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

INTRODUCTION

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

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

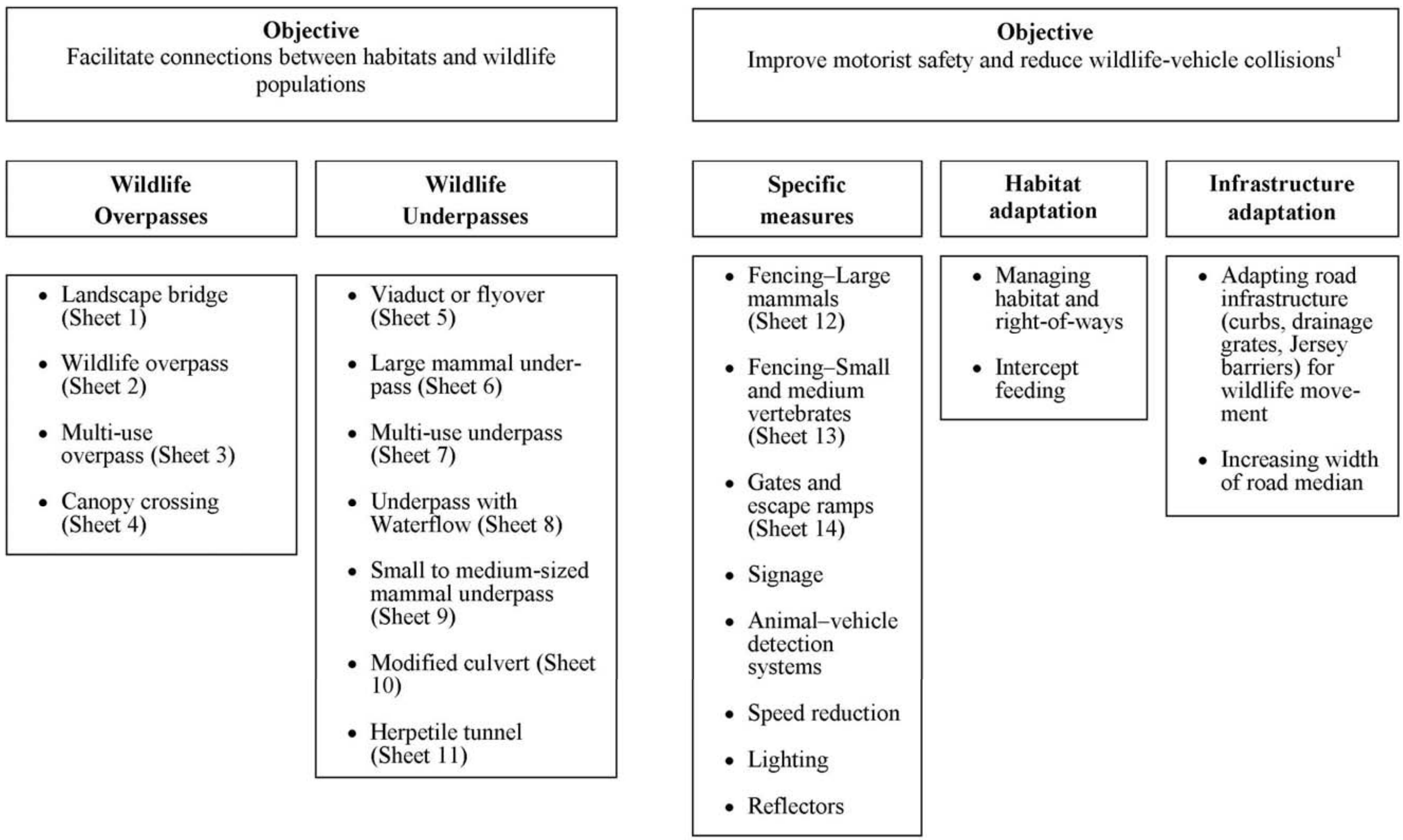
The general questions are followed by many specific questions:

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

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

FUNCTION OF WILDLIFE CROSSINGS AND ASSOCIATED MEASURES

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



[1]See Huijser et al. (2008).

Figure 18. Chart. Types of measures used to reduce the impacts of roads on wildlife (adapted from Iuell 2005).

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Objective 1: Facilitate connections between habitats and wildlife populations

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

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

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

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

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

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

SPACING OF WILDLIFE CROSSINGS

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

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

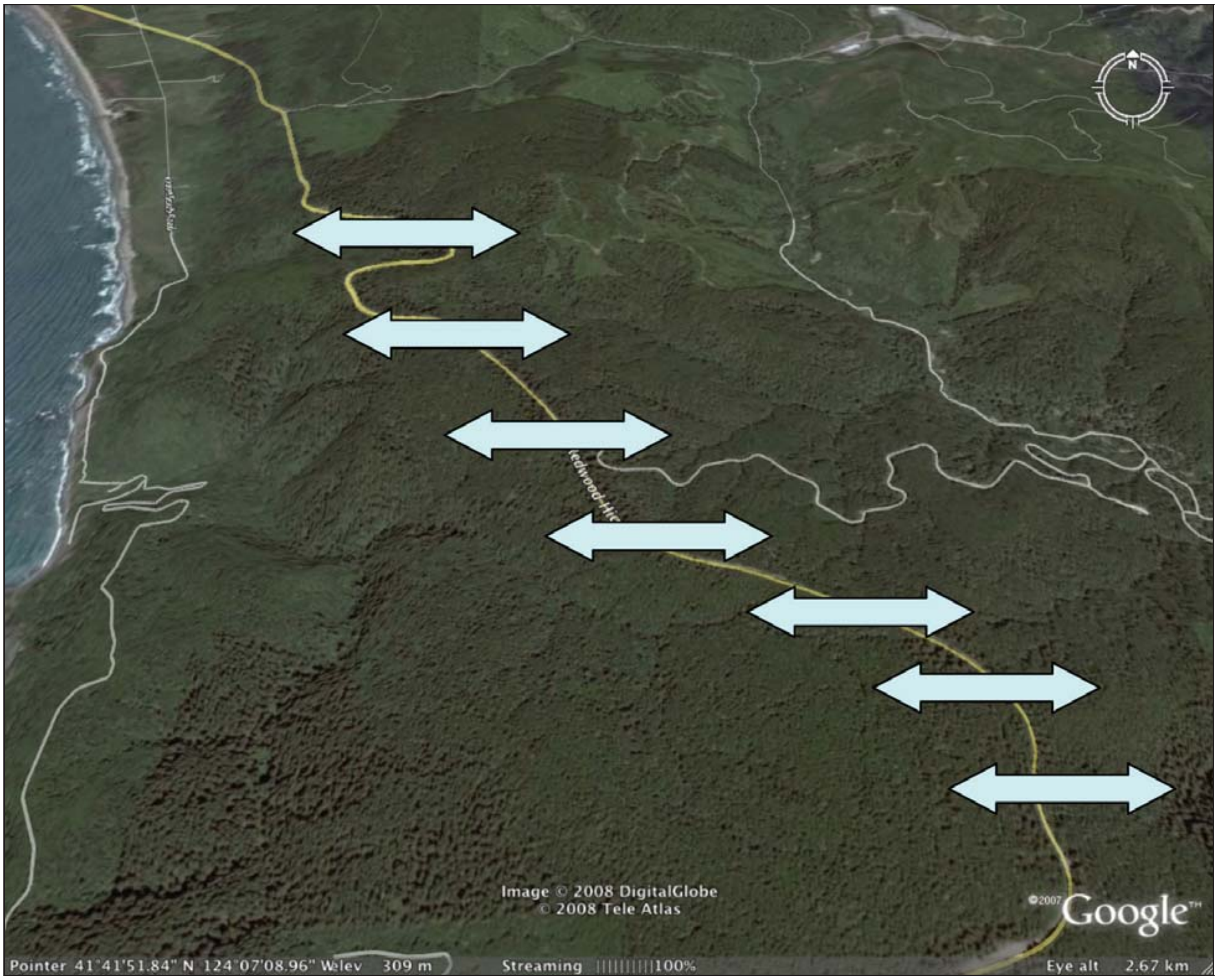

Figure 20. Photo. Hwy 101, Redwood highway, California. Low contrast landscape with low level of habitat fragmentation (adapted from Google Earth).

Wildlife crossings are permanent structures embedded within a dynamic landscape. With the lifespan of wildlife crossing structures around 70–80 years, the location and design of the crossings need to accommodate the changing dynamics of habitat and climatic conditions and their wildlife populations over time. How can we reconcile the dynamic environmental processes of nature with static physical structures on roadways? Environmental change is inevitable and will occur during the lifespan of the crossing structures. Some basic principles that management needs to consider:

- *Topographic features:* Wildlife crossings should be placed where movement corridors for the focal species are associated with dominant topographic features (riparian areas, ridgelines, etc). Sections of roadway can be ignored where terrain (steep slopes) and land cover (built areas) are unsuitable for wildlife and their movement.

- *Multiple species:* Crossings should be designed and managed to accommodate multiple species and variable home range sizes. A range of wildlife crossing types and sizes should be provided at frequent intervals along with necessary microhabitat elements that enhance movement, e.g., root crowns for cover. Unlike the physical structure of wildlife crossings, microhabitat elements are movable and can be modified over time as conditions and species distributions change.

- *Adjacent land management:* How well a wildlife crossing structure performs is partly dependent upon the land management that surrounds them. Transportation and land management agencies need to coordinate in the short and long term to ensure that tracts of suitable habitat adjacent to the crossings facilitate movement to designated wildlife crossings.

- *Larger corridor network:* Wildlife crossings must connect to, and form an integral part of, a larger regional corridor network. They should not lead to "ecological dead-ends." The integrity and persistence of the larger corridor network is not the responsibility of the transportation agency, but that of neighboring land management agencies and municipalities.

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

The spacing interval of some wildlife crossing projects designed for large mammals are found in Table 2. Listed are several large-scale mitigation projects in North America (existing and planned). The spacing interval varies from one wildlife crossing per 0.9 mi (1.5 km) to one crossing per 3.8 miles (6.0 km). The projects listed indicate that wildlife crossings are variably spaced but on average about 1.2 mi (1.9 km) apart.

Table 2. Average spacing interval per mile between wildlife crossings designed for large mammals at existing and planned transportation projects.

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

[a] Phase 1, 2 and 3A reconstruction.
[b] Phase 3B reconstruction.
[c] Includes crossings for small and large mammals.

GUIDELINES FOR THE SELECTION OF WILDLIFE CROSSINGS

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

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

Overpass Design

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

Underpass Design

5. *Viaduct or flyover*—The largest of underpass structures for wildlife use, but usually not built exclusively for wildlife movement. The large span and vertical clearance of viaducts allow for use by a wide range of wildlife. Structures can be adapted for amphibian and reptiles, semi-aquatic and semi-arboreal species.
6. *Large mammal underpass*—Not as large as most viaducts, but the largest of underpass structures designed specifically for wildlife use. Designed for large mammals but small- and medium-sized mammals use readily as well.
7. *Multi-use underpass*—Design similar to large mammal underpass, however management objective is co-use between wildlife and humans. Design is generally smaller than a large mammal underpass because of type of wildlife using the structures along with human use. These structures may not be adequate for all wildlife, but usually results in use by generalist species common in human-dominated environments (e.g., urban or peri-urban habitats). Large structures may be constructed to accommodate the need for more physical space for humans and habitat generalist species.
8. *Underpass with waterflow*—An underpass structure designed to accommodate the needs of moving water and wildlife. These underpass structures are frequently used by some large mammal species, but their use depends largely on how it is adapted for their specific crossing needs. Small- and medium-sized mammals generally utilize these structures, particularly if riparian habitat or cover is retained within the underpass.
9. *Small- to medium-sized mammal underpass*—One of the smaller wildlife crossing structures. Primarily designed for small- and medium-sized mammals, but species use will depend largely on how it may be adapted for their specific crossing needs.
10. *Modified culvert*—Crossing that is adaptively designed for use by small- and medium-sized wildlife associated with riparian habitats or irrigation canals. Adapted dry platforms or walkways can vary in design and typically constructed on the lateral interior walls of the culvert and above the high-water mark.
11. *Amphibian and reptile tunnels*—Crossing designed specifically for passage by amphibians and reptiles, although other small- and medium-sized vertebrates may use as well. Many different amphibian and reptile designs have been used to meet the specific requirements of each species or taxonomic group.

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

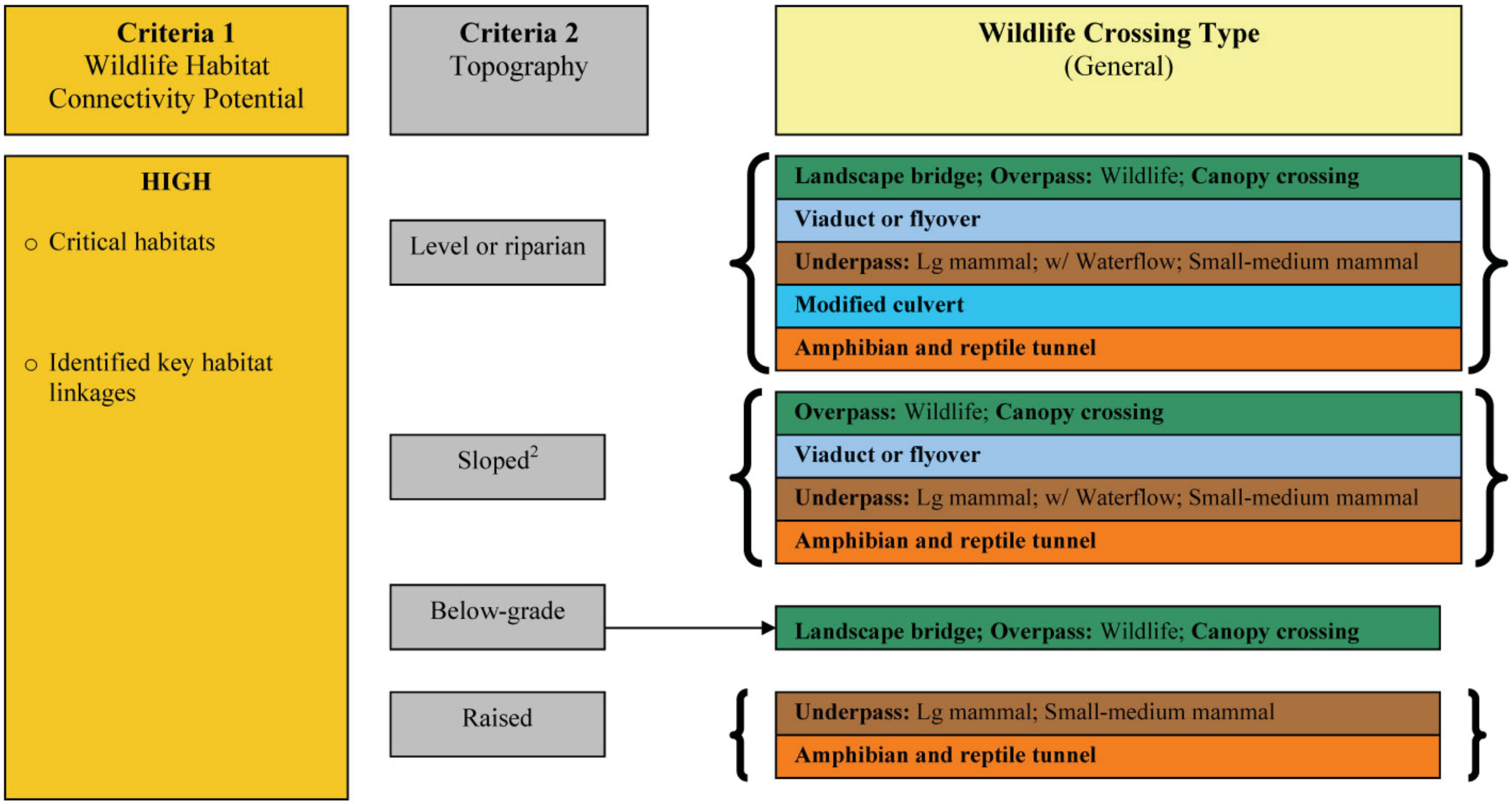

Figure 21. Chart. Criteria for selecting general wildlife crossing type where roads bisect habitats of high conservation value.

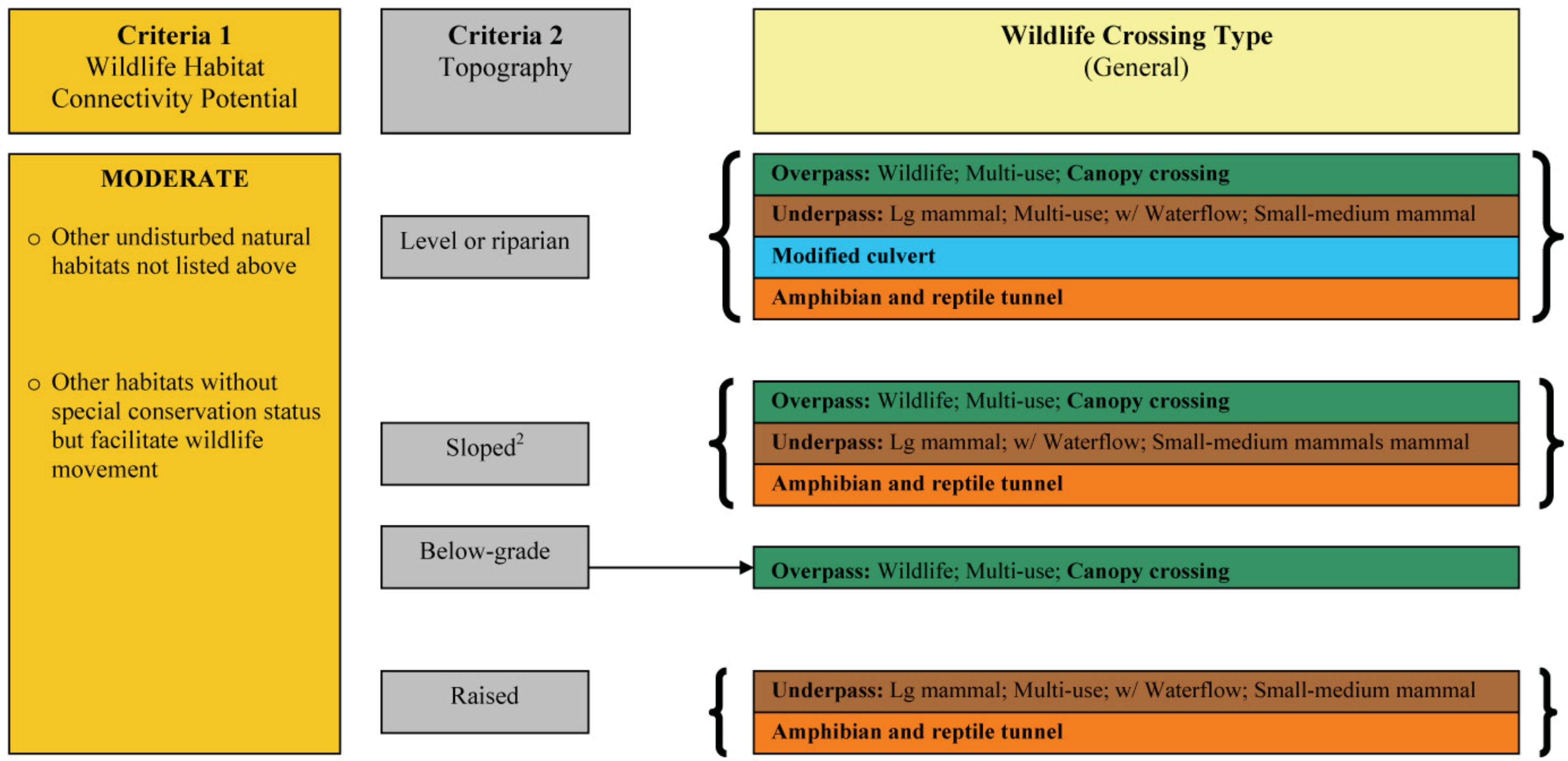

Figure 22. Chart. Criteria for selecting general wildlife crossing type where roads bisect habitats of moderate conservation value.

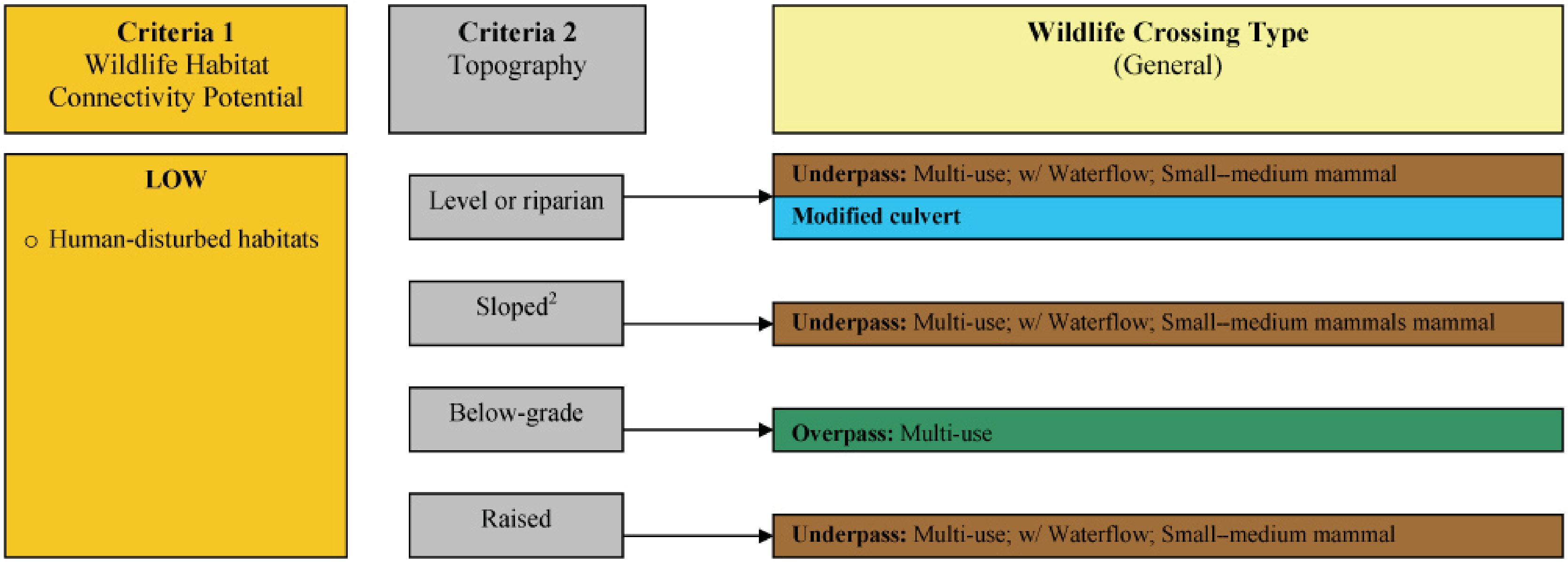

Figure 23. Chart. Criteria for selecting general wildlife crossing type where roads bisect habitats of low conservation value.

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Wildlife Habitat Connectivity Potential

Wildlife habitat connectivity potential can be grouped into three categories:

- *High potential*—Sites that occupy high quality or critical habitats for wildlife and/or are identified as key habitat linkages to facilitate movement of wildlife at a local or regional scale.

  Associated wildlife crossing types: These are prime areas for wildlife habitat connectivity. Mixed-used (multi-use with humans) wildlife crossings should not be used.

- *Moderate potential*—Relatively intact or undisturbed habitats, but not considered critical wildlife habitat, such as: (a) habitats that lack special conservation value or designation but are suitable for moving wildlife, and (b) habitats that may not be suitable at present but future restoration is planned.

  Associated wildlife crossing types: In these areas mixed-use wildlife crossings become an option, but landscape bridges and viaducts or flyovers should not be built.

- Low potential—Habitats with human disturbance or regular human activity.

  Associated wildlife crossing types: These areas are low potential for wildlife habitat connectivity; overpass structures designed specifically for wildlife are not recommended. However, underpasses adapted for wildlife use (wildlife underpasses with waterflow, modified culverts) and mixed-use and specialized smaller crossing types (small- to medium-sized mammal underpass; amphibian and reptile tunnels) are suggested options.

Topography

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

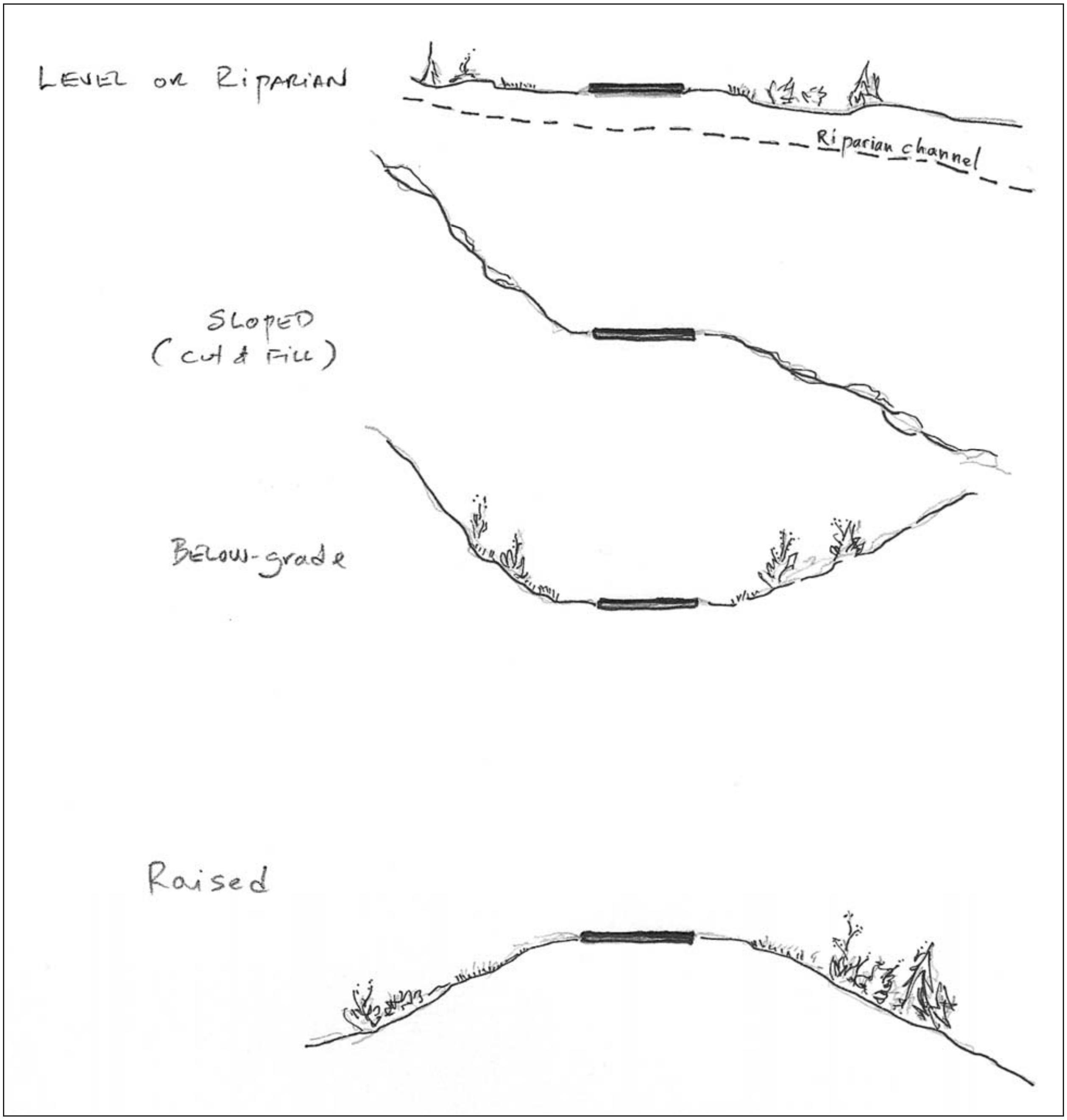

Figure 24. Schematic. Four general types of topography where wildlife crossings maybe constructed on roadways (Credit: Tony Clevenger).

- *Level or riparian*—Sections of road and rights-of-way that traverse level terrain or cross over riparian habitats and drainages.

  Associated wildlife crossing types: Most wildlife crossing types can be constructed in these areas. Some may require raising the road grade to obtain elevation necessary at the crossing site for underpass or lower the road below grade and excavate to allow the overpass design to fit into the local terrain.

- *Sloped*—Road sections on cut-and-fill slopes.

  Associated wildlife crossing types: Road sections on sloped terrain (cut-and-fill) make it difficult to construct overpass designs and canals–adapted design.

- *Below-grade*—Roads that are in cut sections and well below grade level.

  Associated wildlife crossing types: These areas are best suited for overpass structures (landscape connectors, overpasses, canopy crossings) given the ease of construction having embankments and natural support on one or both sides of the highway.

- *Raised*—Road sections built on fill and are elevated compared to adjacent terrain including rights-of-way.

  Associated wildlife crossing types: Raised sections of road are ideal for all underpass structures. Today, small tunnel-boring machines can perforate roadbeds of two-lane roads making underpasses for small- and medium-sized mammals and amphibian and reptile tunnels an option.

WILDLIFE SPECIES GROUPS AND CROSSING STRUCTURE CLASSIFICATION

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

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

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

2. High mobility medium-sized mammals (*Bobcat, Fisher, Coyote, Fox*) – Species that range widely; fragmentation effects of roads may impact local populations.

3. Low mobility medium-sized mammals (*Raccoon, Skunk, Hare, Groundhog*) – Species with smaller area requirements; common road-related mortality; relatively abundant populations.

4. Semi-arboreal mammals (*Marten, Red Squirrel, Flying Squirrel*) – Species that are dependent on forested habitats for movement and meeting life requisites; common road-related mortality.

5. Semi-aquatic mammals (*River Otter, Mink, Muskrat*) – Species that are associated with riparian habitats for movement and life requisites; common road-related mortality.

6. Small mammals (*Ground Squirrels, Voles, Mice*) – Species that are common road-related mortality; relatively abundant populations.

7. Amphibians (*Frogs, Toads, Salamanders, Turtles*) – Species with special habitat requirement; relatively abundant populations at the local scale; populations are highly susceptible to road mortality.

8. Reptiles (*Snakes,Llizards*) – Species with special habitat requirement; road environment tends to attract individuals; relatively abundant populations.

DESIGN AND DIMENSIONS

General Design Specifications For Wildlife Species

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

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

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

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

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

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

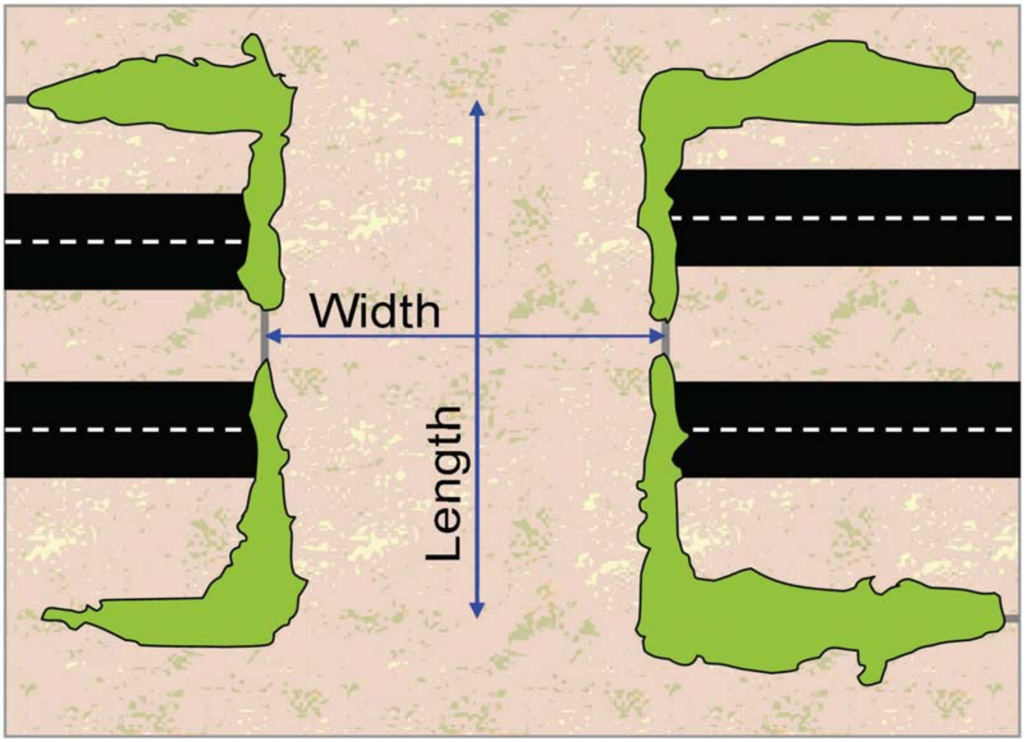

Figure 25. Schematic. Length and width measurements of wildlife overpass (Credit: Tony Clevenger).

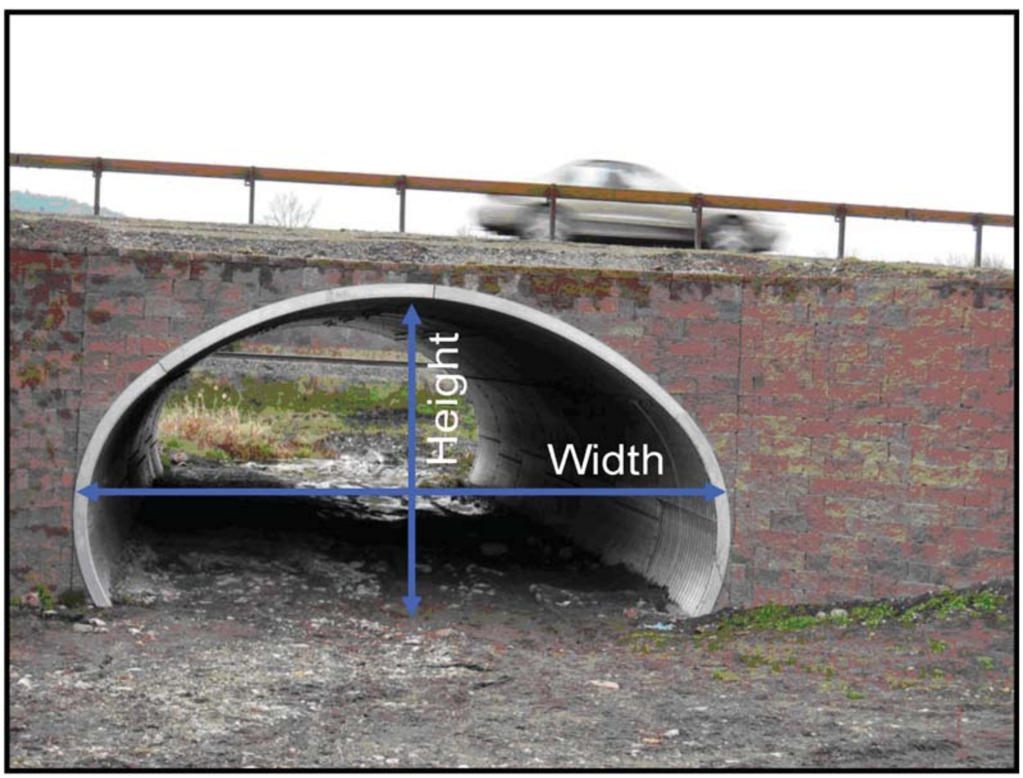

Figure 26. Photo. Width and height measurements of wildlife underpass structure (Credit: Marcel Huijser/WTI).

- Divided vs. undivided highways: Divided highways contain a central median and consist of two separate physical structures; one for each direction of traffic. Undivided highways have traffic lanes bundled and consist of one physical crossing structure. Although crossing structures on undivided highways have less daytime light than those with a central median, the open median generally has higher traffic noise levels. Crossing structures on undivided highways are shorter in length compared to structures on divided highways and have lower noise levels. We recommend that a shorter structure, with less daytime light and lower noise levels will be more effective than crossing structures designed on divided highways. This recommendation is based primarily on structure length and traffic noise levels. The amount of light an underpass receives is not an important factor on which to base crossing structure design when a large part of wildlife movement typically occurs during nighttime hours.

- Normally, wildlife crossings are not be greater than 230–260 ft (70–80 m) in length except in special situations such as spanning ≥6-lane highways or spanning highways in addition to other types of infrastructure, for example, frontage roads and railway line as Figure 27 shows.

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

- The recommended and minimum dimensions for each of the 11 wildlife crossing types are provided below. The measurements are for crossing structures designed for 4-lane highways. The guidelines should be followed if the crossings are at minimum to allow for the simplest and most basic connectivity requirement of crossings structures, i.e., the exchange of individuals within populations. Crossings designed for exchange of individuals may not allow for normal demographic processes, thus allowing passage use by few individuals and biased towards male movement. Both genders need to mix freely across the highway for wildlife crossings to perform effectively, and monitoring should be able to document that.

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

Specific Design of Wildlife Crossings and Adjacent Habitat

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

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

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

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

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

Fisher	●	●	●	●	●	⊙	●	⊙	●	●	—
Marten	●	●	●	●	●	⊙	●	⊙	●	●	—
Weasel	●	●	●	—	●	⊙	●	⊙	●	●	—
Badger	●	●	●	—	●	⊙	●	⊙	●	⊗	—
Low mobility medium	●	●	●	—	●	●	●	●	●	●	⊙
Semi-arboreal mammals	⊙	⊙	⊙	●	⊙	⊙	⊙	⊙	⊗	⊗	⊗
Semi-aquatic mammals	⊙	⊙	⊙	—	⊙	⊙	⊙	●	⊙	●	⊙
Small mammals	●	●	●	⊙	●	●	●	●	●	●	⊙
Amphibians	⊙	⊙	⊙	—	⊙	⊙	⊙	⊙	⊙	●	●
Reptiles	●	●	●	—	●	●	●	⊙	●	●	⊙

● Recommended/Optimum solution; ⊙ Possible if adapted to local conditions; ⊗ Not recommended; ? Unknown, more data are required;
— Not applicable

OPENNESS?

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

The measure of *openness* was used early on to describe and measure the stimulus of a given underpass to approaching Deer, by calculating the above formula. The thought was that, in theory, an underpass could be so long and confining that it could preclude Deer use[1] and that Deer prefer underpasses with a clear view of the horizon. Since then, openness has been used on many occasions in planning the design of wildlife underpasses and researching their effectiveness. Openness has gained popularity, likely due to its ease and assumed validity based on a simple metric or "magic number." Engineers, planners and biologists alike tend to aim for the magical openness measure and expect performance without much critical thought of other factors (structural and environmental) that might influence performance. However the relationship between openness and underpass performance may be species-specific and time dependent.

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

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

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

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

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

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

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

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

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

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

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

SUGGESTED READING

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