and reaching the right-of-way.



Figure 69. Photo. Boulder field at end of wildlife fence (Credit: Tony Clevenger).

Barbed wire overhangs

Similar to outriggers and fence overhangs, barbed wire overhangs are commonly used in urban areas to keep people out of areas. Overhangs of this type are found on Interstate-75 in Florida and have apparently been effective in keeping panthers and black bears from climbing the fence.

Gap below fence material for Pronghorn

The movement and migration of Pronghorn is affected by the network of fences they need to negotiate to meet their biological needs. Although not particular to wildlife fencing for wildlife crossing structures, it is worth noting that standard 4 ft (1.1 m) high road-side fencing, typically of barbed-wire, can be modified to improve Pronghorn movement. Pronghorn do not jump over fences, even 4 ft (1.1 m) fences, but generally try to crawl underneath. Transportation agencies have had success in getting Pronghorn to move through their preferred crossing areas by removing the bottom strand of barbed-wire.

MAINTENANCE

Fences 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 cause continually occurring damage and threaten the integrity of the fence: soil erosion, excavation by animals, and flooding can loosen fence posts and collapse portions of fence.

Fences must be checked every 6 months by walking entire fence line, identifying gaps, breaks and other defects caused by natural and non-natural events.

HOT SHEET 13: FENCING – SMALL AND MEDIUM VERTEBRATES

GENERAL PURPOSE

Most fencing for large mammals (see Hot Sheet 12) does not impede movement by small and medium sized mammals. These smaller mammals need a denser mesh fence material to keep them from entering the right-of-way. Fence design specifications for amphibians and reptiles are covered in Hot Sheet 11. Some small and medium-sized mammals are able to climb or dig under fence material, thus requiring a specific design in order to work effectively.

APPLICATION

- Generally recommended on sections of highway where high rates of mortality occur (or are predicted to occur) for one particular species.
- Designed to meet site- and species-specific needs of preventing animal movement through large mammal fences. Fencing should not be extensive, otherwise movements of non-target small mammals will be affected and populations will become isolated.
- Fencing for small and medium-sized mammals is joined to existing large mammal fencing (or installed simultaneously) and placed at ground level, shown in Figure 70. Fencing should be placed on the outside of the large mammal fence (non-highway side) and fastened to the large mammal fence material.
- Fencing for small and medium-sized mammals should always be used in conjunction with wildlife crossing structures designed for their specific use.



Figure 70. Photo. Small and medium-sized mammal fence material spliced to large mammal fence material (Credit: Nancy Newhouse).

SUGGESTED DESIGN DETAILS

Installation

- Fence material should be buried below ground 6-10 in (15-20 cm).
- Where fencing meets tunnels or other wildlife crossing structures it is advisable that fence material is well connected to the wing walls or sides of the structures, not allowing any gaps where they meet.
- Where fences meet drainage culverts they should either pass above or integrate the culvert into the fence.

Mesh types and sizes

- Fence material generally consists of hardware cloth or welded wire-mesh. The wire mesh comes in a variety of mesh sizes, colors and coatings to meet specific needs of each target species and objective.
- The standard mesh size is ½ in (1 cm), although larger mesh may be used for larger target species.
- The top 2-3 in (4-6 cm) of fence material should be doubled-back away from the highway at a 45-degree angle to discourage animals from climbing over the fence.

Dimensions

- The standard height of fencing is 2 ft (0.6 m) above the ground. This height can be adjusted depending on the target species and project objectives. For example, 16 in (40 cm) above the ground is sufficient for desert tortoises.

POSSIBLE VARIATIONS

For adept climbers (mink, weasels, martens) fences should be constructed at least 4 ft (1.2 m) high, ½-1 in (1-2 cm) welded wire mesh. The top portion should be 6-10 in (15-25 cm) in length and doubled-back away from the large mammal fence material in outrigger fashion.

MAINTENANCE

- Fences 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 cause continually occurring damage and threaten the integrity of the fence: soil erosion, excavation by animals, and flooding can loosen fence posts and collapse portions of fence.
- Fences must be checked every 6 months by walking entire fence line, identifying gaps, breaks and other defects caused by natural and non-natural events.

HOT SHEET 14: GATES AND RAMPS**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, hinged metal door or earthen ramp (or “jump-out”) as Figure 71 shows. A low cost way to provide escape is to lay natural objects (tree trunks or limbs) against the fence. The number, type and location of escape structures will depend on the target species, terrain and habitat adjacent to the highway fence.



Figure 71. Photo. Escape ramp (jump-out) for wildlife trapped inside highway right-of-way (Credit: Tony Clevenger).

APPLICATION**Swing gates**

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 illustrated in Figure 72. 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) as smaller wildlife can escape by hinged doors at ground level (see below) or through large mammal fence material.



Figure 72. Photo. Single swing gate in wildlife exclusion fence (Credit: Tony Clevenger).

Earthen ramps or jump-outs

Earthen ramps or jump-outs allow wildlife (large and small) to safely exit right-of-ways on their own without aid of wardens or rangers. Typically wildlife find the ramps and exit by jumping down to the opposite side of fence shown in Figure 73. 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 access 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 set-back 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.



Figure 73. Photo. Wildlife escape ramp (jump-out; Credit: Tony Clevenger).

Small hinged doors

For small- and medium-sized mammals, natural objects (for climbing species) or small, hinged doors at ground level as shown in Figure 74 allow them to escape the right-of-way on their own.

Natural objects

Natural objects can be used simply, and cost-effectively to help small and medium-sized mammals exit the right-of-way. Stacking of brush and woody debris against the fence line and to fence height will allow climbers to exit safely.

Like fences, escape structures need to be carefully planned for the wildlife they are targeted, their location, design and maintenance over time.

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 perform when needed. Maintenance checks should take place at the same time as fence inspections (see Hot Sheets 12 and 13).



Figure 74. Photo. Hinged door for escape of medium-sized mammals (Credit: Tony Clevenger).

APPENDIX D – FRAMEWORK FOR MONITORING

Framework for evaluating the performance of measures designed to reduce wildlife–vehicle collisions and barrier effects of roads on wildlife movement. Numbers for monitoring questions relate to one another across columns. Black text = Monitoring generally associated with highway corridor; Blue text = Monitoring and research needed to answer management questions from the project area at the landscape scale.

MONITORING OBJECTIVES	Monitoring question	Methods	Study design	Targets
<p>WILDLIFE–VEHICLE COLLISION REDUCTION (PRE- AND POST-CONSTRUCTION)</p>	<p>1. Do crossing structures reduce mortality rates? 1.a. Compared to baseline levels of road mortality; 1.b. Compared to adjacent “control” areas post-construction; 2. Compared to other sections of highway without crossing structures 3. What is the incidence of mortality among a marked sample? [Addressing this question will require large sample sizes and representative sampling of population]</p>	<p>Road-kill data collection: 1 & 2. Road-kill surveys on highway sections with and without crossing structures. Surveys must be extensive in length (see Feldhamer et al. 1986) and systematically conducted at frequent intervals Radiotelemetry: 3. Standard capture-mark-release techniques. Transmitters may consist of VHF transmitters or global positioning system (GPS) transmitters with the latter providing more spatial accuracy in identifying how and where animals cross highways.</p>	<p>Road-kill data collection: 1.a. (1) Pre- vs post-construction comparison of mortality rates on “treatment” areas (crossing structures) with “controls” (BA¹ design) 1.a. (2) Pre- vs post-construction comparison of mortality rates on “treatment” areas (crossing structures) and those without “controls (BA¹ design)” 1.b. Post-construction comparison of mortality rates using “treatment” (crossing structures) sections vs. adjacent sections without crossing structures (CI¹ design) 2.a. Multivariate logistic regression analysis 2.b. Comparison of mortality rates on sections with and without crossing structures, standardized by highway length Radiotelemetry: 3. Proportion of marked sample killed on highway compared to control sections</p>	<p>1 & 2. Reduction in mortality rates compared with baseline conditions (i.e., without crossing structures). Reductions should either be statistically significant or deemed biologically meaningful. 3. Significant (statistical or biological) proportion of the marked sample survives and reproduces in highway environment with crossing structures.</p>

APPENDIX D – FRAMEWORK FOR MONITORING

MONITORING OBJECTIVES	Monitoring question	Methods	Study design	Targets
<p>RESTORING MOVEMENTS IN PROJECT AREA (PRE- AND POST-CONSTRUCTION)</p>	<ol style="list-style-type: none"> 1. What is the frequency of movement across highway with crossing structures and without? 2. What factors influence crossing activity? 3. Do animals cross above-grade or use existing below-grade structures? 4. Where do animals cross the highway 5. What is the genetic structure of focal populations and what are barriers to gene flow? 6. Is the demographic structure of focal population affected by the highway? 	<p>Telemetry (radio or GPS): 1.2.3.4. (See above)</p> <p>Observational data: 3 & 4a. Remote cameras that detect and record animal activity in highway environment over 24-hr period. Remote digital 35mm or video cameras installed on preferably straight and level sections of highway. Some video cameras detect and record animal activity on sections up to 1.0 mile in length 3 & 4b. Trackpads on right-of-way (Hardy et al. 2007) 3 & 4c. Fluorescent dye marking. Method allows for follow-up “tracking” of small animal using ultraviolet light at night (McDonald and Cassidy St Clair 2004)</p> <p>5. Non-invasive genetic sampling methods (e.g., hair snares, scat dogs) 5a/5b. Genetic sampling and genotyping; assignment tests and other spatial genetics modeling approaches 5c. Genetic sampling and genotyping; genetic health analyses (inbreeding, allelic diversity, heterozygosity values);</p>	<p>Telemetry: 1. Frequency of radio-marked animal movements across highway sections using treatment/control; BACI & CI designs or treatment; BA design 2. Frequency of radio-marked animal movements across highway related to traffic volumes and time of day 3 & 4. Radio monitor closely movements in highway environment and existing below-grade passage structures</p> <p>Observational data: 5. Non-invasive genetic sampling surveys on established survey points or transects in study area. 5a/5b. Model (based on maternally inherited mitochondrial markers) landscape resistance that correlate with the genetic structure of the target species 5c. Compare the genetic diversity of treatment (highway) populations to control populations (that are stable or declining)</p>	<ol style="list-style-type: none"> 1. Greater number of marked individual movements occur on treatment sections (crossing structures) 2. Traffic volume, intra-group behavior and time of day may help explain movement behavior and crossing success 3 & 4. Significant (statistically or biologically) greater number of individual movements of radio marked individuals occur on treatment sections (wildlife crossing structures) 4. Greater number of observed crossings occur on treatment sections (crossing structures) compared to control sections 5a. Landscape resistance models will identify both barriers to dispersal and corridors for gene flow (pre- and post-construction) 5b. Distinguish exploratory movements from the successful reproduction and reveal the resistance of a landscape to gene flow 5c. Reveal whether genetic variability has reached critically low levels

APPENDIX D – FRAMEWORK FOR MONITORING

MONITORING OBJECTIVES	Monitoring question	Methods	Study design	Targets (Applications)
POPULATION VIABILITY (POST-CONSTRUCTION)	Do project connectivity measures affect key life-history attributes (e.g., mortality, fertility, survival to reproduction, connectivity) and provide for natural sustaining populations in the project area?	<u>Spatially-explicit population viability modeling:</u> Development of spatially-explicit, individually-based population viability (PV) models using demography data and habitat data collected for other project objectives or obtained from the scientific literature. Use of custom or commercially available PV modeling software (e.g., RAMAS-GIS). Robust demography and spatially-explicit landscape suitability information will be required for such an approach.	<u>Spatially-explicit population viability modeling:</u> Modeling of PV under (a) baseline conditions, (b) highway without wildlife crossings, (c) highway with wildlife crossings	<u>Spatially-explicit population viability modeling:</u> Determination of the mean and variation of demographic parameters necessary to maintain viable populations over the long term; provides different modeling scenarios by varying performance targets, refining target parameters and creating new monitoring questions based on predictions, and future PV models

MONITORING OBJECTIVES	Management question	Methods	Study design	Targets
FENCE INTRUSIONS (POST-CONSTRUCTION)	1. How often do individual animals breach the fence and access the right-of-way? 2. Where do fence intrusions occur, for what species, and how frequently?	<u>Observational data:</u> 1 & 2. Road surveys or opportunistic observations of wildlife inside the highway fence. Can be conducted by both WTI researchers or DOT personnel using PDA/GPS (ROCS ²) units	<u>Observational data:</u> 1 & 2. Summary of fence intrusion data by species, frequency, and location	1. Minimize number of fence intrusions by wildlife 2. Evaluate effectiveness of fence construction and design at various points in study area, including effects of physical and biological factors (e.g., terrain, habitat, snowfall) on intrusion frequency
JUMP-OUTS (POST-CONSTRUCTION)	1. When wildlife breach the fence and access the right-of-way, do they find the jump-outs? (see “fence intrusions”) Of those that visit the jump-out, what proportion exit the right-of-way by using the jump-out? 2. What species visit the jump-outs, how frequently, and how often are they successfully used?	<u>Observational data:</u> 1 & 2. Systematic visits to jump-outs when monitoring wildlife use of crossings. Can be conducted by both WTI researchers or DOT personnel using PDA/GPS (ROCS ²) units	<u>Observational data:</u> 1 & 2. Summary of jump-out visits and use data, by species, frequency, and jump-out location	1. Minimize the number of wildlife visits to jump-outs (see “fence intrusions”) 2. Maximize the use of jump-outs for safe exit from the highway right-of-way

APPENDIX D – FRAMEWORK FOR MONITORING

MONITORING OBJECTIVES	Management question	Methods	Study design	Targets
<p>WILDLIFE CROSSING DESIGN (POST-CONSTRUCTION)</p>	<p>1. Are animals crossing highway using existing below-grade structures (culverts)?</p> <p>2. Do animals use the wildlife crossing structures? With what frequency?</p> <p>3. What are the attributes of existing below-grade structures and wildlife crossings that influence species-specific passage?</p>	<p>Observational data: 1 & 2. Noninvasive detection methods (e.g., track beds, track plates, hair snares, remote cameras) to quantify species-specific use.</p> <p>3a. Detection stations and/or transects</p> <p>3b. Data summary; multivariate analysis; occupancy modeling</p>	<p>Observational data: 1 & 2. Employ non-invasive survey methods with sufficient ability to detect species with high probability.</p> <p>3. Develop species-specific expected use values for calculating performance indices</p>	<p>1. Level of connectivity afforded by existing below-grade structures</p> <p>2. Level of connectivity afforded by wildlife crossings</p> <p>3a/3b. Data on species-specific design requirements of below-grade structures (culverts) and wildlife crossings</p> <p>3c. Adaptive management of future connectivity design plans</p>
<p>SPECIES OCCUPANCY (project-level) (PRE- AND POST-CONSTRUCTION)</p>	<p>1. What species are present - absent in the highway corridor project area?</p> <p>2. How are species’ distributed and what are their relative abundances? How do distribution and relative abundance change over time?</p> <p>3. Can species occupancy models be developed to accurately predict occurrence in subregions of the project area?</p>	<p>Species detection surveys: 1. 2. 3. Species occupancy methodology. Detection stations and transects located at project-level</p> <p>1a 2a 3a. Non-invasive detection methods (e.g., track plates, hair snares, remote cameras, scat detection dogs)</p> <p>3. Species occupancy modeling</p>	<p>Species detection surveys: 1. 2. 3. Fixed system of survey points-transects in highway corridor and adjacent habitats. Repeat monitoring within a relatively short time period (e.g., 10-14 d) to ensure demographic closure. Conduct surveys 1-3 times each year (season?) over long-term.</p>	<p>1. Assess species presence-absence or use of project area</p> <p>2. Evaluate (a) which species are present in project area and, (b) site colonization and extinction estimates if multiple-year datasets are compiled</p> <p>3. Occupancy assessment provides (a) information related to “expected” use of wildlife crossings and more accurate performance indices for design-related analysis; (b) species occurrence probability surfaces</p>

APPENDIX D – FRAMEWORK FOR MONITORING

MONITORING OBJECTIVES	Research question	Methods	Study design	Targets
<p>SPECIES OCCUPANCY (landscape-level) (PRE- AND POST-CONSTRUCTION)</p>	<p>1. What species are present - absent in the greater project area? 2. How are species’ distributed and what are their relative abundances? How do distribution and relative abundance change over time? 3. Can species occupancy models be developed to accurately predict occurrence across the greater project area?</p>	<p>Species detection surveys: 1. 2. 3. Species occupancy methodology. Detection stations and transects located at landscape-level 1a 2a 3a. Non-invasive detection methods (e.g., track plates, hair snares, remote cameras, scat detection dogs) 3. Species occupancy modeling</p>	<p>Species detection surveys: 1. 2. 3. Fixed system of survey points-transects in study area. Repeat monitoring within a relatively short time period (e.g., 10-14 d) to ensure demographic closure. Conduct surveys 1-3 times each year (season?) over long-term.</p>	<p>1. Assess species presence-absence or use of greater study area 2. Evaluate (a) which species are present in greater study area and, (b) Site colonization and extinction estimates if multiple-year datasets are compiled 3. Occupancy assessment provides (a) information related to “expected” use of wildlife crossings and more accurate performance indices for design-related analysis; (b) species occurrence probability surfaces</p>

¹ BACI: Before-After-Control-Impact; BA: Before-After; CI: Control-Impact (see Roedenbeck et al. 2007).

² ROCS: See description in Chapter 3.

APPENDIX E – MONITORING TECHNIQUES**REMOTE DIGITAL STILL OR VIDEO CAMERAS**

Digital still cameras or video cameras equipped with infrared sensors record images of wildlife entering, within, or exiting crossing structures. These “passive-type” sensors detect moving warm objects and can be set to only detect species larger than a predefined threshold size. Such cameras can be deployed outside of culverts attached to trees or posts as shown in Figure 75 or attached directly to culvert walls. Newer generation cameras are weatherproof, can be operated in all seasons, and can record an almost limitless number of images. Video versions provide information on crossing behavior (e.g., degree of animal willingness to cross, speed of crossing), and some still models can also be set to capture multiple photos in a rapid burst, providing some information on crossing behavior.



Figure 75. Photo. Remote digital infrared-operated camera (Credit: Tony Clevenger/WTI).

Benefits

Unambiguous species identification; low labor cost; can be deployed during all seasons and in locations with running water; some (limited in North America) potential for differentiating individuals; permanent record; photos valuable for outreach to public.

Constraints

Low ability to detect all sizes of species—most effective for medium to large species; risk of theft; high initial cost.

Estimated Cost

High initial cost (but lower labor cost during surveys) of \$550-\$800 per camera (including protective, theft-resistant box and data cards).

Applications

Assess use/effectiveness of wildlife crossing structures (existing and proposed)

- Assess rate of wildlife at grade highway crossings (cameras deployed randomly)
- Assess rate of wildlife, at grade, highway crossings (cameras deployed at targeted locations)
- Monitor wildlife use of locations throughout and adjacent to the project area (cameras deployed at scent stations)
- Evaluate effectiveness of jump-outs (cameras deployed on top of jump-outs).

REMOTE DIGITAL STILL OR VIDEO CAMERAS DEPLOYED SPECIFICALLY FOR EVALUATING AT GRADE, WILDLIFE HIGHWAY CROSSINGS

Remote cameras can also be deployed along roadsides with “active-type” sensors composed of “break the beam” components. When an animal approaching the side of the highway breaks the beam between two sensors, a photo is taken or a video camera is turned on. Sensors can be separated by up to 100 ft, can be combined to monitor longer stretches, and can be set-up to fire multiple still cameras.

Benefits

Unambiguous species identification; low labor cost; permanent record; photos/video valuable for outreach to public.

Constraints

High level of complexity with setup and untested for this purpose; likely difficulty in discerning species at greater distances from camera location; low ability to detect all sizes of species—most effective for larger species; only detects crossing attempts, not successful crossings; risk of theft; high initial cost.

Estimated Cost

High initial cost (but lower labor cost during surveys) of \$1000-\$2000 per 200 ft stretch of road (including protective, theft-resistant box and data cards).

Applications

- Assess rate of at grade, wildlife highway crossings (cameras deployed randomly)
- Assess rate of at grade, wildlife highway crossings (cameras deployed at targeted locations).

TRACK BEDS

Track beds are constructed from a mixture of sand and silt deposited in a linear bed (typically about 2 yards in width) across culvert entrances or within the culvert itself as Figure 76 shows. Such beds are raked smooth and are generally checked every three to four days for tracks that indicate animal crossings: species, direction of travel, number of individuals, etc.



Figure 76. Photo. Raking of track bed in culvert Banff National Park, Alberta (Credit: Tony Clevenger/WTI).

Benefits

Detect wide-variety of animal sizes (but generally coyote-size and larger); can provide back-up in case remote camera malfunctions or is stolen; relatively low up-front cost; Generally not

affected by weather events that may obliterate tracks if structure is covered (e.g., underpass or culvert).

Constraints

Unable to deploy at locations with running water unless natural banks or engineered pathways are constructed in structures; occasionally problems with species identification; trampling of tracks (i.e., many overlapping tracks) can make interpretation difficult if not checked regularly; difficult to confirm that an individual animal passed completely through the structure or simply crossed the bed and returned.

Estimated Cost

Low cost (field vehicle and labor cost during surveys for personnel to check track pads regularly); personnel costs: \$1300 for one month of monitoring @ 10 days of work per month @ \$130/day [\$16/hr]; low equipment costs: rake, personal data assistant (PDA), digital camera, tape measure, field guide to animal tracks.

Applications

- Assess use/effectiveness of wildlife crossing structures (existing and proposed)
- Monitor wildlife use of locations throughout and adjacent to the project area (beds deployed as round “plots” and used in conjunction with a bait or scent lure)
- Evaluate effectiveness of jump-outs (beds deployed on top and around the base of jump-outs).

TRACK BEDS DEPLOYED SPECIFICALLY FOR EVALUATING AT GRADE, WILDLIFE HIGHWAY CROSSINGS

Track beds can also be deployed along highway shoulders or in medians, providing a means to detect animals approaching the side of the highway or in the median.

Benefits

Detect wide variety of large mammals; can provide back-up in case remote camera malfunctions or is stolen;

Constraints

Unable to deploy at locations with little or no shoulder, where shoulder is steep or inundated with water, where shoulder is mostly vegetation, or in locations where monitoring and maintenance would be a safety risk to personnel; ambiguous species identification common; tracks cannot easily be collected and reviewed later; over-tracking (i.e., many overlapping tracks) can make interpretation difficult; difficult to confirm that animals leaving tracks actually attempted to cross highway or had simply crossed the bed and returned; only detects crossing

attempts, not successful crossings; installation requires heavy machinery and coordination with Department of Transportation; high labor cost (must be maintained frequently).

Estimated Cost

High initial cost: \$350–\$400 for materials and installation of one 100 ft bed (depends largely on access to sand and machinery); low operational cost: labor cost to conduct surveys=\$1300 for one month of monitoring @ 10 days of work per month @ \$130/day [\$16/hr]; low equipment costs: rake, PDA, digital camera, tape measure, field guide to animal tracks (same as “track bed” monitoring above).

Applications

- Assess rate of at grade, highway wildlife crossings (cameras deployed randomly)
- Assess rate of at grade, highway wildlife crossings (cameras deployed at targeted locations).

UNENCLOSED TRACK PLATES

A metal plate covered partially with a thin layer of soot and then a section of light-colored contact paper with the sticky side up. Animals crossing the plate first walk over soot and then track the soot on the contact paper, leaving a print as captured in Figure 77. Plates are checked for prints every five to seven days and soot/paper is replaced. Contact paper with prints is removed and stored in plastic page protector.



Figure 77. Photo. Sooted track plate with tracks of small and medium-sized mammals (Credit: Robert Long/WTI).

Benefits

Detect wide-variety of animal sizes; provides a high-resolution print that makes identification of species likely; print can be collected, reviewed later, and stored indefinitely; low initial cost.

Constraints

Unable to deploy at locations with running water; difficult to deploy effectively in wide structures (>6 ft); must be deployed under cover or in very dry climate conditions.

Estimated Cost

Low up-front cost (but labor cost during surveys); \$200 for materials; \$800 for one month of monitoring (6 days of work per month @ \$16/hr).

Applications

- Assess use/effectiveness of smaller wildlife crossing structures (existing and proposed)
- Monitor wildlife use of locations throughout and adjacent to the project area (used in conjunction with a bait or scent lure).

ENCLOSED TRACK PLATES

Similar to an unenclosed track plate (Figure E-3) but where the metal plate is typically smaller and inserted (with soot and contact paper) into a rectangular or triangular enclosure. Enclosed plates permit deployment in light rain or snow and can also be fitted with hair collection devices.

Benefits

Readily used by many smaller species (e.g., fisher, marten, raccoon, and smaller); provides a high-resolution print that makes identification of species likely; print can be collected, reviewed later, and stored indefinitely; ability to incorporate hair collection devices; protected from some weather; low up-front cost.

Constraints

Unable to deploy at locations with running water; limited to small species; can only be deployed in very small structures unless used with bait or scent lures.

Estimated Cost

Low up-front cost (but labor cost during surveys); \$200 for materials; \$800 for one month of monitoring (6 days of work per month @ \$16/hr).

Applications

- Assess use/effectiveness of smaller wildlife crossing structures (existing and proposed)
- Monitor wildlife use of locations throughout and adjacent to the project area (used in conjunction with a bait or scent lure).

HAIR COLLECTION DEVICES WITH DNA METHODS

Various hair collection devices are available and selection typically depends on species of interest and specific objectives. Most hair collection at crossing structures is conducted via two barbed-wire strands stretched across the mouth of the structure at heights appropriate for the target species of interest as sketched in Figure 78.

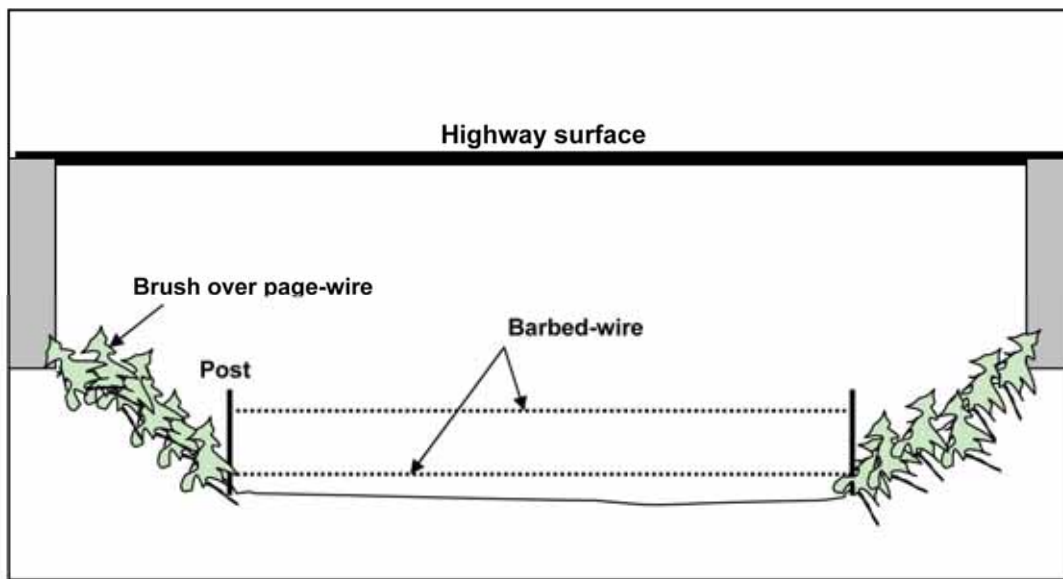


Figure 78. Schematic. Diagram of hair-snagging system at a wildlife underpass used in DNA-based research of population-level benefits of crossing structures (Source: Tony Clevenger/WTI).

Animals using the crossing structure are forced to slide under or between the wires, or step over the top wire, and in the process leave tufts of snagged hair on one or more barbs as Figure 79 shows. If enclosed track plates are used for small and medium mammals, hair snagging devices can be installed that will collect hair in addition to prints. Other options for locating hair snares within or adjacent to crossing structures are available, but most would require a scent lure to entice animals to either rub or interact with a device.



Figure 79. Photo. Grizzly bear passing through hair-snagging device at wildlife overpass in Banff National Park, Alberta (Credit: Tony Clevenger/WTI).

Benefits

Provide both confirmation of animal presence and DNA sample for further analyses; low up-front cost and fairly low labor cost to maintain.

Constraints

Fairly species-specific; some DNA analyses can be relatively expensive; should be used in conjunction with track bed/plate or remote camera.

Estimated Cost

Depends on objectives—identifying a hair sample to species can cost from \$15–25, whereas more detailed DNA analyses (e.g., microsatellite analysis to identify individuals) can cost from \$50–\$120 per sample. In all cases, per-sample costs are highly dependent on the sample quality and specific lab.

Applications

- Assess use/effectiveness of wildlife crossing structures (existing and proposed)
- Monitor wildlife use of locations throughout and adjacent to the project area (used in conjunction with a bait or scent lure)

- Determine relatedness of individuals using crossing structures
- Determine whether numerous crossings are by the same individual or by many individuals.
- Collection of DNA samples for Tier 2 objectives.

TRAP, TAG, AND RECAPTURE/RESIGHT

Animals such as amphibians/reptiles and small mammals that are relatively easy to capture can be trapped or hand-captured and tagged as shown in Figure 80, on both sides of the highway. Subsequent capture efforts can permit the estimation of highway crossing rates.



Figure 80. Photo. Digital barcode tag for frogs (Source: Steve Wagner/CWU).

Benefits

Only effective method for monitoring some species (e.g., amphibians, reptiles, small mammals); direct confirmation that animals have successfully crossed highway; relatively low cost for some species.

Constraints

Difficult to confirm whether individuals are crossing at grade or through crossing structures; labor intensive; potential negative effects on captured/tagged individuals; typically results in few recaptures unless number of tagged individuals is very large.

Estimated Cost

Low to moderate, depending on species.

Applications

- Assess use/effectiveness of wildlife crossing structures (existing and proposed)
- Assess rate of at grade, wildlife highway crossings (in locations without crossing structures)
- Monitor wildlife use of locations throughout and adjacent to the project area

SNOW TRACK TRANSECTS

Snow tracking can be used to detect species that are active during winter. Snow tracking can be conducted while driving the road, traveling off-road parallel to and at close distances (e.g., within 150 ft) from the roadside, or on secondary roads or off-road transects away from the road.

Benefits

Fairly high effectiveness for detecting some species; easily tailored for use in many locations; low cost.

Constraints

Limited to locations with consistent snowfall; short time window to conduct surveys after each snowfall; difficult to schedule surveys; can be labor-intensive to collect substantial amounts of data during relatively few snowfalls (i.e., many personnel may be required to cover multiple transects within a short timeframe); difficult to confirm species unless track and snow conditions are ideal; tracks cannot easily be collected and reviewed later; traffic safety concerns when conducting road surveys;

Estimated Cost

Low to moderate; limited to cost of labor, one-time purchase of skis/snowshoes, and winter safety and avalanche training.

Applications

- Assess use/effectiveness of wildlife crossing structures (existing and proposed)
- Assess rate of at grade, wildlife highway crossings
- Monitor wildlife use of locations throughout and adjacent to the project area (used in conjunction with a bait or scent lure)

SCAT DETECTION DOGS WITH DNA METHODS

Professionally trained dogs can now be used to effectively and efficiently locate scats from target species. A single dog, working with a handler and an “orienteer,” as Figure 81 shows, typically searches a predefined transect or grid. Located scats are collected for DNA analysis.



Figure 81. Photo. Scat-detection dog working to locate scat (Credit: Robert Long/WTI).

Benefits

High degree of effectiveness and cost efficiency (i.e., cost per detection); does not require site preparation before survey; can be easily tailored to specific locations and can quickly adapt to changes in protocol; can be used in most conditions and on most types of topography; provides scat sample for multiple analyses (e.g., species and individual identification, diet, hormone analysis).

Constraints

High initial cost; substantial logistical issues; each dog limited to detecting a fairly discrete number of target species; in most cases requires DNA confirmation, or at least some DNA testing.

Estimated Cost

High up-front cost for training and dog leasing; actual cost depends largely on whether dogs are leased or purchased and whether handlers are hired professionals or are existing personnel that can be trained.

Applications

- Monitor wildlife use of locations throughout and adjacent to the project area
- Collection of DNA samples for Tier 2 objectives.

GPS COLLARING

Some species can be captured and fitted with collars containing a GPS tracking device. Very high-resolution data on movements are recorded and either remotely downloaded by researchers or, more often, downloaded after the collar has either been shed or recovered on recapture.

Benefits

Very high resolution data allows assessment of fine-scale movement and reaction to crossing structures; ability to collect additional data such as mortality and behavioral data; ability to collect information on genetics and demographic parameters of population if sample sizes are large.

Constraints

High initial cost and capture of animals is very labor intensive; substantial logistical issues; generally results in small sample sizes which may not be representative of populations; potential negative effects on captured/tagged individuals.

Estimated Cost

High initial cost for purchase of GPS collars and animal capture; actual cost depends on how long the collars stay on the animal; occasional malfunction of GPS transmitting and receiving system.

Applications

- Assess use/effectiveness of wildlife crossing structures (existing and proposed)
- Assess rate of at grade, wildlife highway crossings
- Monitor wildlife use of locations throughout and adjacent to the project area
- Evaluate effectiveness of wildlife fencing.

DOT MAINTENANCE CREW REPORTING

Data on road-killed wildlife are currently collected during regular work conducted by DOT highway crews. After highway construction is completed, maintenance crews would also be asked to collect data on fence condition and to report wildlife intrusions on the highway right-of-way. Data recording is facilitated by a Roadkill Observation Collection System (ROCS)—a combined PDA–GPS device shown in Figure 82. Regular contacts by monitoring personnel with road crews to emphasize the importance of collecting data will be important to ensure consistent survey effort.



Figure 82. Photo. Roadkill Observation Collection System (ROCS) (Credit: WTI).

Benefits

Can be tailored to include any species that can be recognized as either live or road-killed wildlife; DOT Maintenance crews are regularly traveling the highway and may receive direct reports of wildlife–vehicle collisions or carcasses.

Constraints

Method requires both spatially and temporally consistent survey effort by crews for data collected to be valid and useful for analyses.

Estimated Cost

Low - consisting of training DOT Maintenance crews to operate ROCS units and routine refresher training and meeting with crews to encourage regular use of ROCS units.

Applications

- Assess wildlife–vehicle collision rate
- Evaluate effectiveness of wildlife fencing

STATE PATROL REPORTING

Currently, in many states and provinces information on wildlife–vehicle collisions resulting in vehicle damage (>\$1000) is collected by State patrols and may also be requested from other agencies that collect such data.

Benefits

Effort is consistent and will likely remain so into the future; cost is relatively minimal; species monitored are limited; can be cross-referenced with DOT maintenance crew reports and monitoring personnel.

Constraints

Mortality data are limited to collisions with > \$1000 in property damage (generally Elk and Deer).

Estimated Cost

Negligible.

Applications

- Assess wildlife–vehicle collision rate
- Evaluate effectiveness of wildlife fencing

MONITORING PERSONNEL ROAD-KILL AND FENCE INTEGRITY SURVEYS

Monitoring personnel can collect information on wildlife–vehicle collisions during systematic drives through the project area (e.g., every 1-7 days). Fencing can be visually examined during regular course of work and field-examined twice per year by DOT maintenance crews and/or monitoring personnel.

Benefits

Provides spatially and temporally consistent effort that can be closely controlled; all species coyote-size and larger can be monitored.

Constraints

Relatively high rate of survey (e.g., daily or minimally twice per week) may be required to locate carcasses, especially of small animals; does not detect instances when animals are injured and die undetected at a later time, or where carcasses leave the roadway and are not seen; single drive through may provide little chance of detecting carcasses; limited number and distribution of safe-

stopping locations may make carcass identification impossible; slow required driving speeds often unsafe.

Estimated Cost

Low during seasons when other survey work is being conducted; moderate at other times.

Applications

- Assess wildlife–vehicle collision rate
- Evaluate effectiveness of wildlife fencing

APPENDIX F – OTHER HANDBOOKS AND GUIDELINES

UNITED STATES

Bissonette, J.B. 2007. Evaluation of the use and effectiveness of wildlife crossings. National Cooperative Highway Research Program (NCHRP) 25-27 final report. Transportation Research Board, Washington DC.

Huijser, M.P., J. Fuller, M.E. Wagner, A. Hardy, & A.P. Clevenger. 2007. Animal–vehicle collision data collection: a synthesis of highway practice. National Cooperative Highway Research Program Synthesis 370. Transportation Research Board, Washington, D.C.

Huijser, M.P., A. Kociolek, P. McGowen, A. Hardy, A.P. Clevenger, and R. Ament. 2007b. Wildlife–vehicle collision and crossing mitigation measures: A toolbox for the Montana Department of Transportation. Report no. FHWA/MT-07-002/8117-34. Helena, MT.

Huijser, M.P., P. McGowen, J. Fuller, A. Hardy, A. Kociolek, A.P. Clevenger, D. Smith and R. Ament. 2007. Wildlife–vehicle collision reduction study. Report to US Congress. U.S. Department of Transportation, Federal Highway Administration, Washington D.C.

Southern Rockies Ecosystem Project. No date. Safe passage: A users guide to developing effective highway crossings for carnivores and other wildlife. Southern Rockies Ecosystem Project, Denver, Colorado.

EUROPE

English Language

Iuell, B. (ed.). 2003. Wildlife and traffic: A European handbook for identifying conflicts and designing solutions. KNNV Publishers, Utrecht, The Netherlands.

Trocme, M. (ed.). 2003. Habitat fragmentation due to transportation infrastructure: The European review. European Commission, Directorate General for Research, COST Action 341. Publication EUR 20721. Luxembourg.

Other Languages

Ministerio de Medio Ambiente. 2006. Prescripciones tecnicas para el diseno de pasos de fauna y vallados perimetrales. Documentos para la reduccion de la fragmentacion de habitats causada por infraestructuras de transporte, numero 1. Ministerio de Medio Ambiente, Madrid, Spain.

Rosell, C. and Velasco Rivas, J. 1999. Manual de prevencio i correccio dels impactes de les infraestructures viaries sobre la fauna. Documents dels Quaderns de Medi Ambient, 4. Generalitat de Catalunya, Department de Medi Ambient. 95pp. Barcelona, Spain.

Service d'études sur les transport, les routes et leurs aménagements (SETRA) et Centre d'Etudes Technique de l'Équipement (CETE) 2006. Route et passage à faune. 40 ans d'évolution. Rapport. 57 p.

APPENDIX G – PROFESSIONAL AND TECHNICAL JOURNALS

GENERAL ROAD ECOLOGY

Biological Conservation
Canadian Journal of Civil Engineering
Conservation Biology
Earth Surface Processes and Landforms
Ecological Engineering
Ecology and Society (online)
Environmental Management
Journal of Applied Ecology
Journal of Environmental Management
Journal of Environmental Planning
Landscape Ecology
Landscape and Urban Planning
Transportation Research Record
Wildlife Biology
Wildlife Society Bulletin (now Journal of Wildlife Management)

TERRESTRIAL WILDLIFE

Biological Conservation
Canadian Journal of Zoology
Conservation Biology
Journal of Applied Ecology
Journal of Wildlife Management
Landscape Ecology
Landscape and Urban Planning
Transportation Research Record
Wildlife Biology
Wildlife Society Bulletin (now Journal of Wildlife Management)

TRAFFIC SAFETY

Accident Analysis and Prevention
Canadian Journal of Civil Engineering
Ecological Engineering
Ecology and Society (online)
Journal of Safety Research
Transportation Research Record
Wildlife Society Bulletin (now Journal of Wildlife Management)