MINISTRY OF TRANSPORTATION

APPENDIX B:
Amphibian Tunnel Design Review

Environmental Guide for Wildlife in the Oak Ridges Moraine

Version: October 2006

VERSION HISTORY

VERSION #	DATE	DESCRIPTION OF MAJOR CHANGE

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 de Maynadier 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 over wintering sites to breeding ponds in the spring, post-breeding dispersal, and movements back to over wintering 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 over wintering sites) and young of the year must also cross roadways to over wintering 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 north-eastern

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 (e.g. 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 B.1 Tunnel Design

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 (e.g. 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 (e.g. 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 (e.g. 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. comm.)** 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.

Comments by Researchers

- 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.

<u>Conclusions</u>

- 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.

<u>Tunnel Orientation</u>

- **(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.

Conclusions

- 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.
- **(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.
- **(Chan, 1993)**. Possible fencing materials used for tunnel-fence crossing systems are shown in Table B.2.

Table B.2 Possible Fencing Materials used for Tunnel-Fence Crossing Systems (Chan, 1993)

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)
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.

Conclusions

- 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 B.3 Fencing Design Features

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 authority 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.htmls.**)** 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.

<u>Conclusions</u>

- While there is some suggestion that vegetation may assist with wildlife funneling, 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 funneling 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.

<u>Conclusions</u>

- 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 build up if required.

<u>Conclusions</u>

- 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 B.4.

Table B.4 Tunnel Design Guidelines

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.

Factor/Issue	Amphibian Infrastructure Needs	Roadway and Other Implications	Suggested Approach
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.
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 wing wall 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.

Factor/Issue	Amphibian Infrastructure Needs	Roadway and Other Implications	Suggested Approach
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 e.g. 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.
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

Factor/Issue	Amphibian Infrastructure Needs	Roadway and Other Implications	Suggested Approach
			flooding and high velocity flows, either from surface grates or diverted roadside runoff.