Ministry of Transportation

Wildlife and Transportation Reference for the Oak Ridges Moraine

Photo Credit: Greg Roberts

Part of the Standard Environmental References

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WILDLIFE AND TRANSPORTATION REFERENCE DOCUMENT FOR THE OAK RIDGES MORAINE

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1 INTRODUCTION AND PURPOSE

Highways function to meet society's social and economic needs for safe and efficient transportation, travel opportunities, and the movement of goods and services. In doing so, highways exert various effects on the surrounding landscape, some of which may be positive, or at least neutral, but many of which can be negative.

This document has been created to help address the Environmental Protection Requirements for the Oak Ridges Moraine, specifically sections 1, 2, 11 and 13 which are related to facilitating wildlife movement and maintaining ecological integrity. This document is not intended to apply across the whole of the province.

The purpose of this document is to advise highway proponents on potential wildlife mitigation strategies based on an extensive literature review of the current scientific knowledge supplemented by professional experience. The increased recognition that highway design and landscape ecology (see Appendix 1 for road ecology review) are intertwined, has led to the heightened consideration of roadway effects on wildlife and corresponding wildlife mitigation strategies. Monitoring of the effectiveness of implemented strategies is important, but to date has been variable in extent and design. While the monitoring database is slowly growing, there are still large gaps in knowledge. As new information becomes more available it will help guide planners and designers in highway design. The guidance provided in this document is based on such contemporary information whenever possible.

Much of the content is presented as a tool kit through the use of Fact Sheets, which are interlinked for easy access to information. Pictures are used to illustrate the text (photos credits are Ecoplans / McCormick unless otherwise stated). The material is addressed in the following sections.

- Section 2 - Highway Planning Context;
- Section 3 - Highway Design and Wildlife Conflict Assessment;
- Section 4 - Highway Design Mitigation Measures;
- Section 5 - Habitat Creation Consideration;
- Section 6 - Construction, Operation and Maintenance Issues;
- Section 7 - Quality Assurance and Monitoring.

A detailed discussion of the road and landscape ecology literature is provided in Appendix 1. The reference list provides a snapshot of the current information, which is continually being collected in this dynamic field.

1.2 Relation to Standard Environmental References

This section is in development and will be included in the final document.

2 HIGHWAY PLANNING CONTEXT

This document provides specific guidance on transportation facility design for wildlife once a transportation facility has been identified as required and the facility has already been routed to avoid, or minimize impact on, sensitive habitat areas. Highway undertakings may consist of new highway construction, twinning of existing highways, or upgrading (such as widening) of existing highways. All projects are undertaken through the Environmental Assessment Process. In planning, wildlife habitat avoidance will have been considered to the extent possible in association with other environmental factors and competing resource tradeoffs. In design, further refinements (horizontal and vertical alignment shifts) may be made along the alignment with possible attendant wildlife benefits.

3 HIGHWAY DESIGN AND WILDLIFE CONFLICT ASSESSMENT

Two key questions face the highway designer, engineer, and environmental specialist when considering highways and wildlife resources:

1) Is special wildlife mitigation required?

For minor road upgrading or pavement re-surfacing, where adjacent wildlife habitat is limited or non-existent (as in an urban setting), the answer may be “NO”. However, professional judgement will need to be applied on a case by case basis, particularly where it is evident that wildlife movement opportunities are present and are to be maintained in an urban setting (such as an existing habitat linkage feature).

Where there is evidence of existing or potential wildlife conflict, based on site-specific conditions and information, whether an upgrading or a twinning, the answer may be “YES”.

Where the undertaking is new highway construction on a new alignment through varying habitats, the potential for future wildlife conflict and impact is increased. In such cases, some level of wildlife mitigation to increase highway permeability should be considered. Again, it is assumed that previous planning leading to the approved alignment has attempted to “fit” the highway on the landscape to reduce effects on wildlife habitat and other resource factors to the extent possible. Furthermore, information collected during the planning study should be used in the development of the mitigation strategies for preliminary design and detailed design.

2) If wildlife mitigation is required, where and what should it be?

Suggested approaches to answering this question are identified below and in the following fact sheets for consideration by the highway designer, engineer and environmental specialist.

3.1 Where Might Animals Cross the Road?

The answer to this question requires integration of the following sources of information[1]:

- Identify possible interactions between the highway and landscape network, which consists of the various habitat patches, cover types, vegetation associations, landforms/topography, drainage features, and areas of human influence;
- Landscape elements providing connectivity or wildlife movement opportunities should be identified;
- Review field and aerial reconnaissance materials, information collected during the route planning EA study, agency and naturalist contacts, relevant resource documents, files and mapping resources covering a full suite of biophysical features;
- Generate a map (recent aerial mosaic mapping and contour mapping) with the superimposed highway alignment combining the full suite of biophysical and cultural features including, but not necessarily limited to:
    - Agricultural land use;
    - ORM Natural Core Areas, Natural Linkage Areas, Countryside Areas and Settlement Areas;
    - Drainage features, other waterbodies, and aquatic resources;
    - Terrestrial vegetation, including natural and cultural vegetation:
    - Valleylands and floodplains;
    - Topography;
    - Groundwater discharge areas, recharge areas, and areas with high susceptibility to contamination;
    - Wildlife trails identified through background sources or field surveys;
    - Aerial surveys of wildlife trails;
    - Wetlands, including unevaluated, locally significant, and provincially significant wetlands;
    - Areas of identified significant wildlife habitat (as defined in the MNR Significant Wildlife Habitat Technical Guide, 2000);
    - Municipally, provincially, or federally designated natural or earth science areas, policy areas, environmentally significant areas, conservation areas;
    - Specific information on wildlife habitats and species that can be mapped with agency permission;
    - Information outlined in the Oak Ridges Moraine (ORM) Technical Guide and supporting documents

[1] See Terrestrial Ecosystems (Technical Requirements for Environmental Impact Study and Environmental protection Mitigation) Section 3.2 of the Environmental Reference for Highway Design for additional guidance.

References

Forman et al., 2003; Forman and Hesperger, 1996; Klein. 1999; Barnhum, 2003a, 2003b; Austin et al., 2003; Finder et al., 1999; Clevenger and Waltho, 2000; Rodriguez et al., 1996; Serrano et al., 2002; Philcox et al., 1999; Smith, 1999; Clevenger, 1998; and Alexander and Waters, 2000; Federal Highway Administration, 2002; Wagner et al., 1998; Carr et al., 1998; Ruediger and Lloyd, 2003; Kautz et al., 1999; Smith et al., 1996; Singleton and Lehmkuhl, 1999; Hindelang et al., 1999; Scheick and Jones, 1999.

3.1.1 Stage 1: Identifying Wildlife Conflict Zones

Wildlife conflict zones are identified as locations where animals are most likely to come into contact with the highway, and where mitigation efforts should be considered. They are segments of the highway (or new corridor) that are generally at least 2 km in length (see Barnhum, 2003a; 2003b).

A wildlife conflict zone may embody any combination of the following landscape elements or features that promote wildlife crossings. The following information can be layered on base mapping along the highway alignment to identify the zones (see Figure 3-1).

- Suitable habitat for a particular species typically within 100 m of the highway (see, for example, Finder et al., 1999). This is a helpful guideline for species with specific habitat requirements, but more challenging for habitat generalists (such as deer) where suitable habitat may be present all along the facility;
- Riparian areas, valleys, existing bridges (correlated with deer crossings);
- Gentle ridge lines, fencerow vegetation, or other linear features (tree or shrub cover) intersecting the highway, that act to guide wildlife to the highway;
- Sideroads (such as gravel roads, logging roads), and even rail lines that intersect the highway and that can be travel routes for wildlife;
- Zones where wetlands are crossed, and particularly where a wetland is on one side, and upland forest (fragmented by the highway) is on the other side – these are likely areas for amphibian and reptile movements, and may also need equalization culverts for drainage;
- Areas of low topographic complexity (i.e. no complex slopes, slopes typically less than 5%, ideally relatively gentle topography) – most wildlife species, if provided with a choice, will follow the easiest path;
- Transition areas between habitat types (such as forest/field edges), that intersect the highway, may guide wildlife to a crossing area;
- Vernal pools near the highway may indicate a source or destination area for wildlife movements (particularly frogs and salamanders);
- Exposed sand, in association with wetlands and lakes, are likely turtle breeding sites, and may represent a potential source of turtle movement (to/from) across the highway. Sandy verges of highways are also used for nesting.

Wildlife conflict zones may also coincide with highway sections where median barriers (Jersey barriers) have been installed. Driver safety along problematic stretches of a highway is typically the compelling reason for Jersey barrier installation. It is recognized that these structures can form a complete barrier to wildlife movement. Finding solutions to this issue remains a challenging process. Currently, a wildlife mortality study on Hwy 401 near Kingston, Ontario, is testing the effects of median barriers on wildlife mortality. Information stemming from that work may assist in identifying possible design measures or other solutions) that do not compromise driver safety.

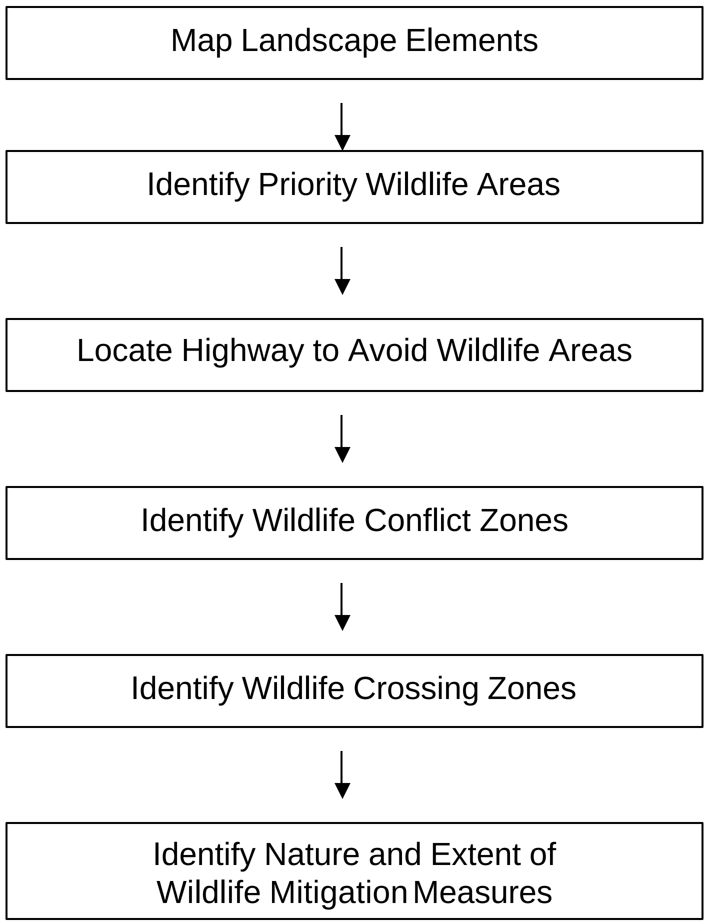

Figure 3-1. Approaches to wildlife conflict assessment.

3.1.2 Stage 2: Identifying Wildlife Crossing Zones

Wildlife crossing zones have been defined as relatively short stretches of the highway (or proposed new facility) that have the highest probability of being crossed by wildlife. These segments may range from 30 to 600 m in length and would usually be located within the broader wildlife conflict zone (see Barnhum, 2003a; 2003b).

The recommended strategy for identifying locations with a high potential to be crossing zones is as follows:

- Employ environmental professionals familiar with the landscape and target wildlife species (same recommendation applies to evaluation of wildlife conflict zones);
- Locate and map features likely to be associated with crossing zones and known to be important to the species present. Pay attention to the location of drainages, highway or other barriers, special habitat features (such as food sources), and the distance to cover (for species that use cover).
- Areas where wildlife cross highways more often than surrounding segments may have higher than average rates of animal/vehicle collisions (AVC) reported. However, AVC data are dependant on traffic volume as well as the number of animals crossing the highway, and therefore cannot replace information about adjacent landscape structure and other cues that influence wildlife crossings. Animal avoidance accidents may not involve documentation of the role of wildlife in the accident. AVC data may also be general in nature if collisions are only estimated relative to the nearest highway marker post – location errors of several hundred metres can consequently occur. Improved reporting and locating collision sites with Global Positioning System (GPS) accuracy would improve the reliability of AVC data.
- Using these maps, determine relative abundance of each feature, and how much variation it exhibits along the existing highway (or new alignment);
- Place greater reliance on features that are highly attractive to resident wildlife species, especially if those features are limited along the highway, and to features that are relatively variable (zones where habitat projections extend to the highway/ROW, or where there are distinct habitat breaks);

The 2-stage approach of identifying wildlife conflict and crossing zones emphasizes desktop and field reconnaissance evaluation of landscape features. The *wildlife conflict zones* will likely comprise discrete portions of the highway alignment where *wildlife crossing zones* will most likely be contained. Consequently, additional field effort can be focused at these smaller zones (such as roadside mapping, track and trail assessment, video surveillance, live trapping, and spring amphibian crossing checks) during detailed design in assessing the final nature and location of wildlife mitigation structures.

References

Austin et al., 2003; Finder et al., 1999; Clevenger and Waltho, 2000; Rodriguez et al., 1996; Serrano et al., 2002; Philcox et al., 1999; Smith, 1999; Clevenger, 1998; and Alexander and Waters, 2000; Forman et al., 2003; Barnhum, 2003a. 2003b; Federal Highway Administration, 2002; Wagner et al., 1998; Carr et al., 1998; Klein, 1999; Ruediger and Lloyd, 2003; Smith, 1999; Kautz et al., 1999; Smith et al., 1996; Singleton and Lehmkuhl, 1999; Hindelang et al., 1999; Malo et al., 2004; Finder et al., 1999; and Scheick and Jones, 1999.

4 HIGHWAY DESIGN MITIGATION MEASURES

Wildlife mitigation approaches have two facets – influencing motorist behaviour and modifying wildlife behaviour (Forman et al., 2003).

4.1 Influencing Motorist Behaviour

4.1.1 Traffic Volume and Speed

- Traffic volume and speed are contributing factors in wildlife highway mortality. Volume may be distributed among parallel roadways, if present. However, increasing road density has wildlife ecology implications and accommodating high volumes on the major highways may be preferable to spreading out volumes on many roads (for social and wildlife reasons);
- Speed limit controls are available, if a case can be made for slower speeds at critical locations. Temporary or seasonal speed limit reductions could be considered in high wildlife mortality zones (such as spring amphibian migration movements, summer turtle movements). Temporarily reduced speeds in association with special signs may also assist. However, the effectiveness of speed reduction signs in reducing animal-vehicle collisions is still unclear (Knapp, 2004 – See Wildlife Warning Sign fact sheet). Education and enforcement are important in this endeavour.

4.1.2 Field of View

- Improving the motorist's field of view to better see roadside animals (and perhaps vice versa) is also a consideration. Variations in the pattern and degree of roadside vegetation have implications on whether views are blocked or open as well as viewing aesthetics. Various examples, adapted from Forman et al. (2003) are provided below:

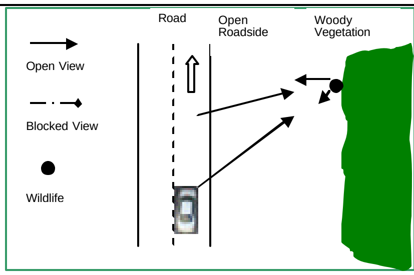

Figure 4-1. Driver-wildlife visibility - Open filed of view.

A completely open roadside bordering wooded areas does not obstruct views between motorists and wildlife. Variability in roadside structure (and perhaps viewing aesthetics) is limited but safety in terms of vehicle/wildlife awareness is enhanced

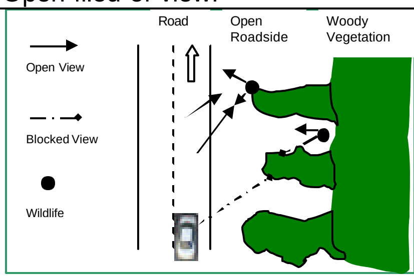

Figure 4-2. Driver-wildlife visibility - Scalloped edges.

A scalloped roadside vegetation scenario occurs where “tongues” of vegetation are retained in the design. Variability in the roadside habitat structure (and perhaps viewing aesthetics) increases. Visibility of wildlife depends on wildlife and vehicle locations relative to the ‘tongues” of vegetation. Some views are open, and some are blocked. Scalloped edges may act to guide wildlife towards the road, which is problematic unless intended in association with a crossing structure.

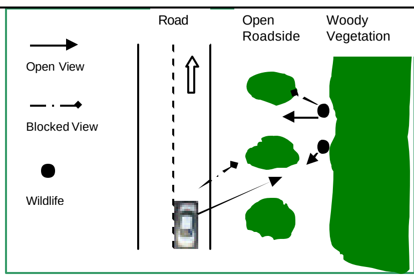

Figure 4-3. Driver-wildlife visibility - Single row plantings.

Roadside vegetation may consist of evenly spaced linear clumps of shrubs/trees. Again, visibility of wildlife varies depending on wildlife and vehicle locations relative to the roadside vegetation. Motorist views ahead may be blocked. Viewing experience for motorists might be monotonous with long lines of planted roadside vegetation

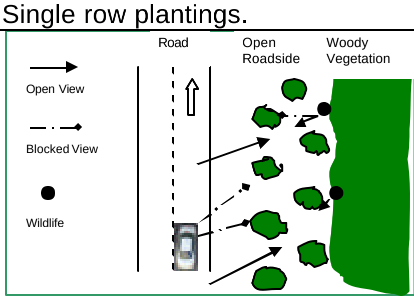

Figure 4-4. Driver-wildlife visibility - Staggered double row plantings.

Staggered double plantings of roadside vegetation can provide some variability in structure and viewsheds. Diagonal views between motorists and wildlife may be unimpeded depending on vehicle/wildlife locations, but views may be blocked from other vantage points;

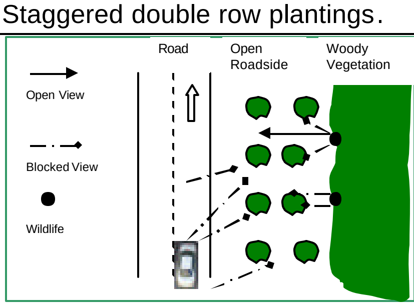

Figure 4-5. Driver-wildlife visibility - Linear double row plantings.

Non-staggered double plantings of roadside vegetation provide a different viewing experience. Diagonal views between motorists and wildlife are largely blocked when wildlife are at the forest edge. Views are only apparent when wildlife are closer to the road, which may make collision avoidance very difficult

4.1.3 Highway Lighting

- Limited research on increased highway lighting to improve driver visibility/awareness suggests it to be an ineffective means of reducing deer-vehicle collisions (Forman et al., 2003; Knapp 2004).
- In fact, some experimental studies and anecdotal evidence suggest that artificial lighting may have varying effects on different wildlife species, including nocturnal foraging and migration movements, predator-prey interactions, light attraction or repulsion, possible influence on social interactions, collisions with lighted structures (towers and bridges), and reduction of habitat quality (see for example, English Nature, 1996; Buchanan, 1993, 2002; Wise and Buchanan, 2002; Gauthreaux and Belser, 2002; Molenaar et al., 2000).
- Where highway lighting intrudes into natural areas, possible wildlife influences might consist of the following (adapted from Molenaar et al., 2000);
    - Prey species may be attracted to the light area. Improved visibility for predators may increase predation pressure;
    - Lighting may lengthen effective "daylight", thereby increasing foraging time for some species, and possibly predation time for predators;
- The extent of knowledge concerning the effects of artificial road lighting is limited, and further research is required before species-specific mitigation measures can be developed. Preliminary mitigation measures identified for insect populations have been summarized in English Nature (1996):
    - Avoid installation of lighting near potentially vulnerable sites;
    - Use low-pressure sodium lamps and lamps with as low brightness as legally possible;
    - Fit shades to restrict light to where it is needed only;
    - Fit ultra-violet filters to mercury lamps (sodium lamps emit negligibly in the UV) or change to low-pressure sodium lamps;
    - Turn off lamps close to vulnerable sites outside key periods of human activity if this does not put people at risk.
- Some of the above measures may be helpful for other wildlife groups – however further research is needed as noted to develop species-specific mitigation measures;
- With respect to highway lighting, the following measures should be considered:
    - Avoid installing lighting unless required for human safety or to meet other highway safety requirements;
    - Avoid installing lighting adjacent to wildlife habitat areas (such as forest) unless unavoidable for reasons above;
    - If required adjacent to wildlife habitat areas, design lighting to emit down and away from the natural area. Use low-pressure sodium

lamps or UV filters and employ whatever other measures are feasible to reduce the intensity and amount of light reaching natural areas;

- o Track and implement new technologies dealing with light pollution mitigation as they become available and tested.

4.1.4 Public Education and Awareness

- Public awareness education, such as dealing with roadside vegetation management and wildlife collision risks, represents a little-tested way to get the message across. For example, an extension education program is underway in Quebec that promotes the driver and wildlife benefits of their highway roadside vegetation management program (Quebec Ministry of Transportation, 2003);
- Public service announcements, education campaigns, and poster-sized hotspot maps are techniques that have been and are being used in the US and Europe and that are considered to be effective in helping reduce wildlife-vehicle collisions. However, these measures need to be combined with other mitigation measures (such as fencing and crossing structures) to maximize potential efficacy (see reviews by Knapp, 2004 and Biota Research and Consulting Inc. (2003);

4.2 Modifying Wildlife Behaviour

This section reviews the "toolkit" of design mitigation measures that are available and that have been put to varying degrees of use. Links to Fact Sheets featuring wildlife crossing structures and implementation considerations as well as specific animal group considerations are provided in the following tables.

Animal Groups
Ungulates
Large Carnivores
Small and Medium Mammals
Amphibians
Reptiles

Wildlife Mitigation Approaches	
Wildlife Underpasses	**Other**
Viaduct	Fencing and Escape Measures
Bridge	Interactive Wildlife Warning Signals
Large Culvert	Wildlife Crossing Warning Signs
Small Upland Culvert	
Standard Drainage Culvert	

The determination of the wildlife mitigation strategy must be site-specific and involving both professional judgment and consultation with agency staff.

Prominent researchers in the field are concluding that a range of mitigation strategies and structures is desirable, not just a few large bridges or numerous small culverts. A combination of structure types and sizes will likely be most appropriate, geared to site conditions, the landscape, collected wildlife information, hydraulic requirements, and agency consultation.

Mitigation dollars are limited, and should be employed responsibly where there is greatest benefit. There is good evidence that smaller structures are well used by a number of species, and provision of such structures spaced at shorter intervals (perhaps 100 to 300 m) along suitable sites is likely more important for road permeability than only a few very widely spaced bridges. Bridges will of course be provided where features/watercourse conditions dictate, and there are additional design elements associated with bridges that can enhance their use by wildlife. On roadway projects a combination of bridges as well as small to medium sized structures, depending on collected data, will likely prove to be the most cost-effective approach to improving permeability to wildlife.

Target wildlife species would be defined by the consultant, based on site-specific wildlife information, landscape conditions, professional judgement, and agency consultation. The Environmental Reference for Design Chapter 3 lays out a number of specific considerations for wildlife and highway design.

A mixed wildlife mitigation strategy will provide movement opportunities for a broad range of species, encompassing small mammals, amphibians/reptiles, and extending up to ungulates. However dedicated facilities for every wildlife group may not be needed, depending on habitat site conditions, land use changes, design constraints or other limitations, and nature/operation of the roadway.

The concept of structure “openness” is discussed in the Fact Sheets. Openness is the ratio between the cross-sectional area of the structure opening and the length of the structure that must be traversed by wildlife (expressed typically as a fraction). The underlying concept is that the openness of a structure may play an important role in acceptance and use by wildlife species that are not tolerant (or less tolerant) of confined areas for movement (the tunnel effect). Early research in the field identified minimum suggested openings for ungulates such as Mule Deer (Reed et al., 1975), and later studies/anecdotal observations have suggested openness ratios ranging from 0.6 or greater for species such as White-tailed Deer. However, deer will use structures with lower openness ratios, and more current research is indicating that a good variety of small to mid-size wildlife species will utilize smaller culverts (see for example Yanes et al., 1995; Brudin, 2003; Clevenger et al., 2001).

At present there is insufficient information to reliably identify required openness ratios for all taxa. What is emerging from the literature is that factors other than structure openness may play an equal, if not greater role in the likelihood that a particular structure will be used. These factors include provision of funnel fencing, nature of cover available at or near the structure, likelihood of long-term persistence of linkage habitat leading to the structure, structure location, and even human activity near the structure. These and other design elements are reviewed in the various fact sheets that follow.

The material that follows provides an overview of highway and wildlife design considerations for various wildlife groups. This review is followed by a series of detailed Fact Sheets providing highway design guidance for various wildlife structures as well as other design elements. Wherever possible, links are provided to the various tables and fact sheets to cross-reference information.

4.2.1 Highway Design Mitigation Measures: UNGULATES

White-tailed Deer and Moose

Goal	Tool	Species-Specific Implementation Considerations
Road Access Reduction	Road Alignment	• Plan route to minimize contact with potential wildlife conflict and crossing zones.
	Fencing and Escape Measures	• Most authors conclude that structures are most effective if funnel fencing is provided, particularly if precise crossing zone is not apparent (see for example, McGuire and Morrall, 2000); • Minimum 2.8 m tall galvanized steel chain-link or high-tensile fixed knot galvanized steel mesh fence is recommended, with no gaps greater than 23 cm through which deer can crawl under or squeeze through. (Exclusion fencing ranging from 3.0 to 3.7 m has been recommended for use around airport perimeters – see Katona et al., 2000); • Parallel to the highway for some distance, ± 500 m on either side of the crossing structure will be adequate for larger mammals if the structures are located in well defined travel corridors – fencing will likely need to extend further where travel corridors are not well defined; • One-way gates or earthen ramps are installed at intervals along fencing often with wildlife crossings. These are provided to enable ungulates trapped in the ROW to escape; • One-way earthen ramps are 10-12 times more effective than the gates, and have lower maintenance requirements.
	Various	• Many other mitigation measures have been described including deer whistles, electro fencing, herd reduction, de-icing salt alternatives, intercept feeding, reflectors/mirrors, and chemical odour and taste repellents. However, their effectiveness is mostly inconclusive and requires further study. Currently, fencing and wildlife crossing structures used together appear to be the most effective mitigation measures (see for example, Biota Research and Consulting Inc., 2003). • Moose-vehicle collision research in Sweden (based on landscape data and road traffic/collision data) suggests that reduced vehicle speed in combination with road fencing and increased roadside clearance (clear zone with no woody vegetation) may provide to be effective in areas which high moose-vehicle collisions (see Seiler, 2005).
Driver Alerting	Various	• Other measures including improved roadway lighting, speed limit reduction, and crossing signs, have been or are under review, with mixed and sometimes questionable results (see for example, Biota Research and Consulting Inc., 2003); • Parks Canada is testing an infrared camera/computer system for its effectiveness in warning drivers of nearby wildlife and thus resulting in reduced speeds; • The Swiss are successfully using a series of solar powered heat sensors to determine animal presence, which then triggers a fibre-optic wildlife warning sign to reduce speed to a designated level.

4.2.1 Highway Design Mitigation Measures: UNGULATES

White-tailed Deer and Moose

Goal	Tool	Species-Specific Implementation Considerations
Wildlife Corridor Maintenance	Bridge	• Funnel fencing to the structure may be beneficial depending on site-specific conditions.
	Large Culvert	• In Pennsylvania, 65% of structures used by deer had ROW fencing funnelling them to the structure; • Funnel fencing should be a minimum 2.8 m high (3.0 to 3.7 m tall fencing has been recommended for use around airport perimeters) with the bottom embedded in ground, and the mesh attached to the outside (ROW side) of poles (as ungulates will push in looking for openings); • Prefer crossings used less often by their predators; • To reduce the tunnel, the minimum recommended dimensions for box culverts providing higher likelihood of use for species such as ungulates reported as 6 x 6 m or 3 x 10 m for a 35 m tunnel length (Openness ratio of about 1.0). However, deer will use smaller structures depending on site conditions and design. As structure length increases, the size of the opening needs to increase to obtain a desired openness ratio. Openness ratios ranging from 0.6 to 1.0 will provide good conditions for deer use – however structures with much smaller openness ratio have been used by deer. Likelihood of use will be enhanced by proper design and funnelling; • To reduce the tunnel effect, an open highway median is recommended wherever feasible for better daylighting; • Provide open, level approaches to structures – vegetation can be used to guide approaches, but plantings at the structure entrances should consider the target species (cover is good for small and larger mammals, but should be avoided for amphibians and reptiles that prefer clear entrance conditions. Also, avoid plunge pools or woody debris at entrances. Deer will use structures containing some water (up to 0.6 m depth in a Pennsylvania study), but will avoid structures in spring if ice is present inside (deterrent); • Deer will use structures with a concrete bottom, although ideally some substrate is desirable.
References	Brudin, 2003; Forman and Hersberger, 1996; Forman et al., 2003; USDA, 2004; Federal Highway Administration, 2002; Jackson, 1999; Clevenger, 1998; Jackson and Griffin, 1998; Scheick and Jones, 1999; Norman et al., 1998; Veenbaas and Brandjes,1999; Knapp, 2004; Ontario Ministry of Transportation, 1992; Federal Highway Administration, 2002; Evnik, 2002; Katona et al. 2000; UMA Engineering Ltd. 2000; Romin and Dalton, 1992; Biota Research and Consulting Inc., 2003; McGuire and Morrall, 2000.	

4.2.2 Highway Design Mitigation Measures: LARGE CARNIVORES

Black Bear, Wolf and Coyote

Goal	Tool	Species-Specific Implementation Considerations
Road Access Reduction	Road Alignment	• Plan route to minimize contact with potential wildlife conflict and crossing zones.
	Fencing	• Should be a minimum of 2.8 m tall, ideally with the bottom buried in ground to prevent jumping over and digging under the structures; • Escape gates or ramps should be provided; • Anti-climbing measures such as angled fence lips are recommended.
	Viaduct	• Structural openness preferred, and is usually available with a viaduct; • Minimizing human activity at the structure is considered important for wildlife use; • Success greatly improved with use of funnel fencing.
	Bridge	• Large carnivores will use underpasses including moving under viaducts, bridges and through large culverts; • Structural openness preferred; • Less likely to use structure if human use (such as a trail or bicycle path) is prevalent; • Success greatly improved with use of funnel fencing.
Wildlife Corridor Maintenance	Large Culvert	• Minimizing human activity near the structure is considered important for wildlife use; • Time for habituation to structure is often required; • Used by bobcats and coyotes as well as bears who do not object to the tunnelling effect.
References	Clevenger and Waltho, 2003; LSA, 2003; Forman et al., 2003.	

4.2.3 Highway Design Mitigation Measures: SMALL AND MEDIUM-SIZED MAMMALS

Rodents up to size of medium Carnivores

Goal	Tool	Species-Specific Implementation Considerations
Road Access Reduction	Road Alignment	• Plan route to minimize contact with potential wildlife conflict and crossing zones.
	Fencing	• Use of smaller mesh along the bottom section of the fencing is applied in Europe to direct small mammals to wildlife structures; • The bottom end of the fencing should be a finer mesh and buried to prevent entry; • Improve funnelling to structure by stretching fencing parallel to the highway for some distance.
	Habitat Creation	• Wildlife structures can be adapted to provide habitat in their own right where specialized wildlife needs are identified. An example is the development of a bat culvert out of a modified drainage culvert in Texas. The new design installed a recessed square dome within the top of each culvert cell. Within each dome a rough-textured roosting surface comprised of recycled plywood forms was installed; • It should be noted that habitat creation initiatives such as this may need to be balanced with structure maintenance requirements. In Ontario, the Migratory Birds Convention Act (MBCA) protects nesting migratory birds from destruction of birds and their nests and young (including during required structure maintenance and cleaning). Consequently, structure designs are increasingly attempting to reduce, rather than promote nesting by such species. Clearly, resolution of conflicting objectives would require further thought and negotiation. For more information refer to Section 5.0.
Wildlife Corridor Maintenance	Viaduct	• Small mammal movement is facilitated by stump placement for cover; • Other types of habitat structure can be provided such as plantings, wood debris, and rock. Large rip rap material can be an impediment to movement by small wildlife species and should not block movement areas.
	Bridge	• Funnel fencing to the structure may be beneficial depending on site-specific conditions.
	Large Culvert	• Funnel fencing should be embedded in ground to prevent entry through digging under the fence; • Ledges increase likelihood of culvert use by mammals and other species at drainage culverts where no terrestrial zone is provided (see for example Foresman, 2004).

4.2.3 Highway Design Mitigation Measures: SMALL AND MEDIUM-SIZED MAMMALS **Rodents up to size of medium Carnivores**		
Goal	**Tool**	**Species-Specific Implementation Considerations**
Wildlife Corridor Maintenance	Small Upland Culvert	• Small mammals will tend to use smaller cross-sections (equal or less than 2 m wide), because their life cycle frequently involves moving along confined spaces; • Large rip rap should be avoided on the terrestrial sides because it impedes movement by small mammals and likely amphibians; • Placement of stumps as cover will facilitate movement by small mammals; • Adding ledges to existing culverts that lack a terrestrial travel zone can provide movement opportunities for a number of mammal species (see for example Foresman, 2004).
References	Rodriguez et al., 1996; Yanes et al., 1995; Foresman, 2004; Texas Department of Transportation, 1999.	

4.2.4 Highway Design Mitigation Measures: AMPHIBIANS

Salamanders, Frogs and Toads

Goal	Tool	Species-Specific Implementation Considerations
Road Access Reduction	Road Alignment	• Plan route to minimize contact with potential wildlife conflict and crossing zones.
	Fencing and Escape Measures	• Funnel fencing at least 40 cm high is recommended to prevent entry and funnel animals towards crossing structures; • Ideally, angle funnel fencing at the tunnel entrance to guide amphibians, if feasible in roadway design; • Top lip of fencing can have an overhang if climbing species are a concern (to prevent roadway entry).
	Other	• Improper drainage can result in ponding of highway runoff in depressions or within the drainage swale system stimulating "vernal pool" conditions potentially attracting amphibians. Such sites are typically contaminated with salt and or other road runoff contaminants, and often do not hold water long enough to allow for successful development. These concerns can be alleviated by ensuring that the highway drainage system provides positive runoff flow, while filtering contaminants, and avoiding unnecessary ponding.
Wildlife Corridor Maintenance	Viaduct	• Amphibian use is feasible with suitable substrate conditions such as cover, damp conditions or watercourse and barriers such as heavy rock rip rap are absent.
	Bridge	• Amphibians can move under these structures if favourable habitat conditions exist (such as cover, damp conditions) or watercourse and barriers (such as heavy rock rip rap) are absent.
	Large Culvert	• Evidence of high ledge use by amphibians. The broader the ledges the more frequently they were used and by more species; • Earthen banks appeared to be used most by a range of species.

4.2.4 Highway Design Mitigation Measures: AMPHIBIANS

Salamanders, Frogs and Toads

Goal	Tool	Species-Specific Implementation Considerations
Wildlife Corridor Maintenance	Small Upland Culvert	• Appendix 2 review indicates that the effectiveness of amphibian/reptile tunnels is dependant on a number of variables, including size and openness, placement, substrate, funnelling to the structure, vegetation cover, moisture, hydrology, temperature and light; • Proper tunnel location relative to known or expected amphibian/reptile crossing areas; • Adequate light and tunnel "see-thoroughness" to enable perception of a tunnel exit; • Moisture and temperature conditions that mimic ambient conditions to the extent possible (larger size and/or provision of slots or grates for ambient light/moisture); • Natural local substrates in the tunnel to retain some moisture, mimic natural ground conditions, and perhaps retain historical scent that may play a role in migration (possibly for some salamanders); • Suitable funnelling to the tunnel (wood, stone, earth or sheet piles) that is at least 0.4 m high (to contain frogs/amphibians), and extending no more than 50 m in either direction (to reduce out-of-way travel and animal possibly aborting the crossing attempt); • Angling the funnel fencing as much as feasible to direct animals to the entrance; • Avoidance of vegetation growth that would impede amphibian movement to the tunnel entrance; • Avoidance of flooding or high velocity water flows through the tunnel during spring and fall migration movements; • Wildlife culverts at waterways can provide movement opportunities for reptiles, amphibians and mammals if riparian zones at least 0.5 to 1.0 m wide on one or both sides of the waterway are retained under the structure. Adding ledges to existing culverts that lack a terrestrial travel zone can provide movement opportunities for amphibian species (see for example Veenbaas and Brandjes, 1999). • Large rip rap should be avoided on the terrestrial sides because it likely impedes movement by amphibians.
	Standard Drainage Culvert	• Some form of funnelling to these culverts would likely improve wildlife use.
References	Rodriguez et. al., 1996; Yanes et. al., 1995; Chan, 1993; CARCNET, 2004; Guyot and Kuchling, 1998; Guyot and Kuching, 1998; Brooks, pers. comm. 2004; Galbriath, pers. comm. 2004; Guyot, pers. comm. 2004; Jackson, pers. comm.. 2002; Veenbaas and Brandjes, 1999.	

4.2.5 Highway Design Mitigation Measures: REPTILES

Snakes and Turtles

Goal	Tool	Species-Specific Implementation Considerations
Road Access Reduction	Road Alignment	• Plan route to minimize contact with potential wildlife conflict and crossing zones.
	Fencing	• Wood, stone, earth, sheet piles, plastic or concrete fencing with a minimum height of 0.4 m. Length of funnel fencing should be dictated by target species and site conditions. At well known crossing locations (for example – turtles), funnel fencing extending 50 m on either side of the structure may be adequate (See Appendix B). MNR (Parry Sound) is examining use of concrete culverts by the Eastern Massasauga Rattlesnake along Highway 69 – temporary funnel fencing (silt fencing) at those sites currently extends several hundred m on either side of the structures (Woodhouse et al., 2002; Brown et al. 2004); • Angle the funnel fencing at the culvert entrance as much as feasible to help direct animals to the entrance; • Top lip of fencing can have an overhang if climbing species are of concern; • Avoid kinks in fencing/walls especially to ease movement by turtles; • Heavy duty silt fence used in construction projects may cause mortality in large-bodied snake species. (see Section 5.0 for details).
	Habitat Creation	• Many Ontario turtles move from wetland sites to upland sites such as highway embankments for nesting. Turtle mortality occurs either as turtles attempt to nest on the highway edge, or attempt to cross the highway to reach a suitable nesting site. Providing alternative nesting habitat through creation of sand deposits near the wetland source area or in the movement path, may be a means of obviating the need for turtles to cross the highway, or the need of providing a dedicated crossing structure. However, it is possible that turtles may ignore new nesting areas due to nest site fidelity. For further information refer to Section 5.0; • Hibernacula sites provide overwinter cover for a variety of Ontario snakes. Where such cover is typically structure piles such as rocks or brush, consideration can be given to creating comparable habitat off ROW, particularly during construction when suitable equipment and manpower is available. Gestation sites are used by gravid snakes during the period of egg/young development. For a threatened species such as the Eastern Massasauga Rattlesnake, preferred sites encompass flat table rocks for sunning, smaller rocks for additional cover, and nearby vegetation cover or brush piles for shelter and protection from the sun, as required. If such sites are present, and the highway presents a barrier for snake access to such sites, there is a real risk of snake mortality as individuals attempt to cross the highway to reach the gestation site. An MNR protocol for creating gestation sites is provided in Appendix 3.

4.2.5 Highway Design Mitigation Measures: REPTILES		**Snakes and Turtles**
Goal	**Tool**	**Species-Specific Implementation Considerations**
Wildlife Corridor Maintenance	Viaduct	• Amphibian/reptile use is feasible provided that suitable substrate conditions such as cover, damp conditions or watercourse are present and barriers such as heavy rock rip rap are absent or located outside the desired travel zone.
Wildlife Corridor	Bridge	• Amphibians and reptiles can move under these structures provided that suitable substrate conditions such as cover, damp conditions or watercourse are present and barriers such as heavy rock rip rap are absent or located outside the desired travel zone.

4.2.5 Highway Design Mitigation Measures: REPTILES

Snakes and Turtles

Goal	Tool	Species-Specific Implementation Considerations
Maintenance	Small Upland Culvert	• Appendix 2 review indicates that the effectiveness of amphibian/reptile tunnels is dependant on a number of variables, including size and openness, placement, substrate, funnelling to the structure, vegetation cover, moisture, hydrology, temperature and light; • Proper tunnel location relative to known or expected amphibian/reptile crossing areas; • Adequate light and tunnel "see-thoroughness" to enable perception of a tunnel exit; • Moisture and temperature conditions that mimic ambient conditions to the extent possible (larger size and/or provision of slots or grates for ambient light/moisture); • Natural local substrates in the tunnel to retain some moisture, mimic natural ground conditions, and perhaps retain historical scent that may play a role in migration (possibly for some salamanders); • Avoidance of flooding or high velocity water flows through the tunnel during spring and fall migration movements; • Effectiveness of culverts is unclear for turtles. Wider culverts may be better for land tortoises, while narrower ones are better for aquatic turtles. It is unclear whether aquatic turtles require water in a culvert to use it; • Wildlife culverts at waterways can provide movement opportunities for reptiles, amphibians and mammals if riparian zones at least 0.5 to 1.0 m wide on both sides of the waterway are retained under the structure; • By installing culverts closer together, snakes would not have to be diverted long distances from their intended routes along fences. Concentrating culverts in potentially high mortality areas would be a practical solution with long stretches of highway; • Provision of natural substrate was considered important for garter snake use of culverts, both as natural material and to assist snakes in providing traction for movement over the surface. Factors such as trying to match ambient air temperature inside culverts coupled with provision of some cover to promote passage of snakes are under review by MNR (Parry Sound); • There is some evidence turtles can be disoriented when following surfaces with kinks or bends (such as kinks in a funnel wall) or a circular structure with no clear "edge". Hence a box style culvert is considered better for this species group (Jackson, pers comm.. 2002). However, turtles have been photographed using large oval culverts with natural bottom substrates in the US.
	Standard Drainage Culvert	• Some form of funnelling to these culverts would likely improve wildlife use.

4.2.5 Highway Design Mitigation Measures: REPTILES **Snakes and Turtles**		
Goal	**Tool**	**Species-Specific Implementation Considerations**
References	Rodriguez et. al., 1996; Yanes et. al., 1995; Chan, 1993; CARCNET, 2004; MNR, 2003; Guyot and Kuching, 1998; Brooks, pers. comm. 2004; Galbriath, pers. comm. 2004; Guyot, pers. comm. 2004; Jackson, pers. comm.. 2002; Woodhouse et al. (MNR, Parry Sound) 2002; Brown et al. (MNR, Parry Sound) 2004.	

4.2.6 Wildlife Mitigation Approaches: Wildlife Underpass: VIADUCT

Wildlife Crossing Structure

DESCRIPTION	• Elevated, long multiple-span bridge used to span entire valleys.

Figure 4-6. Viaduct, Highway 416, Ottawa.

TARGET WILDLIFE GROUPS	• Utilized by ungulates, large carnivores, as well as a variety of smaller mammal species; • Amphibian/reptile use is feasible with suitable substrate conditions but not typically monitored under such structures.
APPLICATION SUITABILITY	• Structures typically located across incised valleys, areas with undulating terrain, and over water bodies; • Typically long (150 to 600 m) and often installed to maintain a variety of functions (hydrology, pedestrian connectivity, vegetation, wildlife movements).
ADVANTAGES	• Broad range of wildlife species can be accommodated; • Typically provides relatively unrestricted wildlife movements under highway alignments.
DISADVANTAGES	• High construction cost; • However, if required for other reasons, limited additional cost for wildlife use is required.
IMPLEMENTATION CONSIDERATIONS	• Ungulates will use readily if there is a clear view to habitat on the other side; • Small mammal movement facilitated by stump placement for cover; • Other types of habitat structure can be provided for wildlife cover and to facilitate movement under the structure, if required (such as plantings, wood debris, rock); • Large rip rap material can be an impediment to movement by small wildlife species and should not block movement areas; • Separation between lanes can improve light and moisture penetration, thereby facilitating vegetation growth;

4.2.6 Wildlife Mitigation Approaches: Wildlife Underpass: VIADUCT

Wildlife Crossing Structure

IMPLEMENTATION CONSIDERATIONS	• Important to maintain connectivity of contributing habitat – clearing and development of adjacent habitat areas may compromise effectiveness of facility; • Funnel fencing would likely improve effectiveness.
CONSTRUCTION COSTS	• Typically high (could be several million dollars depending on design and materials). However, if required for other reasons, limited additional cost for wildlife use is required.
MAINTENANCE IMPLICATIONS	• Removal of debris and other materials on or under the structure as part of the periodic maintenance (removal and destruction of active nests of migratory birds is prohibited under the MBCA and Regulations); • Schedule structure maintenance to avoid the nesting period of migratory species (consult with Environment Canada to verify the breeding period based on geographic location). • Alternatively, implement measures to discourage nesting prior to maintenance (These may include deterrent netting/tarps or other suitable measures). • If the above options are not employed or feasible, and nesting of migratory birds is confirmed at a structure, the mitigation strategies highlighted in Section 6.0 would apply (time the maintenance activity to avoid the nesting period, or develop a mitigation plan in consultation with Environment Canada). • The MBCA and Regulations also prohibit the discharge of "oil, oil wastes or any other substances harmful to migratory birds in any waters or any area frequented by migratory birds". Design measures must be identified to ensure that any cleaning or maintenance materials are properly stored, handled and controlled to prevent substance release to aquatic or terrestrial habitat. The Activity-Specific Environmental Best Management Practices (EBPs) identify specific environmental protection measures for highway structure maintenance and product storage and handling; • Slope stabilization maintenance may be minimized with vegetation, buried riprap, etc.; • Cover for animals should be maintained.
REFERENCES	Federal Highway Administration, 2002; USDA, 2004; Forman and Hersberger, 1996.

4.2.7 Wildlife Mitigation Approaches: Wildlife Underpass: BRIDGE

Wildlife Crossing Structure

DESCRIPTION

- Single span or multi-span structure spanning a watercourse or dry valley;
- Single span bridge rests on abutments with no intermediate support columns (also called open span bridge);
- Multi-span bridge has one or more intermediate support columns between abutments.

Figure 4-7. Single span bridge, Conestogo River.

Figure 4-8. Multi-span 70m bridge, Bayview Avenue extension, York Region.

Figure 4-9. Multi-span bridge with separated traffic directions. Burnhamthorpe Road.

Figure 4-10. Multi-span bridge above waterway. Rebecca Street, Oakville.

TARGET WILDLIFE GROUPS

- Will typically enable movement by a wide variety of wildlife, including ungulates, larger carnivores, small and mid-size mammals;
- Amphibians and reptiles can also move under these structures if favourable habitat conditions exist (such as cover, damp conditions) or barriers (such as heavy rock rip rap) are absent.

4.2.7 Wildlife Mitigation Approaches: Wildlife Underpass: BRIDGE Wildlife Crossing Structure	
APPLICATION SUITABILITY	• Numerous examples in many countries, including Ontario; • Typically installed at larger watercourses and valleys to address hydrology, navigable waters, floodplain, and/or other landscape connectivity requirements/ desires; • Usually include a terrestrial riparian zone in addition to the watercourse zone.
ADVANTAGES	• Broad range of wildlife species can be accommodated; • Where required at watercourse crossing, will also allow for wildlife movement if a terrestrial movement zone is provided.
DISADVANTAGES	• High construction cost compared with smaller structures; • Crossing environment can be noisy depending on traffic volumes.
IMPLEMENTATION CONSIDERATIONS	• Typically provide good day lighting and views of adjacent habitat from either direction which is favoured by many species, particularly ungulates; • Where feasible, funnel fencing to the structure may be beneficial depending on site-specific conditions; • Structures that span a watercourse and also maintain some adjacent terrestrial movement opportunities will meet the needs of a broader array of wildlife groups than will a structure that only spans the watercourse; • These bridges can integrate pedestrian trails as well, if desired. However, encouraging human activity in more remote settings may result in avoidance by intolerant wildlife species, and/or risk of animal/human interaction (safety concern). See comments in Section 7.0; • Low light and moisture conditions due to structure shading discourage vegetation growth. Thus, supplementary material such as stumps and logs should be provided for cover and shelter to facilitate movement by smaller wildlife species.
CONSTRUCTION COSTS	• Construction costs are high and can range from $0.5 million to several million depending on dimensions, materials, and method of construction.
MAINTENANCE IMPLICATIONS	• Structure cleaning typically requires the removal of any debris and other materials on or under the structure as part of the periodic maintenance or prior to activities such as sand blasting and painting. Nest materials would require removal as part of this work. Removal and destruction of active nests of migratory birds is prohibited under the MBCA and Regulations; • Schedule structure maintenance to avoid the nesting period of migratory species (consult with Environment Canada to verify the breeding period based on geographic location); • Alternatively, implement measures to discourage nesting prior to maintenance (These may include deterrent netting/tarps or other suitable

4.2.7 Wildlife Mitigation Approaches: Wildlife Underpass: BRIDGE Wildlife Crossing Structure	
MAINTENANCE IMPLICATIONS	measures); • If the above options are not employed or feasible, and nesting of migratory birds is confirmed at a structure, the mitigation strategies highlighted in Section 6.0 would apply (time the maintenance activity to avoid the nesting period, or develop a mitigation plan in consultation with Environment Canada). • The MBCA and Regulations also prohibit the discharge of “oil, oil wastes or any other substances harmful to migratory birds in any waters or any area frequented by migratory birds”. Design measures must be identified to ensure that any cleaning or maintenance materials are properly stored, handled and controlled to prevent substance release to aquatic or terrestrial habitat. The Activity-Specific Environmental Best Management Practices (EBPs) identify specific environmental protection measures for highway structure maintenance and product storage and handling; • Slope stabilization maintenance may be minimized with vegetation, buried riprap, etc.; • Cover for animals should be maintained.
REFERENCES	Forman and Hersberger, 1996; Forman et al., 2003; USDA, 2004; Federal Highway Administration, 2002; Jackson, 1999; Clevenger and Waltho, 2003; Ecoplans Limited, 2003; Jackson and Griffin, 1998; Evink, 2002.

4.2.8 Wildlife Mitigation Approaches: Wildlife Underpass: LARGE CULVERT

Wildlife Crossing Structure

DESCRIPTION

- Defined as structures at least 1.5 m in height/width or greater;
- Box culvert is 4-sided, typically with a concrete bottom, rectangular or square-shaped – can also have an open bottom configuration;
- Box culverts can be arranged in series forming multiple chambers;
- Culverts may also be arch shaped, with high or low profile, with bottoms or bottomless;
- Openness ratio (OR) is a measure of the "see-throughness" or tunnel effect of a structure which has implications for wildlife use (for some species). It is relevant for culverts (see Figure 4-11);
- Existing culverts may be modified with ledges added to facilitate terrestrial wildlife movement.

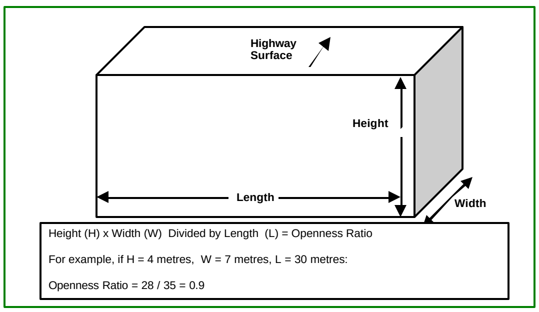

Figure 4-11. Openness ratio calculation for culvert/underpass.

Figure 4-12. Concrete box culvert, Kitchener.

Figure 4-13. Open arch style culvert – Double cell.

Figure 4-14. Multi-cell pre-cast open bottom culvert, Markham.

TARGET WILDLIFE GROUPS

- Depending on structure dimensions, wildlife groups ranging from small mammals and amphibians up to ungulates can be accommodated;
- Culverts under 2 m in height will typically allow passage for small and mid-size wildlife species but are generally too small for ungulates;
- OMNR Parry Sound, infrared detection monitoring of box culvert use on Hwy 69 reported broad range of wildlife detected inside culvert (amphibians, reptiles, and small to mid-size mammals).

4.2.8 Wildlife Mitigation Approaches: Wildlife Underpass: LARGE CULVERT

Wildlife Crossing Structure

APPLICATION SUITABILITY	• Numerous examples worldwide – have been in place for many years and typically installed for drainage reasons; • Culverts at water crossings can employ open bottom design with footings or can be counter sunk with a single box or multi-cell design. The counter sunk approach can provide both low flow conditions and terrestrial movement opportunities with proper design. The open bottom design requires special design consideration to maintain low flow channel integrity coupled with terrestrial passage. Design consideration must also ensure that fish movement requirements are met. The Drainage and Fisheries documents prepared as part of the Standard Environmental References provide additional guidance in this regard. In addition, the reader is directed to the final version of the TRCA/DFO *Urban Stream Crossing Design Guide* when completed. • Dedicated wildlife culvert designs or culvert modifications for wildlife use are less frequent but are emerging in North America, Europe and Australia; • Tunnel "see-throughness" and tunnel effects were first identified in the 1970s and are being increasingly considered in current designs; • Ledges constructed of wood, concrete or earth have been added to existing Dutch waterway culverts to facilitate terrestrial wildlife passage (see Veenbaas and Brandjes, 1999).
ADVANTAGES	• Culvert designs can provide for multi-species use which is beneficial.
DISADVANTAGES	• Passages may be noisy, depending on traffic volume; • Culverts may not match the ambient temperature, moisture and light regimes preferred by various wildlife; • Flooding and ice formation may discourage use by certain animals.
IMPLEMENTATION CONSIDERATIONS	• Planning for multi-species use with a mix of strategies (larger bridges at valleys, expanded creek culverts with dry land component, smaller equalization culverts at wetland locations, amphibian tunnels [if warranted]) is recommended; • In some cases, provision of a number of regularly spaced culverts (150-300 m spacing) may be more cost-effective than poor placement of a few larger structures. Site-specific conditions and professional judgment will be required; • Considerations in retrofitting or designing wildlife ledges for culverts: o Netherlands work has reviewed wildlife use of wood planks, concrete and earth berm ledges installed within culverts over waterways; o Extended earth banks within the culvert were 1.5 to 3.5 m wide. Wood planks fixed to culvert walls were 0.25 to 0.6 m wide. Floating wood planks 0.3 m wide were installed in some culverts (adjust to water level changes). Concrete ledges 0.4 to 1.3 m wide were installed in some culverts. Plastic gutters 0.25 m wide and covered with sand were also tested; o All ledges were used to varying degrees by small to mid-size wildlife provided that the culverts did not experience heavy

4.2.8 **Wildlife Mitigation Approaches: Wildlife Underpass: LARGE CULVERT** Wildlife Crossing Structure	
IMPLEMENTATION CONSIDERATIONS	human use; o All ledges were used by mammals (62% of target species). About 75% were used by amphibians. The broader the ledges were, the more frequently they were used and by more species. Extended banks were used by a range of species. • Wildlife monitoring work in Alberta has documented Black Bear use of culverts ranging from 2.5 to 4 m high, 7 to 13 m wide, and 25 to 68 m long, with Openness Ratios ranging from 0.2 to 1.2.
CONSTRUCTION COSTS	• Costs are moderate to high, depending on size and materials; • Concrete box culvert 3 x 2.5 m is roughly $150,000 to $170,000. Elliptical metal culvert 7 x 4 m is roughly $200,000 to $240,000 (greater cost associated with more fill cover for protection and additional time to bolt culvert pieces together). Smaller structures will be lower in cost (typically under $100,000). These cost estimates have been adjusted from costs for Trans-Canada highway structures summarized in Forman et al. (2003).
MAINTENANCE IMPLICATIONS	• Culverts and bridges are typically inspected for safety and maintenance measures. Standard inspection criteria could be expanded with wildlife use in mind to include vegetation control and woody debris blockages in and around culvert entrances to allow for openness and accessibility; • Maintenance is required for damage due to erosion and deposition of sediments often due to poor construction; • Maintenance activities must consider protection of nesting migratory birds and other wildlife species as discussed in Section 6.0; • The MBCA and Regulations also prohibit the discharge of “oil, oil wastes or any other substances harmful to migratory birds in any waters or any area frequented by migratory birds”. Design measures must be identified to ensure that any cleaning or maintenance materials are properly stored, handled and controlled to prevent substance release to aquatic or terrestrial habitat. The Activity-Specific Environmental Best Management Practices (EBPs) identify specific environmental protection measures for highway structure maintenance and product storage and handling.
REFERENCES	Brudin, 2003; Forman and Hesbnerger, 1996; Forman et al., 2003; USDA, 2004; Federal Highway Association, 2002; Jackson, 1999; Clevenger, 1998; Jackson and Griffin, 1998; Scheick and Jones; 1999; Normal et al, 1998; Veenbaas and Brandjes, 1999; Evink, 2002; Woodhouse et al. (MNR) 2002; Brown et al. (MNR) 2004.

4.2.9 Wildlife Mitigation Approaches: Wildlife Underpass: SMALL UPLAND CULVERT

Wildlife Crossing Structure

DESCRIPTION	• Known as wildlife tunnels, amphibian tunnels, wildlife pipes, ecopipes, ecoculverts; • Generally under 1.5 m in height or width; • May be concrete box culverts, metal culverts (round, oval, elliptical) or ABS plastic culverts (used for some amphibian tunnels in Europe); • Dedicated for wildlife use, typically smaller mammals and amphibians/reptiles in upland setting; • May also act as equalization culverts for seasonal cross drainage.

Figure 4-15. Amphibian Tunnel with native substrate, Bayview Avenue.

Figure 4-16. Amphibian/Drainage culverts, Bayview Avenue.

TARGET WILDLIFE GROUPS	• Small to mid-size mammals; • Reptiles and amphibians (with suitable design considerations). See Appendix 2.
APPLICATION SUITABILITY	• Upland wildlife culverts facilitate overland movement of wildlife between wetlands and uplands, uplands and uplands, and from wetlands to wetlands. Movements to and from wetlands are particularly important for amphibians and turtles; • Dedicated tunnels for amphibians have been in place in a number of locations in Europe for the past 10 to 15 years where migrations to and from breeding sites have been interrupted by roads (see detailed review in Appendix 2); • Use in North America is limited but slowly growing (for example, Quebec, Ontario, Massachusetts). Australia is also somewhat active in the provision of wildlife tunnels; • Wildlife pipes or ecopipes are small dry tunnels primarily designed for passage by small and medium-sized mammals. Such pipes have been used for otter (*Lutra lutra*) crossings in the United Kingdom. More than 300 wildlife pipes have been installed in the Netherlands along Dutch motorways and have assisted in the recovery of badgers in that area;

4.2.9 Wildlife Mitigation Approaches: Wildlife Underpass: SMALL UPLAND CULVERT

Wildlife Crossing Structure

APPLICATION SUITABILITY	• Wildlife culverts, or ecoculverts, are located over waterways, but are designed both to convey drainage and provide terrestrial wildlife movements (e.g. using a constructed channel with earth borders, maintaining the existing channel and riparian zone, or adding ledges); • Although dedicated use of wildlife pipes and tunnels in North America is still limited, interest in this approach is growing and some tunnels are being installed and monitored.
ADVANTAGES	• Broad range of terrestrial wildlife species (small to mid-sized) can be accommodated; • Can accommodate seasonal flow as required, without precluding wildlife use at other times.
DISADVANTAGES	• Culvert may be often blocked with debris by beavers; • Can be noisy, depending on traffic volume. • Requires periodic maintenance.
IMPLEMENTATION CONSIDERATIONS	• A detailed review of amphibian tunnel design considerations is provided in Appendix 2; • The effectiveness of amphibian/reptile tunnels is dependant on a number of variables, including size and openness, placement, substrate, funnelling to the structure, vegetation cover, moisture, hydrology, temperature and light; • Wildlife culverts at waterways can provide movement opportunities for reptiles, amphibians and mammals if riparian zones at least 0.5 to 1.0 m wide on one or both sides of the waterway are retained under the structure. Large rip rap should be avoided on the terrestrial sides because it impedes movement by small mammals and likely amphibians; • The Quebec Ministry of Transportation installed three amphibian tunnels under Highway 220 in the Eastern Townships in 2000. The tunnels were installed where the highway crosses about 400 m of the migration corridor used by amphibians moving from overwintering habitat to breeding sites in the Brompton Lake swamp. The tunnels are pre-cast rectangular ACO Polymer structures with grates along the top (for light and moisture penetration). The tunnels were installed flush with the highway surface and were provided with intercepting funnel walls parallel to the highway. Initial observations have revealed tunnel use by species such as Spotted Salamander. Further monitoring of the tunnel use is underway; • Bayview Avenue, York Region amphibian tunnels –Series of round and oval tunnels, concrete and CSP, ranging in size from 1.2 to 1.7 located in response to amphibian captures. Monitoring to date has shown some use by small mammals, toads and frogs.
CONSTRUCTION COSTS	• Costs for tunnels (materials, installation and funnel fencing) could range from $30,000 to $80,000 depending on length, materials and whether a retrofit or new construction is involved. The average cost of manufacturing and installing the Quebec amphibian tunnels was about $25,500 in 2001.

4.2.9 Wildlife Mitigation Approaches: Wildlife Underpass: SMALL UPLAND CULVERT

Wildlife Crossing Structure	
MAINTENANCE IMPLICATIONS	• Periodic maintenance required to address culvert blockage (debris) and any erosion; • Vegetation at culvert opening needs to be controlled to allow for openness and accessibility, minimum vegetation needed for amphibians; • For non-amphibian culverts, some vegetation leading to and around the entrance is desirable to both guide approaching wildlife and provide cover. • Maintenance activities must consider protection of nesting migratory birds and other wildlife species as discussed in Section 6.0; • The MBCA and Regulations also prohibit the discharge of "oil, oil wastes or any other substances harmful to migratory birds in any waters or any area frequented by migratory birds". Design measures must be identified to ensure that any cleaning or maintenance materials are properly stored, handled and controlled to prevent substance release to aquatic or terrestrial habitat. The Environmental Reference for Construction (ERC) identifies specific environmental protection measures for highway structure maintenance and product storage and handling.
REFERENCES	Brudin, 2003; Ecoplans Limited and McCormick Rankin Corporation, 2002; Forman and Hersberger, 1996; Forman et al., 2003; USDA, 2004; Federal Highway Administration, 2002; Jackson, 1999; Clevenger et al., 2001; Clevenger, 1998; Jackson and Griffin, 1998; Jackson, 1996; Scheick and Jones, 1999; Norman et al., 2998; Veenbaas and Brandjes, 1999; Quebec Ministry of Transportation, 2001; Evink 2002. See also detailed review on amphibian tunnels in Appendix 2

4.2.10 Wildlife Mitigation Approaches: Wildlife Underpass: STANDARD DRAINAGE CULVERT

Wildlife Crossing Structure

DESCRIPTION	• Typically installed along highways for cross-drainage purposes as shown; • Culverts may be box type or rounded (circular, elliptical, pipe arch) and the lower portion may or may not be buried; • Culvert materials can be corrugated steel pipe, metal plate, cast-in-place concrete, or pre-cast concrete; • These culverts may be dry for extended periods, or at least damp, depending on site conditions.

Figure 4-17. Circular CSP Drainage culvert, Kitchener.

Figure 4-18. Circular CSP Drainage culvert, Kitchener.

TARGET WILDLIFE GROUPS	• Drainage culverts are not expressly designed for wildlife movement; • However, anecdotal observations in Ontario, and monitoring work in Alberta, the U.S. and Europe shows that they can be important linkages for local wildlife; • Wildlife species such as rabbit, mice, lizards, snakes, toads, fox, weasels, coyote, snowshoe hare, and red squirrel have been recorded using these passages.
APPLICATION SUITABILITY	• Highway drainage culverts are routinely installed to handle either permanent or seasonal cross drainage flow, or to act as water level equalizers in areas of poor drainage; • Drainage culverts are installed across highway, lower volume roadways, and across railway lines world-wide.
ADVANTAGES	• May accommodate a broad range of small to mid-sized wildlife species. • Provide cross-flow of drainage where needed.
DISADVANTAGES	• Culvert may be blocked with debris by beavers; • Terrestrial wildlife use may be limited if there is permanent drainage flow and no provision for dry land management. • May be noisy inside depending on traffic volumes.

4.2.10 Wildlife Mitigation Approaches: Wildlife Underpass: STANDARD DRAINAGE CULVERT Wildlife Crossing Structure	
IMPLEMENTATION CONSIDERATIONS	• With no special attention, standard drainage culverts will experience local wildlife use by common species, particularly under low or no flow conditions; • Ledges for small mammal use have been retrofitted in 1.2 m steel drainage culverts in Montana (Foresman, 2004). • More frequently placed culverts (150 to 300 m intervals) using a range of sizes (1 to 1.5 m for mid-size animals; 0.5 to 1 m size for small mammals) can improve connectivity across highways for mammal groups, and possibly other species; • The literature suggests that some form of funnelling to these culverts would likely improve wildlife use. Funnelling could consist of any combination of vegetation, earth walls, sheet piles, armour stone or stone wall. Paige wire fencing with silt fence attached at the bottom and heeled into the ground could also be used (to discourage digging). Funnel fencing need not extend great distances – probably 30 to 50 m on either side of an entrance would be sufficient for these smaller species (subject to further review at detail design and depending on specific site conditions); • Care needs to be taken to avoid low points in the culvert where water can collect and block or restrict passage by terrestrial species.
CONSTRUCTION COSTS	• Costs for standard drainage culverts are nominal relative to highway construction costs. Addition of plantings or other funnel materials would not be cost-prohibitive for such applications.
MAINTENANCE IMPLICATIONS	• Maintenance of wildlife tunnels (such as clean out, removal of debris), drainage problems affecting structures, and any vegetation plantings associated with wildlife funnelling; • Vegetation at culvert opening needs to be controlled to allow for openness and accessibility; • Maintenance activities must consider protection of nesting migratory birds and other wildlife species as discussed in Section 6.0**;** • The MBCA and Regulations also prohibit the discharge of "oil, oil wastes or any other substances harmful to migratory birds in any waters or any area frequented by migratory birds". Design measures must be identified to ensure that any cleaning or maintenance materials are properly stored, handled and controlled to prevent substance release to aquatic or terrestrial habitat. The Environmental Reference for Construction (ERC) identifies specific environmental protection measures for highway structure maintenance and product storage and handling.
REFERENCES	Clevenger et al., 2001; Singleton and Lehmkuhl, 1999; Rodriguez et al., 1996; Forman et al., 2003; Evink 2002; Foresman, 2004.

4.2.11 Wildlife Mitigation Approaches: FENCING AND ESCAPE MEASURES Wildlife Crossing Structure	
DESCRIPTION	• Wildlife diversion fences or drift fences vary in height and materials depending on application; • Fences may be constructed of wire, barbed wire, woven wire, chain link, rail, plastic mesh (like silt fence material), or concrete walls. The bottom end of the fencing may be a finer mesh or covered with another type of barrier to prevent entry by small mammals; • Wildlife fencing is typically associated with a variety of wildlife crossing structures, and is usually parallel to the highway for some distance; • **One-way gates** are installed at intervals along wildlife fencing to enable trapped animals (typically ungulates) to escape the highway ROW. Funnelling to the structure is important to prevent animals from bypassing the gates. The gates are opened by pressure from the animal, and only open in one direction (animal can leave the ROW at this location but usually cannot enter at this location); • **One-way ramps** are alternatives to one-way gates. The ramps are earthen and installed to enable wildlife trapped on the ROW to exit using the ramp over the wildlife fencing.

4.2.11 Wildlife Mitigation Approaches: FENCING AND ESCAPE MEASURES

Wildlife Crossing Structure

Figure 4-19. Wildlife fencing with arch culvert (New Brunswick).

Figure 4-20. Frontal view of one-way deer gate with funneling fencing (New Brunswick).

Figure 4-21. Ungulate fencing with 1-way gate (Arizona).

Figure 4-22. Ungulate fencing (2.5 m high) with 1.5 m high escape jump (Arizona).

Figure 4-23. Ungulate underpass with fencing tied to structure (Arizona).

Figure 4-24. Bayview Avenue amphibian tunnel funnel fencing (interlocking retaining wall material (York Region, Ontario).

TARGET WILDLIFE GROUPS	• Can be designed and applied to most wildlife groups.

4.2.11 Wildlife Mitigation Approaches: FENCING AND ESCAPE MEASURES Wildlife Crossing Structure	
APPLICATION SUITABILITY	• Fencing has been widely utilized alone or in combination with various other mitigation structures; • Species specific considerations are required.
ADVANTAGES	• Can serve to keep wildlife away from transportation routes and to funnel wildlife towards crossing corridors; • Broad applicability. • Considered by most researchers to increase likelihood of structure use by wildlife.
DISADVANTAGES	• Requires a high maintenance effort (fence repair, etc.); • May cause wildlife to become trapped on road side unless escape measures are provided. Earthen ramps may be more effective than one-way gates in providing escape routes for animals trapped on roadsides; • Construction cost (see below).
IMPLEMENTATION CONSIDERATIONS	• Must be coupled with crossing structures to retain landscape and population linkages; • The decision to install **funnel fencing** suitable for ungulates and large carnivores should consider such factors as study setting and habitat conditions, densities of large mammals and movements, ability to discern crossing zones and crossing locations, adjacent land uses, and costs to install and maintain; • In Pennsylvania 65% of structures used by deer had ROW fencing funnelling them to the structure. Most authors conclude that structures are most effective if **funnel fencing** is provided, particularly if a precise crossing zone is not apparent; • Extending the fencing 500 m on either side of the structure will be adequate for larger mammals if the structures are located in known travel corridors– fencing will likely need to extend further where travel corridors are not well defined; • **Funnel fencing** to direct ungulates to crossing structures should be at least 2.8 m high and ideally embedded in the ground (to reduce likelihood of wildlife entry under the fence). The mesh should be attached to the outside (ROW side) of poles (as ungulates will push in looking for openings). (Exclusion fencing ranging from 3.0 to 3.7 m has been recommended for use around airport perimeters – see Katona et al., 2000); • The TransCanada Highway Three Sisters Interchange in Canmore Alberta has utilized 2.5 m high wildlife fencing consisting of round pine logs and paige wire configuration with design variations to accommodate installation in stable ground, soft ground, and rock. To accommodate the selective clearing policy for the project, the wildlife fencing was installed adjacent to the tree line, rather than at the ROW boundary; • **One-way gates** are typically installed every 0.5 – 1 km to enable trapped wildlife to exit the ROW (where extensive fencing is employed). The Banff National Park experience has found that animals are learning to gain access to the highway through one-way gates, and that the effectiveness of the gates in providing animal escape from the highway is

4.2.11 Wildlife Mitigation Approaches: FENCING AND ESCAPE MEASURES Wildlife Crossing Structure	
IMPLEMENTATION CONSIDERATIONS	apparently limited; • **One-way earthen ramps** can perform the same function as one-way gates, are considered 10-12 times more effective than the gates, and have lower maintenance requirements (see Forman et al., 2003). These one-way ramps have been used in Wyoming, Utah, Arizona (2005) the Netherlands and Spain. They are also referred to as "wildlife jumps". At the Three Sisters Interchange in Canmore Alberta, these "wildlife jumps" have been installed as escape areas for wildlife that become trapped on the highway side of the fencing. These one-way ramps are 2.5 m high, and are constructed in a corner of the fence line near existing natural cover. The side walls are constructed of interlocking concrete blocks, and sub-drainage is provided using perforated pipe and filter gravel. Native backfill is used behind the wall. Ungulates can walk up the ramp and then jump down to exit the highway zone (Note: Arizona research is finding that their 1.5 m high escape jump structures are too low to prevent Elk from entering the highway ROW in the reverse movement); • "End-run" problems with fencing have been noted in some studies, including the Fredericton-Moncton Highway Project in New Brunswick. These problems occur when wildlife (particularly ungulates) follow the fencing to its end point and then traverse the highway. Solutions that were effective were to close the openings at the ends of the fencing at interchanges and other locations by attaching the fencing to the guardrail; • Additional "end-run" solutions that have been employed at the TransCanada Highway in Canmore Alberta have consisted of the following: o Wildlife fencing has been tied in to the ends of the Bow River bridges at the west end of the project area. At the east end, the wildlife fencing was angled and tied in to the highway (guardrail) edge; o Potential crossing habitat beyond the fence end was rendered inhospitable for ungulates by stripping the topsoil and installing landscape fabric covered with rock or pitrun gravel (creating an unstable walking surface).
CONSTRUCTION COSTS	• Costs for ungulate fencing can range from $30,000 to $50,000 per km based on costs incurred for the Fredericton to Moncton highway where deer structures and wildlife fencing were installed. In British Columbia, 2.4 m high ungulate fencing costs between $40,000 and $80,000 per km to fence both sides of a highway.

4.2.11 Wildlife Mitigation Approaches: FENCING AND ESCAPE MEASURES Wildlife Crossing Structure	
MAINTENANCE IMPLICATIONS	• Fencing in association with wildlife structures is effective, but it does require a long-term maintenance commitment that must be considered in maintenance budgets; • Fences can be damaged by falling trees, vehicle accidents, and unauthorized cutting by ATV and snowmobile operators. In addition, fence poles can shift due to frost heave. Hinges of one-way gates tend to stick under winter conditions. All of these issues require maintenance review and periodic repair; • Vegetation growth may need to be regularly controlled.
REFERENCES	Brudin, 2003; Ecoplans Limited, 1998; Forman et al., 2003; Phillips, 1999; UMA Engineering Ltd., 2000; Evink, 2002; Reed et al. 1974; Sielecki, 2004.

4.2.12 Wildlife Mitigation Approaches: INTERACTIVE WILDLIFE WARNING SIGNALS

Wildlife Crossing Warning

DESCRIPTION	• Series of solar powered or battery operated heat sensors/infra red cameras/motion detectors have been used to detect animals near the road. Drivers are alerted of approaching animals via a digital message board and/or flashing signs; • Cameras are installed at each end of the highway segment.

Figure 4-25. Wildlife Protection System test equipment in Kootenay National Park, An infrared camera (on the pole) and a trailer containing power supply, computer, tracking software, radio controls for signs, camcorder, and radar gun are shown (Kinley et al., 2003).

TARGET WILDLIFE GROUPS	• Developed for ungulates but will detect some other wildlife species as well.
APPLICATION SUITABILITY	• Can be implemented anywhere along a road corridor where wildlife conflicts occur; • Can be used at or near established wildlife structures to alert drivers to animal presence at those specific sites. Can also be used at other locations on a temporary basis when seasonal wildlife-vehicle conflicts are apparent; • Trials are being undertaken by the Insurance Corporation of British Columbia utilizing a combination of high-powered infrared technology and flashing warning signs to detect wildlife, warn drivers and monitor behaviour. Similar systems are also being applied in Saskatchewan and Switzerland; • Effectiveness of system still being researched.

ADVANTAGES	• Drivers are alerted to approaching animals and are more likely to remain alert under such conditions (as opposed to habituation with static signs). • Portable system; • May be used to guide placement of wildlife crossing structures.
DISADVANTAGES	• Expensive equipment; • Alerting system may be set off by animals that are using road side to forage, not necessarily to cross the highway, resulting in false alerts and reduced driver response; • Alerting system may be affected by heat from truck exhaust stacks; • Some drivers may slow down or stop to see the animal they were warned about, possibly causing traffic problems; • Most tested systems identified in the literature have had malfunctions and technical difficulties to varying degrees.
IMPLEMENTATION CONSIDERATIONS	• Can be relocated to high risk areas in response to changing land use or traffic patterns. • Research and development continues in this field and will likely result in technologically advanced and low-maintenance systems in the future. • Overhead digital warning signs have been installed in British Columbia to indicate when a wildlife hazard is imminent or when the historic wildlife collision rate is extreme. These signs are similar in appearance to MTO traffic alerting digital signs. The BC signs are considered useful for short-term and seasonal wildlife movement events, and even salt-lick sites (Sieliecki, 2003).
CONSTRUCTION COSTS	• Relatively moderate operation costs; • High installation costs.
MAINTENANCE IMPLICATIONS	• Equipment checks applied as required.
REFERENCES	Newhouse 2003; Federal Highway Administration, 2002; Rea, 2003; www.wildlifecrossings.info; Biota Research and Consulting Inc., 2003; Sieliecki, 2004.

4.2.13 Wildlife Mitigation Approaches: WILDLIFE WARNING SIGNS

Wildlife Crossing Warning

DESCRIPTION	• Widely used to alert drivers of potential wildlife crossings; • Traditional warning signs are diamond shaped with a yellow background and black silhouettes of animals or potential dangers illustrated in the foreground; • Other diverse signs have also been used.

Figure 4-26. A wildlife warning sign that communicates: Deer regularly cross this road; be alert for animals (MTO 2005).

Figure 4-27. A snake crossing sign from Manitoba.

TARGET WILDLIFE GROUPS	• Can be utilized for all wildlife groups with ungulates being the most typical group. Crossing signs have been developed for amphibians (including toads), waterfowl, turtles, and snakes, for example.
APPLICATION SUITABILITY	• Easy to install and maintain; • Can be installed in areas with higher than average wildlife crossing rates.
ADVANTAGES	• May accommodate a broad range of wildlife species; • Economical in comparison to crossing structures; • Can be modified to enhance their visibility such as with flashing lights; • Can be used seasonally during greatest wildlife road crossing times.
DISADVANTAGES	• Effectiveness of measures have not been conclusively evaluated and are generally assumed to be variable, if not neutral; • Drivers become habituated to static signs and are less likely to respond to the warning by reducing speed or increasing alertness, unless they have had a previous wildlife collision experience (or close call); • Novel signs can be prone to theft as souvenirs. • See reviews by Knapp (2004), Biota Research and Consulting (2003).
IMPLEMENTATION CONSIDERATIONS	• Sign size and placement location are typically based on accident warrants (MTO Book 6). MTO has also received input from MNR on sign type and placement based on their knowledge of wildlife species and the local area; • Various researchers and reviewers have commented that effectiveness of static signs is likely limited unless
CONSTRUCTION COSTS	• Production and installation costs are relatively low (in the range of $150 to $600).
MAINTENANCE IMPLICATIONS	• Easily accessible for maintenance; • May need to be replaced due to deterioration, vandalism or theft.
REFERENCES	Knapp 2004; Biota Research and Consulting Inc., 2003; Sielecki, 2004.

4.3 Other Mitigation Measures

4.3.1 Noise Abatement

Policies for noise abatement on human receptors are in place in Ontario and are applied where criteria are met.

A noise policy dealing with wildlife is beyond the scope of this document.

Our understanding of the effects of roadway noise on wildlife is still in its infancy. Responses to noise do not appear to be consistent among wildlife species, and are difficult to measure in a rigorous way.

The limited amount of work specifically looking at noise effects on wildlife (primarily birds) is based on European research. Research in the Netherlands has concluded that lowered bird densities in grassland and forest adjacent to Dutch highways is best explained with road noise as the independent variable. Effects were influenced by traffic volume (10,000 or 50,000 vehicles per day) and habitat type (grassland or woodland) and ranged from 125 m to 560 m for all bird species combined (Reijnen et al., 1996, 1997).

It is not clear from existing (limited) research how noise pollution may affect wildlife. It is conjectured that highway noise may hinder vocal communication ability amongst birds. However, some species with song frequencies above those of traffic noise may be more abundant near roads, suggesting that they are less susceptible to noise pollution (Rheind, 2003).

It is not clear to what extent other wildlife species are affected by road noise, or whether a similar range of effects is occurring under North American (and Ontario) conditions. The ability to differentiate highway proximity effects and roadway noise in apparently lowering habitat quality adjacent to highway continues to be a research challenge and objective. Carefully designed research in the Ontario setting is needed.

Avoiding and providing some separation (buffering) between new highway facilities and Natural Core areas are good ways to reduce or eliminate the possible effects on wildlife associated with highway noise. Some additional mitigation considerations in the context of highway design are as follows:
:

- Depressing the highway grade for new highways) adjacent to habitat areas may reduce noise effects due to the berming effect of the adjacent embankments. This design measure should be carefully considered in terms of increased potential for snow drifting problems, and groundwater interception, which might create more tangible negative effects relative to the noise reduction benefits. Snow drift control can be provided with careful design of plantings, and groundwater interception may not always be a concern;

- Contour grading and landscaping may also play a role in visual screening and some noise reduction for specific highway sections, particularly if such measures are associated with salt spray control. An example of this approach is shown in Figure 4-28.

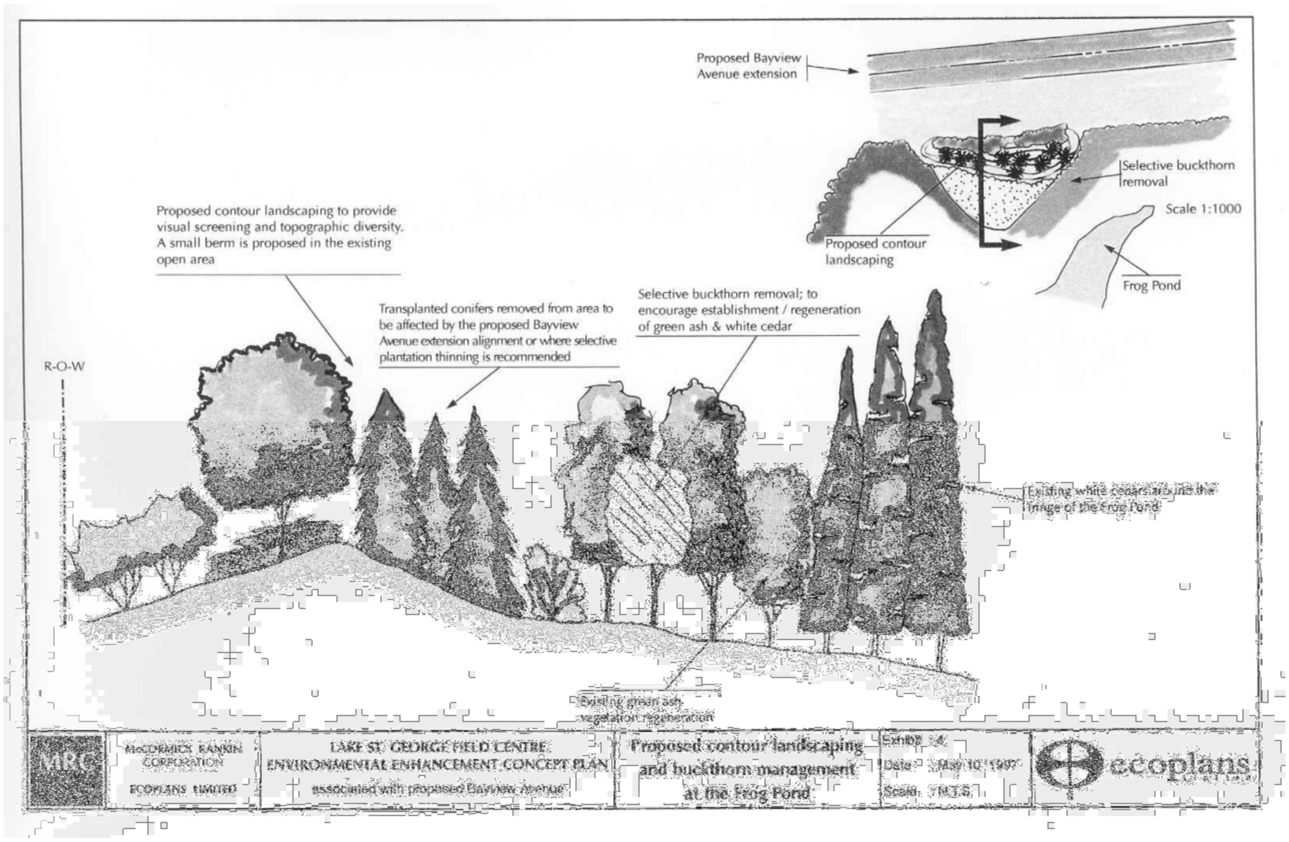

Figure 4-28. Berm and Landscape Buffer – Bayview Ave (York Region).

4.3.2 Woodland Edge Pre-stressing

Woodland edge removal from highway construction or upgrading typically leads to secondary effects associated with edge canopy removal. Increased wind and light penetration facilitates tree damage (such as sun-scald), blow down (of shallow-rooted or hazard trees), spread of light-tolerant invasive plants (to the detriment of native groundflora), and increased susceptibility to salt spray and other contaminants. These effects can combine to reduce wildlife habitat quality.

Woodland edge management and pre-stressing can soften these effects and facilitate development of a new edge, particularly if pre-stressing can be initiated in advance (1 or 2 years) of actual clearing and highway construction.

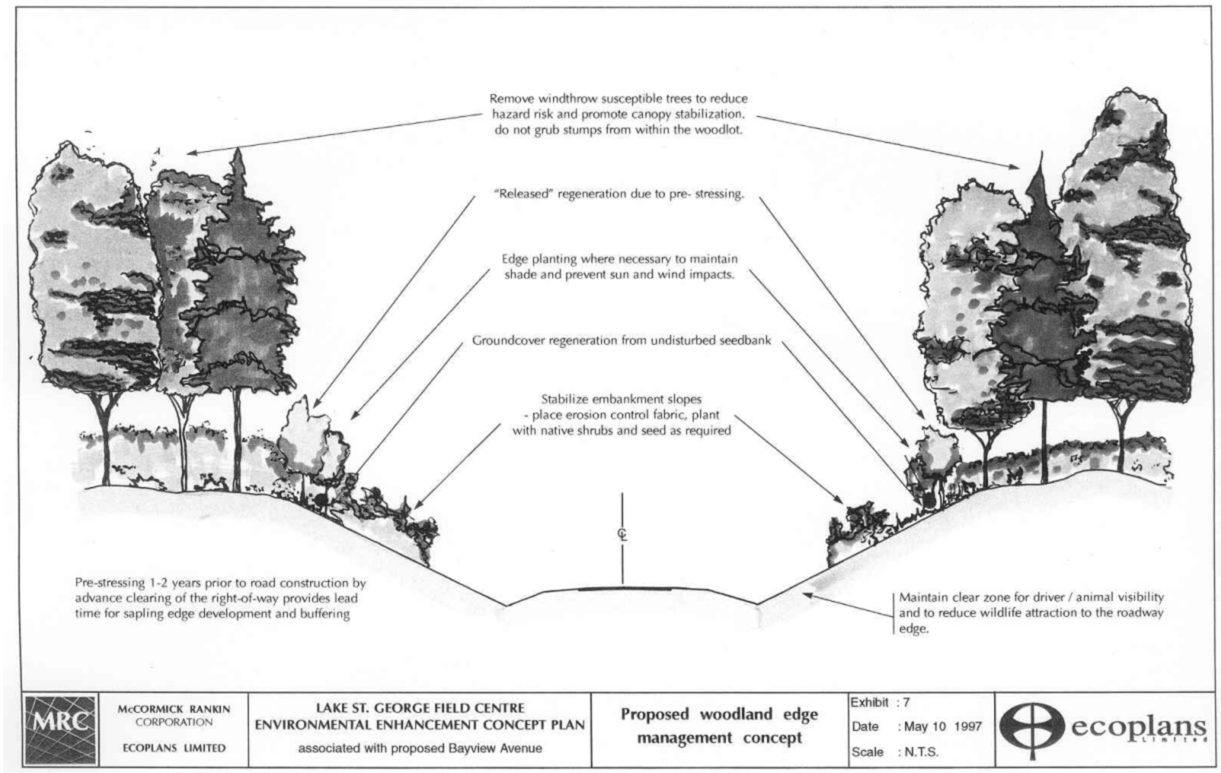

Figure 4-28. Woodland Edge Management Concept (Bayview Avenue)

Figure 4-28 provides an example of a pre-stressing and woodland edge management concept for a major Regional Road in York Region that illustrates this type of approach and that was implemented in advance of construction.

5 HABITAT CREATION CONSIDERATIONS

Habitat creation opportunities can occur in situations where highway undertakings unavoidably cross or affect public lands (for example, Conservation Authority lands, Crown lands). In these instances, there is a public body with the capability and desire to implement various habitat creation measures.

In most of Southern Ontario, similar opportunities are limited because of the limited extent of public land and the predominance of land under private ownership. Habitat creation is not recommended within the ROW for reasons highlighted below. Habitat creation outside the ROW is more challenging in this setting because MTO has no right to or ownership of land outside its ROW. Habitat creation outside the ROW therefore requires any combination of a special land purchase, a willing and able habitat management steward, and agency negotiation.

Some habitat creation examples are provided below that are intended to provide alternative habitats for certain target wildlife species well removed from the roadway ROW. Both have unique circumstances. The Bayview Avenue example (Figure 5-1) involved habitat creation on lands owned by the Toronto and Region Conservation Authority. The snake gestation site example is a pilot project on Crown lands in Central Ontario.

5.1 Wildlife Crossing Deterrents

DESCRIPTION

- A variety of specialized habitat sites to which animals may move seasonally (often across roads), such as nesting or hibernating sites.
- There may be instances where, even with mitigation, there still remain negative ecological effects on wildlife. This may occur where “bottlenecks” cannot be addressed with mitigation, and/or where there is a loss of wildlife habitat function that is considered important (perhaps vernal pools/wetland, loss of valley vegetation or riparian vegetation, reduction of forest patch size).

Figure 5-1. Wetland habitat creation pilot project. Bayview Avenue.

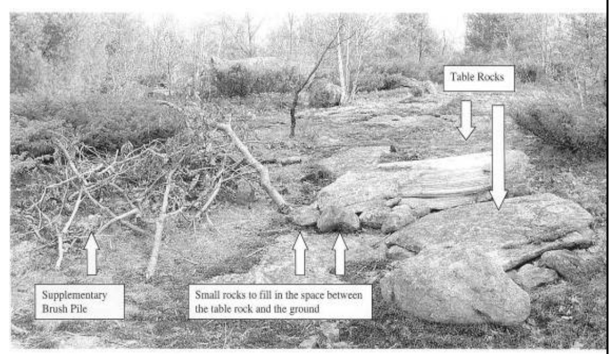

Figure 5-2. Pilot Snake Gestation Site near Highway 69, Ontario.

TARGET WILDLIFE GROUPS

- A diverse range of wildlife groups may be addressed. Here are a couple of examples:

<u>Turtles</u>

- Many Ontario turtles move from wetland sites to upland sites such as highway embankments for nesting. Turtle mortality occurs either as turtles attempt to nest on the highway edge, or attempt to cross the highway to reach a suitable nesting site. Providing alternative nesting habitat through creation of sand deposits near the wetland source area or in the movement path, may be a means of obviating the need for turtles to cross the highway, or the need of providing a dedicated crossing structure. However, it is possible that turtles may ignore new nesting areas due to nest site fidelity. Alternate habitat sites should be used in association with funnel fencing and crossing structures.

<u>Snakes</u>

- Hibernacula sites provide overwinter cover for a variety of Ontario snakes. Where such cover is typically structure piles such as rocks or brush, consideration can be given to creating comparable habitat off ROW, particularly during construction when suitable equipment and manpower is available. Gestation sites are used by gravid snakes during the period of egg/young development. For a threatened species such as the Eastern Massasauga Rattlesnake, preferred sites encompass flat table rocks for sunning, smaller rocks for additional cover, and nearby vegetation cover or

	brush piles for shelter and protection from the sun, as required. If such sites are present, and the highway presents a barrier for snake access to such sites, there is a real risk of snake mortality as individuals attempt to cross the highway to reach the gestation site. A protocol for creating gestation sites, prepared by MNR, is provided in Appendix 3.
APPLICATION SUITABILITY	• In Ontario, resource agencies at the local/municipal, provincial and federal level are emphasizing habitat creation/restoration work that recognizes and addresses habitat removals and residual effects associated with highway construction. Restoration work associated with Hwy 407 has entailed both areas within the ROW and additional areas beyond the ROW (including landlocked parcels); • The Bayview Extension on the Oak Ridges Moraine in Richmond Hill, in addition to providing dedicated amphibian tunnels at strategic locations, also provided strategic contour landscaping and buffering along the ROW, as well as wetland/upland habitat creation area located well off ROW on the Conservation Authority lands. The habitat creation area also integrated identified archaeological sites, provided a new trail network, and is currently being used as part of an outdoor education program.
ADVANTAGES	• Wildlife may be deflected from roads reducing impacts.
DISADVANTAGES	• May require a long time before intended wildlife begins to use the habitat site, due to specific habitat loyalty; • Habitat creation initiatives outside the MTO ROW create challenges because of different ownership – see comments above.
IMPLEMENTATION CONSIDERATIONS	• Land-locked parcels provide opportunities for habitat creation/restoration work. However, if these parcels are located off the ROW and under different ownership, then mechanisms will be required to initiate and manage the selected parcel, whether with the current owner, or through acquisition and involvement of other parties; • Given evidence for reduced habitat quality adjacent to busy highways, as reviewed earlier (at least for birds), planning habitat creation / enhancement projects within the ROW with a focus on birds is not recommended. Off-ROW projects, where feasible, may be more suitable for this purpose; • Contribution to a habitat banking fund under the jurisdiction of a Conservation Authority or other agency (such as the Nature Conservancy) may be another appropriate approach where habitat acquisition or habitat creation/restoration work occurs off-ROW in areas where it makes ecological sense (an ecosystem-based approach); • Habitat creation/restoration plans proposed for ROW areas should be tailored to meet specific and realistic ecological objectives in consultation with appropriate agencies; • Habitat creation/restoration work should utilize compatible indigenous native vegetation wherever possible, particularly adjacent to significant resource areas. Flexibility should be provided by agencies, however, where the use of non-native (but non-invasive) plant species may be warranted for specific buffering functions (such as visual or salt spray).

CONSTRUCTION COSTS	• Vary depending on site size, level of planting effort, and maintenance required.
MAINTENANCE IMPLICATIONS	• Will depend on nature of habitat created and the materials used,
REFERENCES	(MNR – Parry Sound, 2000); MRC and Ecoplans Limited, 1997.

6 CONSTRUCTION, OPERATION AND MAINTENANCE ISSUES

6.1 Vegetation Clearing and Maintenance Works

- Vegetation clearing removes habitat used by wildlife, and can interfere with life cycle activities such as breeding and fledging young depending on when clearing occurs. It can be initiated during both design and construction phases to accommodate survey work, ROW pre-grading, detours and temporary access requirements, works yards (where no other feasible locations are available), and actual construction requirements.
- Vegetation clearing activities have the potential to trigger The *Migratory Birds Convention Act (MBCA)* and the *Migratory Bird Regulations (MBR)* depending on the location of the activity and the time of year it takes place.
- The MBCA and MBR are federal legislative requirements that are binding on both federal and provincial governments. The legislation protects certain species, controls the harvest of others, and prohibits commercial sale of all species. The MBCA and MBR apply to various migratory birds regardless of whether local populations overwinter in Ontario. Compliance to ensure protection of nesting migratory species is required in the mitigation approach.
    - Migratory game birds including ducks, geese, swans, cranes, shorebirds and pigeons;
    - Migratory insectivorous birds including chickadees, cuckoos, hummingbirds, robins, swallows and woodpeckers; and
    - Other migratory non-game birds including gulls, herons, loons and puffins (note: the latter species is not present in Ontario).
- The MBCA and MBR identify prohibitions designed to protect migratory birds. These include, but are not limited to:
    - S.5, MBCA – prohibition against possession of migratory bird or nest, or buying, selling, exchanging or giving a migratory bird or nest or making a bird or nest subject to a commercial transaction;
    - S.6, MBR – prohibition against disturbing, destroying, or taking a nest, egg, or nest shelter of a migratory bird or possessing a live migratory bird, carcass, skin, nest or egg of a migratory bird except under authority of a permit; and
    - S.35, MBR – prohibition against depositing or permitting to be deposited oil, oil wastes or any other substances harmful to migratory birds in any waters or any area frequented by migratory birds.
- In the past, MTO was able to secure an annual Migratory Bird generic permit from the Canadian Wildlife Service, Environment Canada for certain MTO maintenance activities (such as bridge and culvert maintenance) that affected migratory nesting species. MTO was also able to secure a Site-Specific permit for certain other specific activities specified by Environment Canada. These

permits are no longer available. As a result, MTO has identified an Operational Constraint for Migratory Bird Protection: Non Standard Special Provision titled Operational Constraint – Environmental Migratory Bird Protection. The operational constraint indicates that "The Contractor shall not destroy nests of protected migratory birds. When these nests are encountered the ministry's contract administrator must be contacted".

- In view of the above, the following design notes should be provided on the design specifications:
    - o Vegetation clearing should be scheduled to occur outside the identified breeding season for migratory birds, to be confirmed for the area through consultation with Environment Canada, Ontario Region;

If vegetation removal must be conducted within breeding bird habitat during the identified breeding season for migratory birds, a nest survey shall be conducted by a qualified avian biologist prior to commencement of works to identify and locate active nests of species covered by the MBCA. A mitigation plan should then be developed to address potential impacts on migratory birds or their active nests. This plan should be approved by Environment Canada, Ontario Region, prior to implementation.

Structure maintenance activities must also not remove or destroy active nests of migratory species. Maintenance activities should be scheduled outside the identified breeding season. Alternatively, implement measures to discourage nesting prior to maintenance (These may include deterrent netting/tarps or other suitable measures). If migratory bird nesting is occurring on a structure at the time of maintenance activity, then a mitigation plan will need to be developed.

6.2 Wildlife Rescue Mortality

Activities such as temporary channel diversions, beaver dam removal and wetland removal (where unavoidable along the ROW) can result in the trapping/stranding of fish and other aquatic-based wildlife (such as turtles, other reptiles, and amphibians). In such events, the following guidelines are provided:

- Fish should be collected, placed in a water-filled pail, and transported to the nearest watercourse/wetland area source area (with suitable water conditions) for immediate release;
- Amphibians should be collected, placed in a pail, and transported to the nearest watercourse/wetland source area (with suitable water conditions) for immediate release;
- Reptiles such as turtles should be similarly collected and released in the closest suitable habitat conditions. Transport of turtles can be done by hand. Large species like Snapping Turtles should be placed head first in a large bucket to prevent injury from long extendable necks and powerful jaws. If no buckets are available, these turtles should only be handled with gloves and carried by the broad base of the tail with the animal held as far away from the body as

possible.

Often permits for handling wildlife are required from The Ministry of Natural Resources (MNR). Adequate training of rescue crews may also be required for handling animals.

Recently, the MNR in Parry Sound, Ontario issued a Conservation Advisory (2003) indicating that heavy duty silt fence used in construction projects may cause mortality in large-bodied snake species. This type of silt fence is constructed of nylon mesh netting that reinforces the regular woven plastic strand material. The nylon mesh is about one inch square. Large-bodied snakes become entangled in the mesh and typically die (See Figure 6-1 and Figure 6-2 below).

- The silt fencing is often erected to provide sediment control adjacent to riparian areas bordering waterbodies, streams and wetlands. These are often favoured habitats for snakes. Susceptible species include the Lake Erie Watersnake (Endangered) as well as other species that are tracked by MNR, of special concern, or threatened (Eastern Foxsnake, Eastern Hog-nosed Snake, Black Ratsnake, Queen Snake, Eastern Milksnake, Eastern Massasauga Rattlesnake, and Northern Ribbonsnake). (Not all of these snake species, such as the Lake Erie Watersnake or the Northern Ribbonsnake, are found on the Oak Ridges Moraine.) Snakes may encounter this silt fencing where it has been erected across or along a movement zone. Possible attraction to the thermal properties of the fencing material for body temperature regulation has also been speculated by MNR.
- The Conservation Advisory has identified two mitigation approaches for consideration:
    - o Provide improved on - site management of temporary fill stockpiles to reduce or eliminate the need for this reinforced silt fencing;
    - o Ensure that silt fencing is not knocked down by excessive soil volumes through greater spoil pile setbacks from the fencing and improved site management of any migrating soil material

Figure 6-1. Snakes Trapped and Killed in Reinforced Silt Fence Mesh (MNR, 2003).

Figure 6-2. Snakes Trapped and Killed in Reinforced Silt Fence Mesh (MNR, 2003).

6.3 Wildlife Encounters

- Wildlife encounters and awareness training should be provided as part of the required orientation training for any highway project in wildlife areas. Training should be provided by a member of the environmental team. Training sessions should be held at various locations along the highway project. The training should emphasize safety for workers, safety for wildlife, and minimization of work disruption.

Environmental protection notes that should be provided on design drawings include, but are not necessarily limited to, the following:

- Implement sanitary garbage disposal in designated disposal locations to minimize wildlife encounters;
- Hunting of wildlife by project employees on the construction site is forbidden;
- No pets, domestic or wild, will be permitted on the construction site;
- Maintaining work and camp areas free of food scraps and garbage will be a stringent requirement;
- Harassment of wildlife by project workers will not be permitted; and
- Equipment and vehicles will yield the right-of-way to wildlife

6.4 Beaver Dam Removal

- Beaver dam removal may be required during design (pre-grading) or construction phases. Beaver dams that are associated with watercourse crossings should be removed prior to the commencement of the watercourse crossing. The designer must be aware of the presence of a beaver dam/pond/wetland which will affect operations and construction sequences that must be identified on the drawings. Careful drawdown and energy dissipation of the released water is required to protect downstream areas from sedimentation, flooding and erosion. Removal of the beaver itself may be required. A trapping permit from the Ministry of Natural Resources must be obtained for the removal.

- The following note should be included on the contract drawings where applicable: Beaver dams are to be removed in accordance with the Beaver Dam Removal (Environmental Reference for Construction).
- For additional information, please see the Environmental Reference for Construction (ERC) for Beaver Dam Removal.

6.5 Raptor Nesting

- The contractor should notify the Environmental Planner and MNR of any raptor nesting observed in the course of design/construction work that may be affected by highway construction. Mitigation measures will be identified in consultation with MNR and Environment Canada at that time on a site-specific basis.

6.6 General Habitat Protection Measures

In addition to the above, the following OPSS environmental protection measures have wildlife habitat benefits and should be identified on design drawings and/or design specifications where relevant (OPSS 577, 120, 180, 182, 201, 206, 503, 518, 565-1).

6.7 Operation and Maintenance Issues

6.7.1 Roadkills

- Even with mitigation, wildlife roadkills are inevitable. However, collection of some key information by maintenance personnel in the course of roadkill clean up would assist in consideration of future wildlife mitigation planning. The following information is useful in this regard:
    - Species identification (a fact sheet with diagrams of representative species would be helpful for maintenance staff to carry in the vehicle);
    - Location of the roadkill – plotting with a hand-held GPS or at least noting locations on a map based on vehicle odometer readings provides a more accurate location than simply approximating distances from the nearest marker post.

More accurate roadkill location data can be helpful as one tool in assessing potential wildlife conflict zones/crossing areas where future mitigation may need to be considered.

6.7.2 Ditch Maintenance

- Highway ditch maintenance typically involves the periodic dredging out of ditches to remove accumulated soil/sediment and other obstructions, re-contour the ditch profile, and restore positive drainage flow.
- Timing of this activity has some wildlife implications. Dredging in the fall/winter will have minimal effect on wildlife nesting. Dredging in the spring/summer could potential remove active nests of migratory birds. If dredging must occur at that time, the migratory birds mitigation approach highlighted earlier must be employed. A design note to this effect should be provided in the appropriate maintenance contract.

The dredged sediments could contain various runoff contaminants. If left on site, contaminants may be leached into adjacent habitat. The excavated material must be properly handled and disposed of at an approved facility.

6.7.1 ROW Vegetation Management

- The timing (early season, late season) and frequency (such as several times per year, yearly, alternating years or every 3-4 years) of highway ROW vegetation management provide a wide range of management options with varying ecological (including wildlife) effects. Effects may be positive, neutral or negative depending on the management approach adopted.
- Management activities that over-maintain the ROW (such as frequent mowing, fertilizer/pesticide application) are not cost efficient, result in limited habitat variability, promote growth of invasive species, can affect local wildlife productivity, and can result in off-site habitat effects (such as pesticide drift).
- Management activities that incorporate Integrated Pest Management (IPM – use chemical controls sparingly and only when/where needed) and that promote landscape variation to address driver safety, driver/wildlife visibility, habitat variability, and self-sustaining vegetation associations will generally result in positive ecological benefits as well as lower maintenance costs.
- ROW vegetation management can be part of the road ecology framework. However, recognition of this opportunity is only slowly emerging, and implementation of ecological approaches in the U.S, Canada, and overseas is variable and still under review. Although more research in this field remains to be done, the following design guidelines are evident from the above literature:
    - Use indigenous plant species (native to the particular region) in any ROW vegetation planting plans;
    - Incorporate a zoned management approach (variation in vegetation cutting height and frequency) to: 1) provide variation in vegetation and habitat structure; 2) address driver safety and field of view requirements; and 3) promote wildlife benefits in the ROW zones further removed from the paved area and shoulders;
    - Avoid excessive fertilization and nitrogen build-up to reduce dominance by a few aggressive plant species;
    - Identify no or low maintenance in sensitive areas (such as riparian areas, wetlands) other than manual cutting of woody vegetation if required in the highway safety zone;

- o Promote the concept of a "variegated roadside" (Forman et al., 2003).

The attributes of the variegated roadside are:

- o Greater emphasis on native species and natural succession as components of the ROW;
- o Provision of topographic variability with a natural mosaic of plant communities;

Provide variation in any proposed planting, using vegetation nodes and considering how plantings and other materials (such as stump lines) may facilitate and funnel wildlife to designated crossing structures.

If properly managed, highway ROWs and road-side ditches can act as corridors for tallgrasses and their insect pollinators.

References

MNR, 2003; Ecoplans Limited, 1998; Evink, 1998; Varland and Schaefer, 1998; Underhill and Angold, 2000; Quebec Department of Transportation, 2003; Forman, et al., 2003; English Nature, 1996.

7 QUALITY ASSURANCE AND MONITORING

Although not part of MTO practice, quality assurance and control may be required on a project by project basis. Quality assurance and control is normally undertaken to ensure that 1) mitigation design specifications are complete and accurately translated onto contract drawings and documents; 2) that mitigation measures and structures are properly implemented in the field; and 3) that mitigation structures (such as wildlife crossing facilities) are working after the facility (or upgrading) is completed.

An environmental specialist with highway assessment experience should be part of any design review to ensure that terrestrial and aquatic environmental objectives are considered throughout the design process and in any proposed design revisions. The environmental specialist must be fully aware of the environmental setting of the project and the rationale for the environmental protection measures proposed in the original design.

7.1 Quality Check of Design Specifications

The environmental specialist should be involved in the quality check of design specifications before they are finalized and submitted in the tender contract documentation.

7.2 Quality Check of Field Structures

Where warranted, an environmental inspector should field check wildlife mitigation structures during construction to ensure that the design is being adequately constructed in the field. This also provides the opportunity for liaison with the Construction Supervisor if specific construction implementation issues come to light that require adjustments in the field.

7.3 Monitoring – Are Wildlife Crossing Structures Working?

Table 7-1 summarizes a variety of wildlife structure monitoring techniques from selected studies (not exhaustive). Pros and cons of the various techniques are highlighted for consideration.

Unfortunately, there is still limited knowledge of effective and affordable passage designs for most wildlife species. Clevenger and Waltho (2003), who have undertaken nearly seven years of continuous monitoring of wildlife structures and wildlife use patterns at the Banff-Bow valley of Alberta, have offered the following perspectives on structure monitoring:

- Monitoring studies to date have varied considerably in terms of experimental design and duration of monitoring. Consequently, many studies have results that are observational at best;

- In their Alberta monitoring of a number of 12-year old wildlife passages, human influence consistently ranked high as a significant factor affecting species passage. They believe that underpass dimensions had little effect on passage because animals may have adapted to the structures over time (Note: similar structure habituation was identified for the Florida Panther by Land and Lotz, 1996). They also concluded that the best-designed and landscaped underpasses might be ineffective if human activity is not controlled. Others have similarly concluded that structure effectiveness may be limited if adjacent land uses are not managed to retain the landscape features conducive to and influencing wildlife movement (Federal Highway Administration, 2002; Jackson and Griffin, 1998);
- In monitoring wildlife use of newly constructed wildlife structures in Alberta, where habituation to the structures was not possible, study results suggested that attributes of the structure (such as size, openness) were of primary importance in wildlife use compared with landscape and human-related factors (Clevenger and Waltho, 2003). Use of the different structure types varied among the wildlife groups (large carnivores and ungulates);

The authors concluded that mitigation planning when dealing with multi-species ecosystems is a challenging endeavour. They also concluded that monitoring of structures over longer time periods, and at different locations, is required in order to gain a better understanding of the strengths and weaknesses of design characteristics for multi-species wildlife use. Even though quality assurance and monitoring is not part of MTO's current policy, the agency may contribute to this learning endeavour by conducting monitoring exercises which may be required on a project by project basis.

Table 7-1. Wildlife Structure Monitoring Techniques.

Technique	Application	Advantages	Disadvantages	Sample References
Tracks and track beds	ID wildlife tracks in mud bottom of structure or in installed track beds (mud, marble dust or fine white sand) at both ends of structure. Rake beds clean after each check.	Relatively easy to install and check. Have been used in passages ranging from 0.25 to 13 m in width. Variety of wildlife species are detectable. Relatively cost-effective.	Difficult to record tracks of very small, light species (such as amphibians). ID to species unlikely for smaller wildlife. Will only record tracks on terrestrial sections if culvert contains drainage. Water flow may wash out tracks. Some species may jump over narrow beds.	Jackson, 1999; Veenbaas and Brandjes, 1999; Clevenger, 1998; Clevenger and Waltho, 2003; Norman et al., 1998; Abson and Lawrence, 2003; Federal Highway Administration, 2002; Singleton and Lehmkuhl, 1999.
Snow tracking	Assess winter wildlife tracks leading to structures and within structures.	Variety of wildlife species can be detected, particularly species that may not be as evident at other times. Relatively cost-effective depending on design, number of structures, etc.	Not always possible to confirm species. Must be timed after fresh snowfall for best results. Some judgement required interpreting number of animals, whether crossing occurred.	Singleton and Lehmkuhl, 1999; Barnhum, 2003; Alexander and Waters, 2000;
Ink plots and soot plots	Ink beds or soot panels with paper placed on either side to record tracks of animals passing through beds/panels. Installed usually at ends of structure.	Useful for smaller passages and for recording smaller animals. Can provide good prints of small mammals and amphibian tracks will show up. Can distinguish between amphibian groups (not species) if good prints available.	Will not ID to species for some groups (such as amphibians). Prone to wash out if structure flooded. Species moving through drainage course will not be recorded. Requires weekly checks and periodic replacement of plots. Some species may jump over plots.	Jackson, 1999; Veenbaas and Brandjes, 1999; Federal Highway Administration, 2002; Clevenger et al., 2001.

Technique	Application	Advantages	Disadvantages	Sample References
Infrared or motion activated cameras	Camera installed in structure and triggered by either motion detector or infrared beam.	Good for recording medium and large size animal passage – photo ID is usually possible. Range of wildlife species can be recorded with proper placement/design. Motion detectors may be more effective for mammals. Can collect information on movement direction, frequency, time and date. Digital camera units are now available.	Can be prone to breakdown and vandalism. Typically expensive, although costs will decline over time. Requires periodic checking to remove film, make repairs/ adjustments. Infrared systems require heat and motion to be triggered. Typically not reliable for detecting small wildlife species, however, MNR (Parry Sound) has had had good species and photo coverage.	Jackson, 1999; Veenbaas and Brandjes, 1999; Federal Highway Administration, 2002; Norman et al., 1998; Brudin, 2003; Clevenger and Waltho, 2003; Singleton and Lehmkuhl, 1999; Woodhouse et al. (MNR, Parry Sound) 2002; Brown et al. (MNR, Parry Sound) 2004.
Video cameras	Video camera installed in structure. Standard video cameras used in day – infrared cameras used at night (in Europe and also recently observed in Arizona in 2005).	Can detect behaviour of animals using structure. Best for medium and larger wildlife species. Collects information on movement direction, frequency, behaviour, time and date.	Not generally suitable for recording small animals (unless passage is small). High cost for each infrared unit (about $14,000 Cdn). Requires large amount of office time to review volume of videotape.	Jackson, 1999; European work summarized in Federal Highway Administration, 2002. Arizona monitoring work observed by Ecoplans Limited in 2005.
Counters	Stand-alone infrared or motion beam detectors installed at structure to record movement.	Compared with cameras, less obvious, less prone to vandalism or breakdown, less expensive, and lower maintenance.	Only provides information on number of detected movements, but no information on species triggering the counter. Prone to typical limitations of triggering devices noted above. Information might be improved if combined with track beds	Jackson, 1999.
Pitfall traps	Collection pails combined with temporary drift fencing	With proper design, can confirm species ID/sex and use of structure by frogs and salamanders, some reptiles.	Can be labour-intensive for set up and sampling, depending on number of structures and traps. Requires Scientific Collector Permit from Ontario MNR for animal handling, marking and release (lead time of 2-3 months) for application.	Abson and Lawrence, 2003; Ecoplans Limited, 2003.

Technique	Application	Advantages	Disadvantages	Sample References
Direct observations and tagging	Monitoring of tunnel use by amphibians during spring night movements. May include marking or taking of tissue samples	Provides direct evidence of tunnel use, opportunity to observe animal behaviour approaching and within tunnels. Volunteer help is an opportunity (with suitable training).	Requires several field personnel and/or frequent checks of tunnels, usually over a number of nights. Scientific Collector Permit required in Ontario (MNR) for handling and tissue taking.	Jackson, (pers comm. to Ecoplans Limited, 2002); Ecoplans Limited, 2003.
Radio-telemetry tracking	Has been used primarily with ungulates, large carnivores in US, Europe and Canada	Can provide information on crossing rates for individual animals, if continuously monitored. Most useful to determine home range changes in relation to highway facility, and role of wildlife structures. Can enable observation of wildlife behaviour if observed in structure. New GPS transmitters can be programmed to monitor animal locations at desired intervals and to fall off the animal at a pre-selected time (used in Elk monitoring in Arizona – 2005).	Considerable field time, effort and cost can be required to capture, handle and monitor animals. Without continuous monitoring, may not be certain that a crossing through structure has occurred (can be inferred). Cannot get record of number of animal crossings unless continuous monitoring is done.	Jackson, 1999; Woods, 1990 (cited in Forman et al., 2003); Land and Lotz, 1996. Ecoplans field observations in Arizona (2005).

Forman et al. (2003) have provided a "state of our knowledge" review of 17 published studies that have evaluated effectiveness of wildlife passages for animal use. The studies have been undertaken in Europe, Australia and North America. On average, wildlife passages were evaluated for 15 months, using sand transects (n=12), infrared operated 35 mm cameras (n=4) and direct observations of animals (n=1) to detect animal passage.

Based on this review, Forman et al. (2003) highlighted the following conclusions about the state of research and knowledge gaps:

- Results support the general sense that few rigorous studies have been carried out to date. Pre-defined criteria for successful passage have rarely been developed;
- When analysis is limited to a single species, passage requirements for other species may be overlooked;
- There still remains a large research void in addressing factors that affect large carnivore use of passages as well as passage use by amphibians and reptiles, species groups that reflect both ends of the size spectrum;
- Few studies have contemplated how human activity may affect wildlife passage use. Managing human activities around important highway passages may lead to greater road permeability for wildlife, as noted above by others (Federal Highway Administration, 2002; Jackson and Griffin, 1998);
- Frequency of passage is the typical measure of wildlife use, but should be put in the context of relative abundance of a species in the area and therefore its expected passage use. Very small numbers of amphibian use of a tunnel may reflect local rarity for the species rather than tunnel avoidance. In addition, 40 passages by raccoons (a very abundant species) cannot be directly compared with 10 passages by Jefferson Salamander (a rare species in Ontario) which could be very noteworthy. Assessing crossing probabilities at a highway using relative abundance information and comparing these with passage use provides a better measure of effectiveness. However, obtaining abundance information is not without some effort and may require surveys, radio-tracking, track assessments, and/or extrapolation from habitat suitability mapping;
- Animal use of the passage to safely cross the road is a generally agreed measure that structures are functional and effective. However, how is success measured in terms of frequency of use? Frequent passages for a particular species are probably important in maintaining local population size. One passage in an animal's life span plays a role in maintaining genetic variability;
- Evidence that wildlife structures act as prey traps is scant, largely anecdotal, and tends to indicate infrequent opportunism rather than recurring predation, based on a review of the literature completed by Little et al., (2002). Most studies have shown no evidence of predation;

- Research comparing the effectiveness of underpass versus overpass designs in terms of wildlife use and cost-benefits is generally lacking. A key question for highway designers is where to best invest mitigation funds – should we build a few large structures, or several smaller ones, or a combination of both? What is the best return (wildlife passage) for the investment? Is it necessary to build costly overpasses or will a greater number of smaller structures provide similar road permeability?
- Finally, our understanding of where to place wildlife structures and what spacing to provide between them is still limited. It is generally agreed that in terms of risk spreading, and where wildlife conflict zones are confirmed, more than one structure is probably beneficial, and closer spacing of structures may be more important in providing permeability than a few distant structures. However the science is inadequate at present in providing an automatic "formula for success" to calculate how many structures make sense and how big (or small) they should be.

It is clear that effective wildlife passage design and measures of passage effectiveness will be largely influenced by the intended purpose of the passage (s), focal wildlife species groups of interest, and amount of post-construction funding available for monitoring.

The overall objective of wildlife passages is to increase the permeability of the highway corridor. Success means that the wildlife passages reduce road barrier effects, and reduce road kills. Some monitoring perspectives, adapted from Forman et al. (2003) are provided in the fact sheet below.

Monitoring of wildlife structures is important. Funds and/or logistics may be such that only limited monitoring can be undertaken. If so, the simplest monitoring to assess if wildlife passage is occurring will still be helpful, incorporating frequency of use to the extent possible. Where funds and logistics permit, longer term continuous monitoring of wildlife use of structures at case study areas will likely be the only way of assessing structure effectiveness and function at an ecosystem level and to contribute to the science and solutions for highway barrier effects over the next several decades.

Monitoring Wildlife Mitigation Measures		
Goal	**Monitoring Approach**	**Methodology**
Roadkill Reduction	Pre and Post	• Measured by comparing road kill frequencies pre and post-mitigation; • Overall, relatively straightforward information collection.
	Long-term	• For new highway construction, road kill records need to be collected and maintained over a longer period to determine if road kill frequency declines in time as wildlife species find and adjust to the new structures;
Barrier Effect Reduction	Habitat Connectivity	• Measured by passage monitoring, at minimum detecting animal presence through structure; • Overall, relatively straightforward, depending on technique used (such as pitfall traps, sand plots [tracks], direct observation [such as amphibians]). Use of monitoring cameras or other types of equipment can provide more consistent information but it is subject to periodic visits for equipment adjustments, repair and removal of exposed film. MNR work at Parry Sound has had good results monitoring culvert use with infrared cameras.
	Genetic Interchange	• Measured by passage monitoring, need to detect movement by adults (primarily males) during the breeding season; • At a minimum, requires ability to verify that adults are moving through. Combination of direct observation (for example, amphibians/reptiles), tracks, pitfall traps can be used. Photo monitoring cameras can distinguish sexes for some species (such as deer). Ability to distinguish sexes for many species would require capture and radio-telemetry work, or capture/re-capture studies;
	Biological Requirements	• Measured by looking at reproductive rates, physical condition, sex ratios, decreased survivorship; • Requires more involved, longer term monitoring time commitments and financial commitments;
	Dispersal/ Recolonization	• Measured by evidence of juvenile passage through structures; • Also requires collateral study of radio-monitoring movements of dispersing species and ability to detect species returning to area after a long absence; • Requires a major research effort, time and financial commitment;
	Metapopulation/ Ecosystem Processes	• Measured by understanding distribution of herbivores and predators in the area in terms of habitat quality, foraging pressure and predation rates; • Requires a major research effort, time and financial commitment.

8 REFERENCES

Abson, R.N., and R.E. Lawrence, 2003. Monitoring the use of Slaty Creek wildlife underpass in the Calder Freeway, Black Forest, Macedon, Victoria, Australia. In *Proceedings of the 2003 International Conference on Wildlife Ecology and Transportation*, Lake Placid, New York.

ACO Polymer Technologies plc. http://www.acowildlife.co.uk/

Alexander, S.M., and N.M. Waters, 2000. The effects of highway transportation corridors on wildlife: a case study of Banff National Park. *Transportation Research* C8: 307-320.

Austin, J.M., M. Ferguson, G. Gingras, and G. Bakos. 2003. Strategies for restoring ecological connectivity and establishing wildlife passage for the upgrade of Route 78 in Swanton, Vermont: an overview. In *Proceedings of the 2003 International Conference on Wildlife Ecology and Transportation*, Lake Placid, New York.

Barnhum, S.A., 2003a. *Identifying the best locations along highways to provide safe crossing opportunities for wildlife.* Colorado Department of Transportation Research Branch. Report No. CDOT-DTD-UCD-2003-9, Final Report, 67 pp.

Barnhum, S.A., 2003b. Identifying the best locations to provide safe highway crossing opportunities for wildlife. In *Proceedings of the 2003 International Conference on Wildlife Ecology and Transportation*, Lake Placid, New York.

Bell, D. and D. Carter, UMA Engineering Ltd. 2000. Wildlife mitigation measures implemented at the Three Sisters interchange on the TransCanada Highway at Canmore, Alberta.

Biota Research and Consulting, Inc., 2003. Final report. Jackson Hole roadway and wildlife crossing study, Teton County, Wyoming. Prepared for Jackson Hole Wildlife Foundation, Jackson, Wyoming.

Brehm, K., 1989. The acceptance of 0.2-metre tunnels by amphibians during their migration to the breeding site. In: *Amphibians and Roads: Proceedings of the Toad Tunnel Conference*, Rendsburg, Federal Republic of Germany, January 1989. Langton, Thomas (ed). ACO Polymer Products Ltd.: England.

Brown, J., J. D. Rouse, and R. Black. 2004. Monitoring pre-traffic conditions for the Eastern Massasauga and Eastern Hog-nosed snake along the Highway 69 extension. Ontario Ministry of Natural Resources, Parry Sound, Ontario. 26 pp.

Brudin, C.O., 2003. Wildlife use of existing culverts and bridges in north central Pennsylvania. In *Proceedings of the 2003 International Conference on Wildlife Ecology and Transportation*, Lake Placid, New York.

Buchanan, B.W., 2002. Observed and potential effects of artificial light on the behavior, ecology, and evolution of nocturnal frogs. In *Conference Proceedings – Ecological Effects of Artificial Night Lighting*, February 2002, Los Angeles, California. Sponsored by the Urban Wildlands Group and the UCLA Institute of the Environment.

Buchanan, B.W., 1993. Effects of enhanced lighting on the behaviour of nocturnal frogs. *Animal Behavior* 45: 893-899.

CARCNET. http://www.carcnet.ca/

Carr, M.H. P. D. Zwick, and T. Hoctor. 1998. Using GIS for identifying the interface between ecological greenways and roadway systems at the state and sub-state scales. In *Proceedings of the 1998 International Conference on Wildlife Ecology and Transportation*, Fort Meyers, Florida.

Chan, J., 1993*. Evaluation of methods to reduce road mortality of red-sided garter snakes at Narcisse Wildlife Management Area.* A practicum submitted in partial fulfillment of the requirements for the degree of Master of Natural Resources Management. Natural Resources Institute: Manitoba.

Clevenger, A., and N Waltho, 2003. Long-term, year-round monitoring of wildlife crossing structures and the importance of temporal and spatial variability in performance studies. In *Proceedings of the 2003 International Conference on Wildlife Ecology and Transportation*, Lake Placid, New York.

Clevenger, A., B. Chruszcz, and K. Gunson. 2001. Drainage culverts as habitat linkages and factors affecting passage by mammals. *Journal of Applied Ecology* 38: 1340-1349.

Clevenger, A.P. and N. Waltho, 2001. *Dry drainage culvert use and design considerations for small and medium-sized mammal movement across a major transportation corridor.* University of Calgary, Department of Forestry Wildlife and Fisheries, University of Tennessee, York University.

Clevenger, A., and N. Waltho, 2000. Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. *Conservation Biology* 14(1): 47-56.

Clevenger, A.P., 1998. Permeability of the Trans-Canada highway to wildlife in Banff National Park: importance of crossing structures and factors influencing their effectiveness. Department of Forestry, University of Tennessee. In Proceedings *of the 1998 International Conference on Wildlife Ecology and Transportation*, Fort Meyers, Florida.

Cusic, K., 2000. The effects of roads on wetlands, with some mitigation alternatives.

http://www.wildlandscpr.org/

deMaynadier, P.G. and M.L. Hunter Jr.. 2000. Road effects on amphibian movements in a forested landscape. Natural Areas Journal. 20(1): 56-65.

Dexel, R., 1989. Investigations into the protection of migrant amphibians from the threats from road traffic in the Federal Republic of Germany- a summary. In: *Amphibians and Roads: Proceedings of the Toad Tunnel Conference*, Rendsburg, Federal Republic of Germany, January 1989. Langton, Thomas (ed). ACO Polymer Products Ltd.: England.

Ecoplans Limited, 2003. *Bayview Avenue Extension, Region of York. Spring 2003 Amphibian Monitoring Technical Brief.* Prepared for the Regional Municipality of York.

Ecoplans Limited and McCormick Rankin Corporation, 2002. *Bayview Avenue (Y.R.34). Jefferson Complex Salamander Migration Study and Road Mitigation Design Review.* Prepared for the Regional Municipality of York.

Ecoplans Limited, 1998*. Environmental Protection Plan, Fredericton to Moncton Highway*. Prepared for the Maritime Road Development Corporation.

Ecoplans Limited and McCormick Rankin Corporation, 1997. *York Region – Bayview Avenue, Stouffville Road to Bloomington Road. Environmental Management and Enhancement Plan*. Prepared for the Regional Municipality of York.

English Nature, 1996. *The significance of secondary effects from roads and road transport on nature conservation.* English Nature, Peterborough, U.K. English Nature Research Report No. 178.

Evink, G., 1998. Ecological highways. Florida Department of Transportation. In *Proceedings of the 1998 International Conference on Wildlife Ecology and Transportation,* Fort Meyers, Florida.

Evink, G. L. 2002. Interaction between roadways and wildlife ecology. NCHRP (National Cooperative Highway Research Program) Synthesis 305. Transportation Research Board. Washington, D. C. 86 pp.

Fahrig, L., J. H. Pedlar, S. E. Pope, P. D. Taylor, J. F. Wegner. 1995. Effect of road traffic on amphibian density. *Biological Conservation* 73: 177-182.

Federal Highway Administration, 2004. *Keeping it simple. Easy ways to help wildlife along roads.* FHWA website http://ntl.bts.gov/card_view.cfm?docid=22885.

Federal Highway Administration, 2002. *Wildlife habitat connectivity across European highways*. Office of International Programs, Office of Policy, Federal Highway Administration, U.S. Department of Transportation. Report No. FHWA-PL-02-011, Washington, DC.

Federal Highway Administration, 2000. *Critter crossings – linking habitats and reducing roadkill*. Publication FHWA-EP-00-004. Washington, D.C.: U.S. Department of Transportation.

Finder, R.A., J. L. Roseberry, and A. Woolf. 1999. Site and landscape conditions at White-tailed Deer/vehicle collision locations in Illinois. *Landscape and Urban Planning* 44: 77-85.

Findlay, C. S., and J. Bourdages, 2000. Response time of wetland biodiversity to road construction on adjacent lands. *Conservation Biology* 14(1): 86-94.

Foresman, K.R., 2004. *The effects of highways on fragmentation of small mammal populations and modifications of crossing structures to mitigate such impacts.* Final Report. Prepared for Montana Department of Transportation, Research Section, Helena, Montana.

Forman, R.T.T, D. Sperling, J. A. Bissonette, A. P. Clevenger, C. D. Cutshall, V. H. Dale, L. Fahrig, R. France, C. R. Goldman, K. Heanue, J. A. Jones, F. J. Swanson, T. Turrentine, T. C. Winter. 2003. *Road Ecology, Science and Solutions*. Island Press, USA. 481 pp.

Forman, R.T.T., 2000. Estimate of the area affected ecologically by the road system in the United States. *Conservation Biology* 14(1) 31-35.

Forman, R.T.T., 1999. Spatial models as an emerging foundation of road system ecology and a handle for transportation planning and policy. Harvard University, Cambridge. In *Proceedings of the 1999 International Conference on Wildlife Ecology and Transportation*, Missoula, Montana.

Forman, R.T.T., and L.E. Alexander, 1998. Roads and their major ecological effects. *Annual Review of Ecology and Systematics* 29: 207-231.

Forman, R.T.T., and R.B. Deblinger, 1998. The ecological road-effect zone for transportation planning and Massachusetts highway example. Harvard University and Division of Fisheries and Wildlife, Massachusetts. In *Proceedings of the 1998 International Conference on Wildlife Ecology and Transportation*, Fort Meyers, Florida.

Forman, R.T.T., and A. M. Hersperger, 1996. Road ecology and road density in different landscapes, with international planning and mitigation solutions. In *Proceedings of the 1996 International Conference on Wildlife Ecology and Transportation*, Tallahassee, Florida.

Foster, M.L. and S.R. Humphrey, 1995. Use of highway underpasses by Florida panthers and other wildlife. *Wildlife Society Bulletin* 23: 95-100.

Gauthreaux, S.A. Jr, and C. G. Belser, 2002. The behavioral responses of migrating birds to different lighting systems on tall towers. In *Conference Proceedings – Ecological Effects of Artificial Night Lighting*, February 2002, Los Angeles, California. Sponsored by the Urban Wildlands Group and the UCLA Institute of the Environment.

Guyot, G. and G. Kuchling. 1998. Some ecological aspects of populations of oblong turtles *Chelodina oblongata* in the suburbs of Perth (Western Australia). In: Miaud C. and R. Guyetant, editors. Le bourget du lac. France p. 173-181.

Hindelang, M. et al., 1999. Addressing deer-vehicle accidents with an ecological landscape approach. White Water Associates, Inc., Michigan. In *Proceedings of the 1999 International Conference on Wildlife Ecology and Transportation*, Missoula, Montana.

Hubbard, M.W., B. J. Danielson, and R. A. Schmitz. 2000. Factors influencing the location of deer-vehicle accidents in Iowa. *Journal of Wildlife Management* 64(3): 707-713.

Jackson, S.D., 1999. Overview of transportation-related wildlife problems. In *Proceedings of the 1999 International Conference on Wildlife Ecology and Transportation*, Missoula, Montana.

Jackson, S.D., and C. R. Griffin, 1998. Toward a practical strategy for mitigating highway impacts on wildlife. University of Massachusetts. In *Proceedings of the 1998 International Conference on Wildlife Ecology and Transportation*, Fort Meyers, Florida.

Jackson, S.D., and M.N. Marchand, 1998. *Use of a proto type tunnel by Painted Turtles* (*Chrysemys picta*). Unpublished note, Department of Forestry and Wildlife Management, University of Massachusetts, Amherst Massachusetts.

Jackson, S.D., 1997. *Proposed design for an amphibian and reptile tunnel.* Unpublished Note, design guidelines and concept schematics. Provided by faxsimile to Ecoplans Limited, May 2002.

Jackson, S., 1996. Underpass systems for amphibians. In *Proceedings of the 1996 International Conference on Wildlife Ecology and the Environment*, Tallahassee, Florida.

Katona, G. Z., R. A. Davis, and G. F. Searing. 2000. Evaluation of the efficacy of various deer exclusion devices and deterrent techniques for use at airports. Report for Aerodrome Safety Branch Transport Canada. http://www.tc.gc.ca/civilaviation/Aerodrome/WildlifeControl/Deer/menu.htm

Kautz, R., T. Gilbert, and B. Stys, 1999. A GIS plan to protect fish and wildlife resources in the Big Bend area of Florida. In *Proceedings of the 1999 International Conference on Wildlife Ecology and Transportation*, Missoula, Montana.

Kinley, T. A., N. J. Newhouse and H. N. Page. 2003. Evaluation of the wildlife protection system deployed on Highway 93 in Kootenay National Park during autumn 2003. Sylvan Consulting Ltd. Prepared for Material Damage Loss Prevention, Insurance Corporation of British Columbia.

Klein, L., 1999. Usage of GIS in wildlife passage planning in Estonia. In *Proceedings of the 1999 International Conference on Wildlife Ecology and Transportation*, Missoula, Montana.

Knapp, K. K. 2004. Deer-vehicle crash countermeasure toolbox: a decision and choice resource. Midwest Regional University Transportation Centre Deer-Vehicle Crash Information Clearing House. 234 pp.

Krikowski, L. 1989. The 'light and dark zones': two examples of tunnel and fence systems. In: *Amphibians and Roads: Proceedings of the Toad Tunnel Conference*, Rendsburg, Federal Republic of Germany, January 1989. Langton, Thomas (ed). ACO Polymer Products Ltd.: England.

Land, D., and M. Lotz, 1996. Wildlife crossing designs and use by Florida Panthers and other wildlife in southwest Florida. Florida Game and Fresh Water Fish Commission. In *Proceedings of the 1996 International Conference on Wildlife Ecology and Transportation*, Tallahassee, Florida.

Langton, T.E.S. 1989a. *Amphibians and Roads*: Proceedings of the toad tunnel conference. ACO Polymer Products, Shefford, England, 202 pp.

Langton, T.E.S. 1989b. Tunnels and temperature: results from a study of a drift fence and tunnel system at Henley-on–Thames, Buckinghamshire, England. In: *Amphibians and Roads: Proceedings of the Toad Tunnel Conference*, Rendsburg, Federal Republic of Germany, January 1989. Langton, Thomas (ed). ACO Polymer Products Ltd.: England.

Lee, H.; W. Bakowsky; J. Riley; J. Bowles; M. Puddister; P. Uhlig; and S. McMurray. 1998. Ecological Land Classification for Southern Ontario. Ontario Ministry of Natural Resources.

Little, S.J., R. G. Harcourt, and A. P. Clevenger. 2002. Do wildlife passages act as prey-traps? *Biological Conservation* 107: 135-145.

LSA Associates, Inc. 2003. Literature review paper: Ventura 118 Wildlife corridor assessment project. 23 pp.

Malo, J.E., F. Suarez, and A Diez. 2004. Can we mitigate animal-vehicle accidents using predictive models? *Journal of Applied Ecology* 41: 701-710.

McGuire, T.M., and J.F. Morrall. 2000. Strategic highway improvements to minimize environmental impacts within the Canadian Rocky Mountain National Parks. *Canadian Journal of Civil Engineering* 27: 523-532.

Molenaar, J.G.. de, D. A. Jonkers and M.E. Sanders, 2000. *Road illumination and nature III. Local influence of road lights on a black-tailed godwit* (*Limosa l. limosa*) *population*. Directorate-General of Public Works and Water Management. DWW report nr. P-DWW-2000-058. 88 pp.

Naylor, J. Detroit News. Spotted turtles win right-of-way. In: *Canadian Amphibian and Reptile Conservation Network (CARCNET)*.

Newhouse, N., 2003. The wildlife protection system: early successes and challenges using high-powered infrared technology to detect deer, warn drivers and monitor behavior. In *Proceedings of the 2003 International Conference on Wildlife Ecology and Transportation*, Lake Placid, New York.

Norman, T., B. Lean, and A. Finegan, 1998. The role of fauna underpasses in New South Wales. In *Proceedings of the 1998 International Conference on Wildlife Ecology and Transportation*, Fort Meyers, Florida.

Ontario Ministry of Natural Resources, 2003. *Conservation Advisory. Heavy duty silt fence may cause high mortality in large-bodied snake species.* Ministry of Natural Resources, Parry Sound, Ontario.

Ontario Ministry of Transportation, 2003. *Environmental Reference for Highway Design.*

Ontario Ministry of Transportation, 1992. *An Evaluation of the Effectiveness of Swareflex™ Deer Reflectors.* Research and Development Branch, MTO.

Philcox, C.K., A. L . Grorgan, and W. D. Macdonald. 1999. Patterns of otter *Lutra lutra* road mortality in Britain. *Journal of Applied Ecology* 36: 748-762.

Phillips, M., 1999. Wildlife management on arterial highways in New Brunswick. Department of Transportation, New Brunswick, Canada. In *Proceedings of the 1999*

International Conference on Wildlife Ecology and Transportation, Missoula, Montana.

Podloucky, R., 1989. Protection of amphibians on roads – examples and experiences from Lower Saxony. In: *Amphibians and Roads: Proceedings of the Toad Tunnel Conference*, Rendsburg, Federal Republic of Germany, January 1989. Langton, Thomas (ed). ACO Polymer Products Ltd.: England.

Quebec Ministry of Transportation, 2003. *Controlling highway corridor vegetation. The new Quebec approach.* Submitted to Transportation Association of Canada. 10 pp + supporting data and figures.

Quebec Ministry of Transportation, 2001. Amphibian Tunnel installation at Highway 220, Eastern Townships, Case Study. Submitted to Transportation Association of Canada. 10 pp + supporting data and figures.

Rea, R. V. 2003. Modifying roadside vegetation management practices to reduce vehicular collisions with moose *Alces alces*. Wildlife Biology. 9:81-91.

Reading, C.J., 1989. Opportunistic predation of common toads *Bufo bufo* at a drift fence in southern England. In: *Amphibians and Roads: Proceedings of the Toad Tunnel Conference*, Rendsburg, Federal Republic of Germany, January 1989. Langton, Thomas (ed). ACO Polymer Products Ltd.: England.

Reed, D.F., T.N. Woodard and T.D.I. Beck. 1979*. Regional deer-vehicle accident research*. U.S. Department of Transportation, Federal Highway Administration Rep. No FHWA-RD-79-11.

Reed, D.F., T.N. Woodward, and T.M. Pojar, 1975. Behavioural response of mule deer to a highway underpass. *Journal of Wildlife Management* 39: 361-367.

Reed, D.F., T.M. Pojar, and T.N. Woodard. 1974. Use of one-way gates by mule deer. J. Wildl. Manage. 38:9-15.

Reh, W. and Seitz, 1990. The influence of land use on the genetic structure of populations of the common frog *Rana temporaria*. *Biological Conservation* 54: 239-249.

Reijnen R., R. Foppen, G. Veenbaas. 1997. Disturbance by traffic of breeding birds: evaluation of the effect and considerations in planning and managing road corridors. *Biodiversity and Conservation* 6: 567-581.

Reijnen, R., R. Foppen, and H. Meeuwsen. 1996. The effects of traffic on the density of breeding birds in Dutch agricultural grasslands. *Biological Conservation* 75: 255-260.

Rodriguez, A., G. Crema, and M. Delibes. 1996. Use of non-wildlife passages across a high speed railway by terrestrial vertebrates. *Journal of Applied Ecology* 33: 1527-1540.

Romin, L., and L.B. Dalton, 1992. Lack of response by mule deer to wildlife warning whistles. *Wildlife Society Bulletin* 20: 382-284.

Rosell, C., J. Parpal, R. Campeny, S. Jove, A. Pasquina and J.M. Velasco, 1997.Mitigation of barrier effect of linear infrastructures on wildlife. In*: K.Canters (ed.) Habitat Fragmentation and Infrastructure, Proceedings of the International Conference on Habitat Fragmentation*, Ministry of Transport, Public Works and Water Management, Delft, The Netherlands.

Rudolph, D.C., S. J. Burgdof, R. N. Conner, and J. G. Dickson. 1998. The impact of roads on the Timber Rattlesnake, (*Crotalus horridus*), in eastern Texas. In *Proceedings of the 1998 International Conference on Wildlife Ecology and Transportation*, Fort Meyers, Florida.

Ruediger, B., and J. Lloyd, 2003. A rapid assessment process for determining wildlife, fish and plant linkages for highways. In *Proceedings of the 2003 International Conference on Wildlife Ecology and Transportation*, Lake Placid, New York.

Ryser, J. and Gossenbacher, K., 1989. A survey of amphibian preservation at roads in Switzerland. In: *Amphibians and Roads: Proceedings of the Toad Tunnel Conference*, Rendsburg, Federal Republic of Germany, January 1989. Langton, Thomas (ed). ACO Polymer Products Ltd.: England.

Scheick, B.K., and M.D. Jones, 1999. Locating wildlife underpasses prior to expansion of Highway 64 in North Carolina. North Carolina Wildlife Resources Commission. In *Proceedings of the 1999 International Conference on Wildlife Ecology and Transportation*, Missoula, Montana.

Seiler, A., 2005. Predicting locations of moose-vehicle collisions in Sweden. *Journal of Applied Ecology* 42: 371-382.

Serrano, M., L. Sanz, J. Puig, and J. Pons. 2002. Landscape fragmentation caused by the transport network in Navarra (Spain). Two-scale analysis and landscape integration assessment. *Landscape and Urban Planning* 58: 113-123.

Sielecki, L., 2004. *Wildlife accident reporting and mitigation in British Columbia – Special Annual Report.* Prepared for the British Columbia Ministry of Transportation.

Singleton, P.H., and J.F. Lehmkuhl, 1999. Assessing wildlife habitat connectivity in the Interstate 90 Snoqualmie Pass Corridor, Washington. In *Proceedings of the 1999 International Conference on Wildlife Ecology and Transportation*, Missoula, Montana.

Smith, D.J., 1999. Identification and prioritization of ecological interface zones on state highways in Florida. In *Proceedings of the 1999 International Conference on Wildlife Ecology and Transportation*, Missoula, Montana.

Smith, D.J., L.D. Harris, and F.J. Mazzotti, 1996. A landscape approach to examining the impacts of roads on the ecological function associated with wildlife movement and movement corridors: problems and solutions. In *Proceedings of the 1996 International Conference on Wildlife Ecology and Transportation*, Tallahassee, Florida.

Spellerberg, I.F., 1998. Ecological effects of roads and traffic: a literature review. *Global Ecology and Biogeography Letters* 7: 317-333.

St. Clair, C.C.. 2003. Comparative permeability of roads, rivers and meadows to songbirds in Banff National Park. *Conservation Biology* 17(4): 1151-1160.

Texas Department of Transportation, 1999. *Bats and Bridges Study.* Cited in U.S. Federal Highway Administration website – www.fhwa.dot.gov.

Transportation Association of Canada, 1999. *Salt Management Guide, Primer and Codes of Practice.* Prepared by Ecoplans Limited et al., for the Transportation Association of Canada.

Trombulak, S.C., and C.A. Frissell, 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* 14(1): 18-30.

Underhill, J.E., and P.G. Angold, 2000. Effects of roads on wildlife in an intensively modified landscape. *Environmental Review* 8: 21-39.

Varland, K.L., and P.J. Schaefer, 1998. Roadside management trends in Minnesota – 1973 to 1997. In *Proceedings of the 1998 International Conference on Wildlife Ecology and Transportation*, Fort Meyers, Florida.

Veenbaas, G., and J. Brandjes, 1999. Use of fauna passages along waterways under highways. In *Proceedings of the 1999 International Conference on Wildlife Ecology and Transportation*, Missoula, Montana.

Viles, R.L., and D.J. Rosier, 2001. How to use roads in the creation of greenways: case studies in three New Zealand landscapes. *Landscape and Urban Planning* 55: 15-27.

Wagner, P., M. Carey, and J. Lehmkuhk, 1998. Assessing habitat connectivity through transportation corridors on a broad scale: an interagency approach. In *Proceedings of the 1998 International Conference on Wildlife Ecology and Transportation*, Fort Meyers, Florida.

Wise, S., and B. W. Buchanan, 2002. The influence of artificial illumination on the nocturnal behavior and ecology of salamanders. *Conference Proceedings – Ecological Effects of Artificial Night Lighting*, February 2002, Los Angeles, California. Sponsored by the Urban Wildlands Group and the UCLA Institute of the Environment.

Woodhouse, N., J. Rouse, and R. Black. 2002. Monitoring pre-traffic conditions on Highway 69 Extension as part of the Eastern Massasauga Rattlesnake and Eastern Hog-nosed snake-Highway 69 extension impact study. Ontario Ministry of Natural Resources, Parry Sound, Ontario. 24 pp.

Woods, J.G., 1990. *Effectiveness of fences and underpasses on the Trans-Canada Highway and their impact on ungulate populations.* Report to Banff National Park Warden Service, Banff, Alberta.

Yanes, M., Velasco, J.M. and Suarez, F., 1995. Permeability of roads and railways to vertebrates: the importance of culverts. *Biological Conservation* 71: 217-222.

APPENDIX 1: Road Ecology and Wildlife{ TC "APPENDIX 1: Road Ecology and Wildlife" \f C \l "1" }

Road Ecology Synthesis and Terms

The synthesis of *road ecology*, *landscape ecology, landscape connectivity, landscape matrix* and *habitat patches, road density,* and the *road effect zone* has been recently emerging in the literature (Forman et al., 2003, Forman, 1999, 2000; Forman and Alexander, 1998; Forman and Deblinger, 1998; Forman and Hersperger, 1996; Evink, 1998; Federal Highway Administration, 2000, 2002; Jackson, 1999; Jackson and Griffin, 1998; Smith et al., 1996; Viles and Rosier, 2001; Serrano et al., 2002).

A *highway* is an open way for the passage of vehicles. A *highway corridor* can be considered the full right-of-way that includes the travelled highway, medians, ditches, and the highway verges that may be periodically maintained (Forman et al., 2003).

Ecology

- *Ecology* is the study of interactions between organisms and the environment. Natural conditions, human land use, and their mutual interactions impose a pattern on the landscape.

Landscape ecology

- *Landscape ecology* interprets those interactions by considering the occupants (people and other organisms), the structures (such as vegetation, water, topography and road networks), the processes (such as movement of organisms, materials and water), and change (such as growth, land use, ecological succession, road density). Just as properties of the landscape (such as topography) influence road network patterns, road networks have an influence on the landscape and ecosystems on which they are superimposed.

Landscape Connectivity

- *Landscape connectivity* may be defined as the degree to which the landscape facilitates the movements of animals and other ecological flows (Forman et al., 2003);
- A highly connected landscape might be one where *habitat patches* (such as forests, old fields, thickets, wetlands) are surrounded by other lands (the *landscape matrix*) that comprise relatively benign habitat types, with few or no barriers, that allow the relatively free movement of many organisms. This landscape setting is difficult to find in heavily populated areas of Ontario, is more common in rural areas, and is abundant in areas of low road and human population density.

Road Density

- *Road density* is the average total road length per unit of landscape area (such as kilometers per square kilometre). Road density is known to have wildlife, flooding and biodiversity implications (Findlay and Bourdages, 2000; Forman et al., 2003; Forman and Hersperger, 1996);

- o Areas with low density tend to have larger, less constrained habitat areas where wildlife can move more freely, human access is limited, and natural water flow regimes and fluctuations (surface and groundwater) are generally unimpeded;
- o Areas with high road density partition the landscape into smaller parcels where habitats and wildlife populations may be more fragmented, wildlife road avoidance and/or mortality may increase, human access is enhanced, and water flow regimes may be altered;
- o Empirical studies for wolves and mountain lions suggest that a naturally functioning landscape for these species requires a road density less than 0.6 km per square km (summarized in Forman and Hersperger, 1996);
- o The distribution of Timber Rattlesnakes in east Texas is associated with areas of lowest road density, and therefore less habitat disturbance, fragmentation, and road mortality effects (Rudolph et al., 1998);
- o A negative correlation has also been identified between the density of paved roads within 1-2 km of wetlands and the diversity of wildlife and plant species in those wetlands (Findlay and Bourdage, 2000; Findlay and Houlahan, 1997 cited in Jackson and Griffin, 1998).

Road Effect Zone

In addition to the actual highway footprint on the landscape, ecological effects or condition changes can extend outward from the highway for varying distances. These effects may relate to invasive plant spread, wildlife movement and heavy deer use areas, salt spray/drift, stream channelization, changes in wetland drainage, noise effects (people and wildlife), and stream salt intrusion (among others).

This *road effect zone* (Forman and Deblinger, 1998) is typically asymmetric. For example, effects related to wind due to variation in ecological flows and spatial patterns on opposite sides of the highway.

Road Ecology

Road ecology, as defined by Forman et al. (2003) is the interaction of organisms and the environment with road systems in the landscape and vehicles.

This approach goes beyond the more traditional view of the highway footprint effect. It embodies the broader consideration of the interaction between the highway network and the ecological and human network in terms of air quality, highway design, noise, wildlife conflicts and movement opportunities (bottlenecks and mitigation), and environmental management.

Table 1 highlights some goals and guidelines, adapted and expanded from Forman et al. (2003) that reflect a road ecology perspective for highway planning and design.

Table 1. Road Ecology – Policy and Design Initiatives.{ TC "Table 1. Road Ecology – Policy and Design Initiatives." \f C \l "1" }

Goal/Guideline	Environmental Benefit
Use cleaner fuels (underway with ongoing research)	Reduces greenhouse gas emissions as well as release of harmful contaminants to aquatic and terrestrial systems
Increase re-cycling of vehicle parts beyond current levels	Reduces stockpiling and release of contaminants
Close or rehabilitate remote roads that are no longer needed	Reduces human access and disturbance
Concentrate higher speed traffic and truck traffic on primary roads	Reduces the dispersion of noise and road barrier effects across variety of road types
Improve design of road surface, tires, engines, vehicles (ongoing research and development)	Reduces noise generation and contaminant release
Depress road profile (where feasible), provide vegetation and/or soil berms in design	Reduces traffic disturbance and noise spread (for people and wildlife), promotes snow drift control and driver safety
Improve road salt management (underway)	More efficient use of road salt, less wastage, reduced salt contamination of aquatic areas, vegetation, and wells
Avoid intrusive highway lighting into wildlife habitat	Reduces risk of lowering habitat quality or changing wildlife life cycle activities
Perforate road corridors with wildlife crossing structures in areas of wildlife habitat	Reduces road barrier effect and effects of habitat fragmentation

The emerging challenge for highway planners, engineers, and environmental specialists is to take a “fresh look” at how roads and the landscape interact and apply it in highway planning, design, construction, and operation/maintenance.

Overview of Highway Effects on Wildlife

Highway effects on wildlife have been discussed in a number of papers and summarized in several excellent reviews (see for example Clevenger and Waltho, 2000; Jackson, 1999; Jackson and Griffin, 1998; English Nature, 1996; Forman and Alexander, 1998; Reijnen et al., 1996, 1997; Trombulak and Frissell, 2000; Underhill and Angold, 2000; van der Grift and Kuijsters, 1998; Federal Highway Administration, 2002, 2004; Scheick and Jones, 1999; and Spellerberg, 1998).

Four main ecological effects can be condensed from these reviews and summarized as 1) habitat loss; 2) changes in habitat quality; 3) wildlife mortality; and 4) reduced connectivity.

Habitat Loss

Direct removal of habitat by the highway footprint is a relatively straightforward and evident effect as pre-existing habitats are converted to pavement and roadsides.

Ecological effects however may extend well beyond the actual habitat loss zone and will vary depending on species habitat requirements.

- Wildlife species that require large habitat areas for feeding, breeding, shelter and migration movements, and that move extensively through these areas, experience effects beyond just habitat loss. The fragmented habitat areas are smaller in size, and may not meet all life cycle requirements. As wildlife move through their former habitat block, they encounter the highway which now acts either as a barrier or a road mortality risk. White-tailed Deer, Elk, Moose, and Black Bear may be affected in this manner;
- Species with low reproductive rates (few young born in any year, and/or breeding may not occur every year) are less tolerant of habitat loss, particularly if prime breeding habitat is removed or is fragmented from the animal's home range by a highway. Examples might include snake species such as the Eastern Massasauga Rattlesnake;
- For area sensitive bird species, such as Scarlet Tanager, the effective loss of habitat can be much larger than just the area removed by the highway footprint (Forman et al., 2003, Underhill and Angold, 2000). Fragmentation of a large woodland may result in residual woodland patches that are too small to support a viable breeding population. In addition, secondary effects that reduce habitat quality may favour aggressive nest parasite species to the detriment of successful breeding by Scarlet Tanager;
- Conversely, species with high intrinsic mobility, habitat generalists, species that utilize roadside habitat, and species with multiple resource needs are less affected by direct habitat loss. Examples of such species include Woodchuck, Red-winged Blackbird, Red-tailed Hawk, and Meadow Vole.

Changes in Habitat Quality

Reduced habitat quality may occur in the landscape bordering the highway through any combination of the following factors:

- Invasive plants stimulated by highway construction and habitat intrusion can spread into adjacent natural areas to the detriment of native plant species and dependant wildlife. The effects are often localized within 10 to 100 m and are often site specific (Forman et al., 2003);
- Habitat damage can occur from migrating chemicals, salt spray and other contaminants generated from passing vehicles and highway runoff. The zones of influence are site-specific, with elevated concentrations typically near the highway and concentration gradients declining progressively with distance (Transportation Association of Canada, 1999; Forman et al., 2003);
- There is evidence of lowered habitat quality associated with highway traffic noise. Lowered bird densities in forest and grassland in the Netherlands adjacent to highways were best explained in a regression model where road noise was the independent variable. Effects were influenced by traffic volume (10,000 or 50,000 vehicles per day) and habitat type (grassland or woodland) and ranged from 125 m to 560 m for all bird species combined (Reijnen et al., 1996, 1997);
- Some experimental studies and anecdotal evidence suggest that artificial lighting may have varying effects on various wildlife groups, including nocturnal foraging, nocturnal migration movements, light attraction or repulsion, social interactions, collisions with lighted structures (towers and bridges), and

reduction of habitat quality (see for example, English Nature, 1996; Buchanan, 1993, 2002; Wise and Buchanan, 2002; Gauthreaux and Belser, 2002; and Molenaar et al., 2000). The extent of knowledge concerning the effects of artificial road lighting is limited, and further research is required before species-specific mitigation measures can be developed;

- Radio-telemetry tracking of larger mammals (such as ungulates and carnivores), has documented varying levels of avoidance of highways and buffer areas (several studies noted in Forman et al., 2003). This road avoidance tendency may reflect a number of factors, including vehicle presence, road noise, lowered habitat quality, proximity of humans, and/or increased human access.

Highway corridors can also create additional habitat beneficial to some wildlife species. Highway structures such as bridges provide living areas for bats and birds. Utility poles provide perches and nest platforms for raptors. Vegetated highway verges and ditches provide breeding and foraging sites for common grassland birds, numerous insects, small mammals, ungulates and microhabitats that are exploited by some amphibians.

Unfortunately, these apparent benefits can be overridden by the closer proximity of wildlife and vehicles (collision and mortality risk) as well as the sub-optimal quality of amphibian breeding habitat provided by drainage ditches (such as contaminants and unpredictable water levels). Underhill and Angold (2000) provide further comments on this topic.

Wildlife Mortality

A review of the literature provides the following perspectives on highway wildlife mortality:

- Large numbers of animals (vertebrates and insects) are killed on highways based on some systematic record keeping for some species, and estimates for others. Road kills are identified as a premier mortality source (Forman and Alexander, 1998), and an Ontario study of heavy amphibian mortality on roads concluded that road mortality had a significant effect on local densities of amphibians (Fahrig et al., 1995).
- Roadkill rates, although a major mortality source, are not, for a large number of species, considered to be at levels that significantly impact populations at a national level. However, road mortality can exert significant pressure on local wildlife populations in site-specific cases, and on some at-risk species with already small or diminishing populations (see Spellerberg, 1998; Forman and Alexander, 1998; Jackson, 1999; Foster and Humphrey, 1995; Land and Lotz, 1996; Trombulak and Frissell, 2000);
- Vehicle speed and traffic volumes influence the risk of wildlife collisions to varying degrees. Mutual avoidance is made difficult with high traffic volumes and speeds and may be exacerbated under early morning and late evening conditions when visibility may be reduced and wildlife activity is heightened (Forman et al., 2003; Hubbard et al., 2000; Finder et al., 1999; Hindeland et al., 1999; Newhouse, 2003);
- Landscape structure near a highway is also a factor in highway wildlife mortality. Presence of bridges (associated with a travel corridor) was found to influence locations of deer-vehicle collisions in Iowa (Hubbard et al., 2000). Landscape

features that are conducive to bringing wildlife closer to the highway zone may include ridgelines, drainage features and valleys that intersect the highway, habitat transition zones and hedgerows perpendicular to the highway, gentle topographic areas of low complexity, woodland proximity, wetland and vernal pond proximity, low use side roads perpendicular to the highway, and areas of confirmed suitable habitat on both sides of the highway (see Barnham, 2003a, 2003b; Austin et al., 2003; Finder et al., 1999; Clevenger and Waltho, 2000; Rodriguez et al., 1996; Serrano et al., 2002; Philcox et al., 1999; Smith, 1999; Clevenger, 1998; and Alexander and Waters, 2000);

- Wildlife species behaviour and ecology also influence road mortality risk. Species tied to forest interiors rather than openings, and species that exhibit road avoidance behavior, are less likely to experience road mortality. However, wildlife species that are attracted to highway habitat, are more mobile, that have to cross highways in order to meet life cycle needs, and/or have low reproductive rates are more vulnerable to road mortality;
- St. Clair (2003) found that some forest birds were less likely to cross rivers than either roads or meadows, and suggested that based on evolutionary history birds may not perceive the risk of mortality posed by highway traffic.

Effects on Connectivity

Various implications of highways on landscape connectivity and wildlife movement opportunities have been identified in the literature and are highlighted below:

- Highways are sometimes described as wildlife filters, in that they may be crossed by some wildlife species (at some risk), and they may be avoided by other wildlife species, thereby acting as barriers to movement;
- The barrier effect of a highway is most pronounced for wildlife species that tend to avoid roads, have multiple resource needs, exist in low densities or have large area requirements, and have low reproductive rates (Jackson, 1999; Forman et al., 2003). For these species, a highway may act as a barrier or filter for movement to/from important feeding, shelter, breeding or migration sites. In essence, connections needed to sustain the complete life history cycle for these species are severed or greatly reduced by the highway. Turtles, snakes and amphibians (such as frogs and salamanders) are species that can be adversely affected by the road-barrier;
- The barrier effect becomes most problematic when it fragments species populations, reduces access to vital habitats, reduces or eliminates gene flow, and reduces the ability of a population to colonize or re-colonize areas. Where regional populations may persist because animals can move between populations, this ability may no longer exist, or may exist at a reduced level, with the introduction of a highway or twinning/widening of an existing highway. Habitat fragmentation and the barrier effect have been identified as the most pressing concerns related to highways and wildlife (Clevenger, 1998, Jackson and Griffin, 1998; Serrano et al., 2002; Trombulak and Frissell, 2000; Federal Highway Administration, 2002; Underhill and Angold, 2000; Spellerberg, 1998; Forman and Alexander, 1998);

These four ecological effects of highways on wildlife may have time lag effects as illustrated in **Error! Reference source not found.**.

- Habitat loss occurs initially with highway construction/upgrading.
- Reduction in adjacent habitat quality may then occur within a few seasons because of more proximate traffic and noise, and increased light/wind penetration (for wooded areas).
- In time, highway wildlife mortality will become evident at a new facility, or perhaps more evident at an upgraded facility.
- The highway barrier effects may take several generations to be observed, if population monitoring were being undertaken.

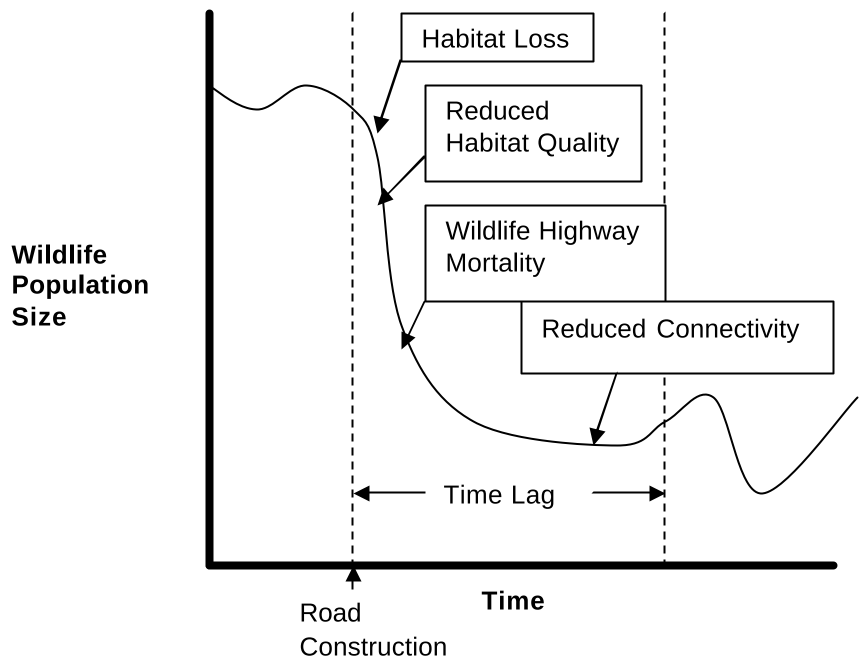

Figure 1. Time lag for Highway Effects (Adapted from Forman et al., 2003)**{ TC "**Figure 1. Time lag for Highway Effects (Adapted from Forman et al., 2003)**" \f C \l "1" }**

Maximizing Highway Permeability

While direct habitat loss is unavoidable with highway construction/upgrading, a mitigation plan that strives to moderate adjacent habitat affects and facilitate safe movement of wildlife across the highway (*highway permeability*) is a key step in softening these ecological effects. In particular, reducing the barrier effect by maximizing highway *permeability* is an important objective of the highway design process and a key component of this technical paper.

Highway Design Mitigation Strategies

Four key highway design mitigation strategies have been identified in the literature that are applicable to wildlife resources (Abson and Lawrence, 2003; Austin et al., 2003; Singleton and Lehmkuhl, 1999; Spellerberg, 1998; Underhill and Angold, 2000; Federal Highway Administration, 2002; Clevenger and Waltho, 2003; Jackson and Griffin, 1998; Barnum, 2003a, 2003b; Forman and Hersperger, 1996):

1) Avoidance - where possible in the EA/preliminary design stage, locate the highway alignment to avoid and/or minimize wildlife habitat effects and to take advantage of any opportunity (such as area topography and vertical alignment) to facilitate future wildlife movement opportunities;
2) Mitigation - identify and implement a suite of mitigation approaches for the highway design for habitat protection and facilitating wildlife movement. These measures should be cost-effective, properly located, and sensitive to anticipated future land use changes bordering the highway. Various measures are reviewed in Section 4.0 of the report;
3) Habitat creation and management - strategies such as wetland substrate salvage, topsoil salvage, habitat creation or improvements (on and off the right-of-way), and more ecologically based highway vegetation management are being advanced and implemented in various jurisdictions to benefit wildlife and soften habitat impact. These issues are reviewed in Sections 5.0 and 6.0 of this report;
4) Monitoring - monitoring at some level is required to determine if wildlife passage facilities are working. In other words, are target wildlife species using the provided passages? If not, are there design retrofits that need to be provided to facilitate passage? The simplest monitoring is to determine if facility use is occurring. Longer term monitoring is being advocated by researchers to help determine if the crossing facilities are reducing the barrier effect for a number of species, and to add to the information base so that more informed decisions can be made in subsequent highway projects. This issue is discussed in Section 7.0 of this report.

APPENDIX 2: Amphibian Tunnel Design Review{ TC "APPENDIX 2: Amphibian Tunnel Design Review" \f C \l "1" }

(Ecoplans Limited and McCormick Rankin Corporation, 2002)

Introduction

Roads, while serving transportation needs, can act as barriers or filters for wildlife (primarily terrestrial species) that need to cross the road. Some species may be reluctant to cross a roadway. Others, such as reptiles, are drawn to the heat of the road (Cusic, 2000). Wildlife effects can therefore occur through hindrance of dispersal and road mortality from vehicles as animals cross the road.

Amphibians are vulnerable to road-induced mortality. They are small, not easily seen by motorists, and tend to move across the road surface slowly. Salamanders are especially at risk because they are very slow moving, and often freeze in response to moving vehicles (Wyman, 1991, cited in deMaynadier and Hunter, 2000). In addition, amphibian movements are typically at night under moist or wet (rain) conditions during spring and fall dispersals. Under these conditions, driver visibility is reduced and response time (for avoidance or braking) is extended. In some instances large numbers of amphibians may cross a roadway during the night, resulting in higher potential road mortality.

Many amphibians have life cycles that encompass movement from overwintering sites to breeding ponds in the spring, post-breeding dispersal, and movements back to overwintering sites in the fall (juveniles and adults). These movements can be quite directed, and will continue across roads if present between these sites. Under these conditions, breeding adults are susceptible to road mortality at least twice a year (to and from breeding ponds and overwintering sites) and young of the year must also cross roadways to overwintering sites (Jackson, 1996, pers. comm. 2002). In extreme cases, road mortality and dispersal effects could result in loss of genetic variability where local populations rely on gene flow from dispersal (Jackson and Griffin, 1998, Reh and Seitz, 1990).

In recognition of this concern, there has been increasing emphasis on wildlife crossing mitigation measures and roadway design, particularly in North America and Europe, but in other areas as well. This emphasis has been reflected in major symposia such as the Toad Tunnel Conference in Germany (1989), and the International Conference on Wildlife Ecology and Transportation.

Information sources have encompassed published papers and symposia, Internet searches, and review of in-house files. In addition, a detailed phone discussion was held on May 3, 2002 with Mr. Scott Jackson, a wildlife biologist with the Department of Natural Resources Conservation, University of Massachusetts, Amherst, Massachusetts. Mr. Jackson presented at the 1989 Toad Tunnel Conference in Germany, and has been actively researching amphibian tunnel systems for many years. His research focus has been on the Spotted Salamander (*Ambystoma* maculatum), a species with migration movements and breeding habitat requirements similar to those of the Jefferson Complex Salamander. This work has been done in the northeastern United States, where habitat and climatic conditions (unlike Europe) are most similar to those encountered in southern Ontario.

Key findings of this review are provided in the following sections. Topic areas covered include types of crossing structures, crossing structure design, microclimate, light, vegetation, predation, noise/vibration, drainage and substrates.

This section presents the results of the review, and identifies recommended crossing structure design guidelines.

Types of Crossing Structures

Crossing structures can take several forms. Some are built specifically for the movement of wildlife, and others are originally designed for other purposes but also facilitate wildlife dispersal across roads (eg. drainage culverts).

Overpass

An overpass is one type of crossing structure. Arch style overpasses have been installed along sections of the Trans-Canada Highway in Banff, Alberta. These large overpasses were required to accommodate migration movement of large ungulate species (such as elk and deer) that were sustaining high mortality crossing the highway. There is evidence that the overpasses are being used by ungulates and other mammal species, and vehicle-ungulate collisions have been reduced.

Overpasses are generally large structures than can range from 50 to 200 m in length. They have proven to be effective for accommodating a variety of wildlife. The advantage of these structures is that they are not confining and provide exposure to ambient conditions such rainfall, temperature and light. Some structures in Europe support vegetation and rainwater fed pools. The disadvantage of these structures is that they are very expensive to build (Jackson and Griffin, 1998). Because of the cost, overpass structures for wildlife are usually restricted to areas where very large numbers of animals (such as deer, elk) are known to disperse and under typically forested conditions. reported in the literature reviewed. For species such as the Spotted Salamander that require good “see-through” conditions when using a structure (Jackson, pers. comm. 2002), use of an elevated arch style overpass is expected to be problematic.

Underpass

Forman and Alexander (1998) described underpasses that were generally 8-30 m long and 2.5 m wide. Underpasses can represent a variety of structures of varying size (larger and smaller) depending on their location and dimensions. All require the road to be elevated, allowing for passage underneath. They are generally not confining, but a higher underpass will increase openness, and therefore produce more natural conditions. These crossings however, can be noisy (Jackson and Griffin, 1998).

Tunnel Systems

Tunnels and culverts are underpass systems that have been utilized by wildlife under road and highway systems in Europe, Canada, the United States and Australia. Some tunnel systems in use today include many "toad tunnels" in Europe, salamander tunnels in Massachusetts, and snake culverts/tunnels in use in Manitoba.

Most of the research on wildlife crossings has dealt with amphibian tunnels. The use of tunnels to transport amphibians under roadways has been in practice for a number of years in Europe. The Amphibian Toad Tunnel Conference in Germany in 1989 was the first to address mitigation measures to reduce amphibian road mortality and fragmentation pressures (Langton, 1989a). Much of the literature dealing with wildlife crossings has been stimulated by these proceedings.

There is documented use of tunnels by amphibians and reptiles. Examples have been published in the Toad Tunnel Conference Proceedings (Langton, 1989a) for a number of locations in Europe. Chan (1993) recorded use of roadway culverts by the red-sided Garter Snake in Manitoba. Jackson (1996, pers. comm.. 2002) has documented salamander use of tunnels in Massachusetts.

Tunnel use by amphibians has had good results in some cases and variable results in others. One tunnel system that has worked reasonably well for toads in Europe (20 cm diameter ACO polymer tunnel system) in some applications was also assessed across a short distance (about 7 m) in Amherst Massachusetts. Initial results were promising for use by the Spotted Salamander (*Ambystoma maculatum*). During the first year of assessment, about 75% of the salamanders that reached the tunnels went through them (Jackson, 1996). However, further work found increasing incidence of salamanders hesitating and aborting going through, unless some light was shone at the end. Jackson (pers. comm.. 2002) has since concluded that these particular tunnels are too small and dark for use by Spotted Salamander, and has concluded that a larger size tunnel is preferable. There are a number of tunnels in Europe that do not appear to be functioning in helping animals pass under roads (Podloucky, 1989). Many tunnels are not monitored after installation, therefore success of use remains uncertain or unknown.

Despite the variability in findings, properly designed tunnels/culverts continue to be promising as conduits for amphibians, as well as other wildlife species. An understanding of the target species crossing locations, "wildlife infrastructure" requirements that must be met, and road infrastructure requirements and issues, is important in increasing the likelihood of successful use of tunnels/culverts by the target species. The sections that follow provide a review and evaluation of tunnel design elements, and culminate in recommended tunnel design guidelines for consideration in highway design.

Tunnel Designs and Materials

Tunnel Designs

Table 2. Tunnel design.{ TC "Table 2. Tunnel design." \f C \l "1" }

TYPE	DESCRIPTION
One-way tunnel	Entrance: pit-fall trap Exit: opposite side. Travel is in one direction only, due to the inaccessibility of the entrance. The exit is orientated several feet above the ground surface with therefore limited entrance access at that end. To facilitate movement in both directions- two tunnels need to be set-up, running in both directions.
Bi-directional tunnel	One tunnel that allows travel in both directions (eg. drainage culverts).
Closed-top system	This type of tunnel does not have any opening in its structure, except for the entrance/exit ends.
Open-top system	This type of tunnel has openings, usually in form of slots or grates long the top of the tunnel.

Preference was originally given to the one-way system due to its success at Etang de Sepey, Germany; a long-term study of a one way system (Ryser and Grossenbacher, 1989). However, bi-directional tunnels are in use and being used by amphibians, as reviewed in subsequent sections.

Tunnel Materials

Materials used for tunnels have included PVC plastic, corrugated steel culverts, concrete and ACO polymer concrete (Chan, 1993). There has not been much research on the effectiveness of these materials. Issues that have been cited are the higher conductivity of steel in the cold and the tendency of concrete to flake off and become ingested by animals (Chan, 1993). The ACO Polymer Concrete wildlife tunnel has been used most extensively in Europe, primarily for toads. Details of the tunnel system materials are provided in (www.acowildlife.co.uk, and www.acowildlife.co.uk). While the ACO polymer concrete is marketed as having benefits in terms of longevity and ability to clean, the small diameter of the tunnels (0.2 to 0.5 metre) and mixed results with the use of 0.2 m tunnels by Spotted Salamanders in the US. (Jackson, pers. comm.. 2002) render them problematic for application in major highway settings. The tunnel units require shipping from Germany, which has logistical and cost considerations.

There is no reason not to consider concrete or CSP type tunnel materials, which are readily obtainable locally. An amphibian tunnel system that is to be used for permanent use should enable migration of adults to breeding ponds, migration after breeding and migration of emigrating juvenile animals (Podloucky, 1989). A tunnel system's effectiveness often depends on many variables including, size, placement, light, temperature, moisture, substrate, vegetative cover and noise levels (Jackson and Griffin, 1998). Effectiveness refers to the utilization of tunnels by wildlife, for the purpose of crossing a roadway.

The variables that affect a tunnel system's effectiveness are reviewed in the text that follows. The results and comments corresponding to each variable mainly deal with amphibians, but other animals are mentioned.

Tunnel Dimensions

Length and Width/Diameter

- **(Rodriguez et. al., 1996). Spain- railway line**. In this study, 17 culverts (non-wildlife passages) were monitored for crossing use (1571 passage days sampled). The lengths of these culverts ranged from 16-64 meters. It was found that reptiles used larger culverts (~2-4 m wide), compared to small mammals, which tended to use smaller cross-sections (equal or less than 2 m wide). It was postulated that the reasons for preference may be better thermoregulation for the reptiles and lower predation risk for the small mammals (larger predators unable or unwilling to go through smaller culverts).
- **(Krikowski, 1989). Etang de Sepey, Switzerland. Average tunnel diameter = 0.3 m.** Experiments showed that tunnels up to 42 m in length do not prevent amphibians from crossing through these systems.
- **(Clevenger and Waltho, 2001). Banff National Park- TransCanada Highway**. Average culvert length = 43 m. This study looked at 24 drainage culverts on 11 sampling days during the winter months. It was found that small dry drainage culverts (0.5-1.0 metre diameter) were preferred by medium and small mammals (eg. mice, hares, weasels), except for coyotes and shrews.
- **(Dexel, 1989). Germany.** This study tested 12 different tunnel systems under standardized conditions (all 15 metre lengths, closed top systems (no grates). It was found that a larger proportion of toads used large tunnels (diameter 1 metre), compared to use of the smaller tunnels (diameter 30 cm). However, the smaller ones were not completely avoided.
- **(Van Haften, 1985 as cited in Rodriguez *et al*., 1996).** Badgers were observed traveling through tunnels as small as 25 cm in diameter.
- **(Yanes et. al., 1995). Spain- 17 culverts under roads and railways.** Small and medium sized mammals (eg. rabbits, foxes, wildcats) use of culverts was negatively correlated with road width and culvert length. The longer the tunnel, the decrease in its use by animals.
- **(Jackson, 1996).** To alleviate the negative effect long tunnels may have on amphibian migration, medians could be used and enhanced, creating a stopover habitat halfway across a wide road. More research needs to be done to determine whether a long tunnel versus shorter tunnels with a medium strip would be more effective in moving animals across wide highways.
- **(Jackson, 2002 pers.com.)** A box culvert may have some advantages over a circular culvert because it may help some animals (such as turtles and toads) by providing a straight wall boundary to follow. Turtles can sometimes become disoriented in a circular tunnel.

<u>Comments by Researchers</u>

- During Dexel's discussion in (Langton, 1989a), Podloucky suggested that a tunnel diameter of 1 metre is optimal, because this size allows large mammals like foxes to pass through as well as amphibians, reptiles and other smaller animals (thereby providing use by multiple species). Dexel agreed with this comment.
- **(Brehm, 1989).** Tunnels designed for amphibian and other small animal use should have a diameter of at least 1 metre. If the road embankment does not allow for a tunnel this large, an ACO tunnel system (diameter = 0.2 metre) can be used.
- **(Beir and Loe 1992; Rodriguez et. al., 1996; Rosell et. al., 1997).** The low visibility related to small culvert aperture (related to diameter) is believed to inhibit the passage of

lagomorphs and carnivore species.

Conclusions

- Amphibians (and other species) will use tunnels that are relatively long (exceeding 40 m) and narrow, but preference was identified by some researchers for a tunnel diameter of about 1 metre to facilitate multi-species use. There is some evidence of differential use of various tunnel sizes by some species, and a suggestion that reptiles may benefit from larger size tunnels (improved thermoregulation).
- There may be a tunnel length limit beyond which wildlife use will be hindered or prevented. Such a limit has not been identified in research work to date. However, consideration of median stopovers to reduce the effective length of tunnels has been raised.
- A box or rectangular tunnel may reduce the potential for some species to be come disoriented (such as can occur with attempts to climb circular walls) and may assist in directing species more quickly along the structure. However, a variety of amphibian species (including salamanders) have successfully used circular tunnels.

Openness

Openness refers to the ratio of the cross-sectional area of the tunnel relative to its length under the roadway. Structures that are very long and narrow provide low openness, and may be constraining for some species.

- **(Clevenger and Waltho, 2001). Banff National Park- TransCanada Highway**. **Average culvert lengths = 43 m**. Culverts with low openness were preferred by all mammals except coyotes and shrews. Again, no amphibian or reptiles were recorded using the tunnels in this study.
- **(Reed et. al.**, **1975; 1979; Foster and Humphrey, 1995).** For some species, openness is more important than absolute size. These studies looked at underpass systems (excluding tunnels) under highways and their use by deer, panthers and other medium to large size wildlife. Guidelines were provided for underpass dimensions that were considered suitable for species as large as deer (at least 4 metre height and width, minimize length to extent possible, provide dirt floor – Reed et. al., 1975).
- **(Jackson, 2002 pers.com).** Openness ratios have mainly been applied to large ungulates (deer) structure design. No data have been advanced to date concerning desirable or minimum openness ratios for amphibian tunnels. However, he has advanced the opinion that "see-throughness" of a tunnel is important for amphibians and reptiles – a tunnel design that enables the animal to "see through" the structure without excessive climbing or descending, and that provides enough of an opening to enable ambient light conditions to guide the movement, will have a higher likelihood of success.

Conclusions

- Openness ratios are applied to structure design in relation to larger mammals. No desirable or minimum ratio has been developed to date for amphibian tunnels.
- Standardized tests specifically looking at the effect of tunnel openness on amphibian use have not been undertaken. Consequently it is difficult to draw specific conclusions based on the range of amphibian use of different tunnel dimensions identified in the literature.
- A tunnel design that enables the animal to "see through" the structure without excessive climbing or descending, and that provides enough of an opening to enable ambient light conditions to guide the movement, will have a higher likelihood of success.

Tunnel Orientation

- **(Chan, 1993). Referring to garter snakes and culvert use.** By installing culverts closer together, snakes would not have to be diverted long distances from their intended routes along fences. However, concentrating culverts in potentially high mortality areas would be a practical solution with long stretches of highway.
- **(Ryser and Grossenbacher, 1989).** Tunnels should not be more than 50 m apart, in order to minimize the amount of redirected travel from an animal's natural path.
- **(Jackson, 2002 pers. comm.)** With respect to species such as Spotted Salamander, **a** key factor facilitating amphibian use of a tunnel is the presence of adequate light, which can be influenced by the orientation of the tunnel entrance. For example, if the entrance is located in a depressed gully, the light from the other side is obscured from view unless the animal is oriented immediately adjacent to the entrance. The "see-through" nature of the culvert is affected by the tunnel orientation under the road.

<u>Conclusions</u>

- Concentrating tunnels in areas of high mortality, or in areas where focal movements have been documented is a recommended approach to increase the likelihood of use by the target wildlife species.
- Tunnels should not be spaced so far apart that animals require extensive re-directed travel to reach them. The fencing review provided below provides specific guidelines on the extent of funnel fencing to be provided to facilitate this objective.
- Tunnel orientation to maximize "see-throughness" is probably one of the most important factors in increasing likelihood of successful use by salamanders.

Fencing and Orientation

Fencing Materials

- A fence, when used in conjunction with a tunnel system, functions to direct animals towards the tunnel and/or pit-trap system entrance and therefore across a road.
- **(Chan, 1993).** There are many factors that may influence the effectiveness of a fence. These factors include fence materials, design, length, height, orientation and durability. Cost plays a large role in the final decision process.

Table 3. Possible Fencing Materials used for Tunnel-Fence Crossing Systems (Chan, 1993). **{ TC "**Table 3. Possible Fencing Materials used for Tunnel-Fence Crossing Systems (Chan, 1993).**" \f C \l "1" }**

TYPE	DESCRIPTION	ADVANTAGE	DISADVANTAGE
Reinforced Plastic	Reinforced polyethylene sheeting	Slippery, little traction for climbing, low cost	Susceptible to wind damage
Window Screening	Fibreglass or Aluminium screening	Perforated design- resistant to wind damage	Re-installed twice/year- not susceptible to cold, high cost
Plastic Mesh Netting	High density polyethylene (diamond/square meshes)	Available in different densities, non-toxic, durable in wind and cold temps.	High cost
Hardware Cloth	Perforated cloth	More pliable than window screening	Durability unknown (not often used for long distances)

TYPE	DESCRIPTION	ADVANTAGE	DISADVANTAGE
TerraJute Fabric (KPN International)	Woven, polypropylene fabric 2.5 ounces (70.87g/sq yard)	Low Cost	Photodegradable, fraying occurs from cutting, sewing of strips
*ACO Fencing	Recycled plastic	Permanent structure. Arch design allows animals to escape over fence from road side	High Cost, unknown durability in cold climates
Retaining Walls	Stone, brick.	Permanent. Noise reduction from traffic, low maintenance	Drainage concerns-possible built-up of water along walls – must be considered in the design.

- **(Jackson, 1997, pers. comm.. 2002).** Funnel fencing can be constructed out of concrete, granite curbing stone, or other materials. The fencing should be at least 45 cm high. The retaining wall fencing should be durable, relatively maintenance free, and smooth enough that salamanders and turtles cannot climb it. Funnel fencing walls should be as straight as possible. Angles and kinks tend to confuse turtles.
- **(Region of York, 2002).** Armour stone funnel walls have been implemented at the Bayview Avenue frog crossing structures at the Forester and Snively Wetland areas. The Region is also experimenting with sheet piling and timber funnel walls at amphibian culverts located on Bathurst Street.

<u>Conclusions</u>

- Durability (for example, ability to withstand winter snow piling), ease of maintenance, and functionality (funnels animals without excessive bends, surface difficult for amphibians or turtles to climb) are the key aspects of the fence material that are important to both the road maintenance authority and the target wildlife.
- A variety of fence materials can be considered, but it is recommended that permanent fencing be employed, with concrete, armour stone, curb stone, wood or sheet metal piling all suitable for use.

Fencing Characteristics and Orientation

- **(Jackson, 1996).** Funnel fencing used in this work in Massachusetts worked relatively well in amphibian funnelling. This study reported that 68.4% of the spotted salamanders that encountered the fence successfully located a tunnel and passed through. In this case temporary drift fencing was employed in the experiment, with fencing angled from the tunnel and about 10 m in length.
- **(Ryser and Gossenbacher, 1989; Meinig, 1989).** Fencing is not always effective, or can pose some problems. Amphibians have been reported stalling at fences and remaining motionless for long periods of time. It is postulated that fencing design may be related to its effectiveness.

<u>Conclusions</u>

- Fencing should be at least 45 cm high, and secured adequately to the ground surface to prevent animals from passing or tunnelling underneath.
- Fencing should ideally be angled away from the tunnel entrance to maximize the funnelling effect to the tunnel. Angles of 60 to 80 degrees have been identified. However, the ability to maximize fence angle will be influenced by the amount of right-of-way (ROW) available for fence installation. Extending fencing beyond the ROW is

problematic because of different land ownership/jurisdiction with associated maintenance and liability issues. The operative guideline will be to maximize the angle of fencing that is practical within the ROW area available.

- Extending fencing from 30 to 50 m beyond the tunnel entrance is recommended. This range should effectively funnel amphibians to the tunnel without requiring excessive movement that might deter amphibians (or reptiles) from following the wall to the tunnel.

Table 4. Fencing design features.**{ TC "**Table 4. Fencing design features.**" \f C \l "1" }**

DESIGN FEATURES	COMMENTS
Amphibian/reptile lip U.S. 441 project	This wall was designed to divert animals (alligators, amphibians and other wildlife to eight highway underpasses in Florida. The 15.2 cm "lip" located at the top of the concrete wall is designed to inhibit snakes, frogs, alligators and other small animals from attempting to scale the wall. In an attempt to get over this "lip", the creatures fall backwards. This type of concrete wall structure is very expensive (Weimer, as cited in www.fhwa.dot.gov/environment/wildlifecrossings/amphibin.htm)
Curved Fence ACO Fencing System	This wall is concave in design on one side, acting to detour animals from crossing over. The roadside of the fence is convex, aiding animals to cross over, in cases when they become trapped between fences on the roadway. www.acowildlife.co.uk/product_f/fence.html
Zigzagging	**(Langton, 1989a).** Fencing should be zigzagged, allowing for an angle of about 60 degrees at culvert/tunnel interface. This helps to funnel the animals into the crossing area. **(Jackson, 2002 pers.com.).** Angled fencing offers the shortest possible route to the tunnel, therefore more tunnel encounters are likely.
Amphibian/small mammal considerations	**(Jackson and Griffin, 1998).** Fences for smaller animals like amphibians, must be designed so as to not allow these creatures to slip or dig underneath the bottom of the fence. In many cases the material can be buried in the soil. Using a short retaining wall is often effective for these reasons. They work well, keeping reptiles, amphibians and small animals from crossing over
Length	**(Jackson, 1996, pers. comm.. 2002). Amherst, MA. - Henry Street.** Spotted Salamanders that encountered the fence further from the tunnels, (30 to 40 metre distance) were as equally successful at reaching tunnels. These fences were placed in a zigzagged fashion, helping to funnel these salamanders creatures to the tunnel entrances. **(Jackson, 1997 and pers. comm.. 2002).** Fencing should be provided as a vertical retaining wall extending for a length of 100 to 150 feet (30 to 50 m) for an amphibian and reptile tunnel design suitable for species such as Spotted Salamander.
Height	**(Meinig, 1989). Wuppertal, West Germany - 2 year study.** A plastic mesh fence helped to funnel 84.9% of small animals through tunnels. However, the fence was too high (1.0m) for hares or hedgehogs to climb, and the tunnels were too small (0.2 m) for these animals to fit through. Height can be a critical variable.

Microclimate

Microclimate refers to climatic conditions inside the crossing structure. This is directly and indirectly affected by temperature, humidity, wind, light and substrate. Amphibians require particular consideration in this regard, particularly salamanders, because of their slow movement and requirement to maintain moist skin conditions. Dispersing juveniles can be particularly susceptible to desiccation when moving through a tunnel, particularly a long one. Poor microclimatic conditions within a structure may deter individuals from using it, or may result in hesitation and undue delay in moving through the structure.

Moisture/Temperature

- **(Langton, 1989). ACO Q200 tunnels.** 'Tunnel hesitation' was observed with most toads, particularly at the start of migration (tunnel temperatures were colder than air temperature within the 20 cm diameter tunnels). Individuals would slow down within a meter of the tunnel entrance and those that managed to enter, slowly or quickly retreated from the tunnel. The reasons for hesitation could be due to localized temperature/light differences existing at the tunnel entrances. Small underpasses may create temperature disparities that deter amphibians from moving through the tunnels.
- **(Jackson, 1996, pers. comm.. 2002).** Amphibians require moist conditions for their migration, therefore a crossing system environment must have a mechanism to allow rainwater to enter and moisten the soil. This can be accomplished by use of grates or slots along the top of the structure (ideally all along, but can consider partial slots or openings at strategic locations), or by providing enough water to move through the tunnel during wet nights without excessive ponding or flooding. Jackson acknowledges that the issue of noise and introduction of contaminants from the roadway into the tunnel via open slots or grates has not been addressed or evaluated to date, and implications of this risk on amphibians are not known (although not expected to be significant relative to the time animals spend moving through the tunnel). It was acknowledged that open grate structures would require periodic maintenance, and that road authorities in Massachusetts are resistant to implementing open grate/slot tunnel systems that are installed flush with the road surface because of issues such as frost heave and snowplow interference.

<u>Conclusions</u>

- Provision of adequate moisture in the tunnel environment is considered particularly important for amphibians, particularly salamanders. This may be accommodated by providing a tunnel structure with slots or grates along the top (all along or strategically located), or by providing enough water to move through the tunnel during wet nights without excessive ponding or flooding. There is some thought that maximizing exposure to ambient air with slots will assist in reducing temperature difference between the tunnel and the outside air. Alternatively, providing a larger tunnel structure (with or without slots) may facilitate this objective. Unfortunately, there has not been sufficient research in this area to date that identifies an optimal tunnel size or configuration for ensuring that temperature/humidity changes within the tunnel are minimized.
- Provision of grates or slots in the top surface of the tunnel is appealing because it enables ambient light and rainfall to filter into the tunnel and presumably reduces the temperature/light differential between the tunnel and the outside. However, periodic maintenance and clean out of debris is required. In addition, provision of a break in the roadway pavement to accommodate the tunnel grate system introduces frost-heave design issues and the potential for shifting of the structure that could interfere with roadway maintenance (such as snow removal). Clearly, there are challenges/issues

relating to wildlife infrastructure and roadway infrastructure needs that are not necessarily the same, and that require creative thinking to resolve.

Substrate

- **(Yanes et. al., 1995). Spain- 17 culverts under roads and railways.** In this study, the ground surface of the culverts used was mostly covered with soil and debris, deposited by water flows. Small mammals, rabbits, reptiles and carnivores passed through these culverts. This may have been a factor in their acceptance.
- **(Mansergh and Scotts, 1989).** Some small animals like possums, have specific substrate requirements, and special attention may be required at wildlife crossings.
- **(Jackson, 1997 and pers. comm.. 2002).** Ideally, sandy soil should be used to cover the bottom of the tunnel and to provide a more natural substrate for salamander and reptile travel. Either an open bottom structure could be employed, or the required substrate could be placed inside the structure. Tunnels should be placed to avoid flooding and excessive flow through of water.
- **(Chan, 1993).** Provision of natural substrate was considered important for garter snake use of culverts, both as natural material and to assist snakes in providing traction for movement over the surface.
- **(Bogart, pers. comm. 2002).** There is evidence that scent (odour) is important in salamander migration. Consequently, utilizing native, local substrates in the tunnel bottom is probably important in helping to maintain scent familiarity. Utilizing non local and non native substrate material may hinder this objective.

<u>Conclusions</u>

- Provision of a natural base within the structure, such as sandy soil, is considered important for movement by a range of wildlife species, including amphibians and reptiles. Natural substrates provide both a firm and familiar medium for movement, and assist with moisture retention which is particularly important for reptiles and amphibians. Use of local native substrates in tunnels is also considered important in maintaining migration scent familiarity for salamander migration.
- Tunnel placement should be such as to avoid flooding and excessive flow through of water. These conditions may deter movement by amphibians. They might also erode and wash out tunnel substrates, resulting in a less conducive environment for animal movement.

Light

Role of Light and Light/Dark Zones in Amphibian/Reptile Use of Tunnels

- **(Jackson, 1996)**. Amherst, MA- ACO tunnels. Spotted Salamander study: Volunteers shone 2 flashlights, one at either end of the tunnel. Hesitant salamanders responded by moving through the tunnels once the lights were introduced. The preliminary conclusion from this anecdotal test was that light had a role to play, however sufficient data have not been collected defining this role further. Jackson concluded that tunnel diameter should be increased (greater than the ACO 20 cm diameter tunnel), and suggested that design feature such as grates be considered rather than slotted tops to permit more ambient light penetration.
- (**Chan, 1993).** Narcisse Wildlife Management Area, Manitoba Garter Snake study: corrugated steel culverts- 0.92 m high, 1.46 m wide Used 2 different hand-held light intensity sources, one in front of the other in the tunnel, to mimic a gradual change in intensity. During Phase 1 of the experiment, lights were placed between the middle

and end of the culvert. During Phase 2, the lights were placed between the middle and the culvert entrance. In both cases, the presence of light had little noticeable effect on snake behaviour. Chan postulated that using a higher intensity light may give different results (for snakes specifically).

- **(Langton, 1989b).** Langton observed many toads and frogs turning back after pausing at a tunnel entrance. Many of these toads returned later to try entering the tunnel again. Langton postulated that differences in light and temperature within and outside the tunnel were the cause for hesitation.
- **(Naylor,** http://eqb-dqe.cciw.ca/partners/carcnet/spotted_turtle_tunnel.html.**)** cites JCK and Associates as indicating that certain species of wildlife, especially turtles, do not like to cross through dark tunnels for safety reasons.
- **(Jackson and Marchand, 1998)**. In a test of a prototype tunnel acting as a simulated underpass system, a 2 foot by 2 foot by 20 foot wooden tunnel (0.5 m by 0.5 m by 6 m) was constructed and placed in an area to intercept female painted turtles as they moved from wetland habitat to an upland nesting area in western Massachusetts. Drift fences 40 m in length were used to funnel turtles to the tunnel. Of the 20 turtles that reached the tunnel all 20 successfully passed through, in an average time of 113 seconds. No grates or slots providing additional light were installed in the prototype tunnel.
- **(Krikowski, 1989). Etang de Sepey, Switzerland.** Amphibians: Tunnel dimensions: 30 cm diameter, length =12 m. In a one-way tunnel system, 1 metre of drift fence on either side of the tunnel was covered, reducing the light entering the tunnel entrance by 100 percent ('dark-light zone'). This was done to darken the pit-trap entry area so that amphibians would not see the pitfall edge. It was also assumed that the dark zone helped to orient amphibians to the only source of light at the tunnel exit. The experimental results showed that the dark-light zone had no negative effect on amphibian movement. Kirkowski also cited work in Kippenheim, West Germany using 0.8 metre diameter one-way amphibian tunnels with pitfall traps. While monitoring the effectiveness of a one-way tunnel system, with deep/steep pitfall traps, it was found that the animals were disoriented and tried to climb out of pitfall traps after falling in. It was suggested that a light-dark zone would help to prevent animals from trying to climb out entrance, and instead travel to tunnel exit.

Comments by Researchers

- During the Krikowski (1989) Discussion Section at the conference, some researchers argued that a dark zone is probably not important for animals that normally move at night, including frogs, toads and newts. It was also pointed out that a tunnel system incorporating slots or grates in the top of the structure would allow ambient light in, thereby making it difficult to achieve a 'light- dark zone'.

Conclusions

- The role of light in wildlife (particularly amphibian/reptile) use of tunnel/underpass systems is still not well understood. Agreement on this matter is not evident in the research community. Amphibians and reptiles have been documented using tunnels that do not have top-mounted slots or grates for light penetration. However, response by amphibians to flashlights at the tunnel exit suggests that some form of light cue at the exit is important. Whether this needs to be provided by provision of dedicated lighting (which has maintenance and vandalism implications), fibre optics, or through over-sizing structures to maximize relative openness and apparent light at the exit, is not clear at present. Further testing in this area would be helpful, as would further monitoring of existing tunnels/underpasses that are in place. In the interim, providing a larger rather than a smaller tunnel/underpass (minimum 0.9 to 1 metre diameter) would appear to be recommended.

Vegetation

Implications of Vegetation Associated with Tunnel Systems

- **(Ryser and Grossenbacher, 1989).** Commented that overhanging vegetation served as a bridge for juvenile frogs to climb over the fence at tunnel entrances in Switzerland. Consequently, provision of vegetation at tunnel entrances may be problematic by increasing the chance some species may use vegetation to by-pass the tunnel and reach the road.
- **(Ryser and Grossenbacher, 1989).** Indicate that many researchers have found that the presence of tall grasses along the fence barrier deters amphibians, especially juveniles, from moving alongside the fencing.
- **(Clevenger and Waltho, 2001). Banff National Park- TransCanada Highway**. Average culvert lengths = 43m. The distance between the tunnel and vegetative cover was a significant factor determining the passage of voles, coyotes and weasels through tunnels (negative correlation). It was postulated that increased cover at passage entrances provides protection and security for animals.
- **Rodriguez et. al., 1996). Spain- railway line**. In this study, 17 culverts (non-wildlife passages) were monitored for crossing use (1571 passage days sampled). Carnivore crossing rates were highest through vegetated tunnel entrances. Vegetation had no effect on the passage of reptiles, small mammals and lagomorphs.
- **(Yanes et al., 1995).** Cited Bennet, 1991 and Carsignol, 1991 in suggesting that artificially increasing the amount of vegetative cover at tunnel entrances, helps to funnel animals to these areas.
- **(Jackson, 1997 and pers. comm.. 2002).** Entrance pads at each end of the tunnel should have stable slopes with no greater than a 50% grade. Entrance pads may be hardtop or natural, but if natural, vegetation should not be allowed to grow up to the extent that it blocks or inhibits animal passage.
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<u>Conclusions</u>

- While there is some suggestion that vegetation may assist with wildlife funnelling, concerns have been raised by researchers that maintaining or providing tall vegetation along funnel fencing or at tunnel entrances can impede amphibian movement, and can facilitate escapes (by climbing vegetation) to the roadway. Provision of dense vegetation near a tunnel entrance likely benefits predators to a greater extent, by providing cover for ambush. For these reasons, and given the fact that salamanders during this study are migrating across open fields (in part), reliance on vegetation for funnelling or shelter at the tunnel entrance does not appear warranted. Discussions with Scott Jackson (2002) suggest that design should focus on providing as unimpeded a route as possible for amphibians (and reptiles) moving to a tunnel/underpass facility.

Predation

Predation Issues Associated with Tunnel Systems

- **(Reading, 1989). Portland, England.** This study showed that there was an increase in the predation of common toads at pitfall/fence sites. The total number of toads caught in the traps remained relatively constant for the 2 year study. However, there was an 86% decrease in numbers caught and an increase in the number of corpses found after this time. Therefore opportunistic predation may occur when amphibians are concentrated together, whether in traps or while using tunnel systems.

- **(Rodriguez et. al., 1996).** Found that small mammals preferred narrow passages. This finding may be related to the fact that potential predators could not fit through the tunnel.
- **(Van Haften, 1985 as cited in Rodriguez et. al., 1996).** Badgers have been known to travel through tunnels as small as 0.25 m in diameter.
- **(Jackson, pers. comm., 2002).** Predation can be a problem, but is often site-specific and usually unpredictable. Jackson's observations to date have not indicted significant predation problems at the tunnels he has worked with. Tunnel design to accommodate a range of wildlife species is preferable than focusing on single species design. While larger tunnels may enable predator access, provision of smaller tunnels that do not work well or that even hinder amphibian use may have a more significant effect on amphibian populations than predation concentrated at a tunnel/underpass.

Conclusions

- Predation is always a risk, but is often site-specific and unpredictable in nature. Focusing on very small tunnels/underpasses to restrict predator entrance is problematic, because predators can still sit at the tunnel entrance, some predators can still utilize small tunnels, and small tunnels can lead to microclimate challenges. Small tunnels also tend to exclude use by a suite of wildlife species. Providing a tunnel design that can be used by a range of wildlife species, and that has a reasonable likelihood of being used by particular target species is considered more important even if it can be used by predators. As noted above, a tunnel design that is intended to exclude predators runs the risk of being inhospitable for salamanders, creating a greater risk (by providing a potential barrier to use) than the possible predation risk.

Noise

- **(Meinig, 1989; Krikowski, 1989).** Amphibians are known to hesitate when vehicles travel over an ACO open slot tunnel system but continued through the tunnel. The ACO concrete polymer is identified as providing some noise cushioning because of the nature of the materials.
- **(Jackson and Griffin, 1998).** Open-top systems are noisy (grates) and inappropriate for species that are sensitive to noise. However, there was no reference to specific species considered noise sensitive, and no conclusion was provided concerning salamander sensitivity to noise.
- **(Jackson, pers. comm., 2002).** An open grate system is considered to provide advantages in terms of transmitting ambient light and rainfall, however vehicle noise is an as yet unevaluated factor. In Jackson's opinion, adequate light (tunnel "see-throughness") and moisture (however provided) are key factors to be considered as reviewed earlier. Noise continues to be an unknown variable in considering tunnel/underpass design.

Conclusions

- Noise effect observations appear to be mainly anecdotal in nature. Some noise can be anticipated in any underpass, with or without grates/slots, and the degree to which such noise will hinder or inhibit amphibian movement is still somewhat conjectural. Hesitation and "freezing" may occur with noise/vibration, but is not likely to be a major concern if movement continues shortly thereafter. Noise can be anticipated to be heightened somewhat with a top grate/slot system with pavement gaps, similar to the vehicle sound across expansion joints. Given the continued uncertainty regarding noise effects, design should be focused on addressing issues such as tunnel "see-throughness" and moisture. Benefits and challenges associated with open grate systems have been reviewed earlier.

Drainage Implications

In this section, drainage refers to tunnel flooding and flow through of water, too much of which may make the structure unusable or less attractive to species such as salamanders. Ditch drainage design implications are also considered.

Structure Flooding and Ditch Drainage

- **(Campbell, 1973).** During storm events, roadside ditches can fill up with water, creating pools that amphibians may be use for spawning purposes. These pools are often contaminated with sediments and oils, and can dry up quickly. This disturbed environment cannot support egg development. Ambystomid salamanders have been observed using silty, murky roadside pools. These animals require clear spawning pools with leafy or grassy bottoms to attach their eggs.
- **(Langton (1989b, discussion by Ahlmann)**. Open top systems allow rainwater to enter but flooding can occur. Sloping roads and heavy rainfall can cause tunnels to be flooded with up to 10 cm of water with ACO tunnels, which would deter amphibians. A parallel drainage pipe placed 1 metre from the crossing tunnel would help flooding problems. Langton (1989b) noted in the discussion that expanding plastic foam can be sprayed into slots of the ACO system, to reduce water flow in areas where needed.
- **(Jackson, 1997 and pers. comm., 2002).** Tunnels should be placed to avoid flooding and flow through of water. Special care should be taken to prevent water from running down the road shoulders and entering grates (if a top grate system is employed), or from running along the retaining wall fencing and collecting at the tunnel entrance. A dry will can be placed at both entrances to avoid pond buildup if required.

Conclusions

- Roadside ditches should be designed for attenuation and positive drainage, with no excessive ponding. This will reduce their attractiveness as potential breeding areas for salamanders and other species (in sub-optimal habitat).
- Tunnel design should avoid flooding and high velocity flows, either from surface grates or diverted roadside runoff. The goal should be moist substrate within the tunnel, to reduce risk of desiccation as salamanders move through the facility.

Other Mitigation Measures

Human Carry-over

- In extreme cases, where peak amphibian migration events across roads are known, human carry-over has been employed in which animals are live trapped (pitfall traps/fence systems) and transported across the road. For example, in Hungary, 1988, the Toad Action Group (TAG) transported 8600 amphibians across a single site on a highway (http://eqb-dqe.cciw.ca). This kind of effort is labour intensive and requires considerable coordination.

Signs and Traffic Controls

- The "Toads on Roads" program was originally developed by Langton in Britain. This program incorporated wildlife warning / crossing signs, slow speed zones and temporary road closures to help protect amphibian populations from the effects of road barriers. These measures have typically been used prior to the installation of tunnel systems (http://eqb-dqe.cciw.ca).

Conclusions

- Live trapping and carry-over have been employed in special circumstances involving very large numbers of migrating amphibians. It is labour intensive and requires considerable coordination. Provision of permanent crossing structures with funnelling is a preferred solution if properly located, designed, and implemented.
- Wildlife tunnel facilities cannot guarantee 100% funnelling of amphibians. Wildlife warning signs for motorists could supplement crossing facilities by alerting motorists to the possibility of amphibians (or reptiles) on the road in the vicinity of a crossing area.

Tunnel Design Guidelines

Based on the above review, tunnel and funnel design guidelines are provided in Table 5.

Table 5. Tunnel Design Guidelines.**{ TC "**Table 5. Tunnel Design Guidelines.**" \f C \l "1" }**

Factor/Issue	Amphibian Infrastructure Needs	Roadway and Other Implications	Suggested Approach
Two-way or one-way tunnel design.	Perceived safe and secure underpass crossing.	One-way design requires two structures, is amphibian specific, more complex, and doe not facilitate larger wildlife. Two-way design less expensive (one structure), more practical, and shown to work.	Implement two-way design (single tunnel with entrance and exit).
Dimensions	Adequate openness – perception of an exit.	Very small culverts reduce amount of road fill, but concerns raised more recently about salamander hesitation/aborts at very small tunnels. Larger structure requires more fill, adds to cost, but improves openness and facilitates use by range of wildlife species.	If open grate system employed, culvert could be smaller due to additional ambient light (Minimum 45 cm). If closed system used, or grates minimized, suggest larger tunnel – minimum 1 to 1.5 metre diameter.
Tunnel Shape	Facility that promotes directed travel as quickly as possible.	Tunnel shape can influence cost considerably (circular CSP or square/rectangular concrete, for example).	Circular tunnels are used by salamanders, so circular or box shape (or combination of both) can be employed. Box shape may direct movements better, and is often employed along highways.
Tunnel Length	Avoid excessively long, dark tunnel environment with no perceived exit. Amphibians will use tunnels at least 40 m in length.	Tunnel length influenced by ROW size. Shortening tunnel (where possible) can assist in this endeavour, coupled with adjusting tunnel size.	Maximizing openness and light in the design will help to reduce effective tunnel length. Make longer tunnels larger to compensate.
Tunnel Orientation	Unobstructed view of entrance and exit – maximize “see-throughness” of the facility.	The entrance/exit of a tunnel should not be obstructed from view or passage. This can occur when its location is in a depressed area or is hidden by excessive vegetation.	Orient tunnel under roadway in manner that maximizes entrance and exit views when amphibian reaches the entrance area.

Factor/Issue	Amphibian Infrastructure Needs	Roadway and Other Implications	Suggested Approach
Funnel Fencing	Must guide the animal to the tunnel with minimal kinks or other obstructions and with minimal out of the way travel.	Angled fencing is recommended, but extent of angle governed by width of ROW available. Extending off ROW may be problematic (ownership/liability)	Provide tunnel wingwall at 45 degrees to tunnel if possible. Angle funnel wall to extent possible within ROW limits. Maximum fencing length of 30 to 50 m recommended to reduce out of way travel to tunnel.
Fence Materials	Must be adequate to guide animals to the tunnel as above. Must be at least 45 cm high and secured to ground to prevent animals moving underneath.	Must be durable to withstand winter weather conditions, snowplow piling, and must be relatively maintenance free.	Use concrete, granite curbing stone, armour stone, sheet piling, or other solid materials in funnel fence construction.
Moisture and Temperature	Temperature and moisture conditions that mimic ambient conditions to the extent possible.	Open grate design assists with providing these conditions, but requires additional maintenance (clean-out). Grate system across the roadway must be designed to resist frost heave and is susceptible to possible snowplow interference.	Provide a tunnel structure with slots or grates along the top (all along or strategically located), If a closed structure is provided, increase the size to maximize air circulation and moderate temperatures.
Substrate	Natural substrate for traction and travel.	Material may come in naturally from runoff (if directed to tunnel) but may need to be added. Wash out from tunnel bottom is possible. Open bottom structure on native substrate avoids this concern.	Maintain natural substrate on bottom, either through providing/maintaining on structure bottom, or through use of an open bottom structure.
Light	Adequate light to enable perception of a tunnel exit.	Requires consideration of open grate or median grate system (see comments above) or larger tunnel sizing to facilitate exit light objective.	If a smaller (for eg. 0.45 metre) open grate system is not employed, provide a larger tunnel (min 1 to 1.5 metre or >) to increase relative exit brightness. Testing of supplementary exit lighting at tunnels is needed.

Factor/Issue	Amphibian Infrastructure Needs	Roadway and Other Implications	Suggested Approach
Vegetation	Unobstructed access to tunnel entrance and exit.	Vegetation along funnel fences can hinder amphibian movement. Vegetation at entrances/exits can obstruct amphibian orientation, provide shelter for predators, and provide travel route to roadway (by climbing vegetation).	Entrance pads at each end of the tunnel should have stable slopes (no > 50% grade). Entrance pads may be hardtop or natural, but if natural, vegetation should not be allowed to grow up to the extent that it blocks or inhibits animal passage. Keep fences free of obstructing vegetation.
Predation	Direct passage, clear area at entrance (may reduce predator attraction).	A tunnel design that is intended to exclude predators (by being very small) runs the risk of being inhospitable for salamanders and creating a greater risk (by providing a potential barrier to use) than the possible predation risk. Predator problems are often site-specific and unpredictable. Predation problems were not evident during the present study.	Providing a tunnel design that can be used by a range of wildlife species, and that has a reasonable likelihood of being used by particular target species, is considered more important even if it can be used by predators. There is no evidence in the literature that tunnel predation in the US is widespread or significant.
Noise/Vibration	If excessive, can result in freezing, but experimental data for salamanders are lacking.	Open grate systems are likely noisier, but they are used by amphibians, as are closed top systems.	Given the continued uncertainty regarding noise effects, design should be focused on addressing issues such as tunnel "see-throughness" and moisture.
Drainage	Adequate moisture in the tunnel to reflect wet migration conditions, and to reduce desiccation risk for dispersing juveniles.	Tunnel design needs to consider factors such as ditch or curb runoff, and runoff along fencing, to avoid flooding concerns. Ditch drainage design (avoid ponding) is also relevant.	Roadside ditches should be designed for attenuation and positive drainage, with no excessive ponding. This will reduce their attractiveness as potential breeding areas for salamanders and other species (in sub-optimal habitat). Tunnel design should avoid flooding and high velocity flows, either from surface grates or diverted roadside runoff.

APPENDIX 3: Construction of Artificial Gestation Sites Eastern Massasauga Rattlesnake{ TC "APPENDIX 3: Construction of Artificial Gestation Sites Eastern Massasauga Rattlesnake" \f C \l "1" } (MNR, Parry Sound)

Overview

Eastern Massasauga Rattlesnakes reach sexual maturity at four or five years of age. Courtship and mating take place in July and August, but fertilization does not occur until the following spring. Unlike many snakes, Eastern Massasauga Rattlesnakes do not lay eggs. Instead, the developing embryos remain in the mother's body until they are fully formed and ready to be born.

To understand the significance of gestation sites to Eastern Massasauga Rattlesnake reproduction, it is important to recognize that rattlesnakes, like all other reptiles, are ectothermic. This means that a rattlesnake's body temperature is not regulated by the use of metabolic energy but instead fluctuates with that of its surroundings. Since their metabolic rate is temperature-dependent, the snakes must maintain body temperatures of approximately 30 °C to achieve optimal physiological performance. This is especially important for gravid (pregnant) females to ensure the successful development of their embryonic young.

To control its body temperature, a rattlesnake alters its exposure to different thermal conditions, a process known as behavioural thermoregulation. A rattlesnake may bask in the sun to warm up or move into the shade to cool off. However, on cold, cloudy days and at night, these thermal options are unavailable, and a rattlesnake's body temperature eventually equilibrates with that of its surroundings.

A rattlesnake's choice of retreat site can strongly influence its ability to thermoregulate. Perhaps because of our relatively cool, short summers, Ontario's gravid Eastern Massasauga Rattlesnakes use characteristic gestation sites, which allow them to maintain warmer and less variable body temperatures than they would likely otherwise be able to.

Description of Gestation Sites

Gestation sites typically occur in open areas and are characterized by the presence of large (typically 2 x 1 m), flat (usually no more than 30 cm thick) rocks, often called table rocks, because of their shape. Due to their size and shape, table rocks are warmed by the sun during the day and slowly release the accumulated heat energy during the night. A rattlesnake that shelters under a table rock overnight can remain 5-10 °C warmer than the outside air temperature. The table rocks of gestation sites are generally surrounded by grass and low lying shrubs. During the day, this vegetation provides gravid females with a variety of thermal environments in which to bask, and also provides cover from potential predators.

Timing

Pregnant female Eastern Massasauga Rattlesnakes typically occupy gestation sites in mid-June and remain until their young are born, usually between late July and early September. Parturition dates are strongly influenced by weather conditions and may vary by as much as six weeks within a population from year to year. Newborn snakes disperse from the gestation site within a week of being born, but little is known about their movements following dispersal.

After giving birth, the female remains at the gestation site with her young for several days, although the newborn snakes receive no parental care. The female then migrates to a foraging area where she feeds for a few weeks before returning to her hibernation site. The limited feeding period between parturition and hibernation is insufficient for female rattlesnakes to regain the energy lost during gestation and birth. As a result, most females reproduce biennially, and forage in the intervening years.

A single gestation sites may be used by multiple snakes in a given year, and female rattlesnakes often return to the same gestation site each time they are pregnant. As a result, a single gestation sites may be occupied repeatedly in successive years by many different individuals.

Building Artificial Gestation Sites

The building of artificial gestation sites involves three stages, including the location of suitable construction sites, the selection, transportation and placement of table rocks, and the development of supplementary habitat (see Figure 2).

Selection of Sites

The selection of locations suitable for the building of artificial gestation sites is based on multiple criteria. The following factors should be considered:

- Artificial gestation sites should be constructed in landscapes that contain suitable Eastern Massasauga Rattlesnake habitat, such as marshes, fens and swamps, fields, grasslands and rock outcrops. Artificial gestation sites should only be constructed in open areas. In forested areas, clearings with a minimum 50 m east-west axis are suitable for the construction of gestation sites.
- To minimize the risk of disturbance to resident gravid females and to increase the probability of successful dispersal of newborn snakes, artificial gestation sites should be located a minimum of 100 m from areas routinely traveled or heavily developed by humans.
- To lift, move and place table rocks, heavy equipment, such as a mid-sized hydraulic excavator (e.g. Caterpillar Model 330B L) is required. Therefore, locations proposed for the construction of artificial gestation sites must be accessible. This requires that machinery can reach

construction locations without the need to traverse wetlands or steep grades. It may be necessary to fell trees to allow for the movement of heavy equipment, but this practice should be kept to a minimum.

- To reduce the costs of building artificial gestations sites, heavy equipment operating time should be minimized by limiting travel distances. Heavy equipment should be transportable by trailer to within 1 km of the construction site. To further reduce operating time, table rocks to be used in the building of gestation sites should be located within 500 m of the construction site.
- Artificial habitat should not be constructed in areas where high quality gestation sites already exist.

Selection, Transportation and Placement of Table Rocks

Three factors guide the selection of rocks for the construction of artificial gestation sites, including their size and shape, location, and existing location.

Size and Shape

Table rocks used in the construction of artificial gestation sites should be 1.5-3.0 m long and 1.0 - 2.0 m wide. At least 75% of the rock should be 20-40 cm in depth. If suitably sized table rocks cannot be located, artificial gestation sites may be constructed by placing two or three smaller table rocks side by side.

Location

To minimize heavy equipment travel distances, table rocks to be used for the construction of gestation sites should be located within 500 m of the construction site.

Existing Configuration

Natural gestation sites should not be destroyed to construct artificial ones. Only those table rocks whose existing configuration makes them unsuitable for use by rattlesnakes (e.g. heavily shaded or buried in soil) should be relocated to construct artificial gestation sites.

Transport of Table Rocks

Table rocks are readily picked up and transported in the bucket of a mid-sized hydraulic excavator. However, because of their shape, table rocks are easily broken and must be carefully lifted from and lowered to the ground.

Placement of Table Rocks

To maximize thermoregulatory opportunities for female rattlesnakes, artificial gestation sites should be constructed in areas where they will be exposed to sunlight throughout the day. Gestation sites built in forest clearings should be located near the centre of the clearings to minimize shading by surrounding trees.

To build functional gestation sites, table rocks must be positioned in such as way that rattlesnakes can shelter beneath them. Table rocks should be placed so that 2-10 cm of space remains between their lower surface and the ground. This can be accomplished by placing table rocks on top of a small depression in the ground or by resting table rocks on top of several smaller rocks.

To provide a variety of thermal environments as well as cover from potential predators, table rocks should be placed in locations that are surrounded on at least two sides by grass and/or low lying shrubs. In the absence of naturally occurring vegetation, supplementary habitat can be constructed (see below).

Table rocks should not be situated directly on bedrock. However, table rocks can rarely be placed in the desired position at first try, and the use of heavy equipment to manipulate them may lead to an accumulation of soil, moss, or vegetation that could block rattlesnakes from taking shelter beneath them. To prevent the accumulation of organic matter, care must be taken to place and manipulate table rocks to minimize the scraping and moulding of surface material. If necessary, excess organic matter may be removed from the position where a table rock is to be placed, although some material should be retained. To the extent possible, soil, moss, and vegetation surrounding the site of a table rock's placement should also be left intact.

Development of Supplementary Habitat

If table rocks are to be situated directly on bedrock, a sufficient quantity of soil should be spread under and around them before they are placed in their final position in order to support the growth of vegetation. In instances where table rocks cannot be placed in areas with naturally occurring grass and/or low lying shrubs, several large brush piles should be constructed within 1-3 m of the artificial gestation site to provide female rattlesnakes with opportunities for thermoregulation.

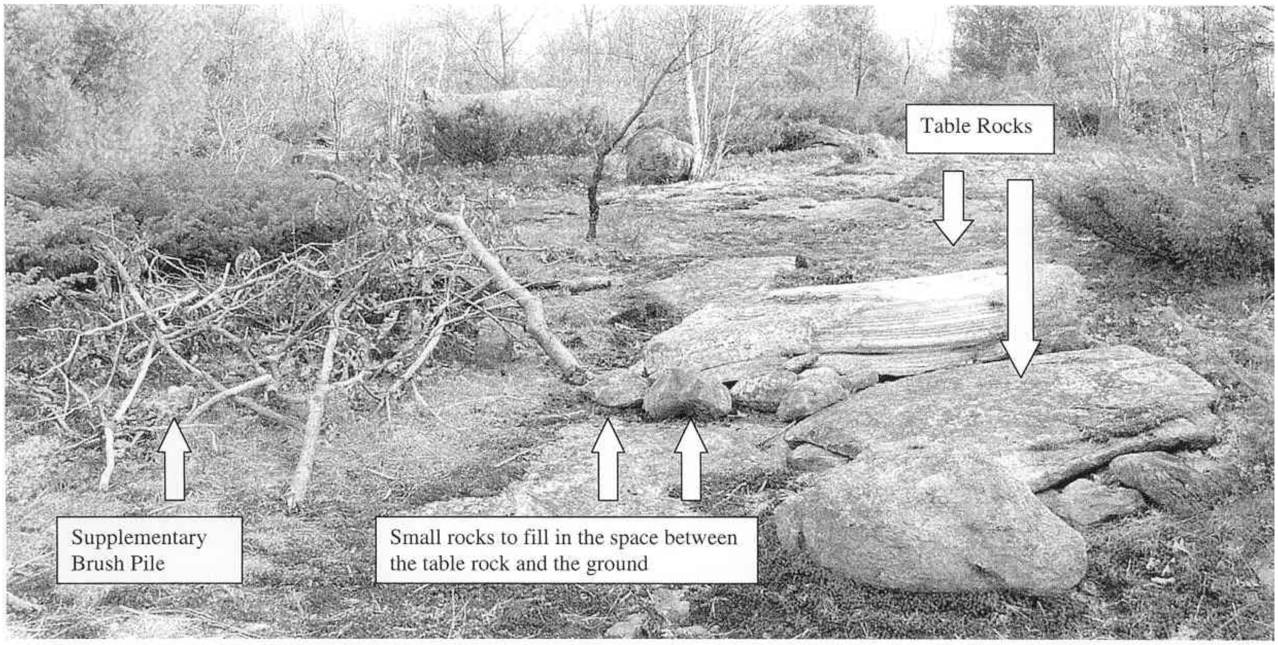

Figure 2. Pilot Gestation Site off Highway 69, Ontario. **{ TC "**Figure 2. Pilot Gestation Site off Highway 69, Ontario.**" \f C \l "1" }**

Once in position, large spaces (> 10 cm) between the edges of a table rock and the ground, or between adjoining table rocks, should be blocked with smaller (20-50 cm) rocks. These smaller rocks improve a table rock's ability to retain heat by limiting airflow beneath. They also prevent potential predators from attacking rattlesnakes sheltered underneath.