APPENDIX C – HOT SHEETS

HOT SHEET 1: LANDSCAPE BRIDGE

GENERAL DESIGN

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

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

USE OF THE STRUCTURE

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

GENERAL GUIDELINES

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

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

DIMENSIONS – GENERAL GUIDELINES

Bridge Width

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

Fence/Berm Height

8 ft (2.4 m)

Soil Depth

5–8 ft (1.5–2.0 m)

TYPES OF CONSTRUCTION

Span

Bridge span (steel truss or concrete)

Arch

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

SUGGESTED DESIGN DETAILS

Crossing Structure

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

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

Local Habitat Management

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

POSSIBLE VARIATIONS

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

MAINTENANCE

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

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

SPECIES-SPECIFIC GUIDELINES

Recommended/Optimum solution for wildlife species/groups

Ungulates

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

Carnivores

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

Low-mobility medium-sized mammals

Small mammals

Reptiles

Possible if adapted to local conditions

Semi-arboreal mammals

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

Semi-aquatic mammals

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

Amphibians

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

Not recommended or applicable

None

Unknown – more data are required

None

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

HOT SHEET 2: WILDLIFE OVERPASS

GENERAL DESIGN

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

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

USE OF THE STRUCTURE

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

GENERAL GUIDELINES

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

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

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

DIMENSIONS – GENERAL GUIDELINES

Overpass Width

Minimum: 130–165 ft (40–50 m)
Recommended: 165–230 ft (50–70 m)

Fence/Berm Height

8 ft (2.4 m)

Soil Depth

5–8 ft (1.5–2.4 m)

TYPES OF CONSTRUCTION

Span

Bridge span (steel truss or concrete)

Arch

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

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

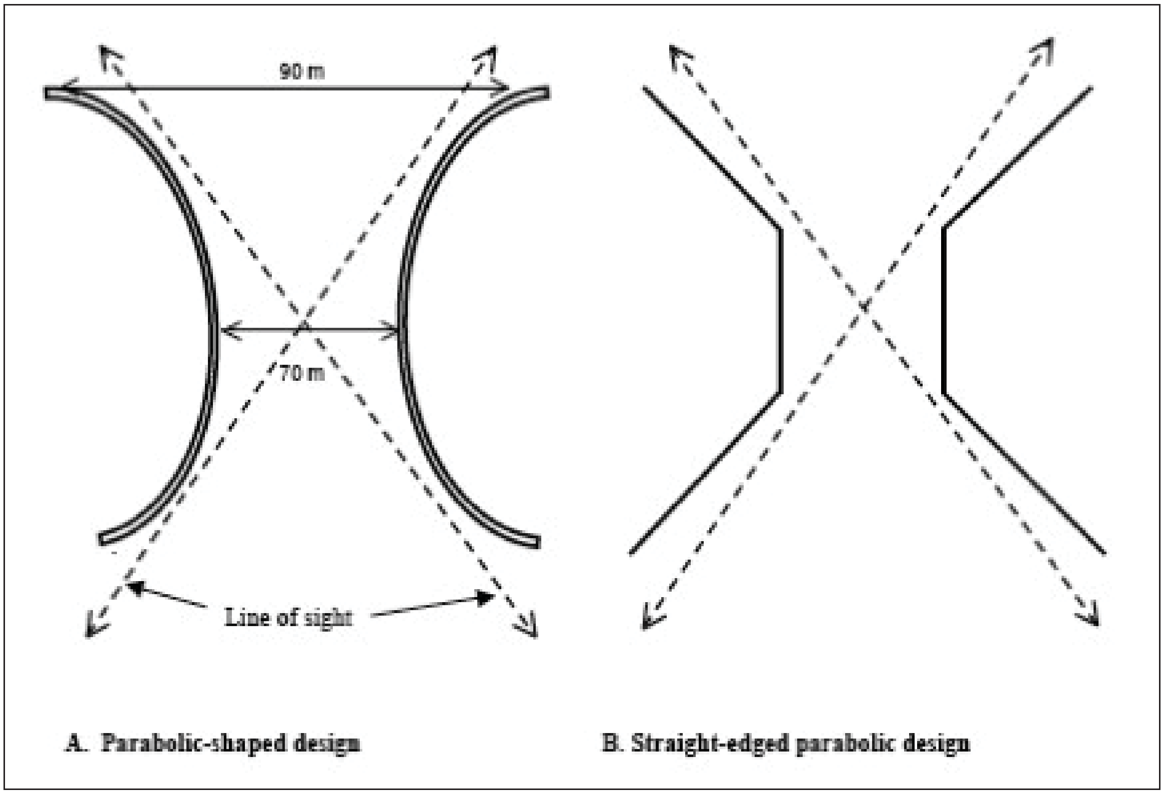

Figure 35. Schematic. (A) Parabolic-shaped design overpass (B) Straight-edged design.

SUGGESTED DESIGN DETAILS

Crossing structure

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

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

Local habitat management

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

POSSIBLE VARIATIONS

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

MAINTENANCE

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

SPECIES-SPECIFIC GUIDELINES

Recommended/Optimum solution for wildlife species/groups

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

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

Low-mobility medium-sized mammals

Small mammals

Reptiles

Possible if adapted to local conditions

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

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

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

Not recommended or applicable

None

Unknown – more data are required

None

HOT SHEET 3: MULTI-USE OVERPASS

GENERAL DESIGN

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

USE OF THE STRUCTURE

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

GENERAL GUIDELINES

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

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

DIMENSIONS – GENERAL GUIDELINES

Width:

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

Fence/berm height:

8 ft (2.4 m)

Soil depth:

1.6–3.2 ft (0.5–1.0 m)

TYPES OF CONSTRUCTION

Span

Bridge span (steel truss or concrete)

Arch

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

SUGGESTED DESIGN DETAILS

Crossing structure

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

Local habitat management

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

MAINTENANCE

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

SPECIES-SPECIFIC GUIDELINES

Recommended/Optimum solution for wildlife species/groups

Ungulates
- Elk, Deer,

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

Low-mobility medium-sized mammals

Small mammals

Reptiles

Possible if adapted to local conditions

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

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

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

Not recommended or applicable

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

Carnivores

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

Unknown – more data are required

None

HOT SHEET 4: CANOPY CROSSING

GENERAL DESIGN

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

USE OF THE STRUCTURE

Canopy crossings are intended exclusively for the use of wildlife.

GENERAL GUIDELINES

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

DIMENSIONS – GENERAL GUIDELINES

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

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

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

SUGGESTED DESIGN DETAILS

Crossing structure

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

Local habitat management

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

TYPES OF CONSTRUCTION

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

POSSIBLE VARIATIONS

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

MAINTENANCE

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

SPECIES-SPECIFIC GUIDELINES

Recommended/Optimum solution for wildlife species/groups

Semi-arboreal mammals

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

Possible if adapted to local conditions

Small mammals

- Some species with arboreal habits may use canopy crossings.

Not recommended or applicable

Ungulates

***Carnivores* (other than those listed above)**

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

Semi-aquatic mammals

Amphibians

Reptiles

Unknown – more data are required

None

HOT SHEET 5: VIADUCT OR FLYOVER

GENERAL DESIGN

The viaduct, or flyover, is the largest of wildlife underpass structures; however, it is usually not built specifically for wildlife movement. The large span and clearance of viaducts shown in Figure 39 allow for use by a wide range of wildlife. Structures can be adapted for amphibians, semi-aquatic and semi-arboreal species. Viaducts with support pillars help keep habitats intact and nearly undisturbed. Viaducts also help restore or maintain hydrological flows and the biological diversity associated with riparian habitats. They are commonly used for crossing wetland habitats. A range of dimensions exist from long structures with low vertical clearance for wetlands to short structures with high clearance spanning deep canyons.

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

USE OF THE STRUCTURE

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

GENERAL GUIDELINES

- Viaducts are an alternative to constructing underpasses on cut-and-fill slopes, which tend to limit wildlife movement and reduce habitat connectivity compared to viaducts.
- Viaducts minimize the disturbance to habitats, vegetation, and riparian areas during construction. Design should be sufficiently wide enough to conserve riparian habitats and maintain local landform as in the Figure 40 example.
- Replant with local native vegetation if the area is disturbed during construction.

Figure 40. Photo. Wide span viaduct designed to conserve floodplain (Credit: Tony Clevenger).

DIMENSIONS – GENERAL GUIDELINES

Variable dimensions depending on location and terrain.

TYPES OF CONSTRUCTION

Concrete bridge span with support structures

Steel beam span

SUGGESTED DESIGN DETAILS

Crossing structure

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

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

- Ponds or wetland habitat may be constructed connecting isolated habitats for amphibian species.
- Stringers of brush and root wads can be used to provide cover and microhabitat for cover-dwelling species until native vegetation can be restored to area.
- Drainage is generally not a problem if spanning water courses, however, riparian habitats should be protected as best as possible during and after construction. Pillars should avoid impacting riparian habitats completely, being outside the high-water mark.

Local habitat management

- If wildlife fencing is used below viaduct to funnel animals, then fencing should tie into the support structures or be close as possible to side slopes, thus providing the widest area for wildlife passage.

- Human use and any signs of human presence (e.g., storage of materials) should be minimized around viaducts.

POSSIBLE VARIATIONS

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

MAINTENANCE

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

SPECIES-SPECIFIC GUIDELINES

Recommended/Optimum solution for wildlife species/groups

Ungulates
- Species will vary based on structure dimensions

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

Low-mobility medium-sized mammals

Small mammals

Reptiles

Possible if adapted to local conditions

Semi-arboreal mammals

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

Semi-aquatic mammals

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

Amphibians

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

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

Not recommended or applicable

None

Unknown – more data are required

None

HOT SHEET 6: LARGE MAMMAL UNDERPASS

GENERAL DESIGN

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

USE OF THE STRUCTURE

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

GENERAL GUIDELINES

- Being generally smaller than a viaduct or flyover, the ability to restore habitat underneath will be limited. Open designs that provide ample natural lighting will encourage greater development of native vegetation as shown in Figure 43.
- To ensure performance and function, large mammal underpasses should be situated in areas with high landscape permeability and that are known wildlife travel corridors and experience minimal human disturbance.
- Motor vehicle or all-terrain vehicle use should be prohibited. Eliminating public or any other human use, activity or disturbance at the underpass and adjacent area is recommended for its proper function and for maximizing wildlife use.
- Underpass should be designed to conform to local topography. Design drainage features so flooding does not occur within the underpass as Figure 44 shows. Run-off from highway near structure should not be directed toward the underpass.
- Maximize continuity of native soils adjacent to and within the underpass. Avoid importation of soils from outside the project area.

DIMENSIONS – GENERAL GUIDELINES

Width:

Minimum: 20 ft (7 m)
Recommended: >40 ft (>12 m)

Height:

Minimum: 10 ft (4 m)
Recommended: >15 ft (>4.5 m)

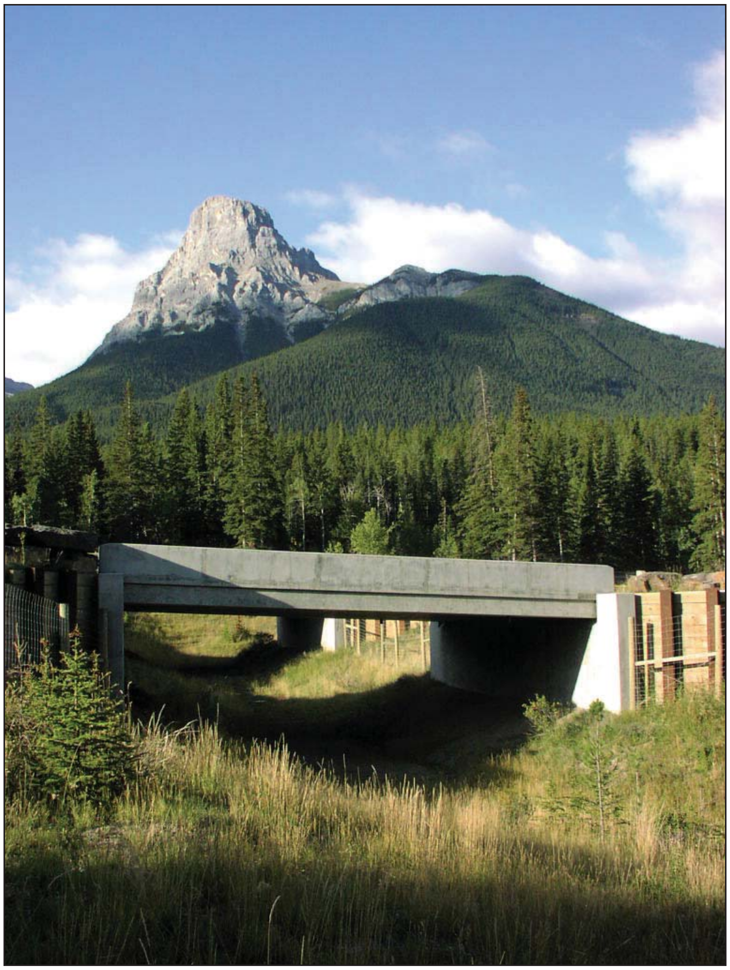

Figure 43. Photo. Open span wildlife underpass (Credit: Tony Clevenger).

TYPES OF CONSTRUCTION

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

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

Box culvert
- Prefabricated concrete

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

SUGGESTED DESIGN DETAILS

Crossing structure

- Structures should be designed to meet the movement needs of the widest range of species possible that live in the area or might be expected to recolonize the area, e.g., high- and low-mobility species.
- Attempt to mirror habitat conditions found on both sides of the road and provide continuous habitat adjacent to and within the structure.
- Maximize microhabitat complexity and cover within the underpass using salvage materials (logs, root wads, rock piles, boulders, etc.) to encourage use by semi-arboreal mammals, small mammals, reptiles and species associated with rocky habitats as Figure 44 showed.
- It is preferable that the substrate of underpass is of native soils. If construction type has closed bottom (e.g., concrete box culvert), a soil substrate $\geq$ 6 in (15 cm) deep must be applied to interior.
- Revegetation is possible in areas of underpass closest to the entrance. Light conditions tend to be poor in the center of the structure.
- Design underpass to minimize the intensity of noise and light coming from the road and traffic.

Local habitat management

- Protect existing habitat. Design with minimal clearing widths to reduce impacts on existing vegetation. Where habitat loss occurs, reserve all trees, large logs, and root wads to be used adjacent to and within underpass.
- Wildlife fencing is the most effective and preferred method to guide wildlife to the structure and prevent intrusions onto the right-of-way. Mechanically stabilized earth (MSE) walls, if high enough, can substitute for fencing and is not visible to motorists.
- Encourage use of underpass by either baiting or cutting trails leading to structure, if appropriate.
- Avoid building underpass in location with road running parallel and adjacent to entrance, as it will affect wildlife use.
- If traffic volume is high on the road above the underpass it is recommended that sound attenuating walls be placed above the entrance to reduce noise and light disturbance from passing vehicles.
- Underpass must be within cross-highway habitat linkage zone and connect to larger corridor network.
- Existing or planned human development in adjacent area must be at sufficient distance to not affect long-term performance of underpass. Long-range planning must ensure that adjacent lands will not be developed and the wildlife corridor network is functional.

POSSIBLE VARIATIONS

Divided road (two structures)

In-line:

Off-set:

Undivided road (one structure)

MAINTENANCE

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

SPECIES-SPECIFIC GUIDELINES

Recommended/Optimum solution for wildlife species/groups

Ungulates

- Elk, Deer

Carnivores

- Black bear, Coyote, Fox1, Cougar, Bobcat

Low-mobility medium-sized mammals

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

Small mammals

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

Reptiles

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

Possible if adapted

Ungulates

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

Carnivores

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

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

Semi-arboreal mammals

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

Semi-aquatic mammals

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

Amphibians

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

Not recommended or applicable

None

Unknown – more data are required

Pronghorn

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

Lynx

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

Wolverine

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

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

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

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

HOT SHEET 7: MULTI-USE UNDERPASS

GENERAL DESIGN

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

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

USE OF THE STRUCTURE

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

GENERAL GUIDELINES

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

- If the structure is > 40 ft (>12 m) wide, human use (e.g., paths, riding trails) should be confined to one side, leaving greater space for wildlife use. Vegetation can be used to shield human use from wildlife.
- Frequent motor vehicle or all-terrain vehicle (ATV) use of underpass should be discouraged. High levels of disturbance from ATVs or other motorized vehicles at the underpass and adjacent area will likely disturb most wildlife in the area and negatively affect the ability of wildlife to use underpass for cross-road movements.
- Low-level vehicular traffic is acceptable through the underpass, e.g., rural or agricultural use. Keep the road unpaved and its margin vegetated providing continuity through the underpass and adjacent habitats.
- Underpass should be designed to conform to local topography. Design drainage features so flooding does not occur within the underpass. Run-off from highway near structure should not be directed toward the underpass.
- Maximize continuity of native soils adjacent to and within the underpass. Avoid importation of soils from outside the project area.

DIMENSIONS – GENERAL GUIDELINES

Width:

Minimum: 16.5 ft (5 m)
Recommended: >23 ft (>7 m)

Height:

Minimum: 8.2 ft (2.5 m)
Recommended: >11.5 ft (>3.5 m)

TYPES OF CONSTRUCTION

Concrete bottomless arch

Concrete bridge span (open span bridge)

Steel beam span

Elliptical multi-plate metal culvert

Prefabricated concrete box culvert

SUGGESTED DESIGN DETAILS

Crossing structure

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

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

Local habitat management

- Protect existing habitat. Design with minimal clearing widths to reduce impacts on existing vegetation. Where habitat loss occurs, reserve all trees, large logs, and root wads to be used adjacent to and within the underpass.
- Wildlife fencing is the most effective and preferred method to guide wildlife to the structure and prevent intrusions onto the right-of-way.
- Discourage building underpass in location with a road running parallel and adjacent to the entrance, as it will affect wildlife use.
- If traffic volume is high on the road above the underpass it is recommended that sound-attenuating walls be placed above the entrance to reduce noise and light disturbance from passing vehicles.

POSSIBLE VARIATIONS

Divided road (2 structures)
In-line:
Off-set:

Undivided road (1 structure)

MAINTENANCE

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

SPECIES-SPECIFIC GUIDELINES

Recommended/Optimum solution for wildlife species/groups

Ungulates

- Elk, Deer

Carnivores

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

Low-mobility medium-sized mammals

Small mammals

Reptiles

Possible if adapted

Carnivores

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

Semi-arboreal mammals

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

Semi-aquatic mammals

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

Amphibians

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

Not recommended or applicable

Ungulates

- Moose, Pronghorn, Bighorn Sheep, Mountain Goat

Carnivores

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

Unknown – more data are required

None

HOT SHEET 8: UNDERPASS WITH WATERFLOW

GENERAL DESIGN

Underpass structures like those in Figure 46 can be designed to accommodate dual needs of moving water and wildlife. Structures are generally located in wildlife movement corridors given their association with riparian habitats; however, some maybe only marginally important. Structures aimed at restoring proper function and connection of aquatic and terrestrial habitats should be situated in areas with high landscape permeability, are known wildlife travel corridors and have minimal human disturbance. These underpass structures are frequently used by several large mammal species, yet use by some large mammals will depend largely on how it may be adapted for their specific crossing requirements. Small- and medium-sized mammals (including carnivores) generally utilize these structures, particularly if riparian habitat is retained or cover is provided along walls of the underpass by using logs, brush or root wads. These underpass structures can be readily adapted for amphibians, semi-aquatic and semi-arboreal species.

Figure 46. Photo. Wildlife underpass designed to accommodate waterflow (Credit: Tony Clevenger).

USE OF THE STRUCTURE

Exclusively for wildlife, but may have some human use

GENERAL GUIDELINES

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

DIMENSIONS - GENERAL GUIDELINES

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

Minimum:
Width: 6.5 ft (2 m) pathway
Height: 10 ft (3 m)

Recommended:
Width: >10 ft (>3 m) pathway
Height: >13 ft (>4 m)

TYPES OF CONSTRUCTION

Concrete bridge span (open span bridge)

Steel beam span

Concrete bottomless arch

SUGGESTED DESIGN DETAILS

Crossing structure

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

Local habitat management

- Protect existing habitat. Design with minimal clearing widths to reduce impacts on existing vegetation. Where habitat loss occurs, reserve all trees, large logs, and root wads to be used adjacent to and within underpass.
- Wildlife fencing is most effective and preferred method to guide wildlife to structure and prevent intrusions to the right-of-way. Mechanically stabilized earth (MSE) walls like the one in Figure 47, if high enough, can substitute for fencing and is not visible to motorists.
- Encourage use of underpass by either baiting or cutting trails leading to structure, if appropriate.
- Avoid building underpass in location with road running parallel and adjacent to entrance, as it will affect wildlife use.
- If traffic volume is high on the road above the underpass it is recommended that sound attenuating walls be placed above the entrance to reduce noise and light disturbance from passing vehicles.
- Underpass must be within cross-highway habitat linkage zone and connects to larger corridor network.
- Existing or planned human development in adjacent area must be at sufficient distance to not affect long-term performance of underpass. Long-range planning must ensure that adjacent lands will not be developed and the wildlife corridor network is functional.

POSSIBLE VARIATIONS

Divided road (2 structures)

In-line:

Undivided road (1 structure)

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

MAINTENANCE

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

SPECIES-SPECIFIC GUIDELINES

Recommended/Optimum solution for wildlife species/groups

Ungulates
- Elk, Deer

Carnivores
- Black Bear, Coyote, Fox1, Cougar, Bobcat

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

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

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

Possible if adapted

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

Carnivores
- Grizzly Bear, Wolf - Tend to prefer large, open structures with good visibility, such as landscape bridges, wildlife overpasses and viaducts. Recommended dimensions may not be sufficient to ensure regular use by individuals of all gender and age classes. Recommend minimum 40 ft (12 m) width and 15 ft (4.5 m) height.

- Fox2 - Species adapted to arid, open grassland habitats that generally experience high levels of mortality from roads and larger predators (e.g., Coyotes). Few documented cases of Swift/Kit Foxes using wildlife crossings, suggesting they avoid them and prefer to cross at grade-level. To encourage Fox use of structures they should be designed for their body size, to limit predation risks associated with the crossings. It is unlikely these structures be designed specifically for Swift/Kit Fox use, thus wide and high underpasses with good visibility for prey species would be the most effective. In larger structures artificial dens should be installed within structures and near entrances to provide escape cover for Swift/Kit Foxes.

- Fisher, Marten – Forest-dwelling species that tend to prefer structures with ample riparian habitat, vegetative cover or form of protection while traveling. Recommended to place brush or root wads along underpass wall (one wall is sufficient; two is preferred, but will depend on width of structure) to ensure regular use by individuals of all gender and age classes. In large underpasses, culvert or pipes can be placed to provide cover.

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

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

Semi-arboreal mammals

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

Amphibians

- Not likely to use structure unless located in migratory route or during dispersal. Amphibian habitat can be created with series of ponds in a stepping-stone pattern connecting wetland habitat separated by highway shown previously in Figure 42 as an example for wildlife overpass. Recommended maintaining riparian vegetation, soil moisture and natural light conditions throughout the wildlife underpass to ensure use and regular movement by the species of concern.

Not recommended or applicable

None

Unknown – more data are required

Lynx

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

Wolverine

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

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

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

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

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

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

GENERAL DESIGN

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

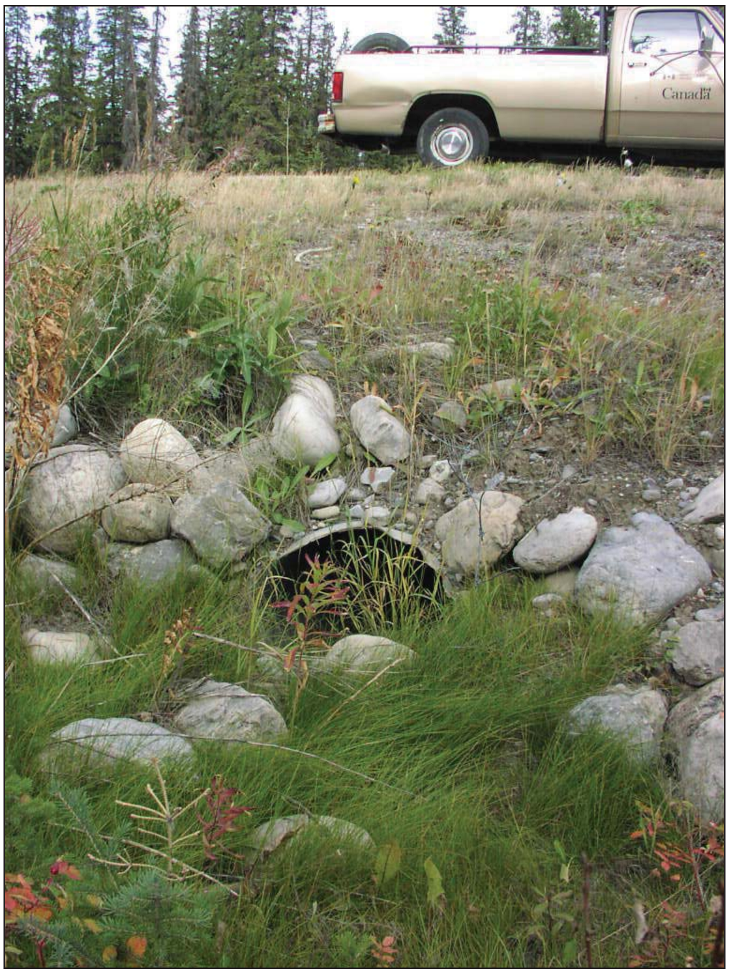

Figure 49. Photo. Small- to medium-sized mammal underpass (Credit: Tony Clevenger).

USE OF THE STRUCTURE

Exclusively for wildlife

GENERAL GUIDELINES

- To ensure performance and function, small to medium-sized mammal underpasses should be situated in areas with high landscape permeability, are known wildlife travel corridors and have minimal human disturbance.
- Underpass should be designed to conform to local topography. Design drainage features so flooding does not occur within underpass. Run-off from highway near structure should not end up in underpass.

DIMENSIONS - GENERAL GUIDELINES

Dimensions will vary depending on the target species. Structures generally range from 1 ft to 4 ft (0.4-1.2 m) diameter culverts or underpass structures.

TYPES OF CONSTRUCTION

Concrete bottomless arch

Circular multi-plate metal culvert

Prefabricated concrete box culvert

SUGGESTED DESIGN DETAILS

Crossing structure

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

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

Local habitat management

- Protect existing habitat. Design with minimal clearing widths to reduce impacts on existing vegetation. Where habitat loss occurs, reserve all trees, large logs, and root wads to be used adjacent to and within larger wildlife crossing structures that may be built during project.
- Attempt to provide continuous habitat leading to and adjacent to the structure.
- Encourage use of structure by using fencing, rock walls, or other barriers along road to direct wildlife into underpass. Use topography and natural features as much as possible.
- Encourage use of underpass by baiting and/or cutting trails leading to structure, if appropriate.
- Avoid building underpass in location with road running parallel and adjacent to entrance, as it will affect wildlife use.
- If traffic volume is high on the road above the underpass it is recommended that sound attenuating walls be place above the entrance to reduce noise and light disturbance from passing vehicles.

Possible Variations

Divided road (2 structures)
In-line:
Off-set:

Undivided road (1 structure)

MAINTENANCE

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

SPECIES-SPECIFIC GUIDELINES

Recommended/Optimum solution for wildlife species/groups

Carnivores

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

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

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

Low mobility medium-sized mammals

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

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

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

Possible if adapted

Carnivores

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

Semi-aquatic mammals

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

Amphibians

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

Not recommended or applicable

Ungulates

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

Carnivores

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

Semi-arboreal mammals – all species.

Unknown – more data are required

None

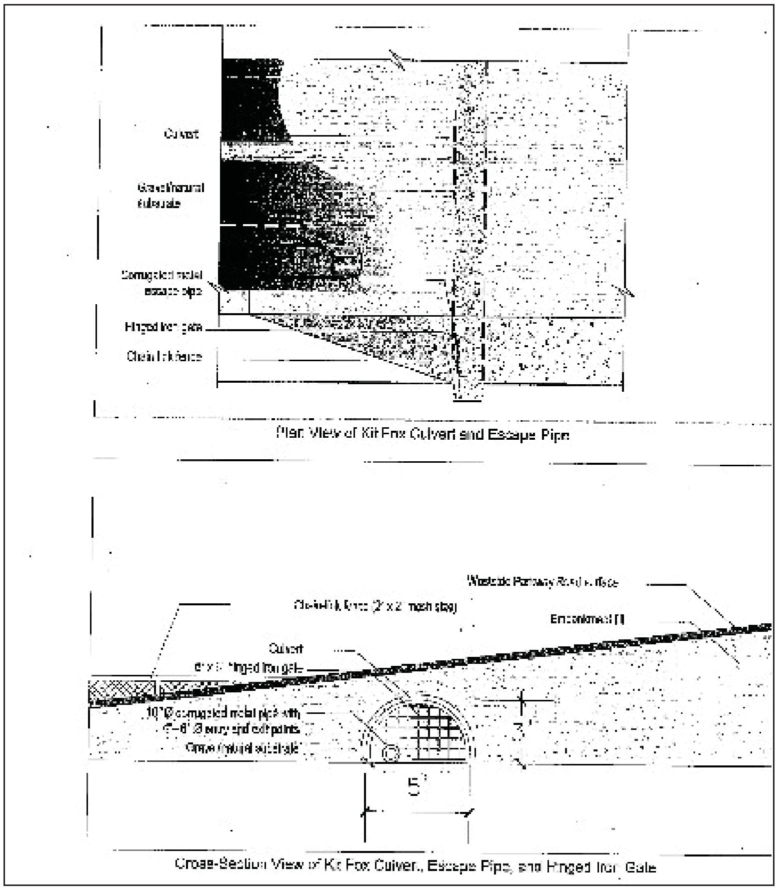

Figure 53. Schematic. Techical design plan for artificial kit fox den in culvert (Credit: US Fish and Wildlife Service).

HOT SHEET 10: MODIFIED CULVERT

GENERAL DESIGN

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

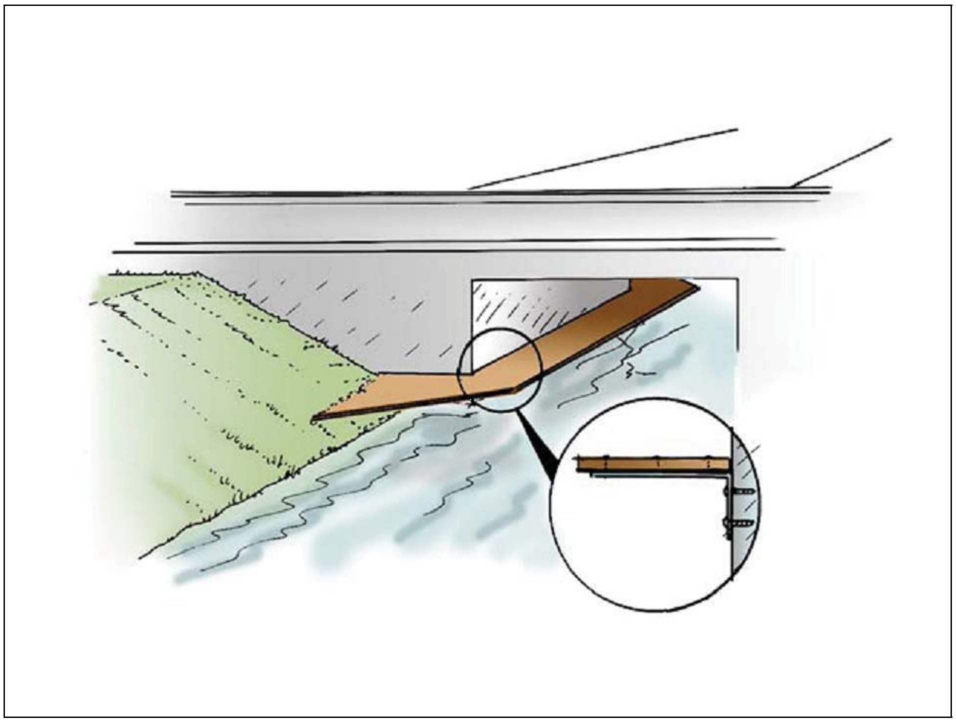

Figure 54. Schematic. Modified culvert (Reprinted with permission from Kruidering et al. 2005).

USE OF THE STRUCTURE

Movement of water and wildlife

GENERAL GUIDELINES

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

concrete or wooden boards ("2 x 10s") work well. It is important to keep the walkway platforms dry, above the high-water mark and accessible from adjacent dry habitat.
- Any work to adapt a bridge structure for wildlife passage should not impede or reduce the bridges hydrologic capacity or function.

DIMENSIONS - GENERAL GUIDELINES

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

TYPES OF CONSTRUCTION

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

SUGGESTED DESIGN DETAILS

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

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

POSSIBLE VARIATIONS

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

MAINTENANCE

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

SPECIES-SPECIFIC GUIDELINES

Recommended/Optimum solution for wildlife species/groups

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

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

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

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

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

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

Possible if adapted

Carnivores

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

Not recommended or applicable

Ungulates

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

Carnivores

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

Semi-arboreal mammals – all species.

Unknown – more data are required

None

HOT SHEET 11: AMPHIBIAN/REPTILE TUNNEL

GENERAL DESIGN

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

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

USE OF THE STRUCTURE

Exclusively wildlife, primarily amphibians and reptiles

GENERAL GUIDELINES

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

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

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

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

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

DIMENSIONS - GENERAL GUIDELINES

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

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

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

TYPES OF CONSTRUCTION

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

SUGGESTED DESIGN DETAILS

Crossing structure

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

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

Guiding wall/fence

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

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

Local habitat management

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

POSSIBLE VARIATIONS

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

Drift fences and translocations

- Due to the seasonality of amphibian movements across roads an option to a wildlife crossing structure consists of installing temporary system of amphibian protection that prevents animals from reaching the roadway. The system consists of constructing a temporary barrier or drift fence, made of a smooth and opaque fabric, staked down, for a predetermined length that impedes the movement of the majority of migrating amphibians towards the road as Figure 60 shows. The drift fence directs the amphibian to collection buckets where they are protected before being picked up and transported across the road. These systems are labor intensive and require collaboration from many people, usually agency and non-governmental organizations. Without citizen support these relatively inexpensive mitigation measures would usually not be possible.

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

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

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

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

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

MAINTENANCE

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

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

SPECIES-SPECIFIC GUIDELINES

Recommended/Optimum solution for wildlife species/groups

Amphibians

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

Reptiles

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

Possible if adapted

Low mobility medium-sized mammals

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

Semi-aquatic mammals

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

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

Not recommended or applicable

Ungulates – all species.

Carnivores – all species.

Semi-arboreal mammals – all species.

Unknown – more data are required

None

HOT SHEET 12: FENCING – LARGE MAMMALS

GENERAL PURPOSE

Wildlife exclusion fencing keeps animals away from roadways. However, fencing alone can isolate wildlife populations, thus creating a barrier to movement, interchange and limiting access to important resources for individuals and long-term survival of the population. Fencing like that in Figure 62, is one part of a two-part mitigation strategy—fencing *and* wildlife crossing structures. Fences keep wildlife away from the roadway, lead animals to wildlife crossings, thus allowing them to travel safely under or above the highway. Fences need to be impermeable to wildlife movement in order to keep traffic-related mortality to a minimum and ensure that wildlife crossings may be used. Defective or permeable fences result in reduced use of the wildlife crossings and increased risk of wildlife–vehicle collisions. Little research and best management practices exist regarding effective fence designs and other innovative solutions to keep wildlife away from roads.

Figure 62. Photo. Wildlife exclusion fencing and culvert design wildlife underpass (Credit: Tony Clevenger).

CONFIGURATIONS

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

Continuous fencing

Most often associated with large tracts of public land with little or no interspersed private property or in-holdings.

<u>Advantages:</u> Long stretches of continuous fence have fewer fence ends and generally few problems of managing wildlife movement ("end-runs") around multiple fence ends, as with discontinuous fencing (below).

<u>Disadvantages:</u> Access roads with continuous fencing will need cattle guards (see Hot Sheet 14) or gates to block animal access to roads.

Partial (discontinuous) fencing

More common with highway mitigation for wildlife in rural areas characterized by mixed land use (public and private land). Generally installed when private lands cannot be fenced.

<u>Advantages:</u> Generally accepted by public stakeholders. Few benefits to wildlife and usually the only alternative when there is mixed land use.

<u>Disadvantages:</u> Results in multiple segments of fenced and unfenced sections of road, each fenced section having two fence ends. Additional measures need to be installed and carefully monitored to discourage end-runs at fence ends and hasten wildlife use of new crossing structures (see Terminations below).

INTERCEPTIONS

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

Roads

- *Cattle guards* – Transportation and land management agencies commonly install cattle guards ("Texas gates" in Canada) shown by Figure 63, where fences intersect access roads. Many different designs have been used, but few if any have been tested. Designs of cattle guards vary in dimension, grate material (flat or cylindrical steel grates), and grate adaptations for safe passage by pedestrians and cyclists. Recently a grate pattern was developed that was 95% effective in blocking Key deer movement and was safe for pedestrians and cyclists (Peterson et al. 2003). A cattle guard roughly 6-8 ft (1.8-2.4 m) long and covering 2 lanes of traffic costs approximately $40,000 (Terry McGuire, Parks Canada, personal communication).

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

- *Electric cattle guards* – These electrified mats act like electric cattle guards to discourage wildlife from crossing the gap in the fence. Pedestrians wearing shoes and bicyclists can cross the mats safely, but dogs, horses and people without shoes will receive an electric shock. The electro-mats are generally 4 feet (1.2 m) wide and built into access roads where they breach fences. ElectroBraid™ and GapZapper® are two companies that currently design and sell electric cattle guards.
- *Painted crosswalks* – Highway crosswalk structures have been used to negotiate ungulates across highways at grade level (Lenhert and Bissonette 1997). White crosswalk lines are painted across the road to emulate a cattle guard. The painted crosswalk serves as a visual cue to guide ungulates directly across the highway. Painted crosswalks have not been tested, but if effective, they would be an inexpensive alternative to the more costly cattle guards.

Trails

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

In areas of high snowfall, gates may be elevated and steps built to keep the bottom of the gate above snow as Figure 64 shows.

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

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

Watercourses

- *Rubber hanging drapes* – Watercourses pose problems for keeping fences impermeable to wildlife movement, as their flow levels tend to fluctuate throughout the year. When water levels are low, gaps may appear under the fence material allowing wildlife to easily pass beneath. Having fencing material well within watercourses will cause flooding problems, as debris being transported will not pass through the fence and can eventually obstruct water flow.

- A solution to this problem would require having a device on the bottom of the fence that moves up and down with the water levels. This could be done by attaching hinged strips of rubber mat-like material, draping down from the bottom of the fence material into the water. The rubber strips are hinged, so float on top of the water and move in direction of flow.

SUGGESTED DESIGN DETAILS

Mesh type, gauge & size

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

- *Woven- or page-wire fencing* – Woven wire fences consist of smooth horizontal (line) wires held apart by vertical (stay) wires. Spacing between line wires may vary from 3 in (8 cm) at the bottom for small animals to 6-7 in (15-18 cm) at the top for large animals. Wire spacing generally increases with fence height. Mesh wire is made in 11, 12, 12 ½, 14, and 16 gauges and fences are available in different mesh and knot designs. The square-shaped mesh may facilitate climbing by some wildlife, such as bears. If climbing is a concern then use of a smaller mesh is recommended. Higher gauge wire mesh is more durable and will last longer than smaller gauge mesh. Wildlife fences along the Trans-Canada Highway in Banff National Park consisted of line wires with tensile strength of 1390 N/sq. mm and 12 ½ gauge. Stay wires had tensile strength of 850 N/sq. mm. All wires were Class 111 zinc galvanized coating at a minimum of 260 gms/sq. m.
- *Chain-link fencing* – Chain-link fence is made of heavy steel wire woven to form a diamond-shaped mesh. They can be made into fences and used in various applications, primarily industrial, commercial and residential. Chain-link was used for highway mitigation fencing along I-75 and SR 29 in Florida. There have been agency and public concerns about the visual aesthetics of chain-link fencing compared to woven-wire as it is less attractive and does not blend into the landscape. Steel posts are always used with chain-link fencing. Chain-link fence fabrics can be galvanized mesh, plastic coated galvanized mesh or aluminum mesh.
- Most wire sold today for fencing has a coating to protect the wire from rust and corrosion. Galvanizing is the most common protective coating. The degree of protection depends on thickness of galvanizing and is classified into three categories; Classes I, II, and III. Class I has the thinnest coating and the shortest life expectancy. Nine-gage wire with Class I coating will start showing general rusting in 8 to 10 years, while the same wire with Class III coating will show rust in 15 to 20 years.
- *Electrified fencing* – Electric fences are a safe and effective means to deter large wildlife from entering highway right-of-ways, airfields and croplands. The 7 ft (2 m) high fence will deliver a mild electric shock to animals that touch it, discouraging them from passing through. It is made of several horizontal strands of rope-like material about a ½ in (1 cm)

in diameter that can deliver a quick shock that is enough to sting, but not seriously harm humans. Wildlife respond differently to standard electric fences; high voltage fences are generally required to keep bears away. There are public safety issues of having electrified fencing bordering public roads and highways as there is high likelihood that people will come into contact with the fence (fishermen, hikers, motorists that run into fence).

Post types

- *Wood* – Wood posts are commonly used and can be less expensive than other materials if cut from the farm woodlot or if untreated posts are purchased. Post durability varies with species. For example, osage orange and black locust posts have a lifespan of 20 to 25 years whereas southern pine and yellow-poplar rot in a few years if untreated.
- The life expectancy of pressure-treated wooden posts is generally 20–30 years depending on the type of wood. Softwoods are the most common wood used for posts when fencing highways. Lodgepole pine and Jack pine are common tree species for fence posts. For Trans-Canada Highway wildlife fences all round fence posts were pressure treated with a chromate copper arsenate (CCA) wood preservative.
- Wood posts are highly variable in size and shape. For typical 2.4 m high fencing 12 ft (3.7 m) and 13.7 ft (4.2 m) long, non-sharpened wooden posts are supplied. Fence posts are sharpened and then installed by preparing a pilot hole approximately 5 in. (125 mm) in diameter, vibrating the post down to specified post height and backfilling with a compacted non-organic material around post to level of existing ground. Strength of wood posts increases with top diameter. Post strength is especially important for corner and gate posts, which should have a top diameter of at least 6.5 in (16 cm). Line posts can be as small as 5 in (13 cm) and should not need to be more than 6.5 in on top diameter, although larger diameter posts make fences stronger and more durable.
- *Steel* – Steel posts are used to support fences when crossing rock substrate. They weigh less and last longer than wood posts; the main disadvantage is they are more expensive than wood posts. Steel posts are supplied in 12 ft (3.7 m) lengths and installed in concreted 3.2 ft (1000 mm) long sleeves for the 12 ft x 3 in. steel posts.
- Tension – Tension between posts can consist of metal tubing on metal posts and reinforced cable on wooden posts.

REINFORCEMENTS

Unburied fence

Unburied fences are used in areas where resident wildlife are not likely to dig under the fence. The fence material should be flush with the ground to minimize animals crawling beneath the fence and reaching the right-of-way.

Buried fence

Strongly recommended in areas with wildlife capable of digging under the fence (e.g., bears, canids, badgers, wild boar). As illustrated in Figure 65, buried fence in Banff National Park significantly reduced wildlife intrusions to the right-of-way compared to unburied fence

(Clevenger et al. 2002). Buried fence consist of a 4-5 ft (1-1.2 m) wide section of galvanized chain-link fence spliced to the bottom of unburied fence material. The chain-link section is buried at a 45-degree angle away from the highway and is approximately 3.5 ft (1.1 m) below ground. Swing gates should have a concrete base to discourage digging under them as shown in Figure 66.

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

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

Cable (protective)

Trees blown onto fences can not only damage fence material but provide openings for wildlife to enter the right-of-way. Typically a problem the inital years after construction, but can continue over time. A high-tensile cable shown in Figure 67 strung on top of fence posts to help break the fall of trees onto the fence material should reduce fence damage, repair costs and maintenance time.

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

TERMINATIONS

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

Each mitigation situation is different and will require a site-specific assessment, but as a general rule, fence ends should terminate at a wildlife crossing structure. If a wildlife crossing cannot be installed at the fence ends, then fences should be designed to terminate in the least suitable location or habitat for wildlife movement—i.e., places wildlife are least likely to cross roads. Some examples are:

- Steep, rugged terrain such as rock-cuts (Bighorn Sheep and Mountain Goats excluded).
- Habitats that tend to limit movement, e.g., open areas for forest-dwelling species.
- Areas with regular human activity and disturbance.

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

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

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

DIMENSIONS - GENERAL GUIDELINES

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

POSSIBLE VARIATIONS

Boulders/terrain

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

Reduced fence height

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

Outriggers/overhangs

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

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

Barbed wire overhangs

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

Gap below fence material for Pronghorn

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

MAINTENANCE

Fences are not permanent structures, neither are they indestructible. They are subject to constantly occurring damage from vehicular accidents, falling trees, and vandalism. Natural events also cause continually occurring damage and threaten the integrity of the fence: soil erosion, excavation by animals, and flooding can loosen fence posts and collapse portions of fence.

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

HOT SHEET 13: FENCING – SMALL AND MEDIUM VERTEBRATES

GENERAL PURPOSE

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

APPLICATION

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

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

SUGGESTED DESIGN DETAILS

Installation

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

Mesh types and sizes

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

Dimensions

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

POSSIBLE VARIATIONS

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

MAINTENANCE

- Fences are not permanent structures, neither are they indestructible. They are subject to constantly occurring damage from vehicular accidents, falling trees, and vandalism. Natural events also cause continually occurring damage and threaten the integrity of the fence: soil erosion, excavation by animals, and flooding can loosen fence posts and collapse portions of fence.
- Fences must be checked every 6 months by walking entire fence line, identifying gaps, breaks and other defects caused by natural and non-natural events.

HOT SHEET 14: GATES AND RAMPS

GENERAL PURPOSE

If wildlife become trapped inside the fenced area, they need to be able to safely exit the highway area. The most effective means of escape are through a steel swing gate, hinged metal door or earthen ramp (or "jump-out") as Figure 71 shows. A low cost way to provide escape is to lay natural objects (tree trunks or limbs) against the fence. The number, type and location of escape structures will depend on the target species, terrain and habitat adjacent to the highway fence.

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

APPLICATION

Swing gates

Swing gates are generally used (with or without ramps) in areas where highways are regularly patrolled by wardens/rangers. As part of their job, if wildlife are found inside the fence, the nearest gates are opened and animals are moved towards the opened gate illustrated in Figure 72. Double swing gates are more effective than single swing gates, especially for larger mammals such as Elk or Moose. Swing gates are used to remove ungulates and large carnivores (e.g., bears) as smaller wildlife can escape by hinged doors at ground level (see below) or through large mammal fence material.

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

Earthen ramps or jump-outs

Earthen ramps or jump-outs allow wildlife (large and small) to safely exit right-of-ways on their own without aid of wardens or rangers. Typically wildlife find the ramps and exit by jumping down to the opposite side of fence shown in Figure 73. Deer and Elk are the most common users, but Moose, Bighorn Sheep, Bears and Cougars use these structures as well. The outside walls of the escape ramp must be high enough to discourage wildlife from jumping up onto the ramp and access the right-of-way. However, the walls should not be so high they discourage wildlife from jumping off. The landing spot around the outside wall must consist of loose soil or other soft material to prevent injury to animals. The outside walls must be smooth to prevent Bears or other animals from climbing up. For best use, escape ramps should be positioned in a set-back in the fence, in an area protected with dense vegetative cover, so animals can calm down and look over the situation before deciding to use the jump out or continue walking along the fence. A right-angle jog in the fence is recommended for positioning the escape ramp but not necessary.

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

Small hinged doors

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

Natural objects

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

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

MAINTENANCE

Like fences, gates and ramps are not permanent structures, neither are they indestructible. They are subject to constantly occurring damage from vehicular accidents, falling trees, and vandalism. Natural events also can cause damage, obstruct gates and affect how well they perform.

Like fences, escape structures must be checked every six months to ensure that they are functioning properly and perform when needed. Maintenance checks should take place at the same time as fence inspections (see Hot Sheets 12 and 13).

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