

Best Practices Manual

Wildlife Vehicle Collision Reduction Study

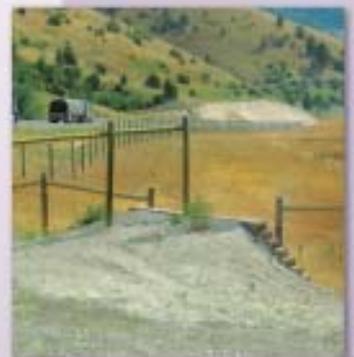
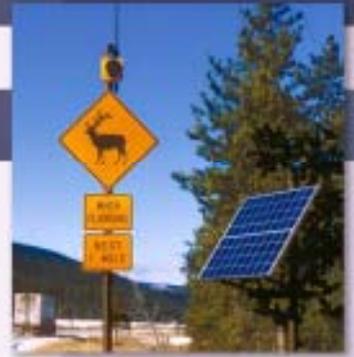
Report to Congress

October 2008



U.S. Department of Transportation
Federal Highway Administration

Making America's Highways Safer for Drivers and Wildlife



Foreword

America's highways allow people and products to travel to every corner of our nation. Along the way, these roads cut across the habitat of many native wildlife species. When these paths cross, collisions can occur, and in greater numbers than most people realize. Collisions present a real threat to human safety as well as wildlife survival. State and local transportation agencies are looking for ways to balance travel needs, human safety, and wildlife conservation.

A national study completed and submitted to the U.S. Congress in November, 2007, detailed the causes and impacts of wildlife-vehicle collisions and identified potential solutions to this growing safety problem. The Report to Congress focused on tools, methods, and other measures that reduce the number of collisions between vehicles and large wildlife, such as deer, because these accidents present the greatest safety danger to travelers and cause the most damage.

This document builds on the information in the Report to Congress to provide a best-practices manual for practitioners responsible for addressing this problem.

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16. Abstract Under the SAFETEA-LU Congressional Bill, the Secretary of Transportation was directed to conduct a national wildlife-vehicle collision (WVC) reduction study. The study was to advance the understanding of the causes and impacts of WVCs and identify solutions to this growing safety problem. A report was submitted to congress in November 2007. This document builds on that report providing a best practices manual for reducing wildlife-vehicle collisions. Design and implementation guidelines are provided for wildlife fencing, wildlife underpasses and overpasses, animal detection systems, vegetation management and wildlife culling. Additionally for a WVC reduction program, information is provided on regional planning, identification of priority areas, alignment and design considerations, guidelines for monitoring effectiveness of mitigations, and potential funding sources.			
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Metric Conversion Table

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

This handbook provides practitioners with information on the best tools currently available to reduce wildlife–vehicle collisions (WVCs). The manual covers the complete range of strategies for reducing WVCs from statewide and regional planning all the way through site-specific mitigations. The major elements of a WVC reduction program are summarized graphically in figure 1, with the corresponding chapters in which they are covered.

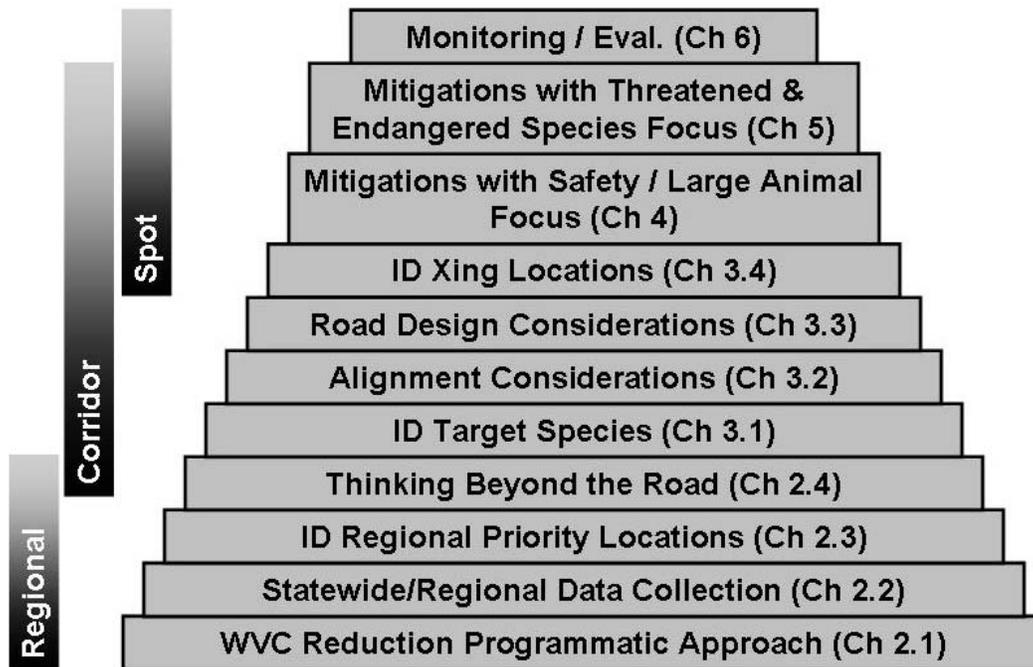


Figure 1. Strategies for reducing WVCs.

1.1. THE CHALLENGE

Reducing WVCs continues to be a significant challenge for the transportation community.

- An estimated one to two million collisions between cars and large animals occur every year in the United States.
- The number of WVCs is steadily increasing.
- Not only are WVCs a human safety threat, but 21 Federally listed threatened or endangered animal species in the United States have been documented as species for which road mortality is a major threat to survival.

Wildlife–vehicle collisions occur:

- Most often on rural two-lane, low-volume roadways.
- Almost all are single-vehicle crashes.
- Most often in the early morning or evening and in the fall or spring, and deer are the most common reported large animal involved.

For a more detailed overview of the WVC challenge refer to the WVC Reduction Study: Report to Congress.⁽¹⁾

1.2. OTHER SOURCES OF INFORMATION

Many other resources are referenced throughout this manual. Some of the key resources that provide information about mitigating WVCs include:

- Report: Wildlife–Vehicle Collision Study for Congress.⁽¹⁾
- Website: Deer–Vehicle Crash Information Clearinghouse: <http://www.deercrash.com>.
- Website: Keeping It Simple toolkit
<http://www.fhwa.dot.gov/environment/wildlifeprotection/index.cfm>.
- Critter Crossings <http://www.fhwa.dot.gov/environment/wildlifecrossings/index.htm>.
- Report: Habitat Fragmentation due to Transportation Infrastructure. Wildlife and traffic: a European handbook for identifying conflicts and designing solutions (COST Action 341).⁽²⁾
- Book: Road ecology science and solutions.⁽³⁾
- Report: Guidelines for Designing and Evaluating North American Wildlife Crossing Systems.⁽⁴⁾

1.3. OVERVIEW OF MANUAL CONTENT

The solutions presented in this manual primarily focus on WVCs involving species that pose a substantial safety risk (e.g., larger species such as deer, elk and moose). Additionally, the manual provides discussion of mitigation measures for threatened and endangered species—animals whose very survival is threatened by these highway collisions.

This manual is organized in chapters that are briefly described below. The marginal tabs are included for quick reference.

- Chapter 1 (this chapter) provides an introduction to the WVC challenge and a roadmap of the manual's contents. 1

- Chapter 2 provides regional and statewide tools important to a WVC reduction program, specifically for statewide data collection and identifying regional priority locations. 2

- Chapter 3 provides guidance on incorporating WVC reduction into roadway design by considering alternate alignments, possible adjustments in elements of highway design, and identifying crossing locations for mitigations. 3

- Chapter 4 provides guidance on the best management practices for reducing WVCs involving large animals. 4

- Chapter 5 provides guidance on the best management practices for reducing WVCs involving threatened and endangered species. 5

- Chapter 6 provides guidance for monitoring and evaluating WVC mitigations. 6

- Chapter 7 identifies potential funding sources for a WVC reduction program. 7

- Chapter 8 includes a checklist for implementing a WVC reduction program. 8

CHAPTER 2: STATEWIDE/REGIONAL PLANNING APPROACH AND DATA NEEDS

Efforts to substantially reduce WVCs would be best built on a foundation of statewide or regional planning (figure 2). This chapter provides a broad overview of planning efforts and data needs aimed at WVC reduction. Conducting statewide/regional data collection programs (section 2.2) and identifying regional priority areas (section 2.3) are discussed in detail.

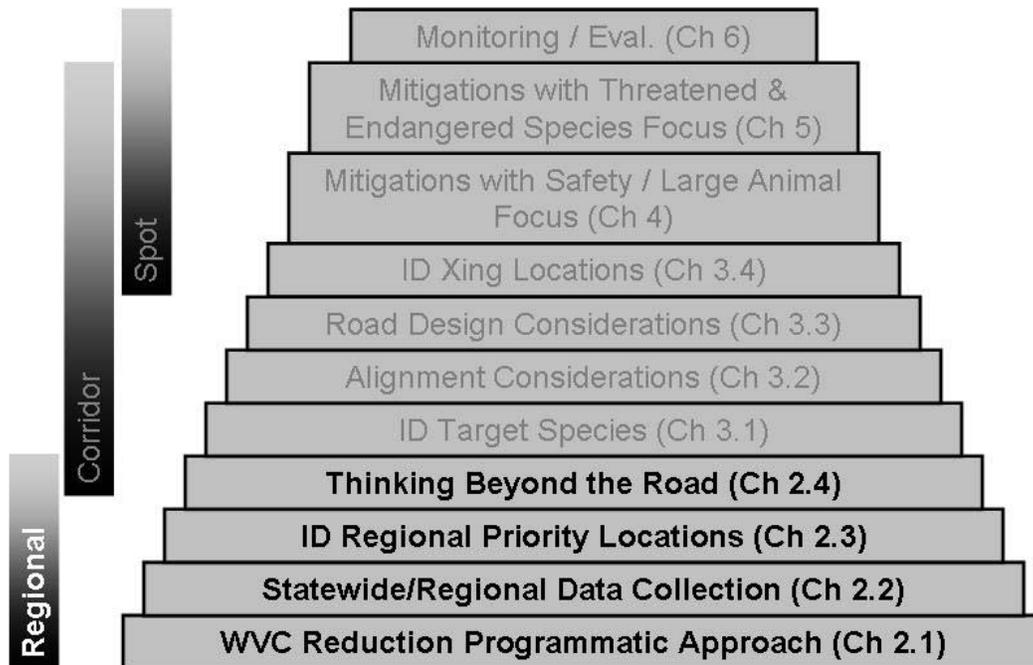


Figure 2. Regional planning as part of a strategy for reducing WVCs.

2.1. REGIONAL PLANNING: A PROGRAMMATIC APPROACH

A Statewide and regional planning approach to achieving WVC reductions should ultimately result in implementing mitigations discussed in chapters 4 and 5. Projects implementing specific mitigations at specific locations should be prioritized and implemented as funding is available.

A more opportunistic approach could include an annual check of the statewide transportation improvement program for reconstruction projects that cross WVC regional priority areas. Incorporating WVC mitigations into a planned reconstruction project will be much less expensive than installing them as separate projects.

A checklist for a statewide WVC reduction program can be found in chapter 8.

One suggested approach to ensure that the WVC reduction program is integrated into long range planning is to establish a state or regional multi-agency committee at the local Metropolitan Planning Organizations, regional planning offices, and/or State DOTs. These committees should

have experts in this area providing input and oversight. Such an oversight committee should establish goals for the WVC reduction program, gather the needed data and maps to establish a baseline assessment of the magnitude and nature of WVCs to support these goals, and develop a strategic approach to integrating these goals into transportation planning

Successfully integrating WVC reduction into planning not only requires the appropriate data but also a data analysis procedure.

2.2. STEP 1: COLLECT STATEWIDE/REGIONAL DATA

While data collection and monitoring do not have direct benefits in reducing WVCs, good data on the magnitude, trend, location, and type of WVCs clearly highlight the issue, document the need for mitigations discussed in this manual, and allow for a procedure to prioritize possible mitigation locations. It is the best way to ensure that appropriate mitigations will be installed at the locations where they will have the most impact. WVC data are crucial in justifying and prioritizing locations for mitigation. Additionally, in order to utilize the most effective mitigations for WVCs, the effectiveness of the measures must be evaluated (described further in chapter 6).

✓ Where to Find the Crash Data

There are three primary sources of WVC data: insurance data, animal carcass counts, and crash reports. **Insurance data** can give an idea of the magnitude of the problem, but is not spatially referenced and rarely is used on a local level.

A good example of a **carcass data collection program** is the Maryland Department of Transportation's Large Animal Removal Reporting System LARRS program. This program is implemented administratively from the top down, so there is a consistent standard across the department. Questions regarding carcass collection are part of a broader form that maintenance workers are required to complete for general maintenance tasks, increasing the likelihood of capturing the data. For information on the Maryland LARRS carcass data collection method, contact William Branch, Maryland Department of Transportation, (410) 545-8626, WBranch@sha.state.md.us.

To assist with carcass data collection, **handheld computers** (personal digital assistants) equipped with global positioning system (GPS) software have been developed, mostly as prototypes. One such system is the Roadkill Observation Collection System (ROCS), currently under development by the Western Transportation Institute (WTI). For more information on handheld GPS units for automatically collecting data (ROCS), contact Rob Ament at WTI, (406) 994-6423, rament@coe.montana.edu.

Crash data from police **crash reports and statewide crash databases** have the benefit of being readily accessible and spatially referenced. Because of standardized reporting and recording methods, this data source is fairly uniform within a state.

✓ Crash Data Issues

The NCHRP Project 20-05–Topic 37-12 provides a **current state of the practice** on WVC data collection.⁽⁵⁾ A survey conducted as part of this report asked State departments of transportation and departments of natural resources if they collected WVC data (crashes or carcasses). Of the 30 States that responded to the survey, 19 collected crash data on WVCs, 13 collected carcass

data, and eight collected neither. It should be noted that although the States reported they did not collect data, a review of crash reports shows that every State except one has "animal" as a check box on the crash form, as mentioned above. Of the 30 responding departments of natural resources, nine said they collected crash data, 15 said they collected carcass data, and 12 said they collected neither. Responses indicated there are substantially less data collected on local and collector roads compared to interstate highways and arterials. Many States discussed problems with the data, including inconsistencies, location accuracy, and underreporting.

Huijser and others found that every State but one had the word "animal" on their crash reports, allowing those reports to be separated from reports involving other types of crashes.⁽⁵⁾ However, the **quality of the data** needs to be considered. Inconsistencies in the manner of data collection among the States can affect the reliability and precision of the data. For instance, many crash reports include domestic animals in this category and, thus, may not be a true indication of WVCs. Another example is that "animal" may be simply a check box under entries asking the investigator to indicate the "most harmful event," "contributing factor" or "first/second/third object hit." If "animal" is under the "most harmful event" category, a crash where a driver swerves to miss an animal and collides with a fixed object on the side of the road may not be recorded as an animal crash.

The largest challenge with using reported crash data is that it **under-represents** the actual number of crashes. Nationally, approximately 300,000 WVCs are reported through crash databases each year. Extrapolating from carcass counts and insurance industry numbers, it is more likely that between one and two million WVCs occur annually. Because of the relatively small sample sizes with crash data, some States utilize carcass data to allow better identification and prioritization of problem road sections.

In addition to wildlife road mortality data, wildlife movement data can also help guide WVC reduction efforts and has the added benefit of providing insight into conservation concerns.

2.3. STEP 2: IDENTIFY AND PRIORITIZE REGIONAL/STATE ROAD MORTALITY AND CROSSING LOCATIONS

The focus of this section is identifying hotspots (or priority locations) on a statewide or regional scale. Identifying priority locations on a corridor scale is discussed in section 3.4. Regional planning for WVCs involves a programmatic approach to prioritizing problem areas in order to maximize investment in mitigations. Many WVC reduction efforts focus on identifying and prioritizing WVC hotspots within a region or State. Including both WVC hotspots and habitat linkage zones in planning efforts provides better insight into animal movements, resulting in both safety and conservation improvements.

- **WVC hotspots** are locations with high incidence of WVCs. A hotspot would be identified as a segment of road meeting some threshold value for the frequency of WVCs. Addressing WVC hotspots have both a human safety (fewer and less severe collisions) and conservation component (fewer animals killed or injured).
- **Habitat linkage zones** are zones that link areas with core habitat for selected species. Depending on the species, the number and size of the habitat patches, and the connectivity between these patches, a certain minimum level of wildlife movements between the individual habitat patches can be vital for the long term survival probability of fragmented populations (meta-populations).

Habitat linkage zones may include but are not necessarily restricted to WVC hotspots as WVC hotspots ignore locations where animals may be crossing the road successfully and where animals may want to cross, but shy away from the road corridor once they get close (aborted crossing attempt).

✓ **Identifying WVC Hotspots**

Available **carcass data** provide a good indication of the occurrence of WVCs if the search and reporting effort for the road section concerned is constant. Keep in mind that consistency and detail of the data may vary among the individuals recording the data and across maintenance districts (i.e., some maintenance personnel or districts may be more diligent in recording carcasses).

Currently, state safety management systems collect and analyze **crash data** to identify safety hotspots typically utilizing an exposure rate such as crashes per million vehicle–miles travelled. Using a traffic exposure rate may not be appropriate for targeting WVCs because, following the underlying logic of using an exposure rate, the number of animals that cross the road, typically an unknown factor, should be considered along with the volume of traffic. Because of this and the fact that WVCs occur more often on two-lane, low-volume, rural roadways, a straightforward **frequency per kilometer (or mile) per year** may be a good measure to identify hotspots.

✓ **Identifying and Prioritizing Habitat Linkage Zones**

Some States have identified and prioritized these habitat linkage zones (e.g., developed wildlife habitat linkage plans). Based on the local situation, linkage zones can be recognized, and proper planning put in place to protect and strengthen these linkage zones. Alternatively, if the natural habitat has almost or completely disappeared (e.g., because of large scale agriculture), then one may consider re-creating (semi-)natural habitat and habitat linkage zones which may direct wildlife movements to specific pre-determined locations where mitigation measures have been provided. By prioritizing these linkage zones, mitigations can be focused on the most critical areas. Mitigations may be aimed at WVC reduction, improved habitat connectivity or, ideally, both. Improving or restoring habitat linkage zones may include mitigation for roads and traffic, but other factors that affect the presence and quality of a habitat linkage zone may need to be addressed as well before a habitat linkage zone may function at the desired level. Such factors may include human presence and disturbance because of agriculture, (sub)urbanization, and other types of habitat alteration or direct or indirect disturbance. Depending on whether an integral approach is taken, addressing such other factors may or may not be part of a transportation project.

Note that habitat linkage zones may relate to large as well as small species, including species that may not be a threat to human safety in terms of collisions, and species that may not be included in carcass or crash databases.

Habitat linkage zones can be prioritized by looking at WVC hotspots, using a method referred to as rapid assessment, using expert-based Geographic Information Systems (GIS) models, using GIS movement or population viability models, and/or local knowledge:

- **Use existing WVC data** to identify WVC hotspots. Although WVC data are used as a primary input for many prioritization methods discussed below, using WVC data by itself it is not very forward looking, as changes in land-use patterns can cause changes in

animal movements and road mortality. In addition, WVC hotspots ignore locations where animals may be crossing the road successfully, or where animals may want to cross but shy away from the road corridor once they get close (aborted crossing attempt). This is especially important to recognize should the barrier effect of the road be increased through such methods as wildlife fencing. Special attention may be required with regard to road mortality and habitat connectivity for threatened or endangered species.

- **Rapid assessment** of statewide wildlife habitat linkage plans involves:
 - gathering pertinent, readily available data including aerial photos, vegetation maps, topography maps, wildlife habitat and range maps, and road mortality information; and
 - gathering local experts at a workshop where, with these data available for reference, linkage zones are identified and prioritized through a consensus-based process.

It is important to record information about the linkage zones identified (e.g., location, species of concern, local agencies and individuals with special knowledge of the linkage zone, major purpose or function of the linkage zone, and a prioritization ranking for the linkage zone). While this approach provides a quick assessment, lack of criteria and weighting rules results in subjective results. In addition, the outcome is heavily dependent on who is invited and not invited to the workshop, the knowledge that the invitees have or do not have, and how strongly their knowledge and opinions are expressed and recognized in a group setting. These issues also apply to other expert-based approaches. For general methodologies for prioritizing habitat linkage zones, contact Bill Ruediger, Wildlife Consulting Resources, wildbill@montana.com.

- **A prioritized linkage-zone map** was used in Arizona. A method similar to the rapid assessment technique described above was used to create a map during Arizona's Missing Linkages Workshop. This initial map was refined during six ecoregional workshops. GIS databases were helpful in obtaining some of the data used in prioritizing the linkage zones. For information on efforts in Arizona, contact Steve Thomas, Environmental Program Manager, FHWA Arizona Division, steve.thomas@fhwa.dot.gov.
- **Expert-based GIS models** that utilize available data may indicate good habitat or likely crossing locations. These models do not predict actual movement, but use weighted criteria based on presence or proximity of certain types of features such as vegetation, development and waterways. The weighted criteria are based on expert knowledge, but may not translate into actual locations of where wildlife cross roadways. Examples of this method are listed below:
 - The Florida Department of Transportation has created a program to identify and prioritize habitat linkage zones that intersect with highways.⁽⁶⁾ The purpose is to consider locations for safe crossing opportunities for wildlife on a statewide level in order to restore habitat connectivity and ecological processes. This method uses a rule-based GIS model to assimilate multiple factors such as road-mortality hotspots, riparian areas, greenways, protected conservation lands, and known wildlife movement routes. An output of this effort is shown in figure 3.

- The Idaho Transportation Department identified wildlife connectivity areas using an approach that integrated GIS spatial data, GIS linkage model analysis, and expert workshops to identify areas of interest for mitigation consideration in the southeast corner of the State.⁽⁷⁾
- A number of other models predict optimal crossing locations for specific species such as Key deer in Big Pine Key, FL, and grizzly bear in the area around Evaro Hill, MT.^(8,9)

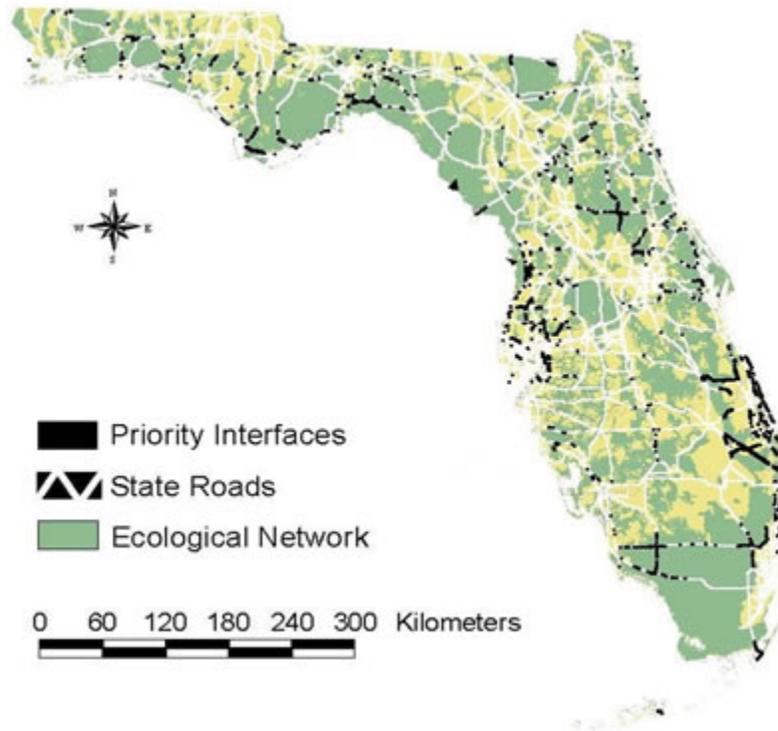


Figure 3. High priority ecological zones in Florida (copyright: FDOT).

- **GIS-based movement models** are landscape-scale models used to identify key habitat linkages, evaluate habitat fragmentation resulting from human activities, and identify areas where highways intersect with locations of frequent animal movements.

Simulated movement models tend to use resource selection functions that map habitat quality and have rules for simulated movements based on habitat quality and permeability of the landscape concerned. The data used to generate a habitat surface for these models are based on some form of animal "presence/absence" or relative suitability information, usually obtained through radio-collared individuals, but can also be derived from other animal detection methods including DNA sampling, sooted track plates, acoustic surveys, and scat-detection dogs.

- **Local knowledge** has historically been important for wildlife biologists conducting research or managing habitats for wildlife. People who live or work in an area for decades can provide valuable information about where, when, and how wildlife move across the landscape. Local participation in project planning is not only good public relations but provides stakeholders with a sense of project ownership, and builds support for the proposed mitigation measures.

2.4. STEP 3: THINK BEYOND THE ROADWAY

Regional planning for WVCs involves a coordinated effort to safely move wildlife across not only the roadway of concern, but also adjacent roadways/railways. Planning should also factor in likely trends in land use for areas adjacent to the roadway in order to maintain future wildlife movement at safe crossing locations. The challenge is to move from a road-oriented approach (i.e., a linear element, ignoring the surrounding landscape) to a landscape-based approach (i.e., a linear element, in the context of its surroundings).



Figure 4. Mitigation on the roadway may have only moved the problem to the railroad (copyright: Marcel Huijser).

This type of effort is inherently multi-agency in nature and should involve local land grants, cities, counties, special interest groups, landowners, resource agencies, rail lines, State departments of transportation, etc. An example of this type of thinking is described below.

Along Interstate 90 on Bozeman Pass, east of Bozeman, MT, is a habitat corridor where two areas of the Gallatin National Forest are separated by a transportation corridor (interstate highway and rail line), combined with private land under heavy development. Increased interstate traffic and increased land development each threaten to block animal movements, but any effort to preserve the habitat corridor by a single agency would be ineffective. By prioritizing specific crossing locations, land trusts can focus their efforts on preserving the areas that are immediately adjacent to existing or potential future safe crossing locations, and the

Montana Department of Transportation can optimize its investment in mitigation measures on the interstate. For information on the Bozeman Pass collaboration in Montana, contact Deborah Wambach, Montana Department of Transportation, (406) 444-0461, dwambach@mt.gov, or the Bozeman-based non-governmental organization American Wildlands, <http://www.wildlands.org>.

2.5. SUMMARY

Further information about the planning process can be found at the American Planning Association web site (<http://www.planning.org>) and from the FHWA (<http://www.environment.fhwa.dot.gov/integ/index.asp>). The FHWA webpage includes resources such as the Eco-Logical report, providing a process for streamlining the mitigation of wildlife impacts, and numerous training opportunities including a workshop for linking planning and conservation to help communities better understand how to improve this linkage.

To most effectively address all the aspects of WVCs during planning:

- Efforts ideally must go beyond prioritizing linkage zones to incorporating them into transportation and conservation planning elements that are developed at both local and State levels of government.
- At a minimum, the statewide transportation improvement program should be reviewed annually for reconstruction projects that cross WVC hotspots or habitat linkage zones.
- Incorporating WVC mitigations into a reconstruction project at the initial project planning stage will be much less expensive than installing them as separate projects.
- Innovative funding sources could also be incorporated into a regional WVC reduction strategy (see chapter 7).

CHAPTER 3: CORRIDOR PLANNING AND DESIGN

While chapter 2 focused on the regional or statewide scale, this chapter focuses on mitigation at the corridor scale, such as a single reconstruction project (figure 5). Many of the principles applied at the regional scale are applicable to the corridor scale, but involve a different implementation.

WVCs should be considered at every step in the highway planning and design process. In order to guide the mitigation of WVCs at the corridor level:

- **Target species and concerns (safety, conservation, or both) should** first be identified (section 3.1). These species could include threatened or endangered species present along the corridor, or the most common large animal species involved in WVCs in the area.
- Consideration should be given to the location and **alignment of the roadway** to avoid potential problem areas that can sometimes avoid WVC issues (section 3.2).
- In addition to alignment, **roadway design** may include principles that reduce the frequency of WVCs (section 3.3).
- Existing and potential **animal crossing locations** should be identified (section 3.4) in order to incorporate mitigations in the highway design.
- Instead of mitigating at all (potential) crossing locations, wildlife may be funneled to a selection of these locations where crossing opportunities are provided. Section 3.5 provides guidelines concerning optimal **distances between crossing opportunities**.

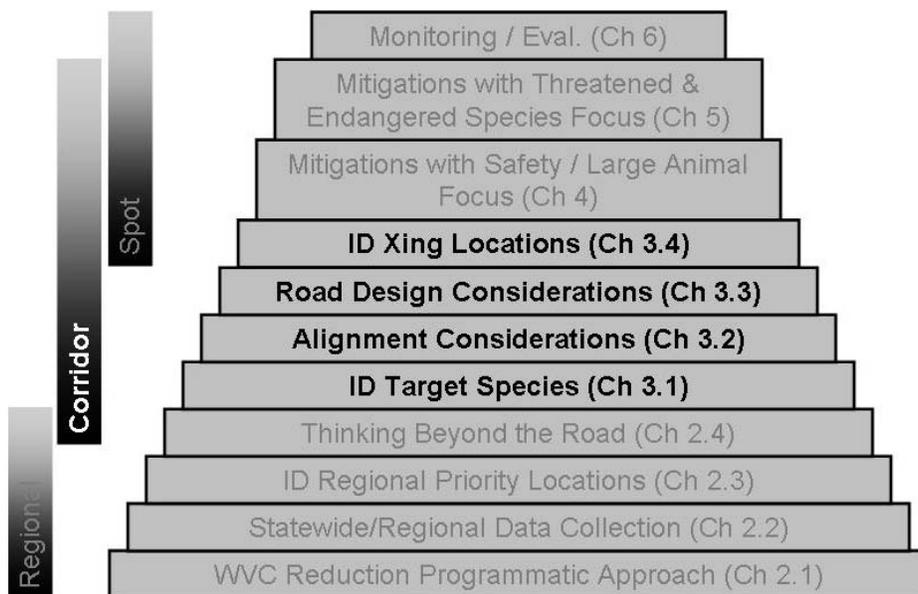


Figure 5. Corridor planning and design as part of a strategy for reducing WVCs.

3.1. STEP 1: TARGET SPECIES

Different species differ in habitat use and can thus have different movement patterns. It is important to identify the target species early in the design process and to understand the movement patterns that need to be considered. Three types of animal movement are most commonly considered (figure 6):

- The **home range** is an area within which an animal typically remains to conduct daily activities. Typical movements within the home range include foraging (figure 6A) and diurnal movements (figure 6B). Different species have different sized home ranges, which has an impact on the suggested distance between crossing opportunities.
- **Dispersal movements** (figure 6C) relate to individuals that leave their home range and establish new home ranges at a relatively great distance away (e.g., many times the diameter of the average home range size). Dispersal movements are relatively rare; not every individual disperses in this way from the home range, and many settle in or adjacent to the home range of their parents. In addition, should an individual disperse, it may only do so once in its lifetime. Depending on the species and the number, size and spatial distribution of suitable habitat, dispersal movements can be essential for the colonization or re-colonization of relatively isolated habitat patches, and, consequently, for the long-term population survival probability in the region for the species concerned.
- Some species are **migratory** (figure 6D)—that is, they display seasonal movements between different areas. These movements can be very predictable in terms of their location and time of year.

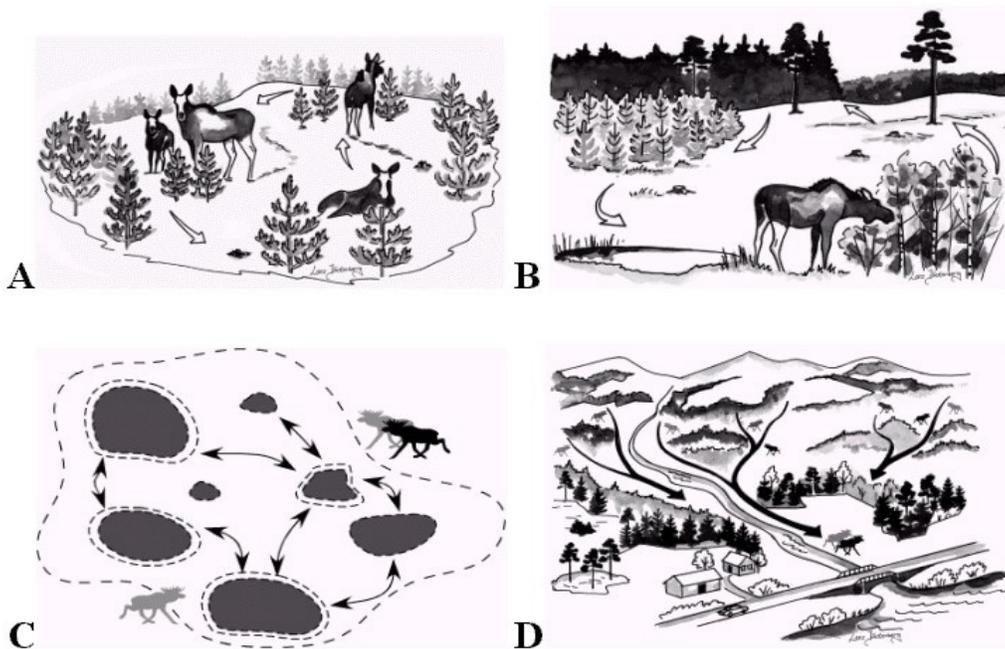


Figure 6. Basic wildlife movements (reprinted with permission from Trocmé et al. 2003).⁽¹⁰⁾

3.2. STEP 2: ROAD ALIGNMENT CONSIDERATIONS

The location or alignment of a roadway can have a substantial impact on the magnitude of WVCs that may occur after the road is constructed. Thus, integration of transportation and conservation planning at the initial design stages, when location/alignment is discussed, is essential to addressing WVCs.

With this integration, the route can be laid out with consideration of animal presence, animal movements, and ecological processes. Typically these efforts are aimed at conservation, but they can also substantially reduce WVCs.

Several models are used to assess the ecological impact on wildlife of new roadway alignment options:

- Maurer developed one such model for the Pennsylvania Department of Transportation.⁽¹¹⁾ A community-based, landscape-level terrestrial decision support system was developed with the objective of maintaining the ecological integrity of Pennsylvania ecosystems. **Variables for Assessing Reasonable Mitigation in New Transportation (VARMINT)** includes habitat importance, stewardship, patch size and shape, connectivity, proximal land use, relative significance, natural processes, diversity, anthropic use, and intangibles. Alternative routes are assigned scores for each of these criteria. Comparison of scores determines relative ranking.
- **Metroquest** is a scenario-planning tool that incorporates expected development and transportation options, providing visualization for stakeholder and public involvement. It works throughout the planning cycle, and can be customized for a given region (<http://www.questforthefuture.com/>).

Context sensitive design/context sensitive solution (CSD/CSS) processes are used to incorporate community values, aesthetics, and environmental and other priorities into the road design process. Using the CSD/CSS process could result in alignments that minimize the impact of WVCs. For more information on the overall CSD/CSS process, refer to the following web site and reports:

- FHWA (<http://www.fhwa.dot.gov/context/what.cfm>).
- NCHRP 480 A Guide to Best Practices for Achieving Context Sensitive Solutions.⁽¹²⁾
- AASHTO Guide for Achieving Flexibility in Highway Design.⁽¹³⁾
- NCHRP Report 69: Performance Measures for Context Sensitive Solutions—A Guidebook for State DOTs.⁽¹⁴⁾ Note that this report details how to develop a CSD/CSS program and track performance with surveys. Although there is some discussion on developing performance criteria (at the project and programmatic level), specific measures are not discussed (despite the title).

3.3. STEP 3: ROAD DESIGN CONSIDERATIONS

Consideration of some basic WVC mitigation principles in designing various elements of a highway could minimize the potential for WVCs. Some of these are discussed in the mitigations chapters (4 and 5) but could also be implemented as part of the initial highway design.

The considerations mentioned in this section should be taken into account when designing roadways that have a high likelihood for WVCs:

- Two-lane rural/suburban roads.
- Low- and medium-volume highways that pass through wildlife habitat.

Consideration 1: Steep Side Slopes

Slopes can hide approaching animals from a driver's view. The AASHTO Green Book recommends slopes of 1 m vertical to 1 m horizontal or flatter.⁽¹⁵⁾ It further recommends that slope transitions be gently rounded. This geometry allows the driver a clear view of the area adjacent to the roadway (whether cut or fill). Designers should use steeper fill slopes with caution, as drivers may not be able to see animals approaching the roadway until the animal leaps over the guardrail. If a steeper fill slope is used:

- ✓ Consider a flat area away from the road on the other side of the guardrail so that the animal and the driver are more visible to each other.
- ✓ Box beam guardrail (figure 7) could be a good alternative to the more typical W-beam guardrail. Small- and medium-sized animals can easily cross under the box beam guardrail, and larger animals may be more visible to drivers. Box beam has the added benefits of being more aesthetically pleasing and causing less snow-drifting, although it is more expensive than W-beam and cannot sustain a second impact.



Figure 7. Example of box beam guardrail (copyright: Marcel Huijser).

Consideration 2: Known or Anticipated Hotspots

If no data exist on hotspots (e.g., for a new road), one can anticipate that problem locations will likely exist at drainage crossings, known migration corridors, or known animal habitat. Ideally such potential problem areas are avoided or minimized during the planning process and selection of the road alignment. However, should these potential problem areas still be present in the final alignment, the designer should take extra caution to make animals visible to drivers at these locations by:

- ✓ Minimizing curves.
- ✓ Avoiding steep side slopes.
- ✓ Providing wide clear zones.

Consideration 3: Culvert or Bridge Installations

- ✓ Consider making the culverts and bridges that are built for purposes other than wildlife movement (e.g., stream or river crossing, intersections with farm roads or other roads) wide enough to include opportunities for animals to cross under the road. This consideration relates especially to terrestrial animals that may require a bank on either side of a stream or river to cross under the road.

Consideration 4: Roadside Ditches and Drainage

- ✓ Consider the impact of drainage on wildlife movement and attraction (drinking water, licking road salt).
- ✓ Avoid creating pooled water in the right of way, which can induce the growth of vegetation that is attractive to animals.
- ✓ Some wildlife will avoid crossing rip-rap. If rip-rap funnels animals to an undesirable crossing location, consider filling gaps in the rip-rap with sand and gravel (which may make it more conducive for animals to cross) or extend the rip-rap to a more suitable crossing location.

Consideration 5: Roadside Vegetation

- ✓ Consider planting or seeding unpalatable plant species.
- ✓ Consider plants that do not grow so tall as to visually obscure animals approaching the roadway.
- ✓ Section 4.8 provides more detail on vegetation.

Consideration 6: Median Barriers

Concrete median barriers (figure 8) can cause problems for wildlife. When crossing the roadway, wildlife may pause at the barrier or turn around, increasing their time in the roadway. A summary of the literature by Clevenger and Kociolek found that "the general hypothesis is that concrete Jersey barriers may increase the risk of direct vehicle mortality [of wildlife]." ⁽¹⁶⁾

Mitigations include:

- ✓ Larger cutouts at the bottom for small to mid-sized species (figure 9).
- ✓ Gaps in the barrier at strategic hotspot locations (figure 10).
- ✓ Using cable barrier designs instead of concrete Jersey barriers.



Figure 8. Long sections of median barriers are thought to increase road mortality and reduce animal movements across the road. Note that the small cutouts at the bottom of concrete median barrier are designed for drainage but also allow small animal species to cross under the median barriers (copyright: Marcel Huijser).



Figure 9. Concrete barriers with scuppers that allow small and mid-sized species to cross under the median barriers (copyright: A.P. Clevenger).



Figure 10. Opening in median barriers designed to allow wildlife to cross the road and the median barriers (copyright: Marcel Huijser).

In summary, the designer should estimate the magnitude of the potential WVC problem and include adaptations when designing a road. If there are areas along the route that have a high potential for WVCs, the designer should consider including mitigations mentioned in chapters 4 and 5.

3.4. STEP 4: IDENTIFY AND PRIORITIZE LOCATIONS WHERE WILDLIFE CROSS THE ROAD

Even if WVCs are considered in road alignment and design, problem locations may still be found following construction. For the target species and the road segment considered, WVC priority locations should be identified and mitigated (see chapters 4 and 5 for mitigation options). There are several data sources that can be used to identify where wildlife cross the road:

- **Road mortality data** might seem best suited for determining where wildlife crossings should be placed. However, research has shown that the locations where wildlife are struck by vehicles may have little in common with where they cross roads safely.⁽¹⁷⁾ Motorist visibility, road width and curvature, and vegetative cover adjacent to the road are some of the factors that explain wildlife–vehicle collision patterns. These may have little bearing on where safe road crossings occur. Road mortality data are good for identifying WVC hotspots, but should not be used as the sole source for the location of wildlife crossing opportunities. Consulting additional sources on wildlife movements (e.g., habitat linkage mapping or movement models) is required to avoid blocking animal movements at locations where wildlife may cross the road successfully and where no or little road mortality is recorded.
- **Radio-telemetry** has been commonly used to identify successful road crossing locations, usually through intensive monitoring of movements of individual animals. Accurate and abundant location data are typically obtained through the use of GPS collars.⁽¹⁸⁾
- **Roadside surveys for tracks** can be used in areas that receive regular snowfall. Animal tracks can be identified and recorded while driving slowly along the road edge.⁽¹⁹⁾
- **Roadside surveys for direct animal sightings.**⁽²⁰⁾
- **GIS-based wildlife movement or population viability modeling** (see also chapter 2).
- Use **local experts** (expert-based GIS modeling, rapid assessment) and knowledge of target species movement if data from above methods are unavailable (see also chapter 2).
- **Locations** where streams or rivers cross the road, or where edge habitat and cover comes close to the road are often associated with areas of frequent wildlife crossing.

3.5. STEP 5: DETERMINE SPACING OF CROSSING IF NEEDED

If mitigation for WVCs causes a barrier to wildlife, crossing opportunities may be needed. These crossing opportunities should be located at identified sites where wildlife cross the road. This section provides guidelines on the spacing of these crossing opportunities based on the size of their home range.

When wildlife fencing is installed alongside a road, the barrier effect of the road corridor is increased. Depending on the species concerned, a wildlife fence may be an absolute or a nearly complete barrier. Such barriers in the landscape are to be avoided as they isolate animal

populations, and smaller and more isolated populations have reduced population survival probability. Therefore, when a wildlife fence is installed, safe crossing opportunities for wildlife should be provided. This section discusses optimal distances between safe crossing opportunities.

The spacing of safe crossing opportunities for wildlife can be calculated in more than one way and is dependent on the goals one may have. Examples of possible goals are:

- Provide permeability under or over the road for ecosystem processes, including but not restricted to animal movements. Ecosystem processes include not only biological processes, but also physical processes like water flow.
- Allowing a wide variety of species to change their spatial distribution drastically, such as in response to climate change.
- Maintaining or improving the population viability of selected species based on their current spatial distribution. This includes striving for larger populations with a certain degree of connectivity between populations (allowing for successful dispersal movements).
- Providing the opportunity for individuals (and populations) to continue seasonal migration movements, like those seen among big horn sheep and mule deer.
- Allowing individuals, regardless of the species, that have their home ranges on both sides of the highway to continue to use these areas. This may result in a road corridor that is permeable for wildlife, at least to a certain degree, and at least for the individuals that live close to the road.

While population viability analyses can be very helpful in comparing the effectiveness of different configurations of safe crossing opportunities, the data required for such analyses are often unavailable or incomplete. Furthermore, the collection of such data is typically very time consuming and can be expensive, especially if multiple species are to be investigated. For this handbook the authors describe two alternative approaches:

- Base the spacing of safe crossing opportunities on current practices on other mitigated road sections.
- Base the spacing of safe crossing opportunities on the diameter of the home range sizes of the target species.

✓ **Current Practice**

Large mammal crossing structure spacing at eight different road sections in the United States and Canada are listed in Table 1. The average spacing for the large mammal crossing structures listed one per 2.1 km (1.3 mi). Note that this spacing does not necessarily have a biological basis, it simply provides a reference on the current practice for the spacing of these large-mammal crossing opportunities.

Table 1. Spacing interval of wildlife crossings for large mammals at existing and future road sections with crossing structures for wildlife.

Number of crossings	Road length km (mi)	Average spacing km (mi)	Location (reference)
17	27 (17)	1.6 (1.0)	SR 260, Arizona ⁽²¹⁾
24	45 (28)	1.9 (1.2)	Trans-Canada Highway Phase 1, 2 and 3A, Banff, Alberta ⁽¹⁹⁾
8	12 (7.5)	1.5 (0.9)	Trans-Canada Highway Phase 3B, Banff, Alberta (Parks Canada, unpubl. data)
32	51 (32)	1.6 (1.0)	Interstate 75, Florida ⁽²²⁾
42	90 (56)	2.1 (1.3)	U.S. Highway 93, Montana ⁽²³⁾
16	24 (15)	1.5 (0.9)	Interstate 90, Washington ⁽²⁴⁾
4	24 (15)	6.0 (3.8)	U.S. Highway 93, Arizona ⁽²⁵⁾
82 ^a	72 (45)	0.9 (0.5)	A-52, Zamora, Spain ⁽²⁶⁾

^a Includes crossing for small and large mammals.

✓ **Spacing Based on Home Range Sizes**

Another approach is to base the distance between safe crossing opportunities on the diameter of the home range of individual species. Estimates of the home range size for various species are presented in appendix A. Using this approach, the distance between safe crossing opportunities is simply set to the diameter of the home range of the species concerned (figure 11). This approach allows access to at least one safe crossing opportunity for individuals that have the center of their home range on the road (such as individuals "x" or "z" in figure 12). However, individuals that have their home range on both sides of the road do not necessarily have access to a safe crossing opportunity (such as individual "y" in figure 12). Finally, this approach assumes homogenous habitat and distribution of the individuals and circular home ranges, while in reality habitat and habitat quality may vary greatly, causing variations in density of individuals and irregularly shaped home ranges.

The authors of this report would like to emphasize that this approach does not necessarily result in viable populations for every species of interest, and that not every individual that approaches the road and associated wildlife fence, will encounter and use a safe crossing opportunity. In addition, the approach described above is not necessarily the only approach or the approach that addresses the barrier effect of the road corridor and associated fencing sufficiently for all species concerned. However, the authors do think that this approach:

- Treats different target species consistently, based on the available data (or lack thereof).
- Seems practical.
- Is likely to result in considerable permeability of the road corridor and associated wildlife fencing for a wide array of species.

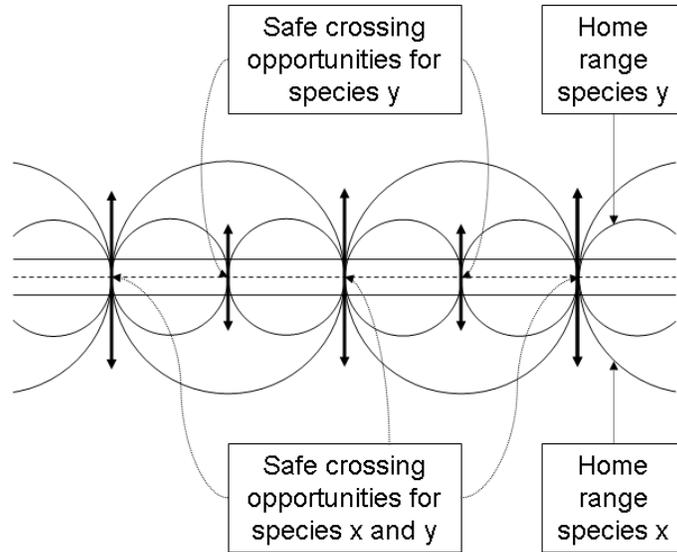


Figure 11. Schematic representation of home ranges for two theoretical species projected on a road, and the distance between safe crossing opportunities (distance is equal to the diameter of their home range).

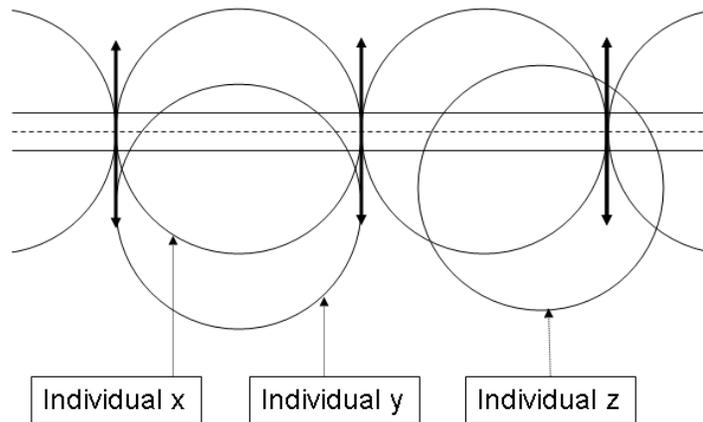


Figure 12. Schematic representation of home ranges for three individuals (x, y and z) with different locations for the center of each home range.

CHAPTER 4: DESIGN AND GUIDANCE OF WVC MITIGATIONS FOR LARGE MAMMALS

This chapter provides guidelines for the design and implementation of WVC mitigations aimed at large animals. These mitigations can be implemented in spot locations along a roadway or continuously along a corridor as part of the total WVC reduction strategy shown in figure 13.

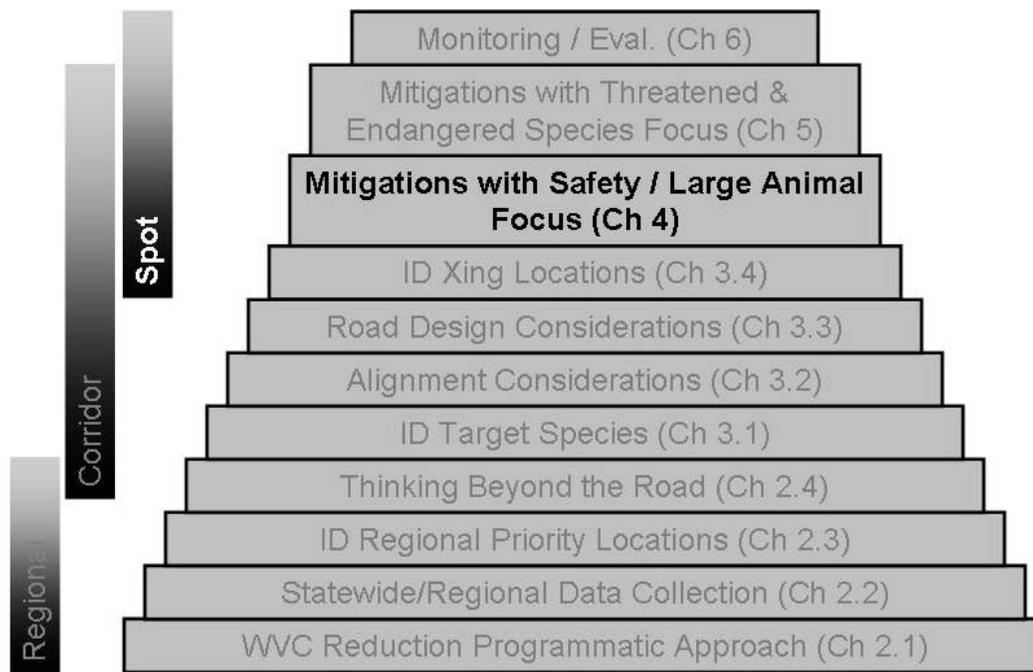


Figure 13. Best practices for WVCs involving large animals, as part of the strategy for reducing WVCs.

4.1. WVC MITIGATIONS INCLUDED IN THIS MANUAL

The application and the characteristics of the 42 mitigation measures listed in table 2 relate to large mammals (deer size and larger) and specifically deer–vehicle collisions. For each mitigation measure, the table lists the estimated effectiveness in reducing deer–vehicle collisions, a measure of its cost effectiveness (referred to as "balance"), a recommendation for implementation, and an assessment of whether or not it qualifies as a "best practice." More specifically:

- The estimated effectiveness of the mitigation measures in reducing deer–vehicle collisions is based on an extensive review of the literature. For further detail on the sources of information, refer to the Report to Congress.⁽¹⁾
- "Balance" refers to the estimated benefits minus the estimated costs (in US dollars) of the mitigation measure per kilometer (0.62 mi) per year for a hypothetical road section that receives five deer–vehicle collisions per kilometer per year. The costs relate to the

expenses associated with the design, implementation or construction, operation and maintenance, and removal over the design life of the mitigation measures. The benefits relate to the effectiveness of the mitigations in reducing collisions with deer and the costs associated with the average deer–vehicle collision. For further detail on the methods refer to the Report to Congress.⁽¹⁾

- FHWA Project Committee for this study categorized each measure as either "best practice" or not (table 2) based on effectiveness in reducing wildlife–vehicle collisions, costs and benefits, and availability of alternatives. The best practices consist of:
 - Mitigations that may reduce deer–vehicle collisions by 80 percent or more and that have a positive "balance."
 - Deer population culling, as it may be the only alternative under certain conditions, for example in certain suburban settings.
 - Mitigation measures that influence deer movements through habitat manipulation in the right-of-way or beyond the right-of-way were also selected as a "best practice" as these measures may be integrated with existing right-of-way management, and habitat alteration away from the road may be an alternative to population culling under certain conditions.

Note that future studies and more information may change which mitigation measures are considered "best practice" and which ones are not. In addition, despite the fact that "public information and education" was not labeled as a "best practice," and despite the fact that this measure is unlikely to substantially reduce collisions with large mammals, it is still considered "good practice," as the measure increases public awareness of the problem and builds public support for the implementation of mitigation measures.

Table 2. Effectiveness, benefit, and ranking of mitigation measures (see the Report to Congress).⁽¹⁾

Mitigation measure	Estimated effectiveness (%)	Balance (\$/km/yr)	Best practice ¹ (yes)	Page no. for more info.
Public information and education	?	?		
Standard warning signs	0%	-\$18		
Enhanced wildlife warning signs	?	?		
Seasonal wildlife warning signs	26%	\$10,878		
Animal detection systems (ADS)	82%	\$3,091	Yes ²	105
ADS linked to on-board computer	82%	?		
On-board animal detectors	?	?		
Increase visibility (roadway lighting)	?	?		
Increase vis. (vegetation removal)	38%	\$15,437	Yes ²	115
Increase vis. (wider striping)	?	?		
Increase vis. (reflective animal collars)	?	?		
Increase vis. (reduce snow bank height)	?	?		
Reduce traffic volume	?	?		
Temporary road closure	?	?		
Reduced posted speed limit	?	?		
Traffic calming techniques	?	?		
Reduced advisory speed limit	?	?		
Wildlife crossing guards	?	?		
Deer reflectors and mirrors	0%	-\$495		
Deer whistles	0%	?		
Olfactory repellents	?	?		
Deer flagging models	?	?		
Hazing	?	?		
De-icing alternatives	?	?		
Intercept feeding	?	?		
Min. nutritional value r-o-w vegetation	?	?	Yes ²	116
Carcass removal	?	?		
Increase median width	?	?		
Population culling	50%	\$18,462	Yes ²	121
Relocation	50%	\$10,710		
Anti-fertility treatment	50%	-\$40,732		
Habitat alteration away from road	?	?		
Fence (including dig barrier)	87%	\$32,728	Yes	28
Boulders in right-of-way	?	?		
Long bridges	100%	-\$739,310		
Long tunnels or long bridges	100%	-\$1,458,060		
Fence with gap and warning signs	0%	-\$3,772		
Fence with gap and crosswalk	40%	\$11,191		
Fence with gap and ADS	82%	\$24,461	Yes ²	28, 105
Fence with underpasses	87%	\$30,628	Yes	28, 56
Fence with overpasses	87%	\$10,003	Yes	28, 56
Fence with under- and overpasses	87%	\$28,978	Yes	28, 56

¹ Determined by Project Committee for National WVC Reduction Study² Experimental

? Unknown

4.2. WILDLIFE FENCING

Wildlife fencing (figures 14 and 15) for large mammals (deer size and larger) is aimed at reducing collisions with large mammals by keeping these species from entering the road or road corridor including the right-of-way. However, wildlife fencing also increases the barrier effect of roads and traffic, not only for the target species but also for species that may not be a concern to human safety on roads. Increased barrier effect of roads and traffic may:

- Reduce or eliminate daily, seasonal and dispersal movements, and result in reducing or eliminating access to potentially critical resources.
- Reduce the long-term viability of certain species population in the region.

To minimize these negative effects, continuous wildlife fencing should typically be combined with safe crossing opportunities for wildlife species affected by the fence (see section 4.3 through 4.7). Safe crossing opportunities can reduce:

- Reduce the barrier effect of the wildlife fencing, roads and traffic.
- Reduce intrusions of large mammals into the road corridor as they no longer need to breach or climb the fence in order to get to the other side of the road corridor.

For these reasons, wildlife fencing should typically be combined with safe crossing opportunities for wildlife.



Figure 14. A 2.4-m-high (8-ft-high) large-mammal fence, with smaller mesh sizes toward the bottom, on U.S. Highway 93 on the Flathead Reservation in Montana (copyright: Marcel Huijser).



Figure 15. A moose fence, along the Glenn Highway (Hwy 1), northeast of Anchorage, AK (copyright: Marcel Huijser).

4.2.1. Effectiveness in Reducing Collisions with Large Mammals

The **effectiveness** of large-mammal fencing in combination with under- and overpasses has been estimated at 80–99 percent, with an average of 87 percent.

4.2.2. Technical Specifications

Wildlife fencing should typically be installed on:

- Both sides of the road corridor, rather than on just one side.
- Fence ends should be directly across the road from each other and not offset.

✓ Fence Type

Wildlife fences for large mammals can be:

- Woven metal wire (figures 14 and 15). Higher gauge and galvanized wire is more durable and has a longer life span, about 20–25 years, than smaller gauge wire.
- Chain-link (figure 16).
- Electric. These may consist of several horizontal strands of rope-like material about 1.3 cm (0.5 in) in diameter. It delivers a mild electric shock to animals that touch it, discouraging them from passing through the fence.



Figure 16. A 3.4-m-high (11-ft-high) chain-link fence along SR 29 in southern Florida, designed to keep Florida panthers off the roadway and to guide them toward underpasses. Note the outriggers pointing away from the road (copyright: Marcel Huijser).

✓ Fence Height

- Woven metal wire fences for large mammals, including deer, elk and moose, are typically 2.4 m (8 ft) high. Higher fences may be required for individual animals that are extremely motivated to get to the other side of the fence, and for species that are able to jump high (e.g., bighorn sheep) (table 3).
- Higher fences are necessary if animals approach the fence from above, as on a sloped roadside.
- Electric fences may be lower, 1.2–2.1 m (4–7 ft), for example, depending on the species.

Table 3. Suggested fence height for selected large mammal species.

Large Ungulates	Woven Metal Wire Fence Height	Further Recommendations
White-tailed deer (<i>Odocoileus virginianus</i>)	2.4-2.7 m (8-9 ft)	
Mule deer (<i>Odocoileus hemionus</i>)	2.4-2.7 m (8-9 ft)	
Elk (<i>Cervus elaphus</i>)	2.4-2.7 m (8-9 ft)	
Moose (<i>Alces alces</i>)	2.4-2.7 m (8-9 ft)	
Mountain goat (<i>Oreamnos americanus</i>)	2.4-2.7 m (8-9 ft)	
Bighorn sheep (<i>Ovis canadensis</i>)	3.0-3.7 m (10-12 ft) ¹	
Cougar (<i>Puma concolor</i>)	3.4 m (11 ft)	Finer mesh size, overhang
Wolf (<i>Canis lupus</i>)	2.4 m (8 ft)	
Black bear (<i>Ursus americanus</i>)	2.4-2.7 m (8-9 ft)	Finer mesh size, overhang
Grizzly bear (<i>Ursus arctos</i>)	2.4-2.7 m (8-9 ft)	

¹The actual height needed for bighorn sheep is unknown, but expected to be higher due to their jumping ability.

✓ Mesh Size, Overhangs

- Woven metal wire fences for large mammals may have mesh sizes of 16 x 16 cm (6 x 6 in).
- Smaller mesh sizes may be advisable for species that can climb fences (black bears, for example, can climb woven metal fences by putting their feet in large mesh openings). In some cases, (barbed) wire overhangs are placed on the top of a fence to discourage animals (e.g. bears, cat species) from climbing over a fence (figure 17).



Figure 17. A 3.4-m-high (11-ft-high) chain-link fence along SR 29 in southern Florida equipped with three strands of outrigged barbed wire to prevent Florida panthers from climbing the fence (copyright: Marcel Huijser).

Fences for large mammals are sometimes combined with:

- Fences for smaller species, including amphibians, reptiles and small mammals. Fine mesh sizes (1 x 1 cm (0.5 x 0.5 in)) may be used at the bottom of the fence for small animals (figures 18, 19 and 20). This is usually a separate fence that is tied into the main large-mammal fence. Plastic sheets or concrete walls, as shown in figure 18, are more durable and are typically used for amphibians and reptiles in combination with a large-mammal fence. Note that fencing may be ineffective for tree frogs because of their climbing ability. Fences for small animals typically have an overhang (4–6 cm (2–3 in)) at a 45–90° or greater angle away from the large mammal fence; the bottom edge of the fence is usually buried 5–20 cm (2–8 in) in the ground (figure 20).
- Fences for medium-sized mammals. For medium-sized mammals, the woven metal wire fencing can have a smaller mesh size toward the bottom (e.g. 16 x 10 cm (6 x 4 in)) (figures 18 and 19).

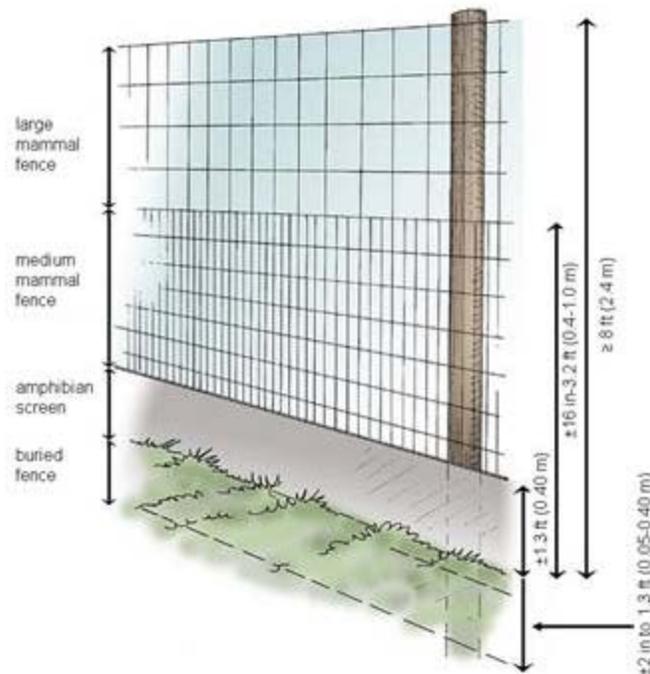


Figure 18. Schematic drawing of a large-mammal fence in combination with barriers for smaller species (adapted and reprinted with permission from Kruidering et al., 2005).⁽²⁷⁾



Figure 19. Large-mammal, medium-mammal and small-animal fence combined at the approach to the De Borkeld wildlife overpass across the A1 motorway in The Netherlands (copyright: Marcel Huijser).

✓Dig barrier

If the species present in the area are unlikely to dig or are unable to dig underneath the fence, large-mammal fences can be flush with the ground. In combination with the tension on the fence, this should prevent large mammals from crawling underneath. Some wildlife fences are partially buried to reduce intrusions into the road corridor by species that can and do crawl underneath the fences (e.g., at depressions in the terrain) or that can dig underneath the fence, such as a coyote (figure 20). The depth of the buried portion of the fence depends on the species—perhaps a few centimeters for amphibians to about 60 cm (2 ft) for coyotes. Instead of burying the main part of the large-mammal fence, a separate fence can be tied toward the bottom and then partially buried. For example, a 1-m-wide (3.2-ft-wide) chain-link fence with a 5 x 5 cm (2 x 2 in) mesh size can be attached to the main large-mammal fence and buried 60–70 cm (2–2.3 ft) in the ground. The "dig barrier" may be buried at a 45° angle away from the fence to further reduce potential for animals to dig under the fence.



Figure 20. A 2.4-m-high (8-ft-high) large-mammal fence with smaller mesh sizes toward the bottom and additional buried apron (dig barrier) along U.S. Highway 93 in Montana (copyright: Marcel Huijser).

✓ Fence Posts

- Pressure-treated wood posts, at least 13 cm (5 in) in diameter for line posts and 16.5–18 cm (6.5–7 in) for braces and corner posts, are most commonly used for woven metal wire wildlife fences. They have a life span of about 20–30 years. Larger diameter posts make fences stronger and more durable. Posts should be placed about 70 cm (2.3 ft) into the ground, but local soil conditions may force deeper or shallower positioning of the posts. Posts may be placed at an interval of 4.2–5.4 m (14–18 ft). Longer life span metal posts set in concrete may be required in some situations, such as places where solid rock is on or close to the surface.
- Metal fence posts typically are more expensive than wood posts. Tension between posts can be achieved using reinforced cable on wooden posts or metal tubing on metal posts. Chain-link fences typically have metal posts.
- Fiberglass posts, typically 2.2 cm (7/8 in) in diameter, set 60 cm (2 ft) into the ground. Electric fences typically have fiberglass posts.

✓ Fence Attachment to Poles

The woven metal wire fencing should be placed on the side of the poles facing away from the road (figure 21). If the wire fencing is attached on the road side of the poles, animals that repeatedly run into the fence mesh may loosen the fence from the posts.



Figure 21. Fence mesh attached to the side away from the road on wildlife fence along Interstate 90 near Bozeman, MT (copyright: Marcel Huijser).

✓Protective Top Cable

Nearby trees can fall and damage the fence, creating openings for large mammals to access the road corridor. A high-tensile cable on top of the fence posts (figure 22) can help break the fall of trees (up to a certain diameter and weight) and maintain the integrity of the fence as a barrier to animals. A protective top cable can also reduce fence repair costs.



Figure 22. Large-mammal fence with protective top cable along the Trans-Canada Highway in Banff National Park, Alberta (copyright: Marcel Huijser).

4.2.3. Implementation Considerations

✓Human Safety

In some situations, there may be public safety concerns with having electrified fencing along public highways. Travelers (e.g., pedestrians, cyclists) as well as recreationists (e.g., fishermen, hikers) may be shocked when touching the fence.

✓Fence Length

Continuous wildlife fencing at least several kilometers in road length or longer is a more effective barrier for large mammals than relatively short sections of wildlife fencing several tens or hundreds of meters in length, mostly because of the home range size of large mammals (see appendix A).

✓ Safe Crossing Opportunities for Wildlife

Continuous wildlife fencing should typically be combined with safe crossing opportunities for wildlife (see sections 4.3 through 4.7). One possible way to evaluate whether a road section that has been fenced is long enough to warrant safe crossing opportunities for selected species is to compare the diameter of the home range for the species concerned to the length of the road section that is mitigated. Examples of home range sizes for some species are provided in appendix A.

If a wildlife fence is targeted at large species such as deer, elk or moose but becomes a barrier for a non-target species, consider making the wildlife fence permeable for such species, particularly where crossing opportunities are far apart (e.g., multiple times the diameter of the species' home range) (figure 23 and 24). An example is a wildlife fence in Florida aimed at Key deer where Lower Keys marsh rabbits could still access the road corridor through the 10 cm (4 in) gap between the bottom of the fence and the ground level (figure 23).



Figure 23. A 1.83-meter-high (6-ft-high) chain-link fence along U.S. Highway 1 on Big Pine Key, FL, with a 10-cm (4-in) gap allowing the endangered Lower Keys marsh rabbit access to the right of way (copyright: Marcel Huijser).



Figure 24. A chain-link moose fence near Kenai, AK, with a gap (and a barbed wire strand) at the bottom allowing small species to crawl underneath the fence (copyright: Marcel Huijser).

✓ Existing structures

Where fencing meets existing bridges, tunnels, drainage culverts, wildlife underpasses or overpasses, or animal detection systems, the wildlife fence should tightly connect to wing walls or sides of the structures or to the sensors of animal detection systems to prevent unintended animal intrusions into the road corridor. Even though a fence may be mainly targeted at large mammals, it should not make existing crossing opportunities such as drainage culverts inaccessible to small- and medium-sized species.

✓ Fence Location

Wildlife fences are typically placed on the edge of the right-of-way at the property boundary. Many roads already have a right-of-way fence, and the wildlife fence should replace the right-of-way fence rather than be positioned parallel to it. In some cases the habitat in the right-of-way may be the only remaining habitat for certain species in an otherwise unsuitable environment (e.g., large scale agricultural fields or areas with housing). In such situations, consider placing the wildlife fence closer to the road allowing animals to access at least a portion of the habitat in the right-of-way. For legal reasons, it may be necessary to keep an additional standard right-of-way fence at the property boundary in these cases.

✓ Fence Ends

Fence ends can be associated with a concentration of wildlife–vehicle collisions. This situation can be mitigated by ending a wildlife fence at or close to:

- A safe crossing opportunity for wildlife (e.g., wildlife underpasses, overpasses, animal detection systems, or existing bridges not specifically designed for wildlife—see sections 4.3 through 4.7).
- Steep, rugged terrain such as rock cuts (though not effective for bighorn sheep or mountain goats— see figures 25 and 26).
- Habitat that may limit movement, such as open areas for forest-dwelling species or open water for terrestrial species.
- Areas exposed to regular human activity and disturbance.



Figure 25. Fence end at top of cliff along U.S. Highway 93 in Montana (copyright: Marcel Huijser).



Figure 26. Fence end at bottom of cliff along U.S. Highway 93 in Montana (copyright: Marcel Huijser).

Potential "fence-end effects" can be further mitigated by:

- Terminating fences on straight sections of highway. This may allow for good visibility, and longer sight distances for drivers.
- Lighting at fence ends. This may improve visibility to drivers (though lighting may discourage certain species, especially carnivores, from crossing).
- Wildlife warning signs, reduced posted speed limits or advisory speeds. It is unknown whether these signs actually reduce vehicle speed or makes drivers more alert.

Additional measures may be required at the fence ends to discourage animals from entering the right-of-way. These measures might include:

- A fence end that is positioned close to the road. Concrete barriers or guardrails may be installed along the road side for human safety (figure 27).
- A boulder field between the fence and the road, and in the median, if applicable (figure 28). This may discourage ungulates from wandering off in the right-of-way. The boulder field may be 50–100 m (165–325 ft) long along roadway. The boulders must extend from the edge of the pavement up to the fence to preclude any path for wildlife to skirt the boulders. Boulder aprons are made of sub-angular, quarried rock, ranging in size from

20–60 cm (10–25 in), however most should be larger than 30 cm (12 in). The boulders are placed on geo-fabric on sub-excavated smoothed ground at a depth of about 40–50 cm (16–20 in) below the surface of the surrounding area. The boulders project about 20–30 cm (10–12 in) above the local ground surface. Concrete barriers or guardrails may be installed along the road side for human safety.

- Wildlife guards (similar to cattle guards) across the road (figure 29).
- Electric mats embedded in the road surface deliver a mild electric shock to animals that touch it.



Figure 27. Fence end brought close to the road with a concrete barrier for safety in Banff National Park, just west of Castle Junction, Alberta (copyright: Marcel Huijser).



Figure 28. The boulder field at the fence end at Dead Man's Flats along the Trans-Canada Highway east of Canmore, Alberta (copyright: Bruce Leeson).



Figure 29. Wildlife guard at a fence end on the two-lane U.S. Highway 1 on Big Pine Key, FL (copyright: Marcel Huijser).

✓Escape Opportunities from the Right-of-Way

Animals that become trapped on the roadway between wildlife fences pose a safety risk to humans and to themselves. Therefore, wildlife fences should typically be combined with escape opportunities for wildlife. Escape opportunities may include:

- Swing gates, which are generally used (with or without ramps) in areas where highways are regularly patrolled by wardens or rangers. As part of their job, if animals are found inside the fenced road corridor, they can open the nearest gates and walk toward the animals, pushing them to the opened gate. A double gate, being wider, is more effective than a single gate, especially for larger species such as elk or moose. Swing gates are used to remove ungulates and large carnivores such as bears, as smaller wildlife species can often escape under the hinged doors.
- Earthen ramps or jump-outs allow medium and large mammals to safely exit right-of-ways on their own, without the aid of wardens or rangers (figures 30, 31, 32 and 33). Animals that are caught between the fences typically follow the wildlife fence until they find an escape opportunity.
- Small, hinged doors placed at the ground level for small- and medium-sized species, (figure 34) allow for escape from the right-of-way. However, these hinged doors may stop functioning properly over time and may eventually remain permanently open after use.
- Natural objects such as tree stumps, tree branches or brush can be staked against the fence until it reaches the top of the fence, allowing small- and medium-sized species to 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.



Figure 30. A short section of perpendicular fence to guide animals on top of a jump-out along a 2.4-meter-high (8-ft-high) fence along U.S. Highway 93 in Montana (copyright: Marcel Huijser).



Figure 31. A jump-out along a 2.4-meter-high (8-ft-high) fence along U.S. Highway 93 in Montana (copyright: Marcel Huijser).



Figure 32. A jump-out intended for Eurasian badger and roe deer along a 2-meter-high (6.6-ft-high) fence along the A73 motorway near Roermond, The Netherlands. Note the wildlife overpass "Waterloo" in the background (copyright: Marcel Huijser).



Figure 33. A jump-out along a 2.4-meter-high (8-ft-high) fence with smooth metal to prevent bears from climbing into the right of way along the Trans-Canada Highway, Banff National Park, Alberta (copyright: Marcel Huijser).



Figure 34. A one-way Eurasian Badger gate in the Netherlands (copyright: Marcel Huijser).

Considerations for jump-outs:

- Jump-outs should be high enough to discourage large mammals from jumping up into the road corridor, and low enough so that animals caught between the fences will readily use them to exit the road corridor. Deer and elk are the most common users, but moose, bighorn sheep, bears and cougars have also used these structures. Little is known about the optimal height of jump-outs, but a height around 2–2.1 m (6.5–7 ft) is common.
- The landing spot around the outside wall should have loose soil or some other soft material to prevent animals from injuring themselves when jumping out.
- In areas frequented by bears, the outside walls of the jump-out should be smooth to prevent them or other animals from climbing up (figure 33).
- Escape ramps should be positioned in a set-back in the fence, in an area protected with dense vegetative cover so animals have time to calm down and look over the situation before deciding whether to jump off, continue walking along the fence or cross the highway.

Escape opportunities should be carefully designed for the target species. Both their location and regular maintenance are essential. There are currently no standards for the spacing of jump-outs, but distances of about 300 m (984 ft) between them have been suggested for mule deer.

✓ Landscape Aesthetics

The visual impact of fences to humans, both looking from the road and looking to the road, may have to be addressed. The visual impacts of a fence can be lessened through:

- Using existing vegetation or structures as a background.

- Planting new shrubs or bushes in front of or behind a fence.
- Dark coating for chain-link fences to make them blend in with the background (figure 35).
- Positioning the fence at a relatively low point along the road, but avoid situations where animals may approach the fence going down slope as this may require a higher fence to be effective.
- Lower fence heights in situations where there are commercial or residential concerns about the visual impact of fencing, and where animals may not be abundant because of human disturbance in the area. Note that lower fence height in selected locations may compromise the effectiveness of the fence.

A wildlife fence may have to be made more visible in cases where:

- The fence makes a high-use area no longer accessible to certain species. For example, steep cliffs were no longer accessible to bighorn sheep after a wildlife fence was placed along the Trans-Canada Highway in Banff National Park, and the bighorn sheep ran into the fences trying to escape from predators. The problem was greatly reduced after the fence was made more visible with green mesh (figure 36).
- The fence is located in an area with low-flying birds.



Figure 35. A 1.83-meter-high (6-ft-high) chain-link fence along U.S. Highway 1 between Florida City and Key Largo, FL, has been coated with colored plastic (copyright: Marcel Huijser).



Figure 36. A 2.4-meter-high (8-ft-high) large-mammal chain-link fence along the Trans-Canada Highway between Canmore and Banff, Alberta, is equipped with green mesh to make the fence more visible to bighorn sheep (copyright: Marcel Huijser).

4

✓ Access Points Requiring Fence Breaks

Where wildlife fences intersect with roads, accommodations must be made to:

- Avoid obstructing vehicles turning on or off the fenced road.
- Allow continued access for people to trails or other specific locations after a fence has been erected.
- Avoid blocking waterways. Fencing across waterways could cause problems for the water flow, floating debris, aquatic and semi-aquatic animals, and boats. These breaks in the fence require special modifications to prevent or reduce animal intrusions into the right-of-way.

✓ Access Roads

- **Wildlife guards:** Transportation and land management agencies commonly install cattle guards ("Texas gates" in Canada) where fences intersect access roads (figures 37 and 38). Many different designs have been used, but few have been tested with regard to wildlife species. Cattle guard designs vary in dimensions, grate characteristics (flat or cylindrical steel grates), and grate adaptations for safe passage by pedestrians and cyclists. A grate pattern was recently developed that was 95 percent effective in blocking Key deer movement and was considered safe for pedestrians and cyclists.⁽²⁸⁾ A similar design was implemented along U.S. Highway 93 on the Flathead Indian Reservation in Montana (figure 39). Small species can fall in the pit under a wildlife guard. Therefore, escape ramps are typically provided (figures 40 and 41).



Figure 37. A wildlife guard, similar to a standard cattle guard, at an on-ramp to Interstate 90 east of Bozeman, MT (copyright: Marcel Huijser).



Figure 38. A wildlife guard, similar to a standard cattle guard, at a forest access road connecting to the road "Hilversumsestraatweg", near Hilversum, The Netherlands (copyright: Marcel Huijser).



Figure 39. A modified wildlife guard (bridge-grate material) at an access road on U.S. Highway 93, south of Ravalli, MT (copyright: Marcel Huijser).



Figure 40. An escape ramp for small species from a wildlife guard pit near the town "De Lage Vuursche", The Netherlands (copyright: Marcel Huijser).



Figure 41. An escape ramp for small species from a wildlife guard pit along the road "Hilversumsestraatweg", near Hilversum, The Netherlands (copyright: Marcel Huijser).

- **Electric wildlife guards:** Mats that are embedded in the pavement or that can be rolled across a low-volume road can deliver a mild electric shock when animals step on them. These mats are intended 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.
- **Swing gates:** Swing gates may be installed at low-volume access roads. Procedures must be in place to ensure that the swing gate is closed after use (figure 42).



Figure 42. A gate at an access road on U.S. Highway 93, north of Ravalli, MT (copyright: Marcel Huijser).

✓Trails

- **Swing gates:** Gates can be used to negotiate fences where they impede public access to popular recreation areas. Gates should have mechanisms to ensure that they close automatically (e.g., spring-activated hinges or positioning the gates at an angle so they are closed by gravity). In areas of heavy snowfall, gates may be elevated and steps built to keep the bottom of the gate above snow (figures 43 and 44).



Figure 43. A swing gate for pedestrians and a wildlife guard at a bicycle path into an enclosure with large mammals (cattle), near the town "De Lage Vuursche", The Netherlands (copyright: Marcel Huijser).

4



Figure 44. Spring-loaded swing gate in fence allowing access for people along the Trans-Canada Highway in Banff National Park, Alberta (copyright: Adam Ford).

- **Angled fence openings:** An alternative (untested) design allows people to walk through an angled opening in the fence, but species such as large ungulates that have trouble bending their back sideways may not be able to pass through (figure 45).



Figure 45. Access point for people along U.S. Highway 93 south of Missoula, MT (copyright: Marcel Huijser).

✓ Watercourses

Watercourses pose problems for keeping fences impermeable to large mammals, as their flow levels tend to fluctuate throughout the year. These problems include gaps that may appear under fencing across the waterways during low water levels, allowing wildlife to pass beneath. Also, fencing that extends close to or below the water surface can cause flooding problems when debris transported by the water is trapped against the fence, obstructing water flow. One solution is to elevate the fencing above the water and hang chains, or hinged rubber strips that float, from the bottom of the fence to the low waterline. This can allow passage of water and debris while maintaining a barrier to wildlife.

4.2.4. Example Cost Estimates

✓ Fencing

Fencing along the western end of the **Trans-Canada Highway in Banff National Park** (the portion of the project known as phase 3-B, constructed in 2006–2007) was estimated at \$69 (in

2007 \$) per meter of fencing (Can\$75 in 2006) (personal communication, Terry McGuire, Parks Canada). This fence was 2.4 m (8 ft) high, had pressure-treated wooden posts and a dig barrier. The fence had smaller mesh at the bottom (16 x 10 cm (6 x 4 in)) and bigger mesh toward the top (16 x 16 cm (6 x 6 in)). The dig barrier consisted of a buried apron (1-m-wide (3.3-ft-wide) chain link with 5 x 5 cm (2 x 2 in) mesh) that extended about 30 cm (1 ft) above ground. The rest of the apron (about 60–70 cm (2 ft)) was buried at a 45° angle away from the fence.

The cost of wildlife fencing installed along **U.S. Highway 93 on the Flathead Reservation in Montana** varied, depending on the road section concerned, from \$27 to \$42 (in 2007 \$) per meter (\$26 to \$41 in 2006) (personal communication, Pat Basting, Montana Department of Transportation). A finer mesh fence was dug into the soil and attached to the wildlife fence for some fence sections at a cost of \$12 (in 2007 \$) (\$12 in 2006) per meter.

✓ Jump-outs

Reported costs for one jump-out range from \$13,241 (in 2007 \$) (\$11,000 in 2000) to \$6,425 (in 2007 \$) (\$6,250 in 2006) (personal communication Pat Basting, Montana Department of Transportation).⁽²⁹⁾

✓ Swing Gates for Access Roads

Costs for single- and double-panel gates along U.S. Highway 93 on the Flathead Indian Reservation in Montana were \$308–370 and \$360–565, respectively (in 2007 \$) (\$300–360 and \$350–550, respectively, in 2006) (personal communication Pat Basting, Montana Department of Transportation).

✓ Wildlife Guards for Access Roads

The reported cost of a specially designed wildlife guard was (\$30,840 in 2007 \$) (\$30,000 in 2006) (personal communication Pat Basting, Montana Department of Transportation).

4.2.5. Maintenance

Fences are subject to damage and wear from numerous sources: vehicular accidents, falling trees, human vandalism, mowing activities in the right-of-way, animals climbing the fence or repeatedly running into the fence, soil erosion, flooding, and digging by animals. Therefore, fences must be checked regularly (e.g., every 6 to 12 months) by walking the entire fence line identifying gaps, breaks and other deficiencies and general wear and tear including:

- Holes.
- Loose fence attachment to the poles.
- Loose embedding of posts in the ground.
- Digging underneath the fence.
- Evidence of animal passage such as wildlife trails and hair caught on the fence.
- Monitor vegetation growing adjacent to the fence and observe whether it allows animals to intrude into the road corridor. This may include trees and shrubs for species that can use them to get across the fence. Smaller species (e.g., amphibians and small mammals)

may also use grasses and herbs to climb the screens or small mesh fences, and then crawl through the larger mesh sizes higher up.

Note: avoid placing the fence where it conflicts with the management of the right-of-way vegetation and/or ditches.

4.3. WILDLIFE UNDERPASSES

Wildlife underpasses are primarily designed to provide connectivity for wildlife species, often in combination with wildlife fencing. However, underpasses are sometimes also deployed as stand-alone mitigation measures. When used in combination with wildlife fencing, they help reduce intrusions into the road corridor as animals are provided with a safe crossing opportunity. When used as a stand-alone mitigation measure, the reduction in wildlife–vehicle collisions may be limited to the immediate vicinity of the underpass.

4.3.1. Effectiveness in Reducing Collisions with Large Mammals

The effectiveness of "crossing structures" (i.e., underpasses and overpasses combined) in reducing large-mammal WVCs has been estimated at 79–97 percent, with **an average of 86 percent, when used in combination with large-mammal fencing** (see section 4.2).

4.3.2. Technical Specifications

✓ Crossing Structure Types

Four different types of crossing structures are described in table 4, with examples in figures 46–50. Note that there are many different types of crossing structures and that their dimensions may vary greatly. Nonetheless, the types of underpasses described in this section serve a wide range of mammal species from small to large. For a more exhaustive discussion on the implementation and design specifications for a large number of wildlife underpasses, please consult Clevenger and others.⁽⁴⁾ In addition, a limited number of underpasses that can be or have been implemented for threatened and endangered species are discussed in chapter 5.

Table 4. Dimensions of the four different types of underpasses.

Crossing Structure Type	Dimensions (as seen by the animals)	Fig. No.
Open-span bridge (underpass)	12 m (39.4 ft) wide, \geq 5 m (16.4 ft) high	40
Large-mammal underpass	7–8 m (23–26.2 ft) wide, 4–5 m (13.1–16.4 ft) high	41,42
Medium-mammal underpass	0.8–3 m (2.6–9.8 ft) wide, 0.5–2.5 m (1.6–8.2 ft) high	43,44
Small- or medium-mammal pipe	0.3–0.6 m (1.0–2.0 ft) in diameter	45



Figure 46. An open-span bridge over Spring Creek, along U.S. Highway 93 south of Ravalli, MT (copyright: Marcel Huijser).



Figure 47. A large-mammal underpass (7–8 m (23-26.2 ft) wide, 4–5 m (13.1-16.4 ft) high) along U.S. Highway 93 south of Ravalli, MT (copyright: Marcel Huijser).



Figure 48. A medium-mammal box culvert (1.2 m (3.9 ft) wide, 1.8 m (5.9 ft) high) along U.S. Highway 93, south of Ravalli, MT (copyright: Marcel Huijser).



Figure 49. A medium-mammal culvert (2 m (6.6 ft) wide, 1.5 m (4.9 ft) high) along U.S. Highway 93, south of Ravalli, MT (copyright: Marcel Huijser).



Figure 50. A small- to medium-mammal pipe (badger pipe) in The Netherlands (copyright: Marcel Huijser).

Table 5 provides an overview of the suitability of the four different types of underpasses for selected species. For the purpose of comparison, wildlife overpasses (see section 4.4) are also included in this table. When evaluating the suitability of the crossing structures, the authors assumed no human co-use of the crossing opportunities. The suitability of the different types of crossing opportunities is influenced not only by the size of the species and their habitat, but also by their behavior. Because suitability depends on the species, and large landscape connectors (e.g., tunneling or elevated road sections over long distances) are rare, providing a variety of different types of safe crossing opportunities generally provides connectivity for more species than implementing only one type, even if that structure is relatively large. Thus, providing a variety in type and dimensions of crossing structures along a corridor appears advisable.

It is important to consider designing wildlife crossing structures for a wide array of species with different home range sizes, mobility and habitat requirements, rather than focusing on a few selected target species. While the immediate concern for human safety may be with large mammals, many other species may be affected by roads and traffic and mitigation measures that increase the barrier effect of the road.

Consider making the interval between wildlife crossing structures, their location, type, and dimensions interval more "attractive" if the crossing structures are to serve:

- Individuals that disperse.
- Individuals, populations, or species that display seasonal migration.
- Individuals or species that may not be habituated to roads, traffic and associated disturbances.

Individuals, populations or species that live in the immediate vicinity of the road or that are habituated to roads and traffic and associated human disturbance may have lower requirements with regard to wildlife crossing structures.

Table 5. Suitability of different types of crossing structures for selected mammal species (mostly based on Clevenger et al., 2008).⁽⁴⁾ For the purpose of comparison, wildlife overpasses (see section 4.4) are also included in this table.

	Wildlife overpass	Open-span bridge	Large-mammal underpass	Medium-mammal underpass	Small- to medium-mammal pipe
Ungulates					
Deer sp.	●	●	●	⊗	⊗
Elk	●	●	●	⊗	⊗
Moose	●	●	◐	⊗	⊗
Mountain goat	●	●	◐	⊗	⊗
Bighorn sheep	●	●	◐	⊗	⊗
Pronghorn	●	◐	◐	⊗	⊗
Carnivores					
Weasel	●	●	◐	●	●
Pine marten	●	◐	◐	●	●
Fisher	●	●	◐	⊗	⊗
Striped skunk	●	●	●	●	●
Badger	●	●	●	?	?
Wolverine	●	●	?	?	⊗
Bobcat	●	●	●	●	●
Canada lynx	●	●	?	?	⊗
Cougar	●	●	●	⊗	⊗
Fox1 (<i>V. vulpes</i> , <i>Urocyon</i>)	●	●	●	●	●
Fox2 (<i>V. macrotis</i> , <i>V. velox</i>)	●	●	◐	?	?
Coyote	●	●	●	●	●
Wolf	●	●	◐	⊗	⊗
Black bear	●	●	●	⊗	⊗
Grizzly bear	●	●	◐	⊗	⊗

- Recommended/Optimum solution
- ◐ Possible if adapted to local conditions
- ⊗ Not recommended
- ? Unknown, more data are required

✓Foundation

A location with stable and dry soil or rock is preferred to simplify foundation requirements and reduce resulting construction costs. Much depends on the type of crossing structure, its weight, and the local soil and hydrology.

✓Surrounding Terrain

Wildlife underpasses are typically constructed at locations where the roadway is relatively high compared to the surrounding terrain (figure 51). This reduces the need to raise the roadbed or to lower the approaches to the underpass, meaning less overall excavation is required.

Regarding wildlife approaches to the underpass, it is advisable to use a design that:

- Allows animals to see through to the other side and not require them to descend into a "cave" or have to climb out on the other side.
- Avoids flooding of the underpasses and the associated soil erosion.

These suggestions notwithstanding, the structures should be located where animals are likely to use them; not all underpasses should be located in road fills.



Figure 51. Wildlife underpasses are often installed in low-lying areas with road fill because construction costs are lower (copyright: Marcel Huijser).

✓ Fence

At wildlife underpasses, the wildlife fencing alongside the road corridor typically ties into the wing walls of the underpass or the structure itself (figure 52).



Figure 52. Wildlife fencing ties in with the underpass wing walls, preventing animals from entering the road corridor (copyright: Marcel Huijser).

Figure 53 shows how gaps between the fence and the crossing structure can allow animals to enter the roadway.



Figure 53. This fence post leaves more space than desired between the post and the wing walls of a crossing structure, allowing some medium- or large-sized mammals to enter the road corridor (copyright: Marcel Huijser).

With small underpasses such as small- to medium-sized culverts, the fencing can continue on top of the structure (figure 54). Naturally, the approaches to a crossing structure are not fenced.



Figure 54. The wildlife fencing continues above a box culvert for medium-sized mammals (copyright: Marcel Huijser).

✓ Soil Depth and Substrate

Because of limited light and moisture, underpasses typically have little or no vegetation. However, natural soil is preferred over unnatural substrate such as corrugated metal or concrete for covering the bottom or floor of the underpass. In such situations, soil, preferably from the immediate surroundings, may be used in a layer greater than 15 cm (6 in) (figure 55). If water would wash the substrate away at certain times of year, consider a concrete layer on top of the corrugated metal of a culvert. Open bottom underpasses typically already have the natural substrate of the surrounding area.



Figure 55. Soil in corrugated metal culvert makes it more suitable for use by wildlife (copyright: Marcel Huijser).

✓ Habitat Inside Underpasses

- The habitat of the approaches and inside the underpasses should reflect that of the surroundings and the habitat requirements of the target species as much as possible. Often, this requires the presence of multiple habitat types, which can also influence the width of the crossing structure as it takes space to create multiple habitat types. The different habitat types should span the entire structure, should continue in the approaches to the underpass, and should be integrated with the adjacent habitat.
- Preferably, use only native species for plantings near underpasses, and if possible use only seeds or plants from the immediate surroundings.
- Wildlife underpasses typically have insufficient light and moisture to allow for plant growth inside the structure. However, if the underpass goes under a divided highway, the underpass may have an "open roof" at the median that would allow for vegetation growth. Wildlife fencing must be installed in the median to prevent wildlife from entering the road corridor.
- Tree stumps, branches, rocks and other natural material is often positioned inside wildlife underpasses to provide cover to small- and medium-sized animals. If wet habitat or streams are present (see also section 4.5), underpasses can also provide habitat for (semi-) aquatic species including amphibians.

4.3.3. Implementation Considerations

✓ Adjacent Land Use

- Adjacent lands, beyond the right-of-way, should be secured where possible. Land acquisition or zoning may need to be considered to protect the land that serves as an approach to the crossing structures. Note that the life span of underpasses is typically projected at about 75 years.

✓ Disturbance in the Surroundings

- Human activity and human-related disturbance should be avoided as much as possible in the vicinity of wildlife crossing structures, including the approaches.
- Depending on local conditions, also consider relocating streetlights or other light sources that may be in the immediate vicinity of a crossing structure.
- Locations with frontage roads should be avoided, or additional mitigation measures for the frontage road may need to be considered.
- Discourage livestock from accessing the wildlife underpasses for shade. The presence and smell of livestock (including their feces and urine) may discourage wildlife from using the underpass. Figure 56 shows the use of livestock fencing (four strands—the top and bottom strands are smooth rather than barbed wire) that keeps livestock from accessing the underpass.
- Consider designing underpasses to minimize noise disturbance from the road (e.g., employing sound-attenuating walls above the entrances).



Figure 56. A wildlife underpass with livestock fencing along U.S. Highway 93 in Montana (copyright: Marcel Huijser).

✓ **Avoid Habitat Destruction During Construction**

- Habitat destruction during construction activities should be avoided or minimized, especially in the areas around the crossing structures themselves. For open-span bridges, this is particularly important with regard to the area under the bridge.
- Consider erosion control and re-vegetation after construction to restore the natural conditions, and to provide cover at the approaches to the crossing structures (figures 57 and 58).



Figure 57. After construction, straw mats were used to protect slopes from erosion and rapid establishment of weeds along U.S. Highway 93 in Montana (copyright: Marcel Huijser).



Figure 58. Native shrubs and trees were planted at the approaches to crossing structures along U.S. Highway 93 in Montana (copyright: Marcel Huijser).

✓ **Baiting or Cutting Trails**

- If appropriate, consider baiting crossing structures with attractants such as salt or hay immediately after completion of the mitigation measures. If crossing structures are combined with wildlife fencing, the usual routes travelled by animals may no longer be available. This may justify luring the animals to the crossing structures and facilitating the approach (e.g., cutting trails that lead to the crossing structures) to help them learn the location of the crossing structures and that it is safe to use them.
- Consider reducing or stopping such efforts after wildlife activity at the underpasses has reached a desired level.

4.3.4. Example Cost Estimates

✓ **Open-span Bridges**

The costs for an open-span bridge along the two-lane U.S. Highway 93 on the Flathead Reservation in Montana (across the Jocko River seasonal side canal) were estimated at \$435,340 (in 2007 \$) (\$423,483 in 2006) (personal communication, Pat Basting, Montana Department of Transportation). The bridge measured 30 m (98.4 ft) in width (road width) and 12 m (39.4 ft) in length (road length). Because of slopes, the effective width of the underpass was less than 12 m (39.4 ft).

Underpasses under open-span bridges across the four-lane Trans-Canada Highway in Banff National Park (Phase 3-A) measure about 12 m (39.4 ft) in width and about 5 m (16.4 ft) in height. Costs were estimated to be between \$675,597 and \$965,139 (in 2007 \$) Can\$700,000–1 million (in about 1996) (personal communication, Terry McGuire, Parks Canada). In 2007, based on the construction on the Trans-Canada Highway in the Lake Louise area, the costs for a 16 to 25 m-wide (52.5 to 82.0 ft wide) underpass structure across a two-lane road, including traffic control and detour, was estimated at \$2,350,000 (in 2007 \$) (Can\$2.5 million in 2007) (personal communication, Terry McGuire, Parks Canada)

✓ **Large-Mammal Underpasses**

In this guide, large-mammal underpasses are defined as structures that are not bridges but, for instance, box culverts or arched culverts that are at least 7–8 m (23.0–26.2 ft) wide and 4–5 m (13.1–16.4 ft) high.

Large-mammal underpasses along the four-lane Trans-Canada Highway in Banff National Park (Phase 3-A) measure about 7 m (23.0 ft) in width and 4 m (13.1 ft) in height. Costs were estimated between \$217,156 and \$241,285 (in 2007 \$) (Can\$225,000 to Can\$250,000 in about 1996) (personal communication, Terry McGuire, Parks Canada).

Three large-mammal wildlife underpasses, all arched culverts, along the two-lane U.S. Highway 93 on the Flathead Reservation in Montana (south of Ravalli) measure about 7–8 m (23.0–26.2 ft) in width and about 5 m (16.4 ft) in height. The length (road width) varies between 18.3 and 21.9 m (60.0–71.8 ft). The costs were estimated at about \$223,076 (in 2007 \$) (\$217,000 in 2006) (personal communication, Pat Basting, Montana Department of Transportation).

In The Netherlands, large-mammal underpasses 7–10 m (23.0–32.8 ft) wide and about 4 m (13.1 ft) high were estimated at \$38,192 to \$63,654 (in 2007 \$) per meter of road width (€30,000–€50,000 in 2005).⁽²⁷⁾ Assuming a road width of 20 m (65.6 ft), the costs were \$763,845–\$1,273,075 (in 2007 \$) (€600,000–€1,000,000 in 2005).

✓ Medium-Mammal Underpasses

Medium-mammal underpasses are defined herein as box culverts or culverts that are between 0.8 and 3 m (2.6–9.8 ft) wide, and 0.5 and 2.5 m (1.6–8.2 ft) high.

Medium-mammal box culverts under the four-lane Trans-Canada Highway in Banff National Park (Phase 3-A) measure about 3 m (9.8 ft) in width and 2.5 m (8.2 ft) in height. Costs were estimated at \$173,725 (in 2007 \$) (Can\$180,000 in about 1996) (personal communication, Terry McGuire, Parks Canada). In 2007, based on construction on the Trans-Canada Highway in the Lake Louise area, the costs for a box or elliptical culvert 3–4 m (9.8–13.1 ft) wide and high across a two-lane road were estimated at approximately \$940,000 (in 2007 \$) (Can\$1 million), including traffic control and detour (personal communication, Terry McGuire, Parks Canada).

Two medium-mammal box culverts 1.2–1.8 m (3.9–5.9 ft) wide, 1.2–1.8 m (3.9–5.9 ft) high and 27.5 m (30.1 yd) long, and one medium-mammal culvert about 2 m (6.6 ft) wide, 1.5 m (4.9 ft) high and 27.5 m (90.2 ft) long along the two-lane U.S. Highway 93 on the Flathead Reservation in Montana (south of Ravalli) were estimated at about \$70,932 each (in 2007 \$) (\$69,000 each in 2006) (personal communication, Pat Basting, Montana Department of Transportation).

In The Netherlands, medium-mammal box culverts 0.8–1.3 m (2.6–4.3 ft) wide, 0.5–0.75 m (1.6–2.5 ft) high were estimated at \$1,528–\$3,183 (in 2007 \$) per m (road width) (€1,200–2,500 in 2005).⁽²⁷⁾ Assuming a road width of 20 m (65.6 ft), the costs were \$30,554–\$63,654 (in 2007 \$) (€24,000–50,000 in 2005).

✓ Small- and Medium-Mammal Pipes

Small- and medium-mammal pipes are defined for the purposes of this guide as those that measure about 0.3–0.6 m (1.0–2.0 ft) in diameter. In The Netherlands, small- and medium-mammal pipes, or "badger pipes," 0.6 m (2.0 ft) in diameter, were estimated at \$891–\$1,528 (in 2007 \$) per m (€700–€1,200 in 2005).⁽²⁷⁾ Assuming a road width of 20 m (65.6 ft), the costs were \$17,823–\$30,554 (in 2007 \$) (€14,000–€24,000 in 2005).

4.3.5. Maintenance

- It is important to ensure that diversity in vegetation and habitat is maintained in later years as the vegetation matures and succession may make an approach to a crossing structure less open than desirable.
- Human use of the area around the crossing structures and of the crossing structures themselves should be monitored. If necessary, consider taking measures to discourage human use.
- If wildlife crossing structures are not being monitored on a regular basis, specific periodic visits should be made to ensure that there are no obstacles or foreign matter in or near the crossing structures that might affect wildlife use.

4.4. WILDLIFE OVERPASSES

Wildlife overpasses are primarily designed to provide connectivity for wildlife species, often in combination with wildlife fencing. However, overpasses are sometimes also deployed as stand-alone mitigation measures, with no or limited fencing. When used in combination with wildlife fencing, they help reduce intrusions into the road corridor as animals are provided with a safe crossing opportunity. When used as a stand-alone mitigation measure, the reduction in wildlife-vehicle collisions may be limited to the immediate vicinity of the overpass.

4.4.1. Effectiveness in Reducing Collisions with Large Mammals

The effectiveness of "crossing structures" (i.e., underpasses and overpasses combined) in reducing large-mammal WVCs has been estimated at 79–97 percent, with **an average of 86 percent, when used in combination with large-mammal fencing** (see section 4.2).

4.4.2. Technical Specifications

✓ Crossing Structure Types

For the purpose of this handbook one type of wildlife overpass is discussed—those that are 50–70 m (164.0–229.7 ft) wide (figure 59). Combined with the wildlife underpasses described in section 4.3, this handbook describes five types of crossing structures that serve a wide range of mammal species from small to large. For a more exhaustive discussion on the implementation and design specifications for a large number of wildlife crossing structure types, please consult Clevenger and others.⁽⁴⁾ In addition, a limited number of crossing structures that can be or have been implemented for threatened and endangered species are discussed in chapter 5. See Table 5 in section 4.3 (Wildlife Underpasses) for the suitability of wildlife overpasses for different species and species groups.



Figure 59. Red Earth Overpass on the Trans-Canada Highway in Banff National Park, Alberta (copyright: A.P. Clevenger).

✓ **Foundation**

A location with stable and dry soil or rock is preferred to simplify foundation requirements and reduce resulting construction costs. Much depends on the type of crossing structure, its weight, and the local soil and hydrology.

✓ **Surrounding Terrain**

Wildlife overpasses are typically constructed at a location where the terrain on either side of the road is higher than the road (figure 60). This situation allows for:

- A more gradual approach (ideally, a 5:1 slope or less) to the overpass and allows the animals to see across to the other side when deciding whether to cross.
- Reduced amount of fill material needed for the approaches.

These suggestions notwithstanding, the structures should be located where animals are likely to use them; not all overpasses should be located in road cuts and not all underpasses should be located in road fills.



Figure 60. A wildlife overpass in Germany. The terrestrial habitat connected by the overpass is at a higher elevation than the roadway (copyright: Mary Gray, FHWA).

✓ **Fence, Screens and Berms**

A wildlife overpass typically has wildlife fencing on both sides to prevent animals from jumping off the overpass into the traffic below. This fence is seamlessly connected to the wildlife fencing along the road corridor (figure 61).



Figure 61. This fence for amphibians and medium- and large-sized mammals connects well to the fence on the wildlife overpass "Waterloo" near the town "Roermond", The Netherlands. Note that the fence on the wildlife overpass also acts as a light and sound barrier (copyright: Marcel Huijser).

Wildlife overpasses usually have berms or screens greater than 2.5 m (8 ft) attached to the side to reduce the exposure of animals on the overpass to the sound and light from the traffic below (figures 62, 63 and 64).

- If a sound and light barrier is high and strong enough it can replace a wildlife fence on top of wildlife overpasses.
- On relatively narrow overpasses care must be taken that these barriers do not create a tunnel effect. To reduce the tunnel effect, the sound and light barrier can be directed slightly outwards.
- Note that lightweight materials other than soil may be used for the core of berms to reduce the weight and thus the required load-bearing capacity of the structure.
- Screens should be placed on the outer edges of a structure as they would otherwise reduce the effective width of the overpass for wildlife.



Figure 62. The wildlife overpass "Waterloo" with wildlife fencing across the A73 motorway near the town "Roermond", The Netherlands, consists of planks that also act as a light and sound barrier (copyright: Marcel Huijser).



Figure 63. The wildlife fencing on the wildlife overpass "Waterloo" across the A73 motorway near the town "Roermond", The Netherlands, consists of planks that also act as a light and sound barrier (copyright: Marcel Huijser).



Figure 64. The wildlife fencing on the wildlife overpass "Waterloo" across the A73 motorway near the town "Roermond", The Netherlands. Note that the concrete barrier prevents small animal species from falling off the overpass (copyright: Marcel Huijser).

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✓ Soil Depth and Substrate

Depending on the target species, different types of habitat may need to be created on top of a wildlife overpass or inside a wildlife underpass. The overpass should be designed accordingly and have sufficient soil depth, sufficient soil fertility, and suitable hydrology if, for example, trees or shrubs are to grow on top of the overpass. The following soil depth is recommended for overpasses in a temperate climate with annual precipitation of approximately 800 mm (31 in):⁽²⁷⁾

- Grasses and herbs: greater than 0.3 m (1 ft).
- Shrubs: greater than 0.6 m (2 ft).
- Trees: greater than 1.5 m (5 ft).

Soil depth can be varied to promote variation in vegetation and physical conditions on overpasses. Use soil from the immediate surroundings as much as possible. On some overpasses concrete beams have been attached across the width of the overpass to keep moisture from running off too quickly. In addition, impermeable soil can be used to create a wetter zone that holds water longer than the adjacent soil to create attractive habitat for (semi-)aquatic species, including amphibians.

✓ Habitat on Overpasses

The habitat on top of overpasses should reflect that of the surroundings and the habitat requirements of the target species. Often, this requires the presence of multiple habitat types, which can also influence the width of the crossing structure, as it takes space to create multiple habitat types. The habitat on top of wildlife overpasses may include:

- Open habitat (grasses, herbs).
- Cover (shrubs, trees, tree stumps, logs, branches, rocks) (figures 65, 66, and 67).
- Ditches or depressions, and berms (on the sides).
- Wet areas or (artificial) streams.



Figure 65. Small trees, shrubs and grass vegetation on top of one of the overpasses along the Trans-Canada Highway in Banff National Park, Alberta (copyright: Marcel Huijser).



Figure 66. A row of tree stumps leading animals to and across the wildlife overpass "Waterloo" across the A73 motorway near the town "Roermond", The Netherlands (copyright: Marcel Huijser).

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Figure 67. Newly planted shrubs (foreground) and a row of tree stumps on the De Borkeld wildlife overpass across the A1 motorway in The Netherlands (copyright: Marcel Huijser).

- The different habitat types should span the entire structure, should continue in the approaches to the crossing structure, and should be integrated with the adjacent habitat.
- Consider planting higher shrubs and trees on the north or east side of an overpass to avoid shading out the overpass entirely.
- Tree species that grow tall and that have large and deep root systems should be avoided on an overpass because of concerns for the integrity of the structure and the potential for the trees to fall on the traffic below. Limit tree height to about 2.5–4 m (8–12 ft).
- Many overpasses have artificially created ponds and attractive vegetation (e.g., berry producing shrubs) on at least one side of wildlife overpasses to encourage animals to visit the location and use the crossing structure (figure 68).
- Preferably, use only native plant species, and if possible use only seeds or plants from the immediate surroundings.



Figure 68. An artificial pond on the approach of the wildlife overpass "Waterloo" across the motorway A73, near the town "Roermond", The Netherlands (copyright: Marcel Huijser).

4.4.3. Implementation Considerations

✓Design Overpass

Different constructions and designs may be considered when designing wildlife overpasses, including steel or concrete arches or bridge spans. A wildlife overpass may be rectangular or hourglass shaped (figure 69), each of which come with their own construction and design considerations and costs. Note that the dimensions in table 6 relate to the minimum width of crossing structures—i.e., the middle of the hourglass.

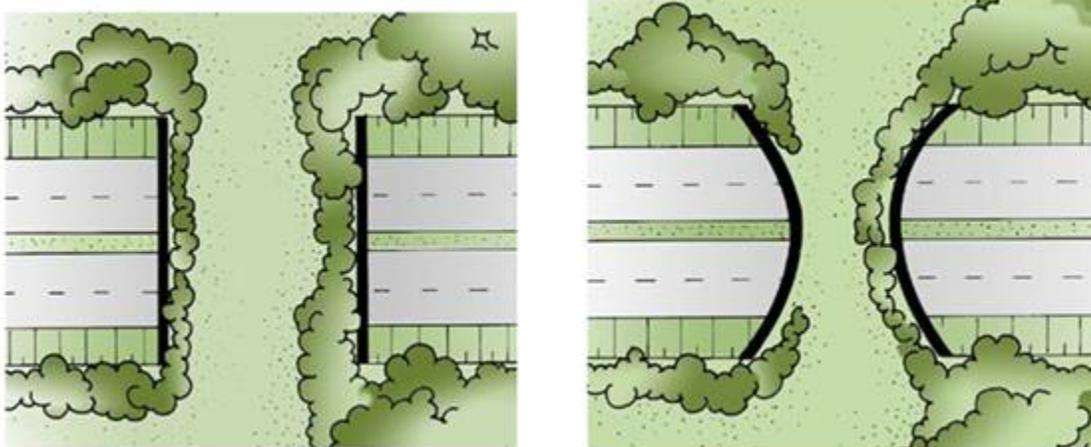


Figure 69. A rectangular and an hourglass-shaped wildlife overpass design (reprinted with permission from Kruidering et al., 2005).⁽²⁷⁾

✓ **Adjacent Land Use**

Adjacent lands, beyond the right-of-way, should be secured for at least the life span of the crossing structures (about 75 years). Land acquisition or zoning may need to be considered to protect the land that serves as an approach to the crossing structures.

✓ **Disturbance in the Surroundings**

- Human activity and human-related disturbance should be avoided as much as possible in the vicinity of wildlife crossing structures, including the approaches.
- Depending on local conditions, also consider relocating streetlights or other light sources that may be in the immediate vicinity of a crossing structure.
- Locations with frontage roads should be avoided, or additional mitigation measures for the frontage road may need to be considered.
- Livestock should be discouraged or prevented from accessing the wildlife overpasses through the use of livestock fencing or other means. The presence and smell of livestock (including their feces and urine) may discourage wildlife from using the overpass.

✓ **Habitat Destruction during Construction**

- Habitat destruction during construction activities should be avoided or minimized, especially in the areas around the crossing structures themselves.
- Consider re-vegetation after construction to restore the natural conditions, and to provide cover at the approaches of the crossing structures.

✓ **Baiting or Cutting Trails**

- If appropriate, consider baiting crossing structures with attractants such as salt or hay immediately after completion of the mitigation measures. If crossing structures are combined with wildlife fencing, the usual routes travelled by animals may no longer be available. This may justify luring the animals to the crossing structures and facilitating the approach (e.g., cutting trails that lead to the crossing structures) to help them learn the location of the crossing structures and to understand that it is safe to use them.
- Consider reducing or stopping such efforts after wildlife activity at the overpasses has reached a desired level.

4.4.4. Example Cost Estimates

Wildlife overpasses across the four-lane Trans-Canada Highway in Banff National Park (Phase 3-A) were estimated to cost \$1,688,993 each (in 2007 \$) (Can\$1.75 million each in about 1996) (personal communication, Terry McGuire, Parks Canada). The overpasses were 52 m wide and 70 m long (170.6 ft x 229.7 ft), crossing four lanes of traffic. In 2007, based on construction on the Trans-Canada Highway in the Lake Louise area, the costs for a 60-m-wide (196.9 ft) overpass across a two-lane road was estimated at \$3,290,000 to \$3,760,000 (in 2007 \$) (Can\$3.5 million to Can\$4 million in 2007), including traffic control and detour (personal communication, Terry McGuire, Parks Canada).

A proposed overpass across Montana Highway 83 near Salmon Lake (a two-lane road) was estimated to cost \$1,542,000 to \$2,467,200 (in 2007 \$) (\$1.5 million to \$2.4 million in 2006) (personal communication, Pat Basting, Montana Department of Transportation).

The costs for six wildlife overpasses (30–50 m wide (98.4–164.0 ft)) across four-lane roads in The Netherlands ranged between \$4,684,045 and \$19,408,640 (in 2007 \$) (€3,500,000 and €14,750,000 in about 2005) (table 6).

Table 6. Characteristics of wildlife overpasses in The Netherlands (Partially based on Kruidering et al. (2005) and personal communication, Hans Bekker, Ministerie van Verkeer en Waterstaat, the Netherlands).⁽²⁷⁾

Name of wildlife overpass	(Rail)road and nearby towns	Dimensions	Costs (in 2007 \$ and in 2004 Euros)	Year completed	Comments
Terlet	A50 between Arnhem and Apeldoorn	50 m (164 ft) wide, 95 m (312 ft) long	\$4,817,875 (€3,600,000)	1988	Across a four-lane motorway and a frontage road. Pond on the east side of the overpass.
Woeste Hoeve	A50 between Arnhem and Apeldoorn	45 m (148 ft) wide, 140 m (459 ft) long	\$4,817,875 (€3,600,000)	1988	Across a four-lane motorway and a frontage road.
Boerskotten	A1 near Oldenzaal	Hourglass shape, 15 m (49 ft) wide in middle of span, 80 m (262 ft) long	\$1,873,618 (€1,400,000)	1992	Across a four-lane motorway.
Harm van de Veen	A1 near Kootwijk, between Amersfoort and Apeldoorn	Hourglass shape, 80 m (262 ft) wide at each end, 30 m (98 ft) wide in middle of span	\$4,817,875 (€3,600,000)	1998	Across a four-lane motorway. Pond on the north side of the overpass.
De Borkeld	A1 near Rijssen	Hourglass shape, 30 m (98 ft) wide at each end, 16 m (52 ft) wide in middle of span, 51.6 m (169 ft) long	\$5,085,534 (€3,800,000)	2003	Across a four-lane motorway. Pond on the south side of the overpass.

Table 6 (Continued)

Slabroek	A50 between Uden and Nistelrode	15 m (49 ft) wide	\$7,494,472 (€5,600,000)	2003	Combined with pedestrian/ bicycle path. Across a four-lane motorway and a frontage road
Leusderheide	A28 between Amersfoort and Zeist	48 m (157 ft) wide, 46 m (151 ft) long	\$4,684,045 (€3,500,000)	2005	Across a four-lane motorway
Groene Woud	A2 between Boxtel and Best	52 m (171 ft) wide	\$11,584,984 (€9,100,000*)	2005	With wet zone, including a water pump and ponds on both sides of the overpass. Across a four-lane motorway and a frontage road
No name	N297 between Nieuwstadt and Sittard	3 m (10 ft) wide, 42 m (138 ft) long	\$369,192 (€290,000*)	2005	A combination of an overpass and a badger tunnel (40 cm diameter), buried inside the overpass as the four-lane road was constructed in a trench
Crailoo	Naarderweg (N524) and railroad between Hilversum and Bussum	50 m (164 ft) wide, 800 m (2,625 ft) long, two bridges and several sections of fill	\$19,408,640 (€14,750,000*)	2006	Combined with pedestrian/bicycle path. Ponds on both sides of the overpass. Across a two-lane road, a railroad, a railroad yard, and sport fields.
Waterloo	A73 near Beesel	40 m (131 ft) wide, 100 m (328 ft) long	\$3,264,000 (€2,400,000)	2007	Combined with pedestrian path. Across a four-lane motorway. Construction costs were part of larger project

* cost in year of completion

Note that some of the wildlife overpasses are actually multi-functional overpasses (see section 4.6)

4.4.5. Maintenance

- Vegetation maintenance on top of wildlife overpasses (e.g., supply water and fertilizer, weed control) may be required in the first few years after planting. The same applies to plantings in the approaches to the crossing structures.
- It is important to ensure that diversity in vegetation and habitat is maintained in later years, as the maturing vegetation and succession may make an overpass or an approach to an overpass less open than desirable.
- Human use of the area around the crossing structures and of the crossing structures themselves should be monitored. If necessary, consider taking measures to discourage human use.
- If wildlife crossing structures are not being monitored on a regular basis, specific periodic visits should be made to ensure that there are no obstacles or foreign matter on or near the crossing structures that might affect wildlife use.

4.5. MULTIPLE USE UNDERPASSES

Multiple use underpasses are not only designed for use by wildlife, but also for water flow, roads or railroads that cross under the main road (including farm roads), and bike or pedestrian paths. Because of this multiple use concept, compromises are inevitable. With regard to connectivity for wildlife, multiple use crossing structures may be exposed to more disturbance than structures that are strictly designed for wildlife. On the other hand, species associated with specific habitat—e.g., streams, rivers, riparian habitat, or vegetation associated with streams—may benefit more from a wildlife crossing structure when it is combined with a stream or river crossing. Similarly, if a crossing structure is constructed because of human transportation needs (e.g., a road or railroad crossing, or a bike or pedestrian path), wildlife may benefit if the crossing structure is not solely designed for human transportation but is modified to encourage co-use by wildlife. A wildlife crossing structure that is adapted for human transportation needs, may affect use by certain wildlife species. Note that many of the considerations for "wildlife only" underpasses (section 4.3) also apply to multiple use underpasses.

4.5.1. Effectiveness in Reducing Collisions with Large Mammals

The effectiveness of underpasses in reducing large-mammal WVCs has been estimated at 79–97 percent, with **an average of 86 percent, when used in combination with large-mammal fencing** (see section 4.2).

4.5.2. Technical Specifications

✓ Stream Sizes and Seasonal Dynamics in Water Flow

- Stream characteristics and stream dynamics must be carefully studied to ensure that the conditions inside the crossing structure are and remain similar to that of the stream up- and downstream of the structure. Parameters of importance can include:
 - Water velocity.
 - Water depth.
 - Turbulence.
 - Variability in water velocity.
 - Sediment.
 - Debris blockage.
 - Erosion of substrate inside the crossing structure or upstream and downstream of the structure (figure 70).
 - Implications of high- and low-water events, including debris and maintenance issues.
- In general, wide crossing structures with open bottoms are preferable to narrow structures with bottoms that are part of the structure (unless the structure bottom is well embedded).



Figure 70. Structures built to pass water typically should be designed to avoid erosion and allow passage of aquatic species. The structure shown has no adaptations for terrestrial species and is also likely to be impassable for many aquatic species (copyright: Matt Blank).

✓Width and Clearance of Walkways

Streams and rivers vary greatly in size and the relative space for the stream or river on one hand, and the terrestrial habitat on the other can also vary greatly. Figure 71 shows a box culvert for a stream that has been modified to allow for the passage of small- and medium-sized mammals along walkways inside the culvert. The walkways can be made out of different materials (e.g., wood, steel, or concrete), and may be integrated in the original construction or added as a retrofit. It is important that the walkways are accessible to the terrestrial animals and that slightly lower or higher water levels do not immediately make the walkways inaccessible.

Dimensions of Walkways:

- For small- and medium-sized species (up to marten and rabbit size), a minimum walkway width of 0.5–0.7 m (1.6–2.3 ft) is recommended. Preferred walkway width is about 1 m (3.3 ft). Minimum clearance between the walkway and the ceiling of an underpass is about 0.6 m (2 ft) or greater.
- For large mammals the minimum width of the walkway is about 2 m (6.5 ft). Preferred walkway width is greater than 3 m (10 ft). For large mammals, minimum clearance

between the walkway and the ceiling of an underpass is about 3 m (10 ft). Preferred clearance is about 4 m (13 ft) or greater.

✓ **Walkways in Culverts Modified for Wildlife Use**

The top side of the walkways should consist of material that has a relatively rough surface that animals will not slip on. In some situations, where erosion danger is low, soil may be placed on the walkways. Some walkway designs have a hollow beam or tube integrated into the walkway design or attached to the walk way to encourage small mammals (mice, voles) to use the walkway.

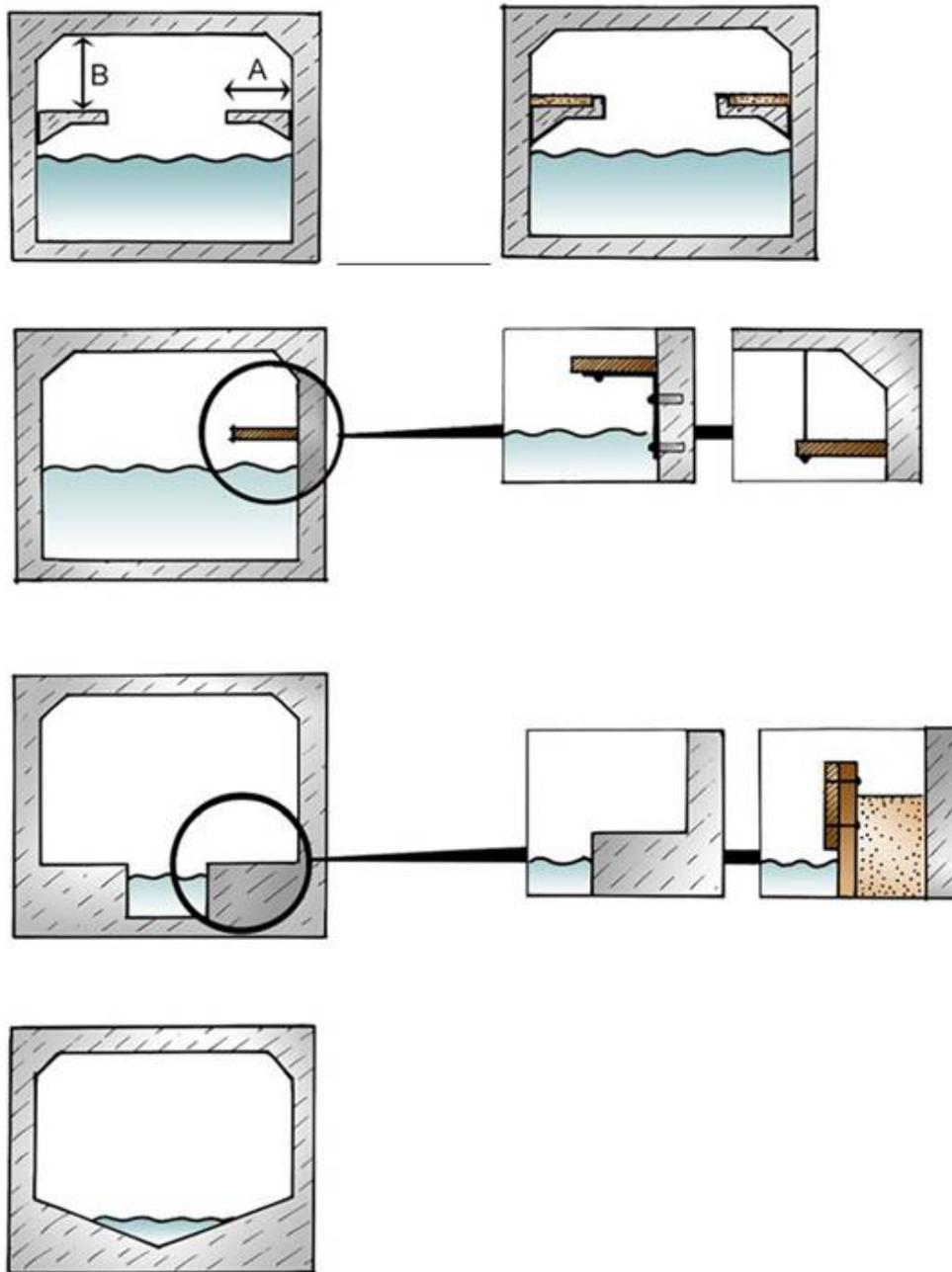


Figure 71. Different walkway designs for small- and medium-sized mammals (e.g., up to marten and rabbit size) in box culverts (retrofitted or integrated design). A = minimum 0.5–0.7 m (1.6–2.3 ft), preferred 1m (3.3 ft), B= 0.6 m (2 ft) (reprinted with permission from Kruidering et al., 2005).⁽²⁷⁾

It is important that walkways are well connected to the banks and that small- and medium-sized mammals can access the walkway regardless of stream level (figure 72). The angle of the walkway where it connects to the bank should be 30–45° at a maximum.

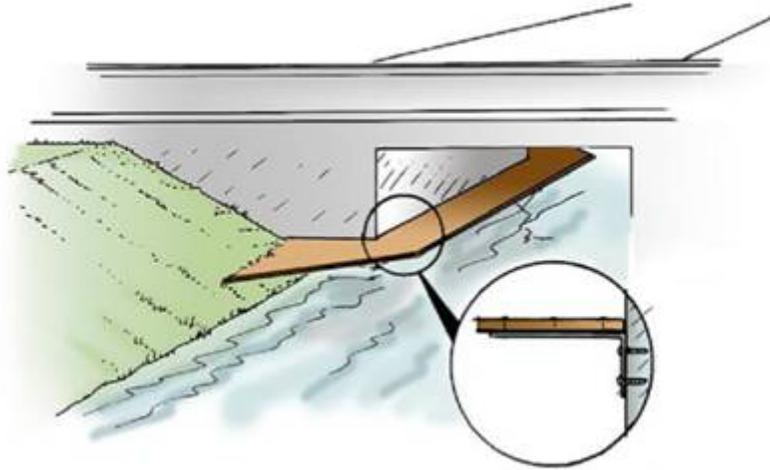


Figure 72. Connection of walkway to adjacent bank (reprinted with permission from Kruidering et al., 2005).⁽²⁷⁾

✓ Wildlife Passage in Stream Underpasses with Variable Water Flow

When underpasses are designed specifically for streams, particularly streams with variable flow rates, they can often easily incorporate wildlife passage. Figure 73 shows the bed of a seasonal creek that is relatively small. Most of the space in the underpass is accessible for terrestrial species.



Figure 73. Wildlife underpass (large-mammal culvert) along U.S. Highway 93 in Montana with a ditch that allows water to flow (seasonally) (copyright: Marcel Huijser).

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Figure 74 shows a creek of a similar size, but this underpass also provides a connection between a larger river and an old arm of the river that will flow when water levels in the main channel rise above a certain level. Note that the straw bundles along the creek were placed to reduce erosion just after construction. Also note the slight berm to the left side of the creek, to allow it to rise some before it overflows, keeping the underpass dry and accessible to terrestrial species.



Figure 74. Wildlife underpass (over-span bridge) in combination with a creek crossing along U.S. Highway 93 in Montana (copyright: Marcel Huijser).

Figure 75 shows the same underpass as in figure 74, except during high water flow. Although the underpass remains mostly unusable for terrestrial animals during high flow, these slight design modifications can make it usable for most of the rest of the year.



Figure 75. The same wildlife underpass as in figure 74 during spring runoff (copyright: Tiffany Holland).

Figures 76 and 77 show larger creeks that flow year-round. The banks have been stabilized with larger rocks, and walkways have been provided to allow terrestrial species to cross under the over-span bridge.



Figure 76. Over-span bridge across a stream, with a bank and walkway for terrestrial large-mammal species along the Trans-Canada Highway, Banff National Park, Alberta (copyright: Marcel Huijser).

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Figure 77. Concrete walkways for wildlife on both banks of a creek at an over-span bridge along U.S. Highway 93, south of Missoula, MT (copyright: Marcel Huijser).

The walkways in figure 77 are made of concrete, which some animals may avoid. Finding a balance between material that will not wash out during high flows but is desirable for animals can be a challenge. One solution is to use concrete covered with several centimeters of topsoil. This topsoil may wash out every few years, but it can be easily replaced. Note that the creek is starting to undercut the concrete path on the left side of figure 77.

Figure 78 shows a bridge across a river where the banks and slope are protected with large rocks. However, a path has been cleared to allow people and large mammal species to pass under the bridge.



Figure 78. Walkway cleared of large rocks, for people and large mammals, along State Highway 75 between Ketchum and Hailey, ID (copyright: Marcel Huijser).

Figure 79 shows a bridge across a river that also spans several tens of meters of bank on either side of the river. This approach allows for some changes in the location of the river bed, it allows for passage of large terrestrial mammals, and it allows for flooding events.



Figure 79. Bridge across the Jocko River, along U.S. Highway 93 in Montana (copyright: Marcel Huijser).

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✓ Roads, Farm Roads and Recreational Bike and Pedestrian Paths

Underpasses constructed to provide access for farmers and livestock may also be used by wildlife (figure 80). To encourage wildlife use, access to the underpass by livestock may be limited to occasional movement between pastures. Gates that can be closed can be installed to prevent livestock from accessing the underpass, except when changing pastures. The gate is not a substantial barrier for most wildlife species, but the gates should be left open if there are no livestock in the area.



Figure 80. An underpass designed for wildlife and human access, farm machinery and livestock along U.S. Highway 93, south of Missoula, MT (copyright: Marcel Huijser).

- Underpasses for roads designed to encourage co-use by wildlife may only be feasible if traffic intensity is relatively low.
- Cover such as tree stumps or rocks may be provided on one or both sides of an underpass (figure 81 and 82).
- If a median and an "open roof" is present in the underpass, trees, shrubs and other vegetation may grow halfway through the underpass (figures 81 and 82).
- In some cases, light from cars may be shielded to minimize disturbance (figures 83 and 84).
- For roads that receive little to no use, consideration may be given to change a paved road into a gravel or dirt road, or remove the road altogether.



Figure 81. An underpass for a road (Lage Vuurscheweg) under the motorway A27 near the town "Hilversum", The Netherlands, that was modified with soil and tree stumps to encourage co-use by wildlife (target species included invertebrates, amphibians, reptiles, and small- and medium-sized mammals). Note that light and moisture allow for shrubs in the gap in the median (foreground) and that tree stumps provide cover under the bridge for northbound traffic (background) (copyright: Marcel Huijser).



Figure 82. An underpass for a road (Hilversumsestraatweg) under the motorway A27 near the town "Hilversum", The Netherlands, that was modified with soil and tree stumps to encourage co-use by wildlife. Note that light and moisture allow for shrubs and trees in the gap in the median (background) and that tree stumps provide cover under the bridge for northbound traffic (foreground) (copyright: Marcel Huijser).



4 Figure 83. An underpass for a road (Hilversumsestraatweg) under the motorway A27 near the town "Hilversum", The Netherlands, that was modified with soil and tree stumps to encourage co-use by wildlife to the right of the fence. The purpose of the fence, which is painted black, is to reduce light and noise disturbance from traffic (copyright: Marcel Huijser).



Figure 84. Close-up of the fence, painted black, aimed at reducing light and sound disturbance from traffic (copyright: Marcel Huijser).

4.5.3. Implementation Considerations

✓ Stream and River Crossings

Adapting stream and river crossings in such a way that they become more passable by terrestrial animal species requires a structure larger than the stream itself, as the banks of the stream or river have to be included to provide a dry passage. Additional benefits of large structures consist of:

- More space for potential ecosystem processes (e.g., room for the channel dynamics in the river or stream).
- Reduced maintenance costs related to removal of debris in undersized structures that may hinder the water flow.

Note: If wildlife crossing opportunities are only provided at stream or river crossings, species of drier habitat away from rivers and streams may not benefit sufficiently from these crossing opportunities.

✓ Farm Roads and Recreational Bike and Pedestrian Paths

- Suitable habitat must be available on both sides of the structure.
- Paths or riding trails intended for human use should be confined to one side of a crossing structure rather than in the middle, leaving greater space for wildlife use. Vegetation or other cover such as tree stumps, rocks or screens can be used to reduce the impact of human use on wildlife.

While co-use opportunities (by people and wildlife) are inherently attractive, several items require careful evaluation before moving ahead with them.

- When the crossing structure is in an important or sensitive ecological area or if the target species for the crossing structure are sensitive to human disturbance, wildlife and human use should probably not be combined in the same structure. Two separate structures should be considered in this case.
- When the crossing structure is located in a multifunctional landscape with considerable human disturbance, and if the target species for the crossing structure are not very sensitive to human disturbance, and perhaps even thrive with a certain level of human disturbance (for example, raccoons thrive in an agricultural landscape), wildlife and human use can probably be combined in the same structure.

4.5.4. Example Cost Estimates

If the main function of a crossing structure is to pass water or traffic, the extra costs for wildlife only apply to the extended length of a bridge or the increased size of an underpass. See section 4.3 for costs for structures that are specifically designed for wildlife.

4.5.5. Maintenance

Inspect the underpasses regularly for problems, including debris (especially with streams and rivers), garbage, and the condition and dimensions of the banks, paths and walkways.

4.6. MULTIPLE USE OVERPASSES

Multiple use overpasses are not only designed for use by wildlife, but also for water flow, roads or railroads that cross over the main road (including farm roads), and bike or pedestrian paths. Because of this multiple use concept, compromises are inevitable. With regard to connectivity for wildlife, multiple use crossing structures may be exposed to more disturbance than structures that are strictly designed for wildlife. On the other hand, species associated with specific habitat—e.g., streams, rivers, riparian habitat, or vegetation associated with streams—may benefit more from a wildlife crossing structure when it is combined with a stream or river crossing. Similarly, if a crossing structure is needed because of human transportation needs (e.g., a road or railroad crossing, or a bike or pedestrian path), wildlife may benefit if the crossing structure is not solely designed for human transportation but is modified to encourage co-use by wildlife. Adapting a wildlife crossing structure for human transportation needs may affect use by certain wildlife species. Note that many of the considerations for "wildlife only" overpasses (section 4.4) also apply to multiple use overpasses.

4.6.1. Effectiveness in Reducing Collisions with Large Mammals

The effectiveness of under- and overpasses in reducing large-mammal WVCs has been estimated at 79–97 percent, with **an average of 86 percent, when used in combination with large-mammal fencing** (see section 4.2).

4.6.2. Technical Specifications

✓ Stream Sizes and Seasonal Dynamics

While most stream crossings involved underpasses rather than overpasses, some overpasses include stream crossings or wetland habitat. Stream characteristics and stream dynamics must be carefully studied to ensure that the conditions inside the crossing structure are and remain similar to that found upstream and downstream of the structure. Parameters of importance can include:

- Water velocity.
- Water depth.
- Turbulence.
- Variability in water velocity.
- Sediment.
- Debris blockage.
- Erosion of substrate inside the crossing structure or up- and downstream of the structure.
- Implications of high- and low-water events, including debris and maintenance issues.

✓ Width of Walkways

Streams and rivers vary greatly in size, and the relative space for the stream or river on one hand and the terrestrial habitat on the other can also vary greatly. However, it is important that the terrestrial space for the walkways is accessible to the terrestrial animals, and that slightly lower or higher water levels do not immediately make the walkways inaccessible.

- For small- and medium-sized species (up to marten and rabbit size), a minimum walkway width of 0.5–0.7 m (1.6–2.3 ft) is recommended. Preferred walkway width is about 1 m (3.3 ft).
- For large mammals the minimum width of the walkway is about 2 m (6.5 ft). Preferred walkway width is greater than 3 m (10 ft).

✓ Walkways for Wildlife Use

- The space for terrestrial mammals may have actual soil and vegetation. However, some overpasses primarily designed for water flow may consist of a concrete structure that may have walkways for terrestrial mammals attached to it. In such cases, the top side of the walkways should consist of material that has a relatively rough surface that animals will not slip on. In some situations, where erosion danger is low, soil may be placed on the walkways. Some walkway designs have a hollow beam or tube integrated into the walkway design or attached to the walkway to encourage small mammals (mice, voles) to use the walkway.
- It is important that walkways are well connected to the terrestrial habitat adjacent to the overpass and that small- and medium-sized mammals can access the walkway regardless of stream level.

✓ Roads, Farm Roads and Recreational Bike and Pedestrian Paths

- Overpasses constructed to provide access for farmers and livestock may also be used by wildlife. To encourage wildlife use, access to the overpass by livestock may be limited to occasional movement between pastures. Gates may be installed that can be closed to prevent livestock from accessing the overpass, except when changing pastures. Typically, gates are not a substantial barrier for most wildlife species, but the gates should be left open if there are no livestock in the area.
- Overpasses for roads can be modified to encourage co-use by wildlife. Such modifications may only be feasible if traffic intensity is relatively low.
- Soil depth of greater than 0.3 m (1 ft) is recommended for structures in a temperate climate with annual precipitation of approximately 800 mm (31 in).
- Cover such as tree stumps or rocks may be provided on one or both sides of an overpass (figures 85 and 86). An overpass may also allow for grass-herb vegetation. The strip should have a minimum width of 1.5–2 m (5.0–6.5 ft) for soil only and a minimum width of 2.5 m (8.2 ft) if combined with a row of tree stumps.
- Depending on the target species (e.g., for amphibians), a physical barrier, or a light and sound screen may be placed on the outer side of a bridge to reduce noise and light from the road below (figures 87 and 88).

- In general there should be no barrier between the strip intended for wildlife use and the area intended for human use so that wildlife experience the maximum dimensions of the crossing structure.
- Naturally, an overpass should be carefully evaluated for the impact of the weight of added soil and other material on its structural integrity.
- Tree stumps or other large or heavy material should be firmly attached on overpasses to prevent them from falling off or being thrown or pushed onto the road.
- The drainage of the crossing structure should not be blocked or hindered by the soil or cover on or inside the crossing structure.
- In dry areas and in areas where vandalism (e.g., setting tree stumps on fire) may be a concern, consider the use of rocks or boulders instead of tree stumps.
- For roads that receive little to no use, consideration may be given to changing a paved road into a gravel or dirt road, or remove the road altogether (figure 89).



Figure 85. A row of tree stumps, grass–herb–shrub vegetation, and a road (road name: Ericaweg, overpass name: Wallenburg) on top of an overpass across the A28 motorway near the town "Zeist", The Netherlands. The overpass was originally designed for a road only (copyright: Marcel Huijser).



Figure 86. The same overpass as figure 85 showing the gentle grade of the concrete curb, which allows small animals to access the vegetated strip (copyright: Marcel Huijser).

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Figure 87. Another view of the same overpass shows the black screen that was attached to the fence to reduce light disturbance from the A28 motorway (copyright: Marcel Huijser).



Figure 88. A row of tree stumps, grass-herb-shrub vegetation, and a road (overpass name: "Mauritskamp") on top of an overpass across the A28 motorway near the town Zeist, The Netherlands. The overpass was originally designed for a road only. Note the black screen attached to a chain link fence to reduce light disturbance from the A28 motorway (copyright: Marcel Huijser).



Figure 89. Road removed on bridge over motorway in Belgium and replaced with soil for vegetation and bike path (copyright: Bethanie Walder).

4.6.3. Implementation Considerations

✓ Farm Roads and Recreational Bike and Pedestrian Paths

- Suitable habitat must be available on both sides of the structure.
- Paths or riding trails intended for human use should be confined to one side of a crossing structure rather than placed in the middle, leaving greater space for wildlife use. Vegetation or other cover such as tree stumps, rocks or screens can be used to reduce the impact of human use on wildlife.

While co-use opportunities (by people and wildlife) are inherently attractive, several items require careful evaluation before moving ahead with them.

- When the crossing structure is in important or sensitive ecological areas or if the target species for the crossing structure are sensitive to human disturbance, wildlife and human use should not be combined on or in the same structure. Two separate structures should be considered in this case. The width of the hourglass-shaped wildlife overpass on the right side of figure 90 is only 16 m (52.5 ft) in the middle and co-use by humans would have jeopardized its functioning for large species or other species that are susceptible to human disturbance. Building a second bridge specifically for bicyclists and pedestrians was preferred over a wider wildlife overpass that would have allowed human co-use.
- When the crossing structure is located in a multifunctional landscape with considerable human disturbance, and if the target species for the crossing structure are not very sensitive to human disturbance, and perhaps even thrive with a certain level of human

disturbance (for example, raccoons thrive in an agricultural landscape), wildlife and human use can be combined in or on the same structure (figure 91).



Figure 90. A bike/pedestrian bridge adjacent to the De Borkeld wildlife overpass (right) across the A1 motorway in The Netherlands (copyright: Marcel Huijser).



Figure 91. A wildlife overpass combined with a bike/pedestrian path in Germany. The roadway underneath is not visible in the photograph (copyright: Mary Gray FHWA).

4.6.4. Example Cost Estimates

If the main function of a crossing structure is to pass water or traffic, the extra costs for wildlife only apply to the increased width of an overpass. See section 4.4 for costs for overpass structures that are specifically designed for wildlife.

4.6.5. Maintenance

- The soil and other material on top of an overpass or inside an underpass should not hinder inspection of the critical elements of the structure.
- Inspect overpasses regularly for problems, including debris (especially with streams and rivers), garbage, and the condition and dimensions of the banks, paths and walkways.
- During the first few years following construction it may be necessary to provide water to irrigate vegetation on the structure, particularly if there are extended periods with little rainfall. Sufficient water will allow vegetation to settle and take root.

4.7. ANIMAL DETECTION SYSTEMS

Animal detection systems use sensors to detect large animals (e.g., deer, elk, moose) as they approach the road. When an animal is detected, signs are activated to warn drivers that large animals may be on or near the road at that time. Drivers may then respond through:

- A higher state of alertness.
- Lower vehicle speed.
- A combination of the two.

Driver response should then result in reduced risk of a collision with large animals and less severe collisions. When used as a stand-alone mitigation measure, animal detection systems do not increase the barrier effect of the road because they do not restrict animals in their movements across the landscape or the road.

4.7.1. Effectiveness in Reducing Collisions with Large Mammals

The **effectiveness** of animal detection systems in reducing large-mammal WVCs has been estimated at 82–91 percent, **with an average of 87 percent**. Note that this measure should still be considered experimental and that the estimated effectiveness of this mitigation measure may be adjusted as more data become available.

4.7.2. Technical Specifications

✓System Types

The technology used for most animal detection systems falls within one of two groups (see Huijser and others for more detail on animal detection systems):⁽³⁰⁾

- **"Area-cover" sensors:** Area-cover sensors detect large animals within a certain range of a sensor (figure 92). Area-cover systems can be passive or active. Passive systems detect animals only by receiving signals from the surrounding environment. The two most common passive area-cover systems are passive infrared and video detection. These

systems require algorithms that distinguish between, for example, moving vehicles with warm engines or moving pockets of hot air and movements of large animals. Active systems send a signal over an area and measure its reflection. The primary active area-cover system uses microwave radar.

- **"Break-the-beam" sensors:** Break-the-beam sensors (figure 93) detect large animals when their body blocks or reduces a beam of infra-red, laser or microwave radio signals sent by a transmitter and received by a receiver.



Figure 92. An area-cover animal detection system (passive infrared, manufactured by ADPRO (Xtralis, USA)), designed to detect large mammals on both sides of the pole, at a WTI-MSU test facility near Lewistown, MT (copyright: Marcel Huijser).



Figure 93. An infrared break-the-beam animal detection system (manufactured by Calonder Energy, Switzerland) at a gap in a wildlife fence near the town 't Harde, The Netherlands (copyright: Marcel Huijser).

Other detection techniques include geophones that record vibrations in the ground as large animals approach, buried sensors that record changes in the electromagnetic spectrum as a large mammal walks by above ground, and radio-collared animals combined with receivers located in the right-of-way. Figure 94 shows a system where beacons are activated when radio-collared elk come within 400 m (1/4 mi) from the receivers placed in the right-of-way.



Figure 94. Activated warning signal and sign in Sequim, WA (copyright: Marcel Huijser).

✓Site suitability

Suggested parameters for evaluating the suitability of a site for installation of an animal detection system are partially based on Huijser and others:⁽³⁰⁾

- Wildlife–vehicle collisions. The site should have a history of a relatively high number of WVCs with large animals, especially ungulates (e.g., deer, elk or moose). This is for two reasons: 1) The costs associated with the purchase, installation, operation and maintenance of an animal detection system may be compensated by the savings associated with reduced WVCs; and 2) If an animal detection system is evaluated for its effectiveness in reducing WVCs, historic data on WVCs should be available. In addition, historic WVCs from control sites are helpful.
- Animal movements. The site should be located in an area where many large animals are known to cross the road (daily movements or seasonal migration). Note: not all animal movements across a road result in WVCs.
- Traffic volume. As traffic volume increases it becomes less desirable to have large animals cross at grade. In addition, above a certain traffic volume the barrier effect of the road may be close to absolute with few animals that even try to cross the road. In that type of situation, the problem of collisions has been largely replaced with the problem of barriers to animal movement.

- **Terrain.** The terrain must allow for the installation of an animal detection system. For example, an abundance of ridges, gullies and rocky outcrops may make a location less suitable for a detection system, especially a break-the-beam system. Difficult terrain may also require more sensors and other equipment than relatively flat areas would require.
- **Access roads.** The number of access roads should be kept to a minimum to avoid gaps (blind spots) or excessive false positives caused by traffic turning on or off the road, depending on what sets off the sensors.
- **Vegetation.** The vegetation should allow for the installation of an animal detection system. For example, bushes and trees that grow up to the edge of the pavement increase the chances for triggering the system—i.e., they would cause excessive false positives for most area-cover or break-the-beam systems.
- **Length of road section.** If an animal detection system is deployed as a stand-alone mitigation measure, the road section must be at least 805–1,609 m (0.5–1.0 mi) long to be able to accommodate for spatial errors in historic road kill data used to select the site. If an animal detection system is installed in a gap in a wildlife fence, the gap width can be variable, but a gap is typically between 30 and 200 m (98–656 ft) wide, depending on the range of the sensors and the local conditions.
- **Changes in road or landscape.** The road and surrounding landscape should not be scheduled to undergo major changes within the life span of the mitigation measure, which, for animal detection systems, is about 10 years. However, should changes in the landscape occur and result in changes where animals cross the road and where animals are hit by vehicles, then consideration can be given to relocating the animal detection system. Of course, there are relocation costs involved with such an effort. In addition, major changes, other than the installation of the animal detection system, would confound the results of any study into the effectiveness of the animal detection system in reducing WVCs.
- **Power.** The site should allow for either solar power or a connection to a 110 V power source.
- **Controlled access.** The site should have a low risk of theft and vandalism, such as a location on a controlled access road.

✓ **Implementation and Research Environment**

- **Project partners.** All the organizations and individuals that have jurisdiction or that are stakeholders in activities at the study site should support the project. This includes support for installation, operation and maintenance.
- **Travel costs.** The site should be close to where operation and maintenance personnel are stationed to reduce travel costs.
- **Pull-out.** The site should have a safe pull-out location for vendors and maintenance and research personnel.

4.7.3. Implementation Considerations

The advantages and disadvantages of animal detection systems when compared to wildlife fencing in combination with wildlife underpasses and overpasses are discussed below (see also Huijser and others).⁽³⁰⁾

✓ Advantages of Animal Detection Systems

- Animal detection systems have the potential to provide wildlife with safe crossing opportunities anywhere along the mitigated roadway, but wildlife crossing structures are usually limited in number and they are rarely wider than about 50 m (164 ft).
- Animal detection systems are less restrictive to wildlife movement than fencing or crossing structures. They allow animals to use existing paths to the road or to change them over time.
- Animal detection systems can be installed without major road construction or traffic control for long periods.
- Animal detection systems are likely to be less expensive than wildlife crossing structures, especially once they are mass produced.

✓ Disadvantages of Animal Detection Systems

- Although the available data on the effectiveness of animal detection systems with regard to collision reduction are encouraging, animal detection systems should currently be considered experimental as opposed to the more robust performance of wildlife crossing structures in combination with wildlife fencing.
- Currently, animal detection systems only detect large animals (e.g., deer, elk, or moose). Small animals are hard to detect, and drivers are not warned about their presence on or near the road.
- Wildlife crossing structures can provide cover (e.g., vegetation, living trees, tree stumps) and natural substrate (e.g., sand, water) allowing better continuity of habitat.
- Above a certain traffic volume, perhaps around 15,000–20,000 vehicles per day, animal detection systems may be less desirable, as animals may shy away from crossing the road at grade and road mortality may be increasingly overshadowed by the barrier effect of the road.
- Some types of animal detection systems are only active in the dark and animals that cross during the daylight may not be protected.
- Animal detection systems usually require the presence of poles and equipment in the right of way, sometimes even in the clear zone, presenting a safety hazard of their own.
- Animal detection systems may substantially reduce the number of WVCs, but since they allow large animals to cross the road at grade, they will never completely eliminate WVCs. Nonetheless, the available data suggest that animal detection systems may reduce collisions with large mammals to a level that is similar to wildlife crossing structures in combination with wildlife fencing.

- Animal detection systems can be aesthetically displeasing because of the equipment placed along the road, including solar panels.
- Wildlife crossing structures and wildlife fencing are likely to have greater longevity (possibly 75 years for crossing structures and 20–30 years for wildlife fencing) than animal detection systems (possibly 10 years) and lower maintenance and monitoring costs.

The choice between:

- Animal detection systems (with or without wildlife fencing), or;
- Wildlife crossing structures in combination with wildlife fencing;

currently depends on whether the success of the project is defined as:

- Accomplishing a certain minimum result in terms of WVC reduction and/or safe crossing opportunities for wildlife (i.e. select wildlife crossing structures in combination with wildlife fencing).
- Acquiring data that helps to further evaluate the effectiveness of other mitigation measures (i.e. select animal detection systems (with or without wildlife fencing)).

The choice also depends on:

- The problem at hand (WVCs and/or lack of safe crossing opportunities for wildlife).
- The species or species groups concerned.
- The local situation, including road, right-of-way, and landscape characteristics.

For additional considerations see Huijser and others.⁽³⁰⁾

✓**Potential Applications**

Animal detection systems may be deployed as a stand-alone mitigation measure or in combination with other mitigation measures. Figure 95 features a schematic representation of potential applications of animal detection systems along a road:

- a) A system installed over a relatively long road section without wildlife fencing.
- b) A system installed in a gap with extensive wildlife fences on either side.
- c) A system installed in a gap with limited wildlife fences on either side aimed at funneling the animals toward the road section with the system.
- d) A system installed at the end of extensive wildlife fencing.
- e) A system installed at the end of extensive wildlife fencing aimed at funneling the animals through an underpass.
- f) A system installed along a low-volume road that parallels a high-volume road with an underpass.

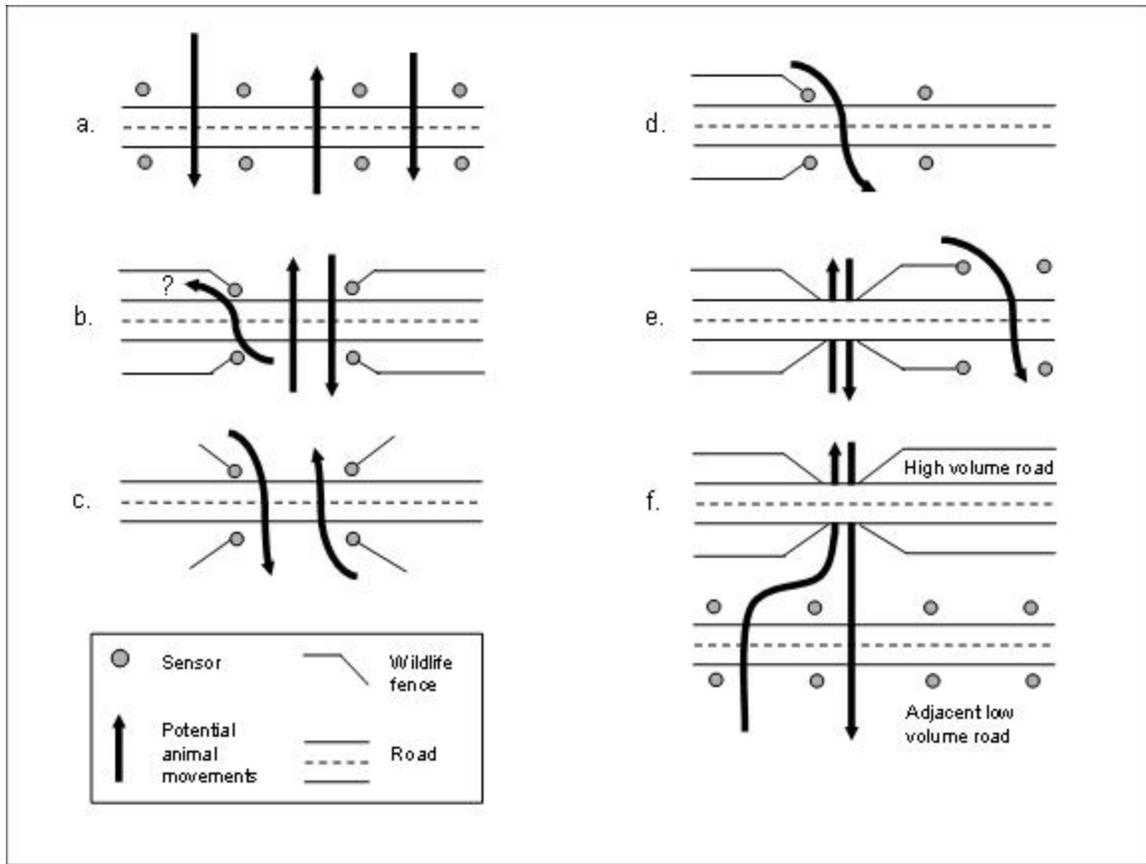


Figure 95. Potential applications for animal detection systems.

Important issues to remember when implementing animal detection systems:

- **Engineering plan:** It is advisable to prepare an engineering plan that shows where and how the equipment will be installed and how the different components (e.g., the detectors and the warning signs) will be integrated.
- **Signage:** Signage will have to be standardized. Signage may have to either target vehicle speed or driver alertness.
- **Technological difficulties and substantial delays:** Prepare for technological problems and delays following the installation of an animal detection system. It may take many months or even several years before an animal detection system may become operational.
- **Monitoring and maintenance:** Even systems that are initially successful will fail without proper monitoring and maintenance.

4.7.4. Example Cost Estimates

Cost depends on many parameters, including system type, the range of the sensors, and the local conditions. However, costs are about:

- \$65,000 (in 2007 \$) per 1.6 km (1 mi) for a system that is deployed as a stand-alone mitigation measure along both sides of a road (excluding installation and signage).
- \$20,000 (in 2007 \$) for a system that covers a gap in a fence on both sides of the road (excluding installation, signs, and wildlife fence).

4.7.5. Maintenance

Many of the systems that were installed at about 30 sites throughout Europe and North America experienced one or more problems during installation, operation and maintenance (table 7). The most common issues fall within four categories (table 7):

- **False positives:** These occur if the system is triggered by causes other than the presence of large animals (target species).
- **False negatives:** False negatives occur if a large animal is present, but the system fails to detect it.
- **Maintenance:** All systems can suffer a variety of maintenance issues. In addition, most systems require a period during which major technical problems are identified and hopefully solved. It is important to recognize this and to treat an animal detection system project as an experiment rather than the implementation of a robust mitigation measure for which most of the issues have been addressed.
- **Landscape, ecology and animals:** Some animal detection systems are considered to affect landscape aesthetics. In addition, some animal detection systems (e.g. radio-collar systems) require capture and handling of animals. Finally, animals may wander and loiter in the right-of-way after the warning signs have already turned off.

Table 7 shows that area-cover and break-the-beam systems seem to be particularly vulnerable to false positives and false negatives.

Table 7. Summary of issues, problems and experience with operations.

	Area-cover systems	Break-the-beam system	Geo-phone system	Radio-collar system
False positives				
High, moving or wet vegetation	√	√		
Flying birds, nesting birds, rabbits	√	√		
Wind, rain, water, fog, snow spray, falling leaves	√	√	√	
Snow and ice accumulation on sensors or ground	(√)	√		
Microwave radio signal reflection off guardrail		√		
Sun, heat, unstable sensors	√	√	√	
Insufficient ventilation in box (fog on lens)	(√)	√		
Frost, low temperatures	√	√		
Lightning	(√)	√	√	(√)
Long distance between transmitter and receiver		√		
Traffic on road	√	√	(√)	
Traffic on driveways or side road	(√)	√		
Passing trains			√	
Signals from other transmitters		√		√
False negatives				
Curves, slopes not covered by sensors	(√)	√		
Loitering animals in right-of-way not detected	(√)	√	(√)	
None of the individuals that cross have collars				√
Not feasible for non-gregarious species/migrants				√
Insufficient warning time	(√)	(√)	(√)	
Some systems are only active during the night	√	√		

Table 7 (Continued)

Maintenance				
Maintenance costs (e.g., mowing, power, fences)	(√)	√	(√)	(√)
Shade/snow on solar panels	(√)	√	(√)	(√)
Vandalism and theft of e.g. solar panels	(√)	√	(√)	(√)
Safety (cars of road)	(√)	√	(√)	(√)
Broken sensors, warning lights or other material	√	√	(√)	√
Period required to solve technical difficulties	√	√	√	√
Signs (standardization, liability)	√	√	√	√
No remote access to data (poor cell phone coverage)	(√)	√	√	(√)
Landscape, ecology, animals				
Landscape aesthetics	(√)	√	(√)	(√)
Animals crossing areas may change overtime	(√)	√	(√)	(√)
Animals may wander between fences (if present)	√	(√)	(√)	(√)
Small animals are not detected	√	√	√	√
Continuous effort to capture animals				√
Stress for the animals involved				√
Not in habitat linkage zones (light disturbance)		√ ¹		

√ = problem has been reported or issue applies

(√) = problem has not been reported, but it could occur

¹ For Swedish system that illuminates the road and right-of-ways once an animal is detected.

4.8. VEGETATION MANAGEMENT IN THE RIGHT-OF-WAY

This section provides a brief overview of mitigations and methods that can be incorporated into roadside vegetation management that may reduce WVCs. For more detail refer to Harper-Lore and Wilson.⁽³¹⁾

4.8.1. Shrub and Tree Removal

Shrubs and trees that grow close to the edge of the pavement appear to be associated with deer- and moose-vehicle collisions. This may be due to:

- Browse and cover sought by deer and moose.
- Limited the sight distance for drivers.

Removal or trimming of shrubs and trees may **increase the sight distance for drivers** while **reducing cover for deer and moose** (figure 96). However, care should be taken that **re-growth of shrubs and trees, or the grass–herb vegetation** that now may grow, does not result in attracting large herbivores due to its accessibility (close to the ground, within reach of the animals) and nutritional value.



Figure 96. Recently cleared shrubs to improve driver visibility and to reduce browse for moose along the George Parks Highway (Hwy 3) in Alaska (copyright: Marcel Huijser).

4.8.2. Nutritional Value of Vegetation

Roadside vegetation or vegetation in the right-of-way may be an attractant to large mammal species, including large ungulates and bears:

- In relatively dry areas runoff from the road may allow for greener and more palatable vegetation immediately adjacent to the road compared to vegetation farther from the road (figure 97).
- In cold climates, snow melt may happen faster immediately adjacent to roads (snow plows, south facing slope of road bed), allowing for access to the vegetation, as well as earlier growth of the vegetation compared to vegetation farther from the road.
- The vegetation in the right-of-way typically differs from the surrounding vegetation because of the species that were planted or seeded, non-native invasive species that may have spread along the road corridor, or because maintenance of the right-of-way vegetation differs from that directed at surrounding areas.
- Mowing favors grass–herb vegetation over shrubs and trees and can be an attractant to large herbivores depending on the climate and the surrounding habitat. For example, in

forested environments or in areas of mixed forest and croplands a grass–herb vegetation may be an attractant to grazers including deer and elk, at least during certain times of the year. Accessible and palatable browse (e.g., re-growth from mowed or clipped shrubs and trees) may be an attractant to deer and moose in an environment dominated by mature forests with low light conditions close to the ground.

- Planted, seeded, or non-native species may be more palatable or nutritional than native species that may dominate outside of the road corridor. For example, black bears are known to feed on dandelions in right-of-way vegetation. Right-of-way vegetation may be made less attractive to large herbivores by planting unpalatable species or reducing forage quality through vegetation maintenance (mowing, cutting, noxious chemicals).
- The nutritional value of the right-of-way vegetation may not be an attractant to large herbivores everywhere, and it may be difficult to change the species composition of the right-of-way vegetation. It is also difficult to time mowing and cutting operations such that it minimizes the nutritional value of the right-of-way vegetation and, as a result, reduces collisions with large mammals.



Figure 97. Pronghorn eating roadside vegetation (copyright: Marcel Huijser).

4.8.3. Effectiveness in Reducing Collisions with Large Mammals

Little has been published on the effectiveness of vegetation clearance or mowing and clipping of vegetation in right-of-ways and its effects on collisions with large mammals. However, clearing vegetation from roadsides resulted in a 20 percent reduction in moose–vehicle collisions in Sweden.⁽³²⁾

In a study examining the effect of scent-marking, intercept feeding and forest clearing, analyses demonstrated that forest clearing resulted in a 49 percent reduction in collisions.⁽³³⁾ While it is

recognized that the results may not translate to a highway setting, the clearing of vegetation across a 20–30 m (70–100 ft) swath on each side of a Norwegian railway reduced moose–train collisions by 56 percent (+/-16 percent).⁽³⁴⁾

4.8.4. Technical Specifications

- Depending on the species and the local situation, including land ownership, shrubs and trees may need to be removed or trimmed up to 20–40 m (66–131 ft) from the edge of the pavement. For moose this distance may need to be up to 100 m (328 ft).
- Thomas provides a summary of a variety of vegetation clearing methods used in Alaska, including hydroaxing, hand clearing, steam clearing, and spray inhibitors.⁽³⁵⁾
- The timing and effect of vegetation clearing depends on the vegetation and climate at the roadway site and needs to be carefully evaluated and is likely to be highly dependent on local conditions. A detailed literature review on roadside vegetation management, plant response to tissue removal, and ungulate foraging behavior yielded recommendations for more carefully designed cutting regimes as a countermeasure for reducing moose–vehicle collisions.⁽³⁶⁾ Willows cut in mid-July were found to be high in digestible energy and protein compared to plants cut at other times of the year and to uncut controls, suggesting that summer brush cutting regimes may inadvertently be attracting moose with nutritious re-growth.^(36,37) Cutting in early June results in browse with significantly less nutritional value for the first two years after cutting compared to plants cut later in the growing season and uncut controls.^(36,37) Rea recommends cutting roadside brush in early spring soon after leaves develop to keep nutritional value and palatability to a minimum, but recognizes operational challenges and limitations (e.g., ground too wet for tractor use, different ungulate species-specific responses to same management regime, etc.) and cautions that this countermeasure may not be suitable for all management areas.⁽³⁶⁾

4.8.5. Implementation Considerations

- Removal of brush or trees may result in fresh growth of attractive forage (re-growth from shrubs or trees or grass–herb vegetation) that may draw herbivores (grazers and browsers) to the right-of-way, counteracting the safety gains of better visibility with increased probability of drivers encountering wildlife (figure 98).



Figure 98. Re-growth of cleared shrubs along the George Parks Highway (Hwy 3) in Alaska (copyright: Marcel Huijser).

- Shrub and tree removal must be carefully evaluated for its potential effect on the landscape (e.g., historic value, regional landscape characteristics), as well as its effect on the vegetation's desirable function in limiting sound, light and pollutants near roadways.
- Reducing or removing large trees near roads may result in fewer collisions with these stationary objects. The removal may extend out further than mandatory clear zones.
- Shrubs and trees that grow close to the road limit sight distance for drivers and may therefore be associated with lower vehicle speed. Removal of trees and shrubs may result in higher operating speeds.
- Removing (semi-)natural vegetation from the right-of-way or making the right-of-way less attractive to large mammals may conflict with conservation interests in landscapes where the few remaining patches of (semi-)natural vegetation may be one of the most important refugia for plant and animal species in an otherwise hostile environment. This may include rare, threatened or endangered plant and animal species (figure 99).



Figure 99. Vegetation management in right-of-way may conflict with conservation interests (copyright: Marcel Huijser).

4.8.6. Example Cost Estimates

Vegetation removal requires a long-term maintenance commitment and may involve expenses to acquire right-of-way in order to manage vegetation as desired. Jaren and others calculated that if collisions are reduced by at least 50 percent as a result of removing vegetation, then the costs of vegetation removal treatment would be economically beneficial if applied in areas where more than 0.3 moose–train collisions occur per km (0.48 per mi).⁽³⁴⁾ Andreassen and others estimated forest clearing for 18 km (11.2 mi) costs \$530 per km (\$853 per mi) or \$9,548 per year (in 2007 \$) (\$500 per km (\$800 per mi) or \$9,000 per year in 2005).⁽³³⁾ He estimated that based on the reduction in moose–vehicle collisions, this technique had a net benefit of \$1,146 (in 2007 \$) per year (\$1,080 in 2005). Andreassen and others state that forest clearing may be more economical than scent-marking and supplemental feeding, and that the initial cutting is the main expense.⁽³³⁾

An experimental study of vegetation removal along a railway line (20–30 m (66–98 ft) on each side) in Norway caused a 56 percent (+/- 16 percent) reduction in moose–train collisions.⁽³⁴⁾ The researchers concluded that there would be an economic benefit to vegetation removal treatments in areas with more than 0.3 collisions per km (0.48 per mi), but that local evaluations are necessary to confirm that vegetation cover is the main contributor to collisions in specific

sections.⁽³⁴⁾ It is possible, however, that the experimental design may have overstated the collision reduction potential of vegetation removal.^(34,38)

Forage repellents, planting or seeding unpalatable species, and roadside brush removal have been used with limited effectiveness or are not cost-efficient when broadly applied.⁽³⁶⁾

4.8.7. Maintenance

Brush or tree removal or clipping, and mowing of grass–herb vegetation in the right-of-way is a long term effort that, depending on the climate, soil and hydrology, may have to be repeated several times per year or once every few years. In Alaska, shrub vegetation in right-of-ways is typically cleared once every two to three years.

4.9. WILDLIFE CULLING

Wildlife culling involves a substantial reduction in the population by eliminating a large number of individual animals over a short period of time. This measure is typically applied to or proposed for white-tailed deer, mule deer or elk in a (sub)urban setting where other measures to reduce human–wildlife conflicts have failed or are not considered feasible (figure 100). In some (sub)urban settings in North America, the presence of white-tailed deer, mule deer and elk has led to a variety of other wildlife–human conflicts including:

- Threats to human safety as a result of a loss of fear of humans.
- Damage to gardens and parks.
- Collisions with vehicles.
- Attraction of large predators that can also be a threat to human safety.

In more natural areas or (sub)urban areas that border relatively natural areas, damages to the ecosystem, for example as a result of overpopulation or concentration in small areas, can also be one of the reasons to consider population culling. Finally, population culling may be considered for non-native species that cause damage to the ecosystem. Culling of the target species leads, at least theoretically, to fewer individuals and reduced wildlife–human conflict, including reduced ungulate–vehicle collisions.



Figure 100. White-tailed deer can cause wildlife–human conflicts, including deer–vehicle collisions, especially in urban and suburban settings (copyright: Marcel Huijser).

4.9.1. Effectiveness in Reducing Collisions with Large Mammals

Actual data on the effectiveness of population reduction programs on wildlife–vehicle collisions are few. A field test showed that a deer population reduction program in Minnesota reduced winter deer densities by 46 percent and deer–vehicle collisions by 30 percent.⁽³⁹⁾ However, reductions in population size of 50 percent or more may be hard to achieve, perhaps capping the potential reduction in deer–vehicle collisions at 50 percent or less.⁽³⁹⁾

Because of the highly variable relationship between population size, population size reduction, and ungulate–vehicle collisions, this measure should be considered experimental.

4.9.2. Technical Specifications

The fertility of white-tailed deer is weakly density-dependent for adult does. However, the fertility of first-year and yearling females is strongly density-dependent, with very low fertility when population densities exceed 30 deer per km² (78 deer per mi²).⁽⁴⁰⁾ These observations suggest that as population density is reduced, increased effort is needed to keep the deer density at the lower level. This phenomenon needs to be addressed in potential population size reduction programs.

The killing of does (females) is more effective for reducing the population size than the killing of bucks (males), not only because the reproductive potential of the herd is more effectively reduced, but also because does tend to stay in their existing home range while bucks have a greater tendency to disperse. The does are less likely to migrate and establish new populations elsewhere.

A modeling project by Porter and others showed that if female dispersal (i.e., animals that leave the area) was 8 percent, culling would have to reduce annual survival to 58 percent to maintain a

population just under ecological carrying capacity (the maximum sustainable population size).⁽⁴¹⁾ A further reduction of the annual survival to 42 percent would keep the population at half the carrying capacity.

Baiting in order to facilitate wildlife culling increases efficacy but is illegal in some areas, and it can lead to undesirable side effects such as increased risk for spreading diseases, reduction in the consumption of natural foods and consequent changes in the ecosystem, population increase and consequent starvation, crowding, fighting and injuries of deer, deer domestication and habituation to unnatural foods and humans, decrease in hunter satisfaction, and increase in concerns of the non-hunting public.

4.9.3. Implementation Considerations

Wildlife culling can be met by strong public opposition, possibly causing delay or abandonment of the effort. A public relations campaign should be considered before a culling effort begins, especially in (sub)urban areas.

Culling efforts are more likely to result in a substantial reduction in deer population size if:

- The herd size is relatively small to begin with.
- It is a closed population that does not allow influx of animals from nearby places.

Culling may not be possible or effective:

- On private lands.
- In remote locations.
- In urban and suburban areas.

If refugia are present, more intensive effort will have to be undertaken at locations that are accessible to hunters or wildlife managers.

Sharp shooting by professionals over bait was deemed to be the most effective and adaptable culling method in an urban setting, as opposed to controlled hunts in large parks and refuges or opportunistic sharp shooting by professionals.⁽³⁹⁾ If the public is to participate in the culling, consider modifying hunting regulations to stimulate hunters to target younger animals and does rather than bucks. But with a decline in the number of hunters, a shift from recreational hunting to professional culling may need to be considered.

4.9.4. Example Cost Estimates

The costs for a controlled hunt were estimated at \$137 (in 2007 \$) (\$117 in 2001) per deer killed. The cost of using professional sharpshooters was \$126, \$142, and \$227 (in 2007 \$) (\$108, \$121, and \$194 in 2001) per deer for conservation officers, park rangers, and police officers, respectively.⁽³⁹⁾ Others estimated these costs at \$110–\$373 (in 2007 \$) (\$91–\$310 in 2000) per deer.⁽⁴²⁾

4.9.5. Maintenance

The culling effort has to be repeated periodically as the deer population will rebound to the same levels if the habitat conditions remain unchanged. In addition, the effort involved for population size reduction programs increases disproportionately with higher population size reduction goals, and substantial reductions (for example greater than 50 percent) may be hard to obtain, perhaps capping the potential reduction in deer–vehicle collisions at 50 percent.

CHAPTER 5: DESIGN AND GUIDANCE OF MITIGATIONS FOR THREATENED AND ENDANGERED SPECIES

This chapter covers mitigation methods focused on reducing WVCs involving threatened and endangered species (figure 101). In the Report to Congress, 21 Federally listed threatened and endangered species were identified in the United States for which direct road mortality is among the major threats to the survival of the species or certain populations of that species (table 8).

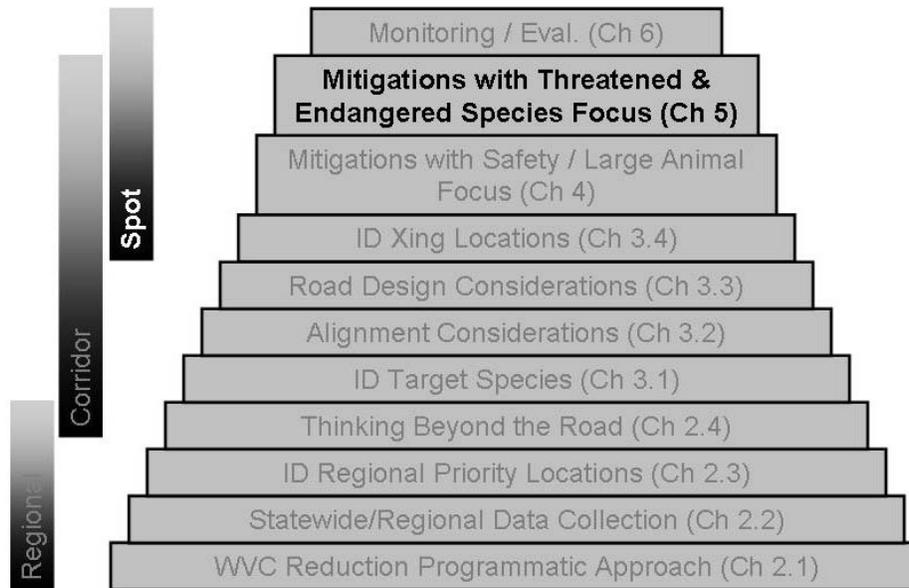


Figure 101. Mitigations for threatened and endangered species as part of a strategy for reducing WVCs.

In this chapter existing mitigation measures for the 21 species and species groups listed in table 8 are discussed. In addition to existing measures, additional measures are suggested for each species or species group that may help reduce collisions with vehicles.

It is important to note that while direct road mortality is among the major threats to these 21 species, it is not necessarily the only or even the most important threat to these species. The survival of the species listed in this chapter is also threatened by other factors, including:

- Habitat loss due to agriculture, urbanization, mining, and changes in hydrology.
- Reduced habitat quality due to agricultural and silvicultural practices such as livestock grazing, logging, fire suppression, introduction of non-native plant species, and water contamination by pesticides and other pollutants.
- Habitat fragmentation due to roads or other unsuitable habitat.
- Competition and predation by non-native species.
- Other sources of natural and unnatural mortality such as off-road vehicles, poaching, direct killing or collection by humans, or disease.

- Low recruitment and loss of genetic diversity due to small population.

This implies that a substantial reduction in road mortality is not necessarily sufficient for the recovery of the species listed in this chapter. For successful species recovery, including mitigation for effects related to roads and traffic, it is advisable to use an integrated approach (e.g., see Brown⁽⁴³⁾). For more information about the road mortality numbers of the species listed in table 8, please consult the Report to Congress.

Table 8. Threatened and endangered species in the United States for which direct road mortality is among the major threats to the survival probability of the species.

Species Group	Species Name		Species Group	Species Name
Amphibians	California tiger salamander (<i>Ambystoma californiense</i>), C. CA, S. Barb., Son. county		Birds	Audubon's crested caracara (<i>Polyborus plancus audubonii</i>), FL pop.
Amphibians	Flatwoods salamander (<i>Ambystoma cingulatum</i>)		Birds	Hawaiian goose (<i>Branta sandvicensis</i>)
Amphibians	Houston toad (<i>Bufo houstonensis</i>)		Birds	Florida scrub jay (<i>Aphelocoma coerulescens</i>)
Reptiles	American crocodile (<i>Crocodylus acutus</i>)		Mammals	Lower Keys marsh rabbit, (<i>Sylvilagus palustris hefneri</i>)
Reptiles	Desert tortoise (<i>Gopherus agassizii</i>), except in Sonoran Desert		Mammals	Key deer (<i>Odocoileus virginianus clavium</i>)
Reptiles	Gopher tortoise (<i>Gopherus polyphemus</i>), W of Mobile/Tombigbee Rs.		Mammals	Bighorn sheep, Peninsular CA pop. (<i>Ovis canadensis</i>)
Reptiles	Alabama red-bellied turtle (<i>Pseudemys alabamensis</i>)		Mammals	San Joaquin kit fox (<i>Vulpes macrotis mutica</i>)
Reptiles	Bog turtle (Muhlenberg) northern population (<i>Clemmys muhlenbergii</i>)		Mammals	Canada lynx (<i>Lynx canadensis</i>), lower 48 States
Reptiles	Copperbelly water snake (<i>Nerodia erythrogaster neglecta</i>)		Mammals	Ocelot (<i>Leopardus pardalis</i>)
Reptiles	Eastern indigo snake, eastern indigo (<i>Drymarchon corais couperi</i>)		Mammals	Florida panther (<i>Felis concolor coryi</i>)
			Mammals	Red wolf (<i>Canis rufus</i>), except where XN

5.1. AMPHIBIANS AND REPTILES

Relatively few mitigation measures were identified that were specifically targeted at one or more of the 10 species of amphibians and reptiles listed in table 8. Mitigations specifically aimed at

the American crocodile, desert tortoise, gopher tortoise, and Alabama red-bellied turtle are summarized in this section.

5.1.1. American Crocodile

There are several mitigations in Florida that target the American crocodile in southern Florida. Warning signs for the crocodiles were erected during road construction projects on U.S. Highway 1 between Florida City and Key Largo in January, 2008 (figure 102).



Figure 102. A warning sign for American crocodiles along U.S. Highway 1 between Florida City and Key Largo, FL (copyright: Marcel Huijser).

The widening of the road was done in combination with the installation of wildlife fencing, which specifically targeted the American crocodile and was intended to discourage them from entering the highway corridor (figure 103).



Figure 103. A 1.83-m-high (6-ft-high) chain-link wildlife fence intended for American crocodile along U.S. Highway 1 between Florida City and Key Largo, FL (copyright: Marcel Huijser).

In addition to the fencing, between 12 and 20 underpasses (about 2.5 m (8.2 ft) wide) were installed specifically for the crocodiles to use (personal communication, Steve Klett, Crocodile Refuge manager, Key Largo, FL). In the underpass shown in figure 104, the 1.83 m (6 ft) fence can be seen in the upper left corner where it ties in with the underpass.



Figure 104. An underpass for American crocodiles along U.S. Highway 1 between Florida City and Key Largo, FL (copyright: Marcel Huijser).

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On Highway 905A just south of the Card Sound Bridge in Key Largo, eight to ten culverts have been installed for the American crocodile (personal communication, Steve Klett, Crocodile Refuge manager, Key Largo, FL). These culverts are about 1.8 m (6 ft) wide, and there are short sections of fencing 30 m (100 ft) long and about 90 cm (3 ft) high to guide American crocodiles to these structures (figure 105). However, the crocodiles appear to be using these underpasses less than it was hoped because vegetation (mainly mangroves) obstructs the entrances. There are no data on effectiveness of these signs, fences or culverts.



Figure 105. A short section of fencing (30 m (100 ft) long, 90 cm (3 ft) high) aimed at directing American crocodiles to 1.8-m-wide (6-ft-wide) culverts along Highway 905A, just south of the Card Sound Bridge in Key Largo (copyright: Marcel Huijser).

5

The fences shown in figure 105 used to be bent at a 45-degree angle away from the road, but right-of-way mowing equipment bent them almost straight again. Note the mangrove vegetation on the right that appears to obstruct the entrance to the culverts.

5.1.2. Desert Tortoise

Mitigation measures for desert tortoises have been installed in California. They include desert tortoise warning signs, such as the one depicted in figure 106, and desert tortoise fencing in combination with retrofitted culverts.



Figure 106. Desert tortoise warning sign along an access road (no name) to the Hyundai Proving Grounds, near Mojave, Kern County, CA (copyright: William I. Boarman, CSRC).

Fences (figure 107) designed to prevent tortoises from crossing the road resulted in 93 percent fewer tortoise roadkills.⁽⁴⁴⁾

The fence extends to 46 cm (18 in) above the ground, and is buried 15 cm (6 in) below ground.⁽⁴⁵⁾ The fence consists of 0.64 cm (1/4 in) mesh hardware cloth, which was a barrier to all but the smallest species in the study area.⁽⁴⁵⁾

More recently, 2.5 x 5 cm (1 x 2 in) hog wire (with the 2.5 cm being the horizontal dimension and 5 cm the vertical) has been used more often (but it remains unstudied) because it is less expensive and is not a substantial barrier to smaller non-target species (personal communication, William Boarman, Conservation Science Research and Consulting, Spring Valley, CA).

However, those smaller animal species still access the road corridor where they are susceptible to road mortality. The mesh fence was attached to a five-strand barbed-wire fence, with the bottom two strands above the mesh wire fence left unbarbed to allow easy crossing by coyotes, kit foxes, and rabbits.⁽⁴⁵⁾



Figure 107. Tortoise barrier fence erected along State Highway 58 near Kramer Junction, San Bernardino County, CA (copyright: William I. Boarman, U. S. Geological Survey).

5

The fence tied into or went above existing culverts, which were located for drainage and not for tortoise movements (figure 108). These culverts (24 total) vary in size, but they are typically made from corrugated metal and are 142–163 cm (56–64 in) in diameter and 48–63 m (158–208 ft) long (personal communication William Boarman, Conservation Science Research and Consulting, Spring Valley, CA). The entrances of the culverts were flush with the ground, and small boulders were installed to prevent undercutting the apron. These small boulders were covered with soil so that desert tortoises could access the culverts.



Figure 108. Desert tortoise exiting a culvert retrofitted to allow tortoises to cross beneath State Highway 58 near Kramer Junction, San Bernardino County, CA (copyright: William I. Boarman, U. S. Geological Survey).

5.1.3. Gopher Tortoise

Fences and culverts were installed along a section of Highway 63 in Green County, south of Leakesville, Mississippi, to reduce gopher tortoise road mortality (personal communication, Matthew J. Aresco, Nokuse Plantation, Bruce, FL; Claiborne Barnwell and Chuck Walters, Mississippi Department of Transportation).

The aim of the mitigation measures is to allow gopher tortoises to cross under the road (figure 109). Highway 63 has 24.1 km (15 miles) of gopher tortoise fencing and, because of the nature of the terrain, there is only one culvert (between Lucedale and Leakesville) that was specifically designed for the gopher tortoise. At this culvert the fence stretches out about 914 m (3,000 ft) on each side. Some of the fencing was installed as early as 1998, and along those road sections the number of reported road-killed gopher tortoises was reduced from one to two per year to zero (personal communication, Chuck Walters, Mississippi Department of Transportation).



Figure 109. Fences lead gopher tortoises toward a culvert along Highway 63 in Green County, south of Leakesville, MS (copyright: Chuck Walters).

5.1.4. Alabama Red-Bellied Turtle

Mitigation measures to reduce road mortality for the Alabama red-bellied turtle were installed along the Mobile Bay Causeway (U.S. Highway 90/98) between Spanish Fort and Mobile. Phase 1 of the project was still ongoing in April, 2008, and involved 4.2 km (2.6 mi) of chain-link fence (personal communication, David Nelson, Department of Biological Sciences, University of South Alabama) (figure 110). Most of the fence is on the north side of the road where there is fresh water rather than the brackish or salt water on the south side of the road.



Figure 110. Fences keep Alabama red-bellied turtles from entering the roadway and lead them toward bridges where they can cross under the road (copyright: ALDOT).

5.1.5. General Amphibian and Reptile Mitigations

- Mitigation measures used for other amphibian and reptile species that are not necessarily endangered or threatened include screens, 40–50 cm (16–20 in) above ground and about

10 cm (4 in) underground, placed alongside the road that guide amphibians toward underpasses (figure 111-119).

- Smooth plastic screens are preferred over mesh wire as some amphibians can climb the mesh wire and small individuals may go through the mesh. Mesh wire fences also are often damaged during vegetation maintenance practices. Screens that are curved back to the side away from the road are not recommended because of problems with vegetation and right-of-way maintenance.
- It is critical that the fence screens fit tightly to the underpasses.
- The fences are most successful if they do not deflect amphibian movements by more than 60 degrees. Thus the orientation of the fences in relation to the direction of movement of the amphibians is important (figure 114).



Figure 111. Concrete barrier leads amphibians toward an underpass along the road "Hilversumsestraatweg" near the town Hilversum, The Netherlands (copyright: Marcel Huijser).



5 Figure 112. Plastic sheets that guide amphibians to an underpass, near the town Hilversum, The Netherlands (copyright: Marcel Huijser).



Figure 113. Plastic screens combined with a badger fence along the road "Hilversumsestraatweg" near the town Hilversum, The Netherlands (copyright: Marcel Huijser).



Figure 114. Plastic screens combined with a badger fence guiding the animals towards an underpass for amphibians under the road "Hilversumsestraatweg" near the town Hilversum, The Netherlands (copyright: Marcel Huijser).

5



Figure 115. Concrete barrier and planks guiding amphibians toward an underpass under the road "Bussumergrindweg", near the town Hilversum, The Netherlands (copyright: Marcel Huijser).



Figure 116. Plastic screens combined with a medium- and large-mammal fence guiding the animals toward an overpass (Waterloo) along the A73 motorway near the town Roermond, The Netherlands. Note that the screw that holds the two plastic sheets together is broken, allowing for a gap and potential intrusions of amphibians and other small species into the road corridor (copyright: Marcel Huijser).



Figure 117. Plastic screens combined with a medium- and large-mammal fence guiding the animals toward an overpass (Waterloo) along the A73 motorway near the town Roermond, The Netherlands. Note that two adjacent sheets have a gap that is covered by fine mesh wire fence to prevent amphibians and other small species from entering the road corridor (copyright: Marcel Huijser).



5 Figure 118. Plastic screens that collapsed were intended to guide amphibians toward an underpass near the town Hilversum, The Netherlands. The gap allows amphibians and other small species to enter the road corridor (copyright: Marcel Huijser).



Figure 119. The vegetation on both sides of a concrete barrier for amphibians was mowed to prevent small species from using the vegetation to climb the barrier and enter the road corridor, near the town Haywards Heath, West Sussex, England (copyright: Marcel Huijser).

- It is important that soil and air humidity inside the underpasses are similar to that of the surroundings. Light conditions may be important as well. Therefore, open top structures are usually recommended (figure 120, 121, 122 and 123).
- Rectangular structures are preferred over round or half-round structures because of the increased openness of the top of the structure and associated physical conditions inside the structure. In addition, rectangular structures are harder to climb for amphibians than round or half-round structures, and fences can connect more tightly to rectangular structures.
- A layer of soil is strongly recommended inside the structures. Standing water inside the underpasses should be avoided.

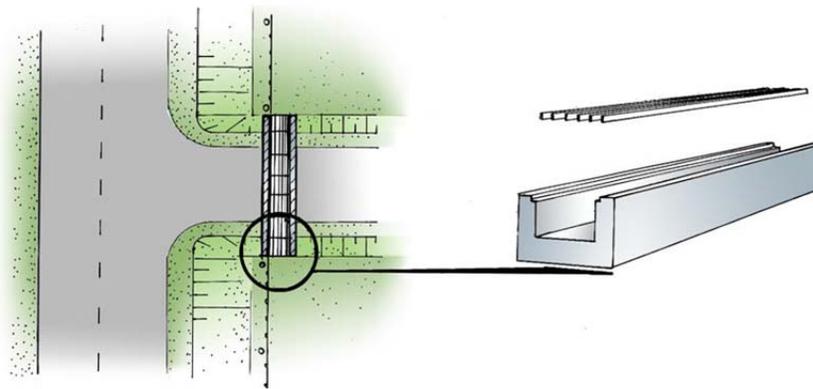


Figure 120. Open tops for underpasses for amphibians are often recommended so that air, soil humidity and light conditions inside the tunnels are similar to conditions outside (reprinted with permission from Kruidering et al., 2005).⁽²⁷⁾

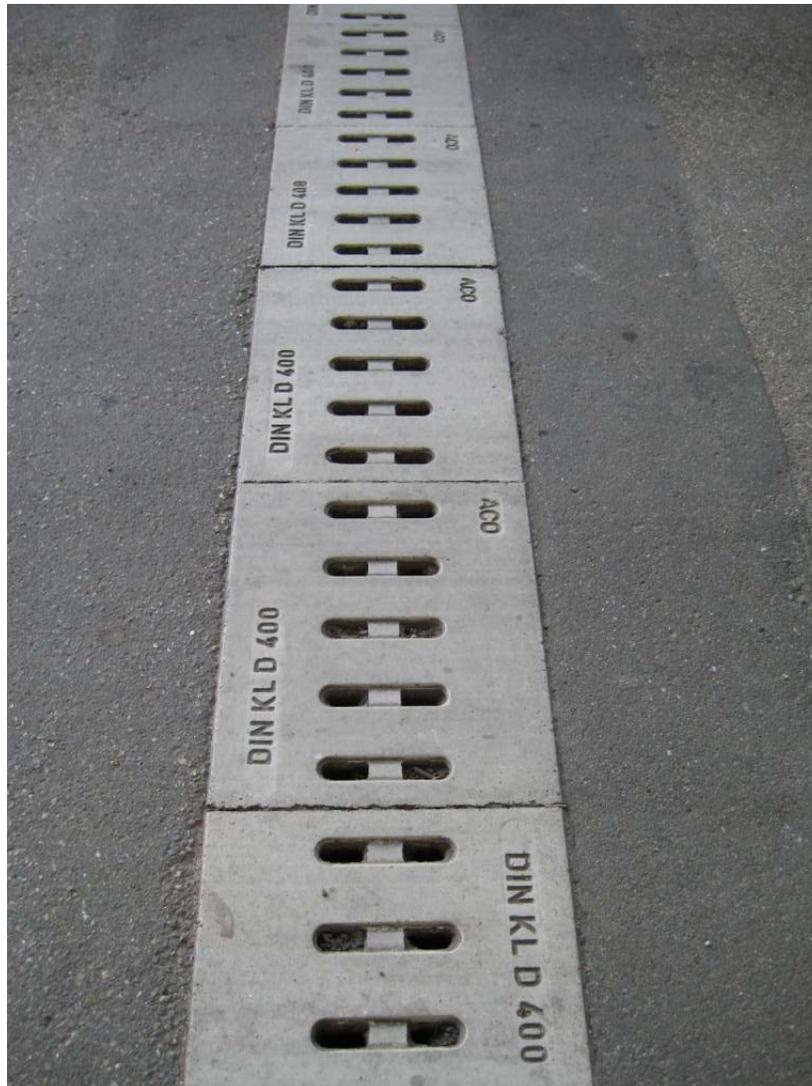


Figure 121. The open concrete top of an underpass for amphibians, allowing light, air, and moisture to enter, near the town Hilversum, The Netherlands (copyright: Marcel Huijser).



Figure 122. The open metal top of an underpass for amphibians, allowing light, air, and moisture to enter, under the road "Hilversumsestraatweg" near the town Hilversum, The Netherlands (copyright: Marcel Huijser).



Figure 123. Close-up of an underpass for amphibians along the road "Hilversumsestraatweg" near the town Hilversum, The Netherlands. Note that the open roof allows light, air, and moisture to enter the underpass (copyright: Marcel Huijser).

- For suggested minimum dimensions of underpasses for amphibians see table 9.

Table 9. Recommended minimum dimensions (width x height or diameter) for amphibian crossing structures (adapted from Kruidering et al., 2005).⁽²⁷⁾

Structure type	Length structure (road width)				
	< 20 m (66 ft)	20–30 m (66-98 ft)	30–40 m (98-131 ft)	40–50 m (131-164 ft)	50–60 m (164-196 ft)
Rectangular (box) culvert	1.0 x 0.75 m (3.3 x 2.5 ft)	1.5 x 1.0 m (4.9 x 3.3 ft)	1.75 x 1.25 m (5.7 x 4.1 ft)	2.0 x 1.5 m (6.6 x 4.9 ft)	2.25 x 1.75 m (7.4 x 5.7 ft)
Round pipe	1.0 m (3.3 ft)	1.4 m (4.6 ft)	1.6 m (5.2 ft)	2.0 m (6.6 ft)	2.4 m (7.9 ft)
Half-round structure	1.0 x 0.7 m (3.3 x 2.3 ft)	1.4 x 0.7 m (4.6 x 2.3 ft)	1.6 x 1.1 m (5.2 x 3.6 ft)	-	-

- Similar to fencing for large animals (section 4.2), mitigation measures for reptiles may consist of concrete barriers (figures 124 and 125). These types of barriers are typically very effective for most amphibian and reptile species except tree frogs, which were able to climb the barrier. Because of the climbing ability of many amphibians and reptiles, an overhang is recommended (figure 126).



Figure 124. A concrete barrier for amphibians and reptiles along U.S. Highway 441 through Paynes Prairie, south of Gainesville, FL (copyright: Marcel Huijser).



Figure 125. A concrete barrier combined with an underpass for amphibians and reptiles along U.S. Highway 441 through Paynes Prairie, south of Gainesville, FL (copyright: Marcel Huijser).



Figure 126. A closeup of the concrete barrier for amphibians and reptiles along U.S. Highway 441 through Paynes Prairie, south of Gainesville, FL (copyright: Marcel Huijser).

- Breaks in the barrier at access roads may be mitigated by gates (figures 127 and 128). To prevent amphibians and small reptiles from crawling under the fence, the fence must connect closely to the ground (figure 127). Alternatively, flaps that hang down from the bottom of the gate can be installed (figure 128).



Figure 127. A gate that allows for access to a field with crops through an amphibian barrier, and a medium- and large-mammal fence, near wildlife overpass "Schinheuvcl," near the town Roermond, The Netherlands. Note that the gate connects closely to a hard surface to prevent amphibians and other small species from entering the road corridor. (copyright: Marcel Huijser).



Figure 128. A gate for pedestrians through a badger fence and an amphibian barrier. Note that the gate has sheeting at the bottom to prevent amphibians and other small species from entering the road corridor. Note also that the gate is angled, so that gravity will automatically close the gate (copyright: Marcel Huijser).

- Suitable habitat for amphibians may also be created on overpasses designed for multiple species. The habitat in figure 129 has a pump installed that pumps water to the center of the overpass, creating a wet zone that connects with ponds on both sides. The great crested newt, an endangered species in The Netherlands, was one of the target species for this connectivity project. Great crested newts were found on top of the overpass within a few months of completion. The square wooden boards shown in figure 129 are for monitoring amphibians on the overpass. During the day the amphibians crawl under the wooden boards for cover, and researcher lift the boards regularly to check for their presence.



Figure 129. The wildlife overpass "Groene Woud" in The Netherlands, with amphibian habitat (copyright: Marcel Huijser).

- In some cases, instead of guiding amphibians toward crossing structures, screens are installed to lead the animals to pitfalls. The animals are trapped in these pitfalls until volunteers collect them and carry them to the other side of the road. These activities, including the presence of the screen fence, are usually restricted during spring migration.
- Temporary road closures, such as during warm, wet, spring nights, are sometimes used to reduce amphibian road mortality. These road closures usually involve small low-volume roads.
- Guardrails can be painted black to reduce glare and light disturbance for amphibians (figure 130).



Figure 130. Guardrail painted black near amphibian tunnels and a multiple-use underpass, along the road "Hilversumsestraatweg", near the town Hilversum, The Netherlands. The painted guardrail is expected to reduce glare and light disturbance for amphibians and other species groups (copyright: Marcel Huijser).

5.2. BIRDS

5.2.1. Hawaiian Goose (Nene)

- Mitigation measures for the Hawaiian goose, or Nene, consist of roadside warning signs, advisory speed limit reductions, signs requesting people to not feed the animals (especially alongside roads or in parking areas), and speed bumps (figure 131 through 134). There are no data available on the effectiveness of these signs.



Figure 131. Hawaiian goose warning sign in Volcanoes National Park, HI (copyright: Marcel Huijser).



Figure 132. Hawaiian goose warning sign in combination with advisory speed limit in Volcanoes National Park, HI (copyright: Marcel Huijser).

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Figure 133. Hawaiian goose "no feeding" sign in Kokee State Park, Kauai, HI (copyright: Marcel Huijser).



Figure 134. Speed bump, specifically installed to reduce vehicle speed for nearby breeding, roosting and feeding area for the Hawaiian goose in Volcanoes National Park, HI (copyright: Marcel Huijser).

- Other mitigation measures that may be considered for the Hawaiian goose include at-grade and below-grade (underpasses) safe crossing opportunities. The geese do not fly when they change feathers or when they protect and guide the goslings between breeding, roosting, and feeding sites. This makes them vulnerable to road mortality.
- Roads that are lower than surrounding areas, and berms, poles, shrubs or trees adjacent to roads have been suggested to encourage birds to fly higher than passing vehicles (figures 135, 136, and 137). In 1994, a bridge along state route A-1-A over the Sebastian inlet in Florida was equipped with 122 poles, each 3m (9.8 ft) long and 3.7m (12.1 ft) apart (figure 135). These bridge poles reduced vehicle collisions with royal terns and brown pelicans by 64 percent.⁽⁴⁶⁾
- The trees that encourage birds to "hop over" the road above traffic should be sufficiently tall, and shrubs close to the road should be removed (figure 136). Furthermore, lower branches should be trimmed at the trunk to discourage birds from spending time at lower heights close to the road.
- For raptors and other scavengers, the removal of road-killed animals reduces the risk of collisions with vehicles.



5 Figure 135. Poles across State Road A-1-A over the Sebastian Inlet in Florida (copyright: Marcel Huijser).

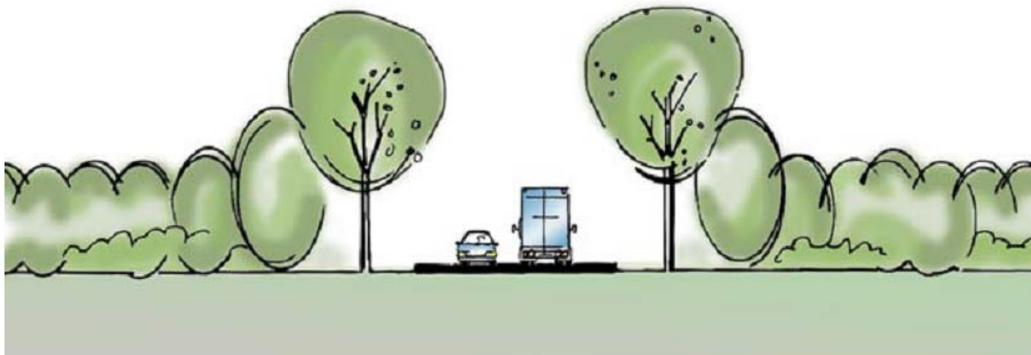


Figure 136. "Hop-over" for birds to encourage them to fly above traffic (reprinted with permission from Kruidering et al., 2005).⁽²⁷⁾



Figure 137. Embankment for birds to encourage them to fly above the traffic on the A27 motorway near Huizen, The Netherlands. Embankments are on both sides of the road, and also serve to reduce sound and light disturbance into the open grasslands. Note that the yellow top of a freight truck shows just above the embankment (copyright: Marcel Huijser).

5.3. MAMMALS

Lower speed limits, general information signs, signs warning of animals on the road, rumble strips to increase driver alertness, wildlife fencing and wildlife under- and overpasses have all been applied to one or more mammal species listed in table 8.

In general, wildlife fencing combined with under- and overpasses are considered the most effective and robust mitigation measure for medium- and large-sized mammals. Animal detection systems are also an option but they should still be considered experimental.

5.3.1. Florida Key Deer

Species specific examples of unique signing have been implemented for Key deer in Florida (figures 138 to 141). In addition to warning signs, a lower nighttime speed limit is posted on U.S. Highway 1 on Big Pine Key.



Figure 138. Warning signs for Key deer along the two-lane U.S. Highway 1 on Big Pine Key, FL (copyright: Marcel Huijser).



Figure 139. Signs showing the road mortality numbers of Key deer on a side road of U.S. Highway 1 on Big Pine Key (copyright: Marcel Huijser).



Figure 140. Warning sign for Key deer combined with message to not feed the deer along a side road of U.S. Highway 1 on Big Pine Key (copyright: Marcel Huijser).



Figure 141. Permanently flashing warning signs for Key deer along U.S. Highway 1 on Big Pine Key (copyright: Marcel Huijser).

Fencing similar to that discussed in section 4.2 has been used for Key deer in Florida (figure 142). The fencing is shorter than that used for other deer because of the abilities of the target species.



Figure 142. A 1.8-m-high (6-ft-high) fence for Key deer along U.S. Highway 1 on Big Pine Key (copyright: Marcel Huijser).

At locations where the road surface was at least as high as the fence (1.8 m (6 ft)), the fence was replaced by the concrete wall of the roadbed (figure 143).



Figure 143. The approach to an underpass for Key deer along U.S. Highway 1 on Big Pine Key (copyright: Marcel Huijser).

An example of an underpass used for Key deer is shown in figure 144. For more detail on underpasses and overpasses refer to sections 4.3 and 4.4.



Figure 144. One of the two underpasses for Key deer along U.S. Highway 1 on Big Pine Key (copyright: Marcel Huijser).

5.3.2. Florida Panther

Reduced speeds, warning signage, fencing and underpasses have been used in mitigation efforts related to the Florida panther. Figures 145 through 150 show some of the unique warning signs used.



Figure 145. Warning sign for the Florida panther along SR 29 in southern Florida (copyright: Marcel Huijser).



Figure 146. Warning sign for the Florida panther along SR 29 in southern Florida (copyright: Marcel Huijser).



Figure 147. Warning sign for the Florida panther along SR 29 in southern Florida (copyright: Marcel Huijser).



Figure 148. Warning sign for Florida panther in southern Florida (copyright: Marcel Huijser).

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Figure 149. Warning signs for Florida panther along SR 29 in southern Florida (copyright: Marcel Huijser).



Figure 150. Permanently flashing warning sign for Florida panther, combined with a rumble strip along SR 29 in southern Florida (copyright: Marcel Huijser).

- Fencing (figure 151) and crossing structures (figure 152) have been used for the Florida panther. For more detail on fencing refer to section 4.2. For more detail on crossing structures refer to sections 4.3 and 4.4.



Figure 151. Wildlife fencing, with barbed wire overhang, for the Florida panther on SR 29 in southern Florida (copyright: Marcel Huijser).



Figure 152. Underpass for hydrology (water flow) and the Florida panther along Interstate 75 in southern Florida (copyright: Marcel Huijser).

CHAPTER 6: GUIDELINES FOR MONITORING

This chapter provides guidelines for major elements of a monitoring/evaluation plan as well as some common pitfalls to be avoided. Of the dozens of mitigations listed in table 2, section 4.1, most are considered experimental in nature. Additional monitoring and evaluation is needed to continue to improve best practices and adequately assess the performance of the mitigation measures that are more experimental in nature, both with regard to WVC reduction as well as habitat connectivity for wildlife. A monitoring and evaluation program is the capstone of any WVC reduction program (figure 153).

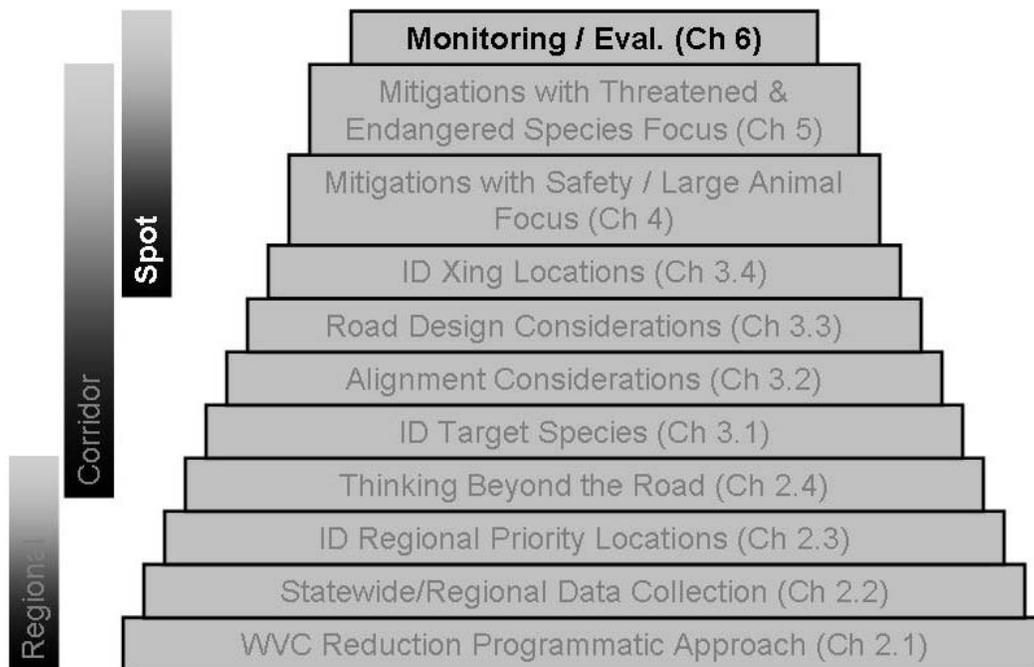


Figure 153. Monitoring and evaluation as part of a strategy for reducing WVCs.

A plan for evaluating the effectiveness of mitigation measures should be developed well before the mitigation is implemented. One of the greatest challenges in executing an evaluation plan is **lack of pre-installation data**.

The mitigation plan should identify the goals of the mitigation. The goals of the mitigation measures typically have a safety and a habitat connectivity component:

- Safety—the desired level of reduction in WVCs.
- Habitat connectivity—the acceptable number of animal movements of the target species across or under the road.

Based on these goals the evaluation plan should state specific questions to be answered, such as:

- Were WVCs reduced, and if so, by how much?
- Did the potential safe crossing opportunities provide "sufficient" connectivity across or under the road for the target species?
- Were there negative side effects of the mitigation measure?
- What was the cost of construction and installation?
- What were the maintenance requirements?
- Were there specific modifications in the design of the mitigation measure to address the local situation or project goals and, if so, which modifications?
- What changes should be made when designing similar measures in the future?
- What are the perceptions of staff involved (e.g., State DOT maintenance and resource agency staff) regarding the effectiveness, costs and benefits of the mitigation?

These types of questions can be used to define the specific parameters that must be measured to evaluate the performance of the mitigation, and decide on the specific methods that are to be used for the evaluation.

For the monitoring plan, it is important to consider the appropriate data study design, data collection protocols, and the required sample sizes. When designing the WVC or habitat connectivity research, be as specific as possible with regard to the research question, and make sure that the dependent variable (e.g., number of WVCs or numbers of animal crossings of the target species) and the associated data collection and data analysis procedures allow for answering the research questions. If some data are available already from the same or a different location, consider conducting **power analyses** to make sure the potential sample sizes will be large enough to detect the differences or effects that might be expected or desired. Consider the **empirical Bayes approach** and **BACI-analyses** (Before-After-Control-Impact) as mitigation location selection will impact the needed sample size.

A critically important aspect of monitoring effectiveness is to **publish the results**, regardless of the outcome or thoroughness of the evaluation effort. Providing information that other agencies can use is extremely helpful in the continuing effort to reduce WVCs nationwide.

The remainder of this chapter discusses common data collection methods and some of the related mistakes and pitfalls commonly encountered therein.

6.1. MEASURING REDUCTION IN WVCs

The most common method for evaluating effectiveness of mitigation measures on WVCs, is to compare the number of WVCs that occurred before and after implementation of the mitigation. Typically periods of **three or five years of crash data before and after implementation** are compared. Mistakes commonly made in these comparisons are discussed below.

- **Simply comparing mean crash frequencies before and after the mitigation measure is installed to assess effectiveness:** Typically evaluations of WVC mitigations are implemented at locations with the highest frequency of WVCs. This incorporates a selection bias, known as "regression to mean error," that could skew results. By contrast,

this error would not occur if locations for mitigation are chosen randomly. Refer to Hauer for a methodology, known as the empirical Bayes method, to account for this error.⁽⁴⁷⁾

- **Assuming a change in crash frequency is solely the result of the mitigation that was implemented:** The frequency of wildlife crossing the road obviously has a strong impact on the number of crashes. Animals may avoid the area because of construction, maintenance and/or monitoring activities associated with the implementation, a wider road and increased traffic volume, or changes in the landscape adjacent to the road, all of which can affect the number of attempts by wildlife to cross the road and, thus, the number of WVCs. Another important factor is fluctuating herd sizes; fewer or more WVCs may simply be related to lower or higher population density. There are several approaches to normalizing results to account for changes in animal movement:
 - Use control sites (comparison in space) as well before/after data from the same sites (comparison in time).
 - Use population size estimates as a measure of exposure.
 - Monitor animal movement in the area before and after the installation.
- **Changing crash data collection methods after the mitigation is installed:** It is important to compare apples to apples. For instance, crash reports should not be compared to carcass counts. Carcass search and reporting efforts are sometimes increased after the mitigation is installed when carcass counts are used in the before/after comparison. It is important that the same methods for collecting WVC data be used both before and after the installation. It is not essential to report every crash or carcass, but it is essential to have consistency in the search and reporting effort.

In the case of mitigation measures that are aimed at changing driver behavior (e.g., alerting drivers to the potential hazard so they are more attentive), vehicle speeds can be collected as an indicator to numbers of WVCs. This approach may be desirable as more data can be collected (e.g., thousands of vehicle speeds compared to a few WVCs per year). A statistically significant difference is easier to find if the sample size is larger. This method can be used to verify that the mitigation does, in fact, modify driver behavior. However, there is no agreed upon relationship between reduced driver speed and reduced WVCs, and reduced speed may not necessarily translate into reduced WVCs.

6.2. MONITORING WILDLIFE MOVEMENT

The most common method for evaluating effectiveness of mitigation measures on habitat connectivity is to simply measure the number of animal crossings. Monitoring wildlife use of wildlife crossing structures with fencing may show a substantial number of crossings. However, without a reference or pre-stated goal, it is difficult to conclude whether the observed wildlife use of the crossing structures is sufficient to deem them effective. Examples of references that can be used for comparison are:

- The number of animal movements across the road before the mitigation measures were put in place.
- The number of animal movements in a comparable but undisturbed landscape, away from the road and beyond the zone that may be affected by roads and traffic.

Examples of references that can be used to determine habitat connectivity are:

- A certain minimum number of animal movements by target species over a certain time period. This may be a management goal only, not necessarily with a biological basis.
- Enough movement to maintain or restore viable populations of the target species on both sides of the road. Population viability analysis can provide insight into the minimum number of animal movements across or under the road over a certain time period in order to maintain or restore the population viability of selected species in an area.

Methods to monitor animal presence or movements include tracking beds, cameras, DNA sampling, GPS collars and trapping/tagging.

Tracking beds of sand, or ink beds, or other tracking media can be installed to measure the number of animal movements across a road. Tracking beds may be used before construction of the mitigation measures to provide a reference for the wildlife use of safe crossing opportunities.⁽⁴⁸⁾ Tracking beds may also be used to measure wildlife use of the safe crossing opportunities. Depending on the medium, environmental conditions, and the number of animal movements, tracking beds may have to be checked daily, twice a week, or weekly. In northern locations, snow can be an inexpensive medium used for tracking beds.

Another method to document wildlife movements along roadways is the use of wildlife **cameras**. Camera sampling stations are usually placed in the study area along the road corridor, or at safe crossing opportunities. The range of the sensors, the delay between a detection and taking a picture, the potential disturbance of wildlife (e.g., normal visible flash vs. infrared), and potential theft or vandalism are important factors to consider.

Counters, such as those that count animals when they break an infra-red beam, can be a surrogate for cameras. Adjusting the height of the counter may help focus the count on species of interest, but all species that trigger the counter will be pooled together, making it hard to relate the data to one or more specific species.

Non-invasive **DNA sampling** can be a practical method to distinguish between individual animals. For example, ten passages of a species through an underpass could represent ten passages of different individuals, or ten passages by the same individual. Minimum population size estimates can be acquired by also sampling DNA in a grid in the areas adjacent to the road. Strands of barbed wire are often used to collect hair samples from animals. A track bed, barbed-wire hair snag, and camera are shown in figure 154.

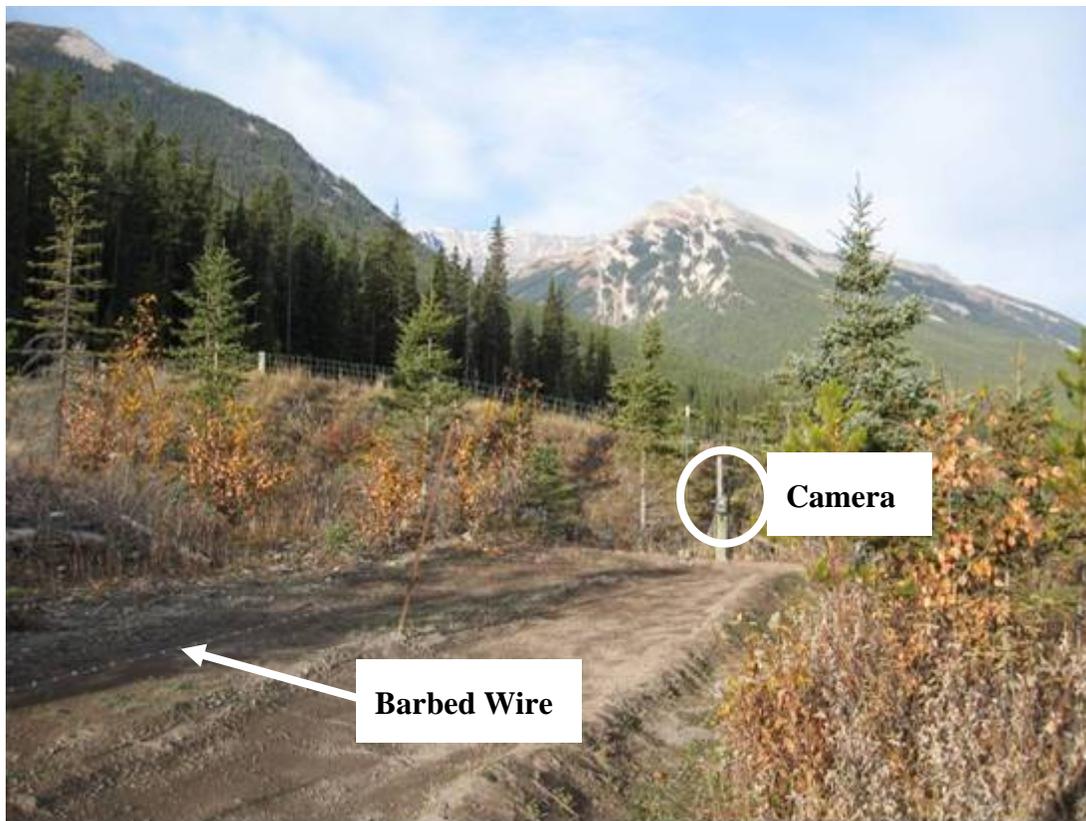


Figure 154. Tracking bed, photo camera and DNA hair snag (copyright: Marcel Huijser).

GPS collars and radio telemetry can be used to track individuals to investigate when and where they cross the roadway. This approach allows for detailed movement tracking, but only for the individuals that have been equipped with the tracking device.

Trap, tag and recapture methods (typically for smaller animals) can be used to identify individuals that cross the roadway. Individuals are captured at grid locations on each side of the roadway, tagged to identify the initial location, and recaptured sometime later. If an individual is recaptured at a location on the opposite side of the roadway, it is certain the individual crossed the roadway. Typically, life traps are used that are customized for the target species.

When collecting and analyzing wildlife movement data consider the following:

- With wildlife fencing in combination with wildlife crossing structures, it may take three to four years (ungulates) or five to seven years (grizzly bears) before the increase in **wildlife use of crossing structures** levels off, indicating that the animals have learned the location of the crossing structures and that they are safe to use. This does not necessarily mean that all species and all individuals use the crossing structures after seven years, but the use of the crossing structures is likely to have stabilized by then. Measuring wildlife use in the first years after completion of the crossing structures is likely to show an increase in use that represents a "learning curve," whereas measuring wildlife use five or more years after completion of the crossing structures is more likely to indicate the eventual normal level of wildlife use. Note that it may take longer for the

increase in wildlife use to level off if relatively naive individuals are targeted that may not have had exposure to roads, traffic and mitigation measures, and may be unfamiliar with the location of the crossing opportunities (e.g., those in seasonal migration or dispersal movements).

- **Consider measuring variables that are likely to influence animal movements across or under the road over time.** For example, changes in traffic volume, changes in human disturbance or changes in the landscape adjacent to the road, and changes in wildlife population sizes can influence the number of animal movements across or under a road. Thus potential changes in the number of animal movements across or under a road are not necessarily related to just the presence and performance of the mitigation measures.

For more detail on monitoring methods refer to Hardy and others.⁽⁴⁸⁾

CHAPTER 7: POTENTIAL FUNDING SOURCES

Potential funding sources for wildlife–vehicle collision reduction projects and research include a mix of traditional transportation programs and agencies and new non-transportation partners. Reducing WVCs can have benefits beyond safety, including reduced wildlife mortality, protection of threatened or endangered species, improved habitat connectivity, and reduced maintenance costs for carcass removal. Since these benefits reach beyond transportation safety, WVC mitigation has the potential for developing new sources of funding from non-transportation partners.

7.1. FEDERAL FUNDING—TRANSPORTATION

Traditional Federal funding sources for WVC mitigation activities originate with the Safe Accountable Flexible Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU, U.S. Public Law 109-59 2005). Pertinent programs that could support wildlife–vehicle collision reduction planning, projects or research that are funded by SAFETEA-LU are summarized in table 10.

Table 10: SAFETEA-LU Funding Sources

Funding Source	Amount (2005-2009)	Notes
Highway Safety Improvement Program (HSIP)	\$5.1 bill.	This program has \$90 million set aside each year for high-risk rural roads (WVCs are commonly a rural challenge). To be eligible for these funds, WVC mitigation projects need to be part of a State's Strategic Highway Safety Plan.
Bridge	\$21.6 bill.	Bridge projects can provide an opportunity, with limited wildlife exclusion fencing and a limited extension to the length of a bridge, to funnel wildlife under the bridge, removing the hazard from the roadway.
Interstate Maintenance, Surface Transportation, National Highway Programs.	\$25.2 bill. \$32.5 bill. \$30.5 bill.	Incorporate WVC mitigations within reconstruction and maintenance projects that are funded by these programs
Planning, Environment, and Realty (HEP) Programs	Numerous sources	Other Federal transportation resources for WVC mitigation can be found in Department of Transportation agencies and programs. A list of programs funding environmental activities is on its web site at: http://www.fhwa.dot.gov/hep/index.htm (accessed 6 June 2008).
Public Lands Highways Discretionary Program	In 2006, 77 projects designated to receive \$95.2 mill.	This program is authorized to fund projects on an annual basis in 11 western States that contain at least 3 percent of the total public land in the United States. See web site at: http://www.fhwa.dot.gov/discretionary/ (accessed 6 June 2008).

Table 10, Continued

Funding Source	Amount (2005-2009)	Notes
Surface Transportation Environment and Planning Cooperative Research Program (STEP)	\$67.5 mill.	STEP is the sole source of funds for all FHWA research on planning and environmental issues. One environmental emphasis area called Natural Environment includes wildlife habitat. The FHWA will provide ongoing opportunities for funding collaborative research. See web site at: http://www.fhwa.dot.gov/hep/step/step.htm (accessed 6 June 2008).
Technology Deployment Program	\$4.1 mill.	Administered by FHWA, this program includes the Innovative Bridge Research and Deployment Program, which is intended to promote, demonstrate, evaluate and document innovative designs, materials, and construction methods of bridges and other highway structures.
Transportation Enhancement Program (TEP)	Part of the Surface Transportation Program	TEP funds transportation-related projects designed to strengthen the cultural, aesthetic, and environmental aspects of the U.S. intermodal transportation system, offering communities additional non-traditional transportation choices. See web site at: http://www.fhwa.dot.gov/environment/te/ (accessed 6 June 2008).
Federal Lands Highway Program (FLHP)	\$893 mill.	The primary purpose is to provide funding for a coordinated program of public roads to serve the transportation needs of Federal lands that are not a State or local government responsibility. This program contains five categories: Indian Reservation Roads, Park Roads and Parkways, Forest Highways, Public Lands Highways and Refuge Roads. The FLHP roads serve recreational travel and tourism, protect and enhance natural resources, provide sustained economic development in rural areas, and provide needed transportation access for Native Americans. See web site at: http://www.fhwa.dot.gov/flh/flhprog.htm (accessed 6 June 2008).

Table 10, Continued

Funding Source	Amount (2005-2009)	Notes
Coordinated Federal Lands Highway Technology Implementation Program (CTIP)	Numerous Sources	This is a cooperative technology deployment and sharing program between the FHWA Federal Lands Highway office and Federal land management agencies. It provides a forum for identifying, studying, documenting, and transferring new technology to the transportation community. Many new innovative technologies, such as measures allowing fish passage through culverts, have been funded through the CTIP program. CTIP funds are normally used for technology projects related to transportation networks on Federal public lands. Research projects are not eligible under this program. See web site at: http://www.fhwa.dot.gov/flh/ctip.htm (accessed 6 June 2008).
Federal Transit Administration	\$45.3 bill.	This has a grant program for funding for transit-related planning and other projects. See web site at: http://www.fta.dot.gov/grants_financing.html (accessed 6 June 2008).
State and Community Highway Safety Program	Variable	Administered by National Highway Traffic Safety Administration, this program provides grants for the States, Federally recognized Indian tribes, the District of Columbia, Puerto Rico, American Samoa, Guam, Northern Marianas, and the Virgin Islands. See web site at: http://www.federalgrantswire.com/state_and_community_highway_safety.html (accessed 6 June 2008).

7.2. FEDERAL FUNDING—OTHER SOURCES

Another Federal resource for funding WVC projects is the **U.S. Fish and Wildlife Service (FWS)** which administers a variety of natural resource assistance grants to government agencies, public and private organizations, groups and individuals. Links to information about available grants can be found at: <http://www.fws.gov/grants/> (accessed 6 June 2008).

Twenty **Natural Resource Assistance Grant Programs** for State agencies are administered by the FWS. Several of these programs are for wildlife protection and restoration; more information is available at: <http://www.fws.gov/grants/state.html> (accessed 6 June 2008).

One such program is the **Cooperative Endangered Species Conservation Fund** (Section 6) Grants to States and Territories, which is designed to provide financial assistance to States and Territories to participate in a wide array of voluntary conservation projects for candidate, proposed and listed species. More information is available at: <http://www.fws.gov/endangered/grants/section6/> (accessed 6 June 2008).

7.3. PRIVATE FOUNDATIONS

While transportation infrastructure is generally financed through a combination of local, State, and Federal funds, private philanthropy can be productive by applying resources to research, education, outreach, and advocacy efforts that help leverage or match public funds. Most private foundation philanthropy is focused on giving to non-profit organizations organized under Section 501(c)(3) of the Internal Revenue Code. Thus, for WVC mitigation projects to receive private funding, it is incumbent on Federal and State transportation agencies to collaborate with non-profit organizations.

A report in 2004 to the Henry P. Kendall Foundation, "Highway Funding for Nature: A Major Conservation Opportunity?" by Charles C. Chester, has a page of private grant-makers interested in road ecology issues and projects. The report is available at: <http://www.kendall.org/publications/reports/Highways.pdf> (accessed 6 June 2008).

A web-based entity that facilitates the funding of smart growth and other related transportation initiatives is the **Funders' Network for Smart Growth and Livable Communities**. It has a search engine for grant seekers at its web site: <http://www.fundersnetwork.org/directory2784/directory.htm> (accessed 6 June 2008).

The **Foundation Center** has an extensive directory of private philanthropic and grant-making foundations that could support WVC projects and research. The center's web site is at: <http://foundationcenter.org/> (accessed 6 June 2008). Extended search engines can be accessed for a fee.

7.3.1. Innovative Funding Developments: Software Tools

The fee-based fundraising software program **BigDataBase.com** lists 20,000 of the top private foundations in the United States. A search using the keyword "transportation" lists 190 private U.S. foundations. A search using the keywords "transportation" and "wildlife" lists 44 private foundations. Big Data Base is at: <http://www.bigdatabase.com> (accessed 6 June 2008).

7.3.2. Private Foundations for Federal Agency Purposes

The **National Fish and Wildlife Foundation** is a private, non-profit, tax-exempt organization, established by Congress in 1984 and dedicated to the conservation of fish, wildlife, and plants, and the habitat on which they depend. The foundation meets its goals by creating partnerships between the public and private sectors and strategically invests in conservation and sustainable use of natural resources. It awards matching grants to projects benefiting conservation education, habitat protection and restoration, and natural resource management. Information on this foundation is available at: <http://www.nfwf.org/> (accessed 6 June 2008).

The **National Park Foundation** has helped to fund important conservation, preservation and education efforts. The National Park Foundation grants over \$31 million annually in cash, services or in-kind donations to the National Park Service and its partners. Grants range from

small "seed" or start-up funding to larger, multi-year projects. Its web site is at: <http://www.nationalparks.org/about/> (accessed 6 June 2008). Individual national parks may also enjoy the assistance of a local foundation developed for their benefit, such as the Yellowstone Park Foundation or Grand Teton National Park Foundation. Other parks have subsidiaries of the National Park Foundation (for example, the Glacier Fund of Glacier National Park).

7.4. CORPORATE PHILANTHROPY

Thousands of U.S. corporations have a long history of philanthropy and many have established their own foundations to facilitate their giving. They also have programs that match employee contributions, provide in-kind gifts or provide volunteers for projects. Local WVC projects may be eligible to receive support from corporate conservation, environmental, or community programs.

An excellent resource for information on corporate philanthropy is the **National Directory of Corporate Giving** (New York: The Foundation Center). It describes the charitable activities of 2,586 major U.S. corporate foundations and 1,468 direct-giving programs. Entries include the company's name, address, affiliates, subsidiaries (if any), amount and range of grants, and types of non-cash support such as staff time and products.

An on-line search for corporate funding is available at **Fundsnet Services Online**. It is free at <http://www.fundsnet.com/> (accessed 6 June 2008) and lists both corporate and private foundation programs with links to their web sites.

Similarly, the Foundation Center (previously mentioned) has a corporate funding section. It can be found at <http://www.foundationcenter.org/> (accessed 6 June 2008). The search engine on this web site is fee-based.

The fee-based fundraising software program at <http://www.bigdatabase.com> (previously mentioned) lists the 500 largest corporations in the United States. A search using the keyword "transportation" lists 43 companies. A search using the keywords "transportation" and "environment" lists 24 companies.

7.5. A NOVEL APPROACH: LOCAL TAXES

For the first time in a citizen-led ballot measure, voters in Pima County, Arizona, approved funding for wildlife crossing structures. A \$2 billion transportation plan, funded by a ½-cent **sales tax**, includes an unprecedented \$45 million dollars to specifically fund wildlife crossing structures. The plan and tax were overwhelmingly supported by voters on May 16, 2006. According to County Administrator Chuck Huckleberry, "Investment in conservation and transportation are not mutually exclusive. With this funding vast landscapes can be reconnected, improving wildlife movement through the region and making roadways safer for both animals and people." The "critical landscape linkages" funding will be overseen by a team of non-government agencies and agency biologists and transportation officials from the region's various jurisdictions. The team will identify, evaluate and prioritize locations and design appropriate structures. Funding is available for design and construction of wildlife crossing improvements within future and existing roadways and highways, and will include improvements such as expanded culverts or underpasses, overpasses, fencing and signage.

CHAPTER 8: WVC REDUCTION STRATEGY CHECKLIST

This manual provides a number of strategies for reducing WVCs. The relevance to readers of different sections of this manual will vary depending on the purposes and needs of the particular reader. A brief checklist is provided here for different kinds of activities related to WVC reduction.

8.1. STATEWIDE WVC REDUCTION PROGRAM

When implementing a statewide WVC reduction program, consider these actions:

- ✓ Establish a multiagency coalition to oversee the program. The makeup and structure of the oversight committee should be tailored to include appropriate agencies and to most effectively integrate into the organizational structures of these agencies (section 2.1).
- ✓ Determine the baseline magnitude of the problem for the State (i.e., annual WVCs, threatened and endangered species, etc.).
- ✓ Implement a statewide data collection and monitoring plan (section 2.2).
- ✓ Identify regional priority locations (section 2.3).
- ✓ Establish annual goals, potential funding sources and program guidance strategy (section 2.4 and chapter 7).
- ✓ Identify specific improvements/mitigations (chapters 4 and 5).
- ✓ Educate State DOT staff and incorporate consideration of WVCs into the highway design process.
- ✓ Establish an evaluation and monitoring program for specific mitigation implementations (chapter 6).

8.2. INCORPORATING WVC REDUCTION INTO CORRIDOR PLANNING/DESIGN

If a specific highway that is expected to have challenges with WVCs is being rehabilitated or reconstructed, or if a corridor is selected specifically for mitigating WVCs, consider the following tasks:

- ✓ Identify the magnitude of the WVC problem and determine the target species for WVC reduction (section 3.1).
- ✓ For existing roadways, identify locations of wildlife crossings and WVC hotspots (section 3.4).
- ✓ For designing new or realigned roadways incorporate WVC considerations into the alignment selection (section 3.2).
- ✓ Throughout the road design process consider designs that may minimize the potential for WVCs (section 3.3).
- ✓ For WVC problem locations that cannot be avoided through alternative alignment or road design techniques, consider mitigations for the entire corridor, or at the problem locations

(chapter 4 for large animal mitigations; chapter 5 for threatened and endangered species mitigations).

- ✓ For the corridor project, consider alternative funding sources to increase the level at which WVCs can be mitigated (chapter 7).
- ✓ Throughout the design process, try to consider ecological, development, and other interactions beyond the roadway (section 2.4).
- ✓ If WVC mitigation strategies are included in the corridor, develop an evaluation plan to track the success of the mitigation (chapter 6).

8.3. SPECIFIC MITIGATIONS

If a specific mitigation is implemented independent of a highway/corridor design, refer to the information in this manual relating to the specific mitigation:

- ✓ For fencing design and implementation guidance refer to section 4.2.
- ✓ If an animal detection system is being considered refer to section 4.7.
- ✓ For guidance on vegetation management strategies to reduce WVCs refer to section 4.8.
- ✓ If wildlife culling is being considered refer to section 4.9.
- ✓ If mitigating for a threatened or endangered species, refer to the mitigations in chapter 5. Many of the mitigations for large mammals provided in chapter 4 are also applicable to threatened and endangered species.
- ✓ If fencing is selected as a mitigation, consider providing safe crossing opportunities through:
 - Wildlife underpasses (section 4.3) and overpasses (section 4.4).
 - Shared use (bicycle, pedestrian, vehicle, livestock) wildlife underpasses (section 4.5) and overpasses (section 4.6).
- ✓ For the mitigation implemented, consider monitoring and evaluation (chapter 6).

APPENDIX A: INDICATIVE HOME RANGE SIZES FOR SELECTED SPECIES

Home range size and home range diameter estimates for selected large ungulate species. The estimates relate to female individuals where possible.

Species	Home range (ha)	diameter (m)	Source(s)
White-tailed deer	70 ha	944 m	70.5 ha for adult females in summer ⁽⁴⁹⁾ , <80 in summer ⁽⁵⁰⁾ , 60–70 ha for females in summer ⁽⁵¹⁾ , 89 ha (range 17–221 ha) for females in summer and 115 ha (range 19–309 ha) in winter ⁽⁵²⁾
Mule deer	300 ha	1,955 m	301 ha on average for males and females in winter ⁽⁵³⁾ , 90–320 ha for adult females in summer and 80–500 ha in winter ⁽⁵¹⁾ , 617 ha (range 25–4,400 ha) for females in summer and 1,267 ha (range 32–9,070 ha) in winter ⁽⁵²⁾
Elk	5,000 ha	7,981 m	3,769 ha (range 820–9,520 ha) for females in summer and 181 ha (range 152–210 ha) in winter ⁽⁵²⁾ , 5,296 ha for adult females in summer and 10,104 ha in winter ⁽⁵⁴⁾ , 8,360–15,720 ha for elk populations ⁽⁵⁵⁾
Moose	2,500 ha	5,643 m	2,612 ha (range 210–10,300 ha) for females in summer and 2,089 ha (range 200–11,300 ha) in winter ⁽⁵²⁾
Mountain goat	300 ha	1,955 m	280 ha for adult males, 480 ha for adult females ⁽⁵⁶⁾
Bighorn sheep	900 ha	3,386 m	541 ha for females ⁽⁵⁷⁾ , 920 ha (range 650–1,140 ha) for females in summer and 893 (range 880–1,320 ha) in winter ⁽⁵²⁾ , 640–3,290 ha ⁽⁵⁷⁾
Pronghorn	2,000 ha	2,523 m	1,200–1,400 ha in summer ⁽⁵⁸⁾ , 2,259 ha ⁽⁵⁹⁾ , 2,841 in winter ⁽⁶⁰⁾

Home range size and home range diameter estimates for selected carnivores. The estimates relate to female individuals where possible.

Species	Home range (ha)	Diameter (m)	Source(s)
Weasel	180 ha	757 m	52 ha (males) and 180 ha (females) ⁽⁶¹⁾
Pine marten	500 ha	2,524 m	200 ha (range 0.7–2.3 ha) for females ⁽⁶²⁾ , 1,300–3,900 ha ⁽⁶³⁾
Fisher	10,000 ha	5,642 m	18,900 ha for females and 33,700 for males ⁽⁶⁴⁾ , 5,400 ha (females) and 9,200 ha (males) ⁽⁶⁵⁾
Badger	4,000 ha	7,138 m	240–1,700 ha ⁽⁶³⁾ , 3,400 ha ⁽⁶⁶⁾ , 4,150 ha (range 1,800–7,900 ha) for females ⁽⁶⁷⁾
Wolverine	20,000 ha	15,962 m	16,700 ha (range 7,600–26,900 ha) for females ⁽⁶⁸⁾ , 10,500 for adult females ⁽⁶⁹⁾ , 38,800 for females ⁽⁷⁰⁾ , 32,500–40,500 ha for females ⁽⁷¹⁾
Bobcat	2,500 ha	5,643 m	1,780 ha for adult female ⁽⁷²⁾ , 1,930 ha for females ⁽⁷⁰⁾ , 3,120 ha for females ⁽⁷³⁾
Canada lynx	15,000 ha	13,823 m	2,800 ha (range 1,110–4,950 ha) for adults ⁽⁷⁴⁾ , 9,000 ha (range 5,800–12,100 ha) for adult females ⁽⁷⁵⁾ , 20,600 ha (range 7,700–40,800 ha) for females ⁽⁷⁶⁾
Cougar	4,000 ha	7,138 m	3,500 ha (range 1,900–5,100 ha) for adult females in summer and 2,600 ha (range 1,400–4,300 ha) in winter ⁽⁷⁷⁾ , 6,730 ha for females ⁽⁷⁰⁾ , 9,700 ha (range 3,900–22,700 ha) for adult females in summer and 8,700 (range 3,100–23,900 ha) in winter ⁽⁷⁸⁾
Fox1 (V. vulpes, Urocyon)	1,500 ha	4,371 m	Red Fox (V. vulpes): 350 ha ⁽⁷⁹⁾ , 1,611 ha (range 277–3,420 ha) ⁽⁸⁰⁾
Fox2 (V. macrotis, V. velox)	8,000 ha	505 m	Kit fox (V. Macrotis): 4,300–11,600 ha ⁽⁸¹⁾
Coyote	2,500 ha	5,643 m	1,130 ha (range 280–3,200 ha) ⁽⁸²⁾ , 2,010 ha (range 1,600–2,420 ha) for females ⁽⁷⁰⁾ , 2,420 ha (range 880–5,460 ha) for adult females ⁽⁸³⁾ , 3,186 ha (range 670–9,140 ha) for females ⁽⁸⁴⁾

Wolf	50,000 ha	25,238 m	6,250 ha (range 700–6,800 ha) ⁽⁷⁰⁾ 26,000–67,500 ha for a large pack ⁽⁶³⁾
Black bear	4,000 ha	7,138 m	1,960 ha for females ⁽⁸⁵⁾ , 5,960 ha (range 2,300–16,000 ha) for adult females ⁽⁸⁶⁾
Grizzly bear	25,000 ha	17,846 m	22,700 ha (range 3,500–88,400 ha) for adult females ⁽⁸⁷⁾ , 28,500 ha (112–482 ha) for adult females ⁽⁸⁸⁾

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