Best Management Practices for Mitigating the Effects of Roads on Amphibian and Reptile Species at Risk in Ontario

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Cover photo provided by Joe Crowley

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1 INTRODUCTION

1.1 Purpose

The purpose of the Ontario Ministry of Natural Resources and Forestry (OMNRF) Best Management Practices for Mitigating the Effects of Roads on Amphibian and Reptile Species at Risk in Ontario (hereafter referred to as the best management practice (BMP) document) is to provide information on designing, implementing and monitoring mitigation measures to restore connectivity and reduce road mortality for species at risk (SAR) amphibians and reptiles. This information will assist in providing information on mitigation planning for amphibians and reptiles at risk in Ontario in order to meet the requirements of the *Endangered Species Act, 2007* (ESA) or its associated regulations. The intended audience includes planning authorities (local or provincial government), individuals applying ESA requirements on the landscape, consultants working on their behalf and conservation organizations involved in the planning and design of impact mitigation for all new roads and road rehabilitation (improvement) projects.

The focus of this BMP document is on crossing structures and fencing. While there is no singular solution for mitigating road effects on amphibians and reptiles, this document offers information for developing site-specific mitigation based on best practices and findings from current peer-reviewed and grey literature (e.g., websites and conference proceedings), government documents, academic theses and personal communication surveys with experts in road ecology and other areas of relevance (e.g., engineering, species biology). When knowledge gaps were identified, the recommendations are based on the best available information and expert opinion, as well as logical interpretation from species-specific needs and life-history traits.

This document presents current information as of the date of publication and is meant to be updated through time as improved information becomes available. If you are interested in providing pertinent information for consideration in updates of this document, please email esapermits@ontario.ca.

1.2 Endangered Species Act, 2007 (ESA)

The ESA provides the legislative framework for the protection of species at risk in Ontario. Section 9 of the ESA includes prohibitions against activities such as killing, harming, harassing, capturing or taking a living member of a species that is listed as extirpated, endangered or threatened on the Species at Risk in Ontario (SARO) List. Section 10 of the ESA includes prohibitions against damage or destruction of the habitat of an endangered or threatened species.

The ESA contains provisions that enable the Minister to issue permits and enter into agreements to authorize activities that would otherwise be prohibited and Ontario Regulation 242/08 sets out conditional exemptions from prohibitions under the Act for certain activities. For additional information, visit the government website or read the full text of the legislation on e-Laws using the links provided below.

How species at risk are protected:
https://www.ontario.ca/page/how-species-risk-are-protected

Endangered Species Act, 2007 on e-Laws:
http://www.ontario.ca/laws/statute/07e06

Ontario Regulation 242/08 on e-Laws:
http://www.ontario.ca/laws/regulation/080242

1.3 Document Outline

This document is organized into the following sections:

Section 1 (Introduction) provides background information on the threats of roads to amphibian and reptile species and the overall objectives of the document.

Section 2 (The Impacts of Roads) details background information on the impacts of roads on amphibians and reptiles and the need for road mitigation measures.

Section 3 (Mitigation Planning) provides information about considerations for developing a mitigation plan in a landscape context within project planning processes.

Section 4 (Road Mitigation BMPs) addresses design variations and applications of three crossing systems for amphibians and reptiles, in addition to detailed considerations for siting, designing, enhancing and maintaining crossing structure and fencing systems.

Section 5 (Supplementary Measures) provides recommendations about using mitigation measures other than crossing structures and fencing systems to reduce road impacts on amphibians and reptiles. These measures may be used when crossing structures are not required, or as a complement to an effective mitigation plan.

Section 6 (Temporary Mitigation During Road Construction) provides considerations for reducing impacts from construction activities, including timing construction activities to avoid construction-related impacts, and considerations regarding the use of temporary mitigation measures to minimize impacts during construction.

Section 7 (Monitoring) highlights where there are knowledge gaps about effectiveness of mitigation measures for reducing road impacts on amphibians and reptiles. Study design and monitoring techniques for measuring crossing structure and fencing effectiveness, in an adaptive approach, are discussed.

References

Appendix A (SAR Amphibian and Reptile Habitat Use and Movement) provides a general summary of seasonal habitat use, general movement distances within and between habitat and when this occurs for species at risk amphibians and reptiles in Ontario.

Appendix B (Definitions) provides a glossary of terms used throughout the document.

Appendix C (Crossing Structure Summary from Literature) summarizes the findings from the literature-based review that informed the recommendations throughout the document.

Appendix D (Links and Other Resources) contains a list of useful references, which may be cross-referenced when developing a mitigation plan for SAR amphibians and reptiles.

Appendix E (Sample Tunnel Cost Table (2014) contains the cost per metre for round and box tunnels, as well as special installation considerations.

2 IMPACTS OF ROADS

Globally, there are significantly more amphibian and reptile species at risk than either mammals or birds (IUCN 2010). Amphibians and reptiles were the most negatively affected species groups in a meta-analysis using data from 75 studies that quantitatively measured the relationship between roads or traffic and population size (Rytwinski and Fahrig 2012). The threats of roads to amphibian and reptile populations in Ontario are well-documented, and primarily include direct mortality of animals as well as habitat loss, degradation and fragmentation (e.g., Fahrig et al. 1995, Ashley and Robinson 1996, Findlay and Houlahan 1997, Vos and Chardon 1998, Haxton 2000, MacKinnon et al. 2005, Crowley 2006, Seburn 2007, Eigenbrod et al. 2008a, Eberhardt et al. 2013).

In southern Ontario the network of major roads increased from 7000 km to over 35 000 km from 1935 to 1995 (Fenech et al. 2001). Consequently, there is no point in southern Ontario that is further than 1.5 km from a road (Gunson et al. 2012), and remaining natural habitat is isolated into patches. In addition, human population growth is projected to increase by at least 30% over the next 20 years in the Greater Golden Horseshoe, increasing traffic volume and pressure for road expansions and rehabilitation. With properly planned and implemented road ecology solutions, these impacts can be lessened across Ontario.

Monitoring has documented significant levels of road mortality (van Gelder 1973, Rosen and Lowe 1994, Ashley and Robinson 1996, Aresco 2005) and road barrier effects (Andrews and Gibbons 2005) for amphibians and reptiles. Snakes are particularly vulnerable to road mortality because some species immobilize in response to a passing vehicle (Andrews and Gibbons 2005), or may bask on the roadway for thermoregulation (Andrews et al. 2008). Snakes may also avoid crossing roads altogether, which may disrupt normal behaviours, prevent access to key habitats, and lead to reduced genetic diversity (Shine et al. 2004, Rouse et al. 2011, Robson and Blouin-Demers 2013). Road mortality of more than three adult females per year can lead to declines for some long-lived snake populations such as the Gray Ratsnake (Row et al. 2007).

Modelling studies suggest that populations of many turtle species are declining because of the high rates of annual traffic mortality in some areas (Gibbs and Shriver 2002). Turtles are particularly vulnerable to traffic mortality because their life history strategy is characterized by long life spans, delayed maturity (sometimes taking more than 20 years), and very high adult survivorship. As a result even small, but ongoing, increases in adult mortality can lead to population declines (Congdon et al. 1993) and recovery is slow (Brooks et al. 1991). Females are threatened by traffic mortality because of overland movements to nesting areas (Steen et al. 2012) and populations of some species have been found to be male-biased in wetlands in areas with high road density (Marchand and Litvaitis 2004, Steen and Gibbs 2004).

Amphibians are subject to road mortality when migrating to wetland breeding sites and this can range from 19% (Gibbs and Shriver, 2005) to as high as 98% (Hels and Buchwald, 2001) depending on traffic volumes (Bouchard et al. 2009). Road mortality of just 10% of the adult population can lead to population extinctions (Gibbs and Shriver, 2005), resulting in lower species richness and abundance of individuals near roads (e.g., Carr and Fahrig, 2001; Eigenbrod et al., 2008). In addition, Karraker and Gibbs (2011) found road mortality reduced the life expectancy of Spotted Salamanders (*Ambystoma maculatum*) next to roads, and because younger salamanders lay smaller egg masses this also reduced reproductive output. In addition to road mortality, roads also inhibit movements of amphibians (deMaynadier and Hunter 2000) which can potentially restrict gene flow (Marsh et al. 2008).

3 MITIGATION PLANNING

3.1. Project-Level Impact Avoidance and Mitigation

Project planning and design for roads is a stepwise process that begins with defining the study area for new road construction or other major road rehabilitation projects. Meese et al. (2009) identifies the potential impacts of different types of road projects on wildlife species in general (Table 1). The list of project types is not meant to be exhaustive but rather to include major road improvements and rehabilitations within the scope of this document. There are other impacts to SAR during road operations and maintenance activities such as shoulder grading and paving that are not covered in this document. Projects should be designed to avoid impacts whenever possible, and this is best achieved by locating roads to avoid species at risk habitat altogether. When impacts are unavoidable, appropriate authorizations need to be obtained and the necessary mitigation measures incorporated into the project design.

3.2 Project Planning Considerations and Sources of Information

The information in this document outlines considerations for devising and integrating a mitigation plan into the road planning process in situations when avoidance cannot be achieved. New roads or road improvements present opportunities to lessen the impacts on SAR by integrating mitigation measures. These mitigation measures include specialized tunnels for wildlife passage as well as modifying or retrofitting existing drainage crossings for both water and wildlife use.

Table 1: A summary of project types during road improvement and rehabilitation activities, and potential impacts on amphibians and reptiles (adapted from Meese et al. 2009).

Road Activity	Project Type	Impacts on SAR
Road improvement	New road alignment or extension	Bisection of existing habitat and movement routes; genetic isolation of populations; road mortality; habitat loss
Road improvement	Road widening	Increased traffic volumes and road width increase risk of road mortality (Gibbs and Shriver 2002); habitat loss
Road improvements	Creation of median and installation of shoulder barriers	Increased barriers and road corridor width increase risk of road mortality
Road rehabilitation	Culvert or bridge improvements	May provide opportunities or barriers to movement, depending on resulting permeability of structure (Kintsch and Cramer 2011); risk of destroying turtle nests if work is carried out during the nesting period
Road rehabilitation	Improved road pavements	Increased risk of road mortality and disturbance of animals

Implementation of the mitigation plan begins during the construction phase, and particular attention to design details is important for amphibians and reptiles. It is important for all individuals involved in construction projects, including road crews, to be aware of the mitigation measures to be implemented for the project. Oversight by individuals with the greatest understanding of the mitigation measures is imperative to ensure that effective road mitigation solutions are implemented. For example, a fence with a gap or a fence buried improperly can render the mitigation measures ineffective. Quality assurance and adherence to the mitigation specifications needs to be practiced for each project. Routine quality checks to ensure that implementation of mitigation measures is not misinterpreted during construction, and routine maintenance of mitigation measures following construction is required.

Compiling field and geographic information system (GIS) data can support the development of an effective mitigation plan. Standard data compilations include species occurrence data obtained from the MNRF or other sources; these data are best supplemented with additional road survey data and species presence data collected in the project study area using standard survey techniques (see section 7.2.1). In the case of larger road projects, the duration of the environmental assessment (EA) process can last up to ten years, especially if there are time lapses between the preliminary assessment, detail design and construction. This provides opportunities for formal data collection within the project study area that can inform both mitigation planning and assessments of the effectiveness of mitigation.

Georeferenced data that may be available to support project planning and design may include the following:

- Existing and future land use and ownership maps,
- Habitat mapping (e.g., Southern Ontario Land Resource Information System, or Ecological Land Classifications),
- Species at risk occurrence information (Natural Heritage Information Centre),
- Terrain features,
- Natural Heritage Systems, and
- Existing and future road network and other infrastructure (i.e., existing barriers or passageways, including culverts, median and shoulder barriers, and adjacent railroads, local or private roads).

3.3 Recommended Process

The recommended steps for developing a comprehensive mitigation plan for SAR amphibians and reptiles are outlined in Figure 1 and described below.

Step 1: Identify and prioritize sections of roads that will impede connectivity and/or pose mortality risk to amphibians and reptiles using field data collections and additional landscape information (see section 3.4). Defined road impacts and objectives for mitigation will provide the content and scope of the mitigation plan.

Step 2: Design and determine the location of mitigation measures such as crossing structures and fencing by combining ecological data (e.g., species, habitat and landscape information) with engineering data (e.g., geomorphological, hydrological and topographical). This step requires collaboration between the ecological and engineering design team to ensure fluid integration of information into the mitigation plan. For a road rehabilitation project, there may be opportunities to retrofit existing infrastructure. Through careful evaluation, existing bridges and drainage culverts may be used or adapted for amphibians and reptiles (see section 4.1.4).

Step 3: Consider a multi-species perspective to ensure that a strategy for an individual species does not create unintended impacts for other wildlife species. Supplementary measures such as warning signs at fence ends may complement a multi-species strategy (see section 5).

Step 4: Identify temporary mitigation measures. This could include carrying out road construction when animals are not active, timing construction at particular road sections when animal activity is minimal (see section 6.1) and installing temporary mitigation measures (see section 6.2).

Step 5: Develop a monitoring plan for evaluating the effectiveness of the mitigation. Refer to section 7 for information on developing a complete monitoring plan that addresses the uncertainty with respect to mitigation design.

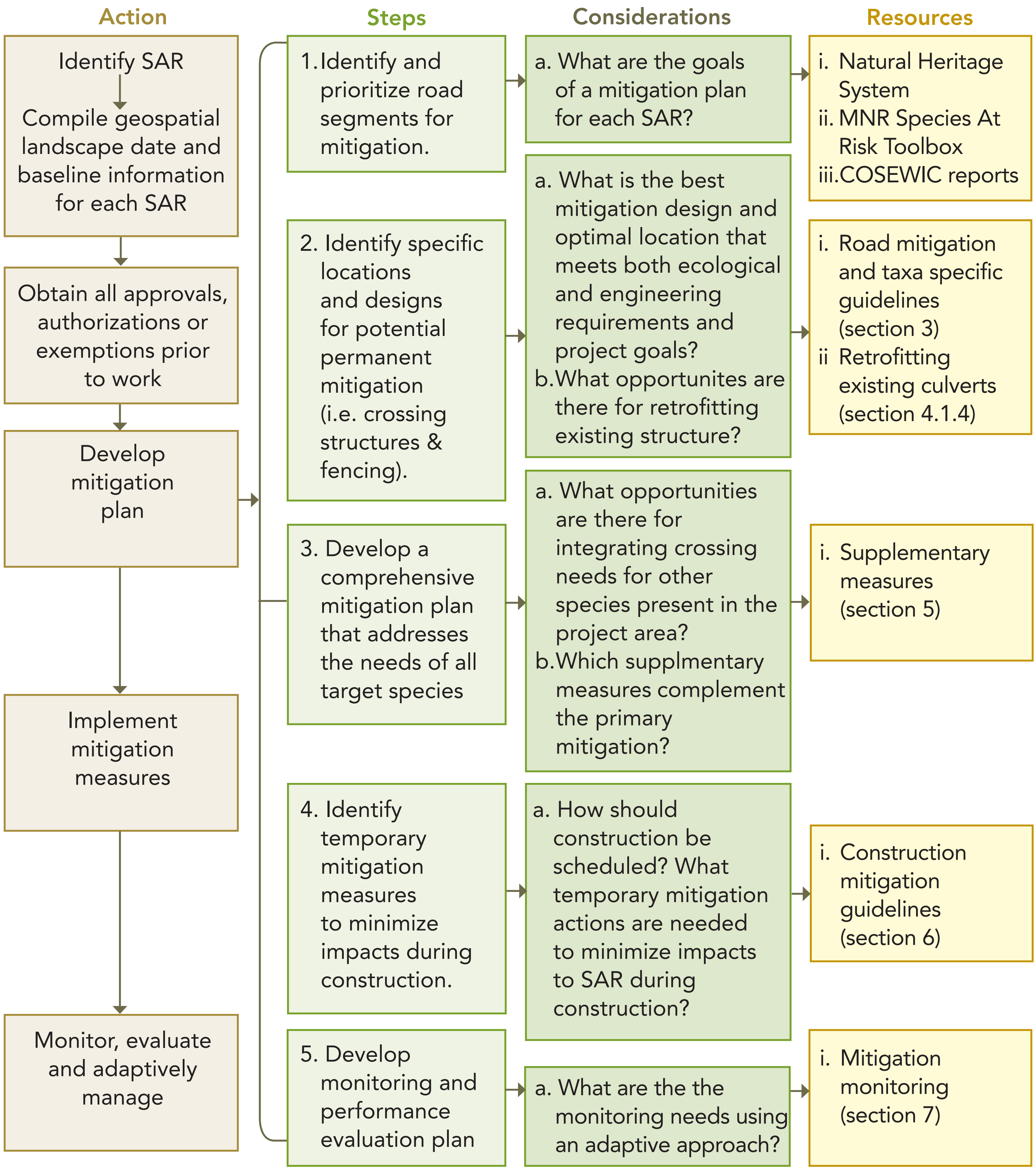

Figure 1: Flowchart summarizing the development of a mitigation plan (individual steps, considerations and supporting resources) within the established authorization processes for major road activities.

3.4 Landscape Considerations

Consideration of the larger landscape context is a vital component of effective mitigation planning for transportation projects because amphibians and reptiles require protection from adverse impacts at both the local and landscape scales (Semlitsch 2008). In other words, animals need to move within habitat patches to access resources (local scale), but also between habitats at different times of year, when habitat becomes inhospitable or to maintain genetic interchange (regional metapopulation scale).

In Ontario, natural heritage systems (NHS) have been developed at a variety of scales. Some are local in scale, while others span multiple jurisdictions, such as the systems in the Greenbelt Plan which span multiple regional municipalities. Natural heritage systems will often include a variety of habitat types including important amphibian and reptile habitat. The natural heritage system identified in the Greenbelt Plan 2005 is an example of a landscape level system approach to cores and linkages for natural heritage conservation. NHS can connect important natural heritage features and areas used by amphibians and reptiles, such as wetlands and upland habitat. Applicable conservation planning efforts, such as NHS, can be refined with taxa specific models for amphibians and reptiles (Gunson et al. 2012) and identified SAR habitat. This information can be used to identify where roads will pose the highest risk for road mortality and isolation of habitat, and should be integrated into early phases of mitigation plan development.

Consideration of the broader landscape context is required because impacts to wildlife are rarely caused by transportation alone (Clevenger 2012). The following landscape level considerations will contribute to the development of a comprehensive mitigation plan:

- Identifying the location of SAR populations and their habitat, including seasonal habitat usage and movement routes (described in Appendix A);
- Identifying connectivity at a regional scale that integrates an ecosystem approach (e.g., natural heritage systems);
- Understanding adjacent land security (i.e., the condition and ownership of land adjacent to a project, and the potential for land-use change); and
- Coordination with other jurisdictions (e.g., municipalities and conservation authorities that own adjacent infrastructure and land).

4 ROAD MITIGATION BMPS

This section provides a summary of BMPs specific to crossing structures and fencing (see sections 4.1 and 4.2). The focus is on the best structural design for all amphibians and reptiles, with species-specific considerations noted when relevant. Following these BMPs, taxa specific (turtles, snakes and lizards, salamanders, frogs and toads; see section 4.1.5) considerations are summarized and supplemented with a rationale section based on a comprehensive literature review. All BMPs are further illustrated and supported with relevant examples, photos, references, and caveats specified throughout. Although SAR amphibians and reptiles found in Ontario are the focus for this document, information also derives from research on related species in other regions for each taxa. This document provides the minimum recommended design specifications (e.g., height, length and width for crossing tunnels and fencing) based on the best available information. All mitigation plans will be subject to trade-offs as presented by engineering, budget, public safety, and site specific constraints.

To date, crossing structures (see section 4.1) combined with fencing (see section 4.2) offer the most effective mitigation of road impacts for amphibians and reptiles by facilitating landscape connectivity and reducing road mortality by excluding animals from the road (Dodd et al. 2004, Aresco 2005). Crossing structures and fencing integrated into road improvement and rehabilitation projects provide the greatest opportunity for creating functional passages, although, in some cases, existing structures may be retrofitted to facilitate wildlife passage (see section 4.1.4). The recommendations herein focus primarily on crossing structure tunnels less than 3 m wide because these structures are typically used for amphibians and reptiles and are available as precast or prefabricated structures. When a tunnel exceeds 25 m in length, a larger structure such as an overpass, multi-span bridge, or viaduct should be considered (see section 4.1.1). Larger structures can be integrated into a multi-species design strategy to increase effectiveness for both large and small species. Multi-species considerations are provided in this document, in addition to approaches for combining mitigation measures to achieve an overall mitigation plan.

4.1. Crossing Structures

Crossing structures can play an integral role in mitigating the impacts of roads on SAR amphibian and reptiles in Ontario. Recommendations regarding the use of different types of crossing structures, design considerations, location and spacing of crossing structures and taxa specific guidelines are provided. The retrofitting of existing drainage culverts and associated considerations are also covered.

In this document, the term tunnel is used to differentiate between crossing structures intended for amphibian and reptile use as opposed to culverts that are designed to transport water under the road. Box tunnels with natural substrate, arch tunnels and round tunnels buried 0.3-0.4 m into the ground are the primary recommended tunnel types because they meet essential criteria, such as providing natural substrate bottoms and a flat crossing surface.

4.1.1 Types of Crossing Structures for Amphibians and Reptilesa

<table>
<tr><th colspan="2">BOX TUNNEL</th></tr>
<tr><td colspan="2">
• Traditionally used for drainage, but also increasingly being placed and modified specifically for amphibian and reptile passage.
• Tunnels up to 3 m wide or high typically made from precast concrete (Photo 1).
• Maximum recommended tunnel length of 25 m.
• Variations include open-top (Photo 2) or open-grate (Photo 3), open-bottom (Photos 4) or variations of these (Photos 5 - 7).
• Straight walls may be perceived by target species as increased openness.
• Provide more cross sectional area or openness than round or elliptical culverts with the same width.
</td></tr>
<tr><td rowspan="2">STRUCTURAL VARIATIONS</td><td>
OPEN-TOP
• Achieved with slots or grooves along the top (Photo 2), or open-grate set upon two concrete footings (Photo 5).
• Allows for more consistent ambient conditions, including moisture, light and temperature (Photo 8).
• Possible concerns with influx of road debris, pollutants, or traffic noise.
• Installation at a downward incline from middle of road to road edge to allow for drainage and natural cleaning of the tunnel.
</td></tr>
<tr><td>
OPEN-BOTTOM
• Three-sided structures (Photo 4).
• Allows natural substrate conditions to be retained (e.g., streambed or grass floor) (Photo 9).
</td></tr>
<tr><td>APPLICATION</td><td>
• A smaller sized open-top tunnel may increase crossing success or provide microhabitat conditions equivalent to the openness created by larger tunnels.
• Open-top grate tunnels have previously been used on low-use cottage roads or roads in protected areas (e.g., Wild Rice Trail, Algonquin Provincial Park, Killbear Provincial Park (Photos 5 and 6)).
• For divided highways with two structures that end in the median, tunnels should be connected with a fence (Photo 10).
• Headwalls may be used at entrance to shorten length of structure or for a seamless join to a concrete guide wall (Photo 11).
• For box culverts, the tunnel floor should be buried with natural substrate and cover objects (Photos 12 and 13).
• An open-top in the road shoulder and a closed-top along the road pavement may be more suitable for high volume roads (Photo 7).
</td></tr>
</table>

BOX TUNNEL	
ENGINEERING CONSIDERATIONS	• Open-top tunnels must be at grade with road surface. • Design variations may require special design drawings if not prefabricated. • Size of tunnel must fit within the vertical road profile so that top load is adequate for structural stability.
MAINTENANCE CONSIDERATIONS	• Smaller tunnels will be more difficult to keep clear of debris. • Open-top tunnels may have to be periodically flushed with water (e.g., with a fire hose) to clean build-up of road pollutants. • Larger structures allow better maintenance accessibility while having relatively minor cost increases relative to cost of road project. • Open-top tunnels are thought to interfere with snow removal; however, this has not been the case in other tunnel installations in cold countries and the top of the tunnel wears away with the road surface (see review in Langton 2014). • Natural substrate and other cover objects must be maintained.
COST (relative material comparison in 2014)	• Costs/m vary from CAN $800.00 for prefabricated open-top ACO tunnel (0.5 m x 0.5 m) to CAN $3,000 for enclosed box tunnel (1.8 m x 1.8 m).

Photo 1. Precast box culvert along highway 69, Ontario. © K. Gunson

Photo 2. Open-top tunnel in Waterton Lakes National Park, Alberta. © K. Gunson

BOX TUNNEL

Photo 3. Open-grate tunnel at Killbear Provincial Park, Ontario. © K. Gunson

Photo 4. Open-bottom tunnel along highway 69, Ontario. © K. Gunson

Photo 5. Open-bottom and open-top grate tunnel at Killbear Provincial Park, Ontario. © K. Gunson

Photo 6 Open-top and open-bottom at Wild Rice Trail, Six Mile Lake. © K. Gunson

BOX TUNNEL

Photo 7. Open- and closed-top variation, Germany. © ACO International

Photo 8. ACO open-top tunnel allowing light into tunnel. © Kari Gunson

Photo 9. Open-bottom box tunnel with natural stream on Trans Canada Highway in Banff National Park, Alberta. © K. Gunson

Photo 10. Box tunnels in median that should be connected with a fence when intended for wildlife passage. © K. Gunson

BOX TUNNEL

Photo 11. Tunnel with headwalls connected to concrete guide fencing in Cuba. © G. Barrett

Photo 12. Adding soil to box tunnel near Ucluelet, B.C. © Barb Beasely

Photo 13. Soil and branches inside tunnel bottom, Ucluelet, B.C. ©Barb Beasley

ARCH/ROUND TUNNEL	
• Arch tunnels have natural bottoms (Photos 14 and 15) and are recommended for tunnels greater than or equal to 1.5 m diameter (common widths 1.8, 2.4 and 3.0 m). • Round tunnels work well in aquatic conditions for turtles and semi-aquatic snakes. • In terrestrial conditions, round tunnels should be filled 0.3-0.4 m with local soil/debris to create a level crossing surface, and it is recommended that the size be increased from the minimum recommendations in section 4.1.5 to compensate for this area that is lost due to infilling. • Maximum recommended tunnel length of 25 m. • Terrestrial pathways alongside stream or creek bed are possible with additional structural width. • Recommended design specifications for arch tunnels are slightly larger than box tunnels to compensate for the loss of openness as a result of tunnel shape.	
STRUCTURAL VARIATIONS	**OPEN-TOP** • Slotted open-top (Photos 16 and 17) or vertical skylight risers along the length of the tunnel to provide natural light.
	OPEN-BOTTOM • Achieved by burying round tunnels (0.3 to 0.4 m) to accommodate natural terrestrial floor (Photo 18).
APPLICATION	• Arch structure may be preassembled and dropped in place or assembled at site (Photo 19). • Corrugated steel arch or concrete side slabs are placed on footings (Photo 15).
ENGINEERING CONSIDERATIONS	• Footings required for arch tunnels. • Buried tunnels may be more suitable when tall footings are required.
MAINTENANCE CONSIDERATIONS	• Larger structures allow better maintenance accessibility while having minor cost increases relative to cost of road project. • Natural substrate and other cover objects must be maintained.
COST (relative material comparison in 2014)	• Costs/m vary from CAN $145.00 for corrugated steel pipe (CSP) (1.2 m) to CAN $990.00 for arch (0.6 m rise; 1.22 m span). • Costs/m vary from CAN $500.00 for CSP (3.0 m) to $1500.00 for arch (1.45 m rise; 2.99 m span).

ARCH/ROUND TUNNEL

Photo 14. Arched tunnel allowing natural stream crossing. © D. Seburn

Photo 15. Aluminum arch culvert on metal footings. © K. Williams

Photo 16. Pipe culvert with slotted top installed for Timber Rattlesnakes in Illinois, U.S. © S. Ballard

Photo 17. Zoom-in of open-top pipe culvert at road for Timber Rattlesnakes in Illinois, U.S. © S. Ballard

Photo 18. Buried plastic round culvert allowing terrestrial flat floor in Sweden © K. Gunson

Photo 19. Arch culvert preassembled off site © K. Williams

<table>
<tr><th colspan="2">LARGE UNDERPASS OR WILDLIFE OVERPASS</th></tr>
<tr><td colspan="2">• Larger multi-species crossing structures greater than 3 m wide such as tunnels (Photo 20) and bridges, viaducts or overpasses (Photo 21) that are generally not prefabricated or precast.
• Possible to maintain natural landscape if road is tunneled, (e.g., Herb Gray Parkway in Windsor) or elevated (e.g., viaduct).
• Consider when tunnel length will exceed 25 m.
• Integrated as a multi-species strategy for both large and smaller animals.</td></tr>
<tr><td rowspan="2">STRUCTURAL VARIATIONS</td><td>UNDERPASS
• Designs include crossing structures that are below grade (e.g., tunnel, single or multi-span bridge, arches, and viaducts).
• Larger multi-span bridge, arches and viaducts have opportunity to maintain natural ecosystem and physical properties.
Allows for the integration of dry pathways at creek and river crossings.
• Two structures that open in median allow more openness (Photo 22).</td></tr>
<tr><td>OVERPASS
• Design includes bridge deck spanning over road.
• Requires natural landscape planting strategy and drainage system on top of structure.
• Slope on approach ramps should be minimized for greatest visibility.
• Overpass width has varied from 20 m to > 70 m.</td></tr>
<tr><td>APPLICATION</td><td>• Large structures provide greater opportunity to provide cover objects such as flat rocks, vegetated mounds composed of branches and logs and covered with sod, or rock piles (Photos 23 and 24).
• Design enhancements for amphibians and reptiles include small ponds as ‘stepping-stones’ along or through the length of a structure. Natural or artificial substrate may be used to retain pond water or natural rainfall (Van der Grift et al. 2003; Figure 2).
• For multi-use structures, wildlife and human use should be separated or human use should be mitigated. For example, the Rt. Hon. Herb Gray Parkway, which leads to the international crossing between Ontario and Michigan, incorporates a crossing structure for Butler’s Gartersnake and Eastern Foxsnake into the multi-use trail system to minimize disturbance impacts from recreational trail users.
• Multi-species fencing designs should be used. For example, the Highway 69 fencing combines ¼ inch mesh with 2.4 m high, large animal mesh fence (Photo 25).</td></tr>
</table>

LARGE UNDERPASS OR WILDLIFE OVERPASS	
ENGINEERING CONSIDERATIONS	• Overpass decks can integrate natural footings such as rock cliffs (Photo 26). • Engineering measurements and road design will determine best options for large crossing structure type in the road.
MAINTENANCE CONSIDERATIONS	• Require maintenance checks for initial establishment of vegetation on overpass structures; may require irrigation for pools and vegetation.
COST (relative material comparison in 2014)	• Approximately CAN $7,800 for large concrete box culvert (2.8 m x 3.3 m, Appendix E); range from CAN $2-4 million for installation, design, and materials of wildlife overpass.

LARGE UNDERPASS OR WILDLIFE OVERPASS


Photo 20. 3.4 x 2.4 m concrete box culvert connecting wetland habitat used by turtles on highway 69. © K. Gunson


Photo 21. 30 m wide overpass installed near Sudbury on highway 69. © K. Gunson

LARGE UNDERPASS OR WILDLIFE OVERPASS

Photo 22. 3.4 m x 2.4 m tunnel on Highway 69. © K. Gunson

Photo 23. Brush piles on top of overpass on highway 69. © K. Gunson

Photo 24. Rock and wood piles on top of overpass in Brandenburg, Germany. © K. Gunson

Photo 25. Small animal fence attached to the base of large animal barrier fence. © K. Gunson

Photo 26. Wildlife overpass on highway 69 showing rock footing K. Gunson.

LARGE UNDERPASS OR WILDLIFE OVERPASS

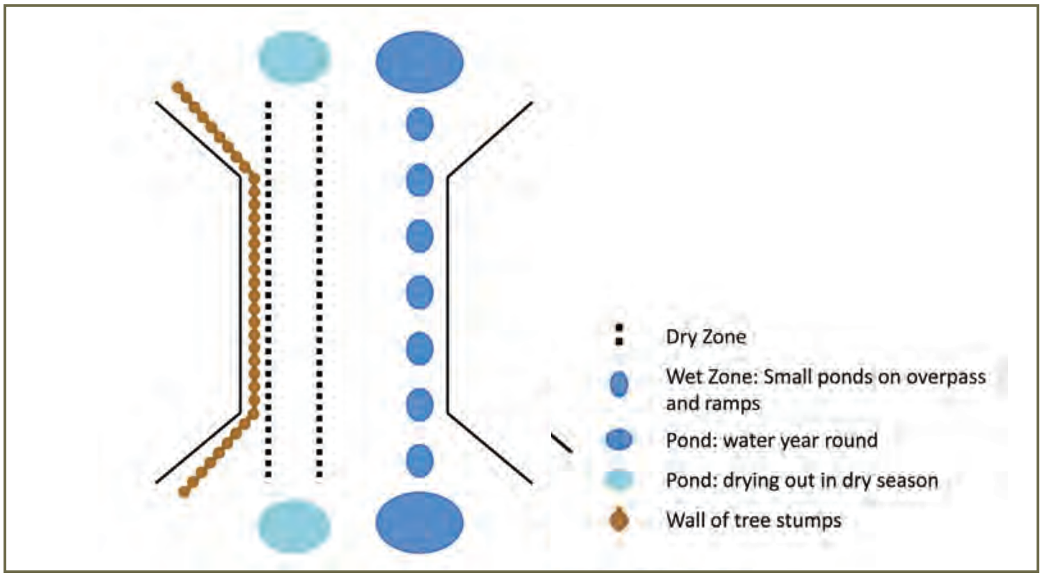

Figure 2: Example of a series of pools created along one side of an overpass (50 m long x 65 m wide). Amphibian passage was at least 1.5 times higher through the wetland zone than the dry zone. Adapted from van der Grift et al. 2009

4.1.2 Crossing Structure Design

Design of effective crossing structures must account for the ecology, behaviour and movement patterns of amphibians and reptiles. For example, amphibians and reptiles possess a number of physiological vulnerabilities that require particular microhabitat conditions when using tunnels to cross roads (Andrews et al. 2008). High skin permeability and vulnerability to water loss necessitates warm and damp conditions in tunnels for amphibians. These microhabitat specializations require additional design modifications (e.g., natural substrate, cover) in and near crossing structures. General recommendations based on the literature and expert opinion for tunnel design (<3 m wide), to facilitate amphibian and reptile use, are outlined below:

Design Specifications

- Refer to minimum design specifications and tunnel types summarized in structural (see section 4.1.1) and taxa recommendations (see section 4.1.5) for each species group; where existing culverts are being replaced, upsize tunnels to at least minimum design specifications and tunnel type.
- Tunnels should be as open as possible to maximize air flow and light inside the tunnel. This may be achieved by designing tunnels with larger (typically wider) openings, using two structures connected with fencing when a median is present (Photo 22), or with an open-top or partial open-top tunnel (Photos 2 and 7).
- Artificial and ambient lighting inside a culvert has been shown to encourage tunnel use by turtles (Yorks et al. 2011) and entry by salamanders (Jackson et al. 2006).
- Generally, larger tunnel dimensions are more effective for amphibians and reptiles. For example, Smith (2003) showed amphibians and reptiles in Florida used tunnels more often that were at least 1.5 m wide and 0.6 m high as compared to smaller tunnels. See section 4.1.5 for additional information on tunnel dimensions for each taxa group.

- In general, the recommended tunnel length for SAR amphibians and reptiles is less than 25 m. There is reduced crossing success as tunnels get longer (e.g.,Yorks et al. 2011) and other jurisdictions suggest tunnels are less effective beyond 20-25 m in length (e.g., British Columbia Ministry of Forests, Lands and Natural Resource Operations 2004).
- In locations where tunnels will be longer than 25 m, consider the following:
- A large underpass (> 3 m) or overpass
- Elevating or tunneling the road
- Using two separate, shorter tunnels under each of the opposing traffic lanes with head walls; ensure the tunnels are connected with appropriate fencing in the median (Photo 22).
- On divided highways, crossing structures should never end in the center median (Photo 27) unless they are connected to other structures through fencing.
- When possible include skylights, or fenced gaps at medians and shoulders (Photos 28 and 29).

Microhabitat and Cover:

- All terrestrial crossings should have a natural substrate that consists of soil, sand, branches and other natural materials on the tunnel floor to increase structure use (Photos 13 and 35). The use of local soil in crossing structures is widely recommended for amphibians (e.g., Jackson 2003, Smith 2003, Schmidt and Zumbach 2008, Amphibian and Reptile Conservation 2009, Beasley 2013). For example, salamanders will cross through tunnels with or without natural substrate, but fewer individuals cross through bare concrete tunnels (Patrick et al. 2010). Considerations for substrates:
- Soils should be from the local area
- Soils that consist of large stones should be avoided
- Sediment baffles such as open plate may be used to 'hold' natural substrate in place (Photo 36).
- Cover objects (flat rocks and/or woody debris) should be placed in larger tunnels along the sides to provide shelter and escape from predators. These cover objects should not block sightlines or impede individuals from crossing straight through the tunnel. Sufficient cover objects (1 large or 2-3 small per 10 m^2) should be present near the entrances to all terrestrial crossing structures to provide shelter and cover. Cover objects should be used for all crossing structures to encourage multi-species use. Retain as much natural vegetation as possible during construction; where needed, additional planting should occur after construction.

Other Design Considerations:

- Terrestrial tunnels should be as level as possible for the entire length of the structure. One exception to this is that open-top tunnels should be installed with the highest point in the middle of the tunnel to allow for drainage and natural cleaning of the tunnel.
- Tunnel entrance bottoms should be at ground-level so animals do not need to 'step up' or 'step down' to enter the structure (Photo 30).
- At terrestrial tunnels, water should be diverted away from the entrances with drainage ditches or sloped excavation (Photo 31).
- If culverts are intended for drainage, or tunnels are large enough, a dry bench placed above the water mark can be integrated into the tunnel, in which case the bench must access dry ground at both entrances to be effective (Photo 32).
- When new highway alignments will bisect provincially significant wetlands and SAR habitat, consider elevating or tunneling the

road (e.g., Rt. Hon. Herb Gray Parkway road mitigation project for Butler's Gartersnake and Eastern Foxsnake).

- When arch tunnels are used at road-stream crossings, terrestrial pathways can be created along the stream by using wider tunnels (Photo 14). This design can better accommodate seasonal high water and flooding events (Lesbarrères and Fahrig 2012).
- When dealing with multi-species issues and variable site conditions, a mixed array of structure types and sizes should be provided along the site (see section 4.1). Structural diversity can compensate for landscape variations, such as land use change, and can also provide an experimental setting to test species-specific crossing preferences (see section 7).

Photo 27. Drainage box tunnel left open in median along highway 69 © K. Gunson

Photo 28. Open grate skylight in median on Terry Fox Extension, Ottawa, Ontario. © D. Seburn

Photo 29. Zoom-in of skylight in median on Terry Fox Extension, Ottawa, Ontario. © D. Seburn

- Aquatic crossing structures should never be fully submerged (e.g., Caverhill et. al. 2011, Photo 37).
- Water in aquatic tunnels should be standing or have low flow rates.
- Many crossing structures are no longer effective due to a lack of maintenance (Iuell et al. 2003). Regular maintenance is required for long-term effectiveness of all tunnels to ensure the microhabitat is intact, passageways are clear of debris, and that suitable substrate remains.

Photo 30. Earth excavated to allow at grade entrance to tunnel. © D. Filip

Photo 31. Water accumulation at tunnel entrance. © K. Gunson

Photo 32. Dry bench in drainage culvert for small animals, could be modified for snakes. © K. Foresman

BOX 1. OPENNESS OR OPENNESS RATIO

Openness Ratio (OR) was first conceived by Reed et al. (1979) as a threshold measure for comparing the relative openness of box culverts for use by Mule Deer (*Odocoileus hemionus*), given their preference for a clear line of site through a structure. This measure has since been extrapolated beyond this original use and applied to a variety of species and structure shapes; see review of OR application to small mammals, deer, and amphibians and reptiles in Gartner Lee and Ecoplans (2009). The ratio is defined as the cross-sectional area of a structure (square metres) divided by the length of the tunnel (metres) ([rise x span] / length). The intent of OR is to provide a measure of the tunnel effect of a structure, which may influence use by various wildlife species.

BOX 1. OPENNESS OR OPENNESS RATIO

The use of OR as a sole measure to inform road mitigation design should be used with caution, especially for amphibians and reptiles, because of the following:

- Cross sectional definition needs to be modified to account for shape.
- OR does not account for the effect that a structure's width versus its rise has on openness and whether this influences wildlife use (Jacobson 2007). For example, once a minimum height has been achieved, wider rather than taller structures may be recommended to enhance openness for some wildlife, such as turtles (Smith 2003) and elk (Kintsch and Cramer 2011).
- Tunnel effectiveness may be improved beyond manipulating structural dimensions by providing natural cover, substrate and light via open-tops into the tunnel design (Woltz et al. 2008, Yorks et al. 2012).
- Openness may be less important for tunnel use when animals become more familiar with new structures then when encountering a structure for the first time (Clevenger et al. 2002).

4.1.3 Crossing Structure Location and Spacing

Species that need to move between different habitats are also particularly susceptible to road mortality and landscape fragmentation by roads. Amphibian and reptile species need to move among breeding sites, summer foraging areas and overwintering sites during their active seasons. When these habitats are not adjacent, animals must move up to several kilometers to find necessary habitat. In areas with high road density, it is likely these movements will cross roads, putting animals at higher risk of road mortality (Gibbs and Shriver 2002, Beaudry et al. 2008).

An effective crossing structure should function as a movement corridor connecting suitable habitat on both sides of a road. Tunnels and fencing are best located where SAR movement paths cross existing and planned roads as determined from field surveys or spatial analyses (see examples in Gunson et al. 2012, Patrick et al. 2012). Examples of predictable movements include an annual spring migration of amphibians from upland forest to breeding ponds (Patrick et al. 2010, Faggyas and Puky 2012, Pagnucco et al. 2012) or an annual snake migration to and from overwintering hibernaculum (e.g., Fortney et al. 2012). Turtles are likely to interact with roads during terrestrial nesting migrations and inter-wetland movements (Gunson et al. 2012).

Amphibians and reptiles have specific microhabitat needs, smaller home ranges and restricted movement capabilities relative to larger fauna (Jochimsen et al. 2004). The following considerations are outlined below to assist with siting the optimal placement and number of crossing structures along a road improvement or rehabilitation project:

- In general, crossing structures should be considered when the road bisects habitat used by the target species (photo 33), when the road is between seasonal habitat used by a species (e.g., wetland and upland forested habitat for Jefferson Salamanders), or when the road bisects a movement corridor (e.g., riparian pathway, hedgerow, or ridge valley). Appendix A provides a general summary of movement distances, home range areas, and habitat used by each species, but more detailed species-specific information should be used to inform mitigation plans.

- When roads bisect large expanses of continuous habitat (e.g., forest), crossing structures should generally be spaced 300 m apart for small animals depending on species, budget, and site-specific engineering and ecological considerations (Carsignol 2005). This is generally applicable to most turtles and snakes; however, Schmidt and Zumbach (2008) recommend that tunnels be spaced no more than 50 m apart for amphibians.
- Species with smaller home ranges usually require crossing structures to be placed closer together and the numbers of crossing structures will depend upon the road length where animals are interacting with the road (preferably measured with road encounter data, see section 7.2.1). The approximate distance between crossing structures can be determined based on the average home range size of the species in question. Another, similar approach is to use the square root of the home range area (Bissonette and Adair 2008).
- Man-made features (e.g., ditches, retaining walls) in the right-of-way may influence species movement and access to crossing structures (Gartner Lee and Ecoplans 2009).
- Likely crossing locations for turtle and amphibian SAR are where aquatic features and wetlands intersect with roads (Photo 34).
- Hydraulic and engineering information should be used to determine the amount of water and flow through the tunnel and whether this is appropriate for the target species. Refer to taxa specific BMPs for aquatic and terrestrial crossing types in section 4.1.5, in addition to site-specific conditions measured in the field.
- Vertical alignment and location of the tunnel should be based on environmental conditions at the site, such as water level. For example, terrestrial tunnels should be above high water marks defined by wetlands and riparian corridors.
- Integrate crossing structures with the natural landscape. For example, take advantage of valleys for crossings under roads and incorporating fencing into natural landscape features, such as existing steep rock faces.

Photo 33. Road bisecting open water wetlands, Victoria Street, Whitby, Ontario. © K. Gunson.

Photo 34. Where drainage meets road would be likely location for tunnel for SAR amphibians and reptiles. © K. Gunson.

Photo 35. Turtle using open-grate tunnel with natural substrate at bottom© A. Mui

Photo 36. Tunnel structure with sediment baffles at bottom © B. Steinberg

4.1.4 Retrofitting Existing Drainage Culverts

Historically, culverts have been used to convey water under roads, and these structures have also been used by some species of amphibians and reptiles (e.g., Caverhill et al. 2011). Road improvement and rehabilitation projects provide opportunities to retrofit or enhance existing drainage culverts to facilitate use by amphibians and reptiles. When replacing a culvert, consider implementing a tunnel-fencing system with specifications for the target species (see section 4.1.5). In some cases, existing drainage culverts may already be sited and designed correctly for use by the target species and may only require

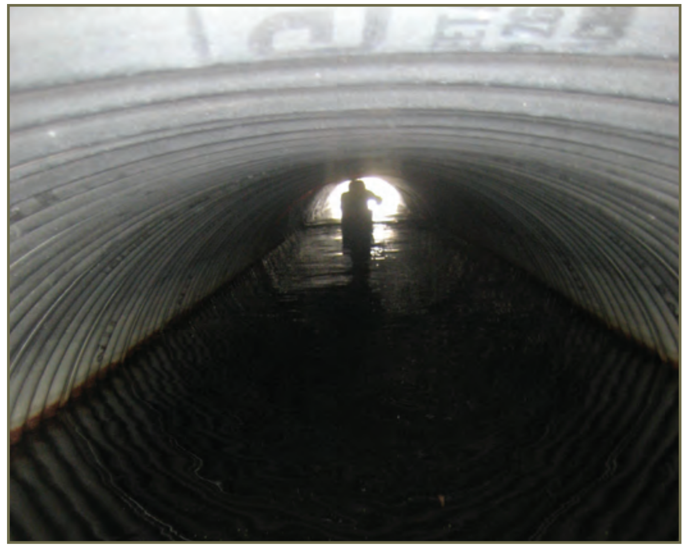

Photo 37. Large 1.8 m drainage culvert partially filled with standing water allows light into tunnel, Highway 24, Aurora, Ontario. © K. Gunson

guide fencing to facilitate crossing use and reduce road mortality (Caverhill et al. 2011). A formal evaluation of existing wildlife crossing structures for wildlife passage for the intended species is recommended (Kintsch and Cramer 2011, Central Lake Ontario Conservation Authority 2015).

4.1.5 Taxa-specific Recommendations

In addition to the general design considerations for reptiles and amphibians that are outlined in section 4.1.2, the following are specific recommendations that are unique to each taxa group. The following sections focus on the threatened and endangered SAR in each taxa group; however, the information is generally applicable to all other reptile and amphibian species in Ontario. In general, these recommendations make the assumption that as tunnels get longer an increase in width is more important than an increase in height (see Box 1).

The salamander section only addresses the Jefferson Salamander. The Jefferson Salamander is the only SAR salamander that is likely to be affected by road development in Ontario. In Ontario, the Small-mouthed Salamander and the two Dusky Salamanders have extremely small distributions (only a few isolated sites) and are unlikely to be affected by road construction. To date, the Fowler's Toad is the only endangered or threatened frog or toad species in Ontario, so the information in this section is specific to that species.

SPECIFICATIONS FOR TURTLES

Structure type and minimum size based on tunnel length

Tunnel Length	Box Tunnel (w x h)	Arch Tunnel (w x h)	Round Tunnel (diameter)	Overpass
15 m	1.5 x 1.0 m	1.8 x 0.9 m	1.5 m	NA
15-25 m	1.8 x 1.0 m	2.0 x 1.0 m	1.8 m	NA
> 25 m	NA	NA	NA	Yes

ADDITIONAL DESIGN CONSIDERATIONS

- Terrestrial and aquatic structures are suitable for most turtle species; terrestrial crossing structures are not appropriate for Eastern Musk Turtle or the Spiny Softshell, which are highly aquatic and rarely move over terrestrial areas.
- Open and closed top tunnels have been used by turtles; open-top tunnels may increase crossing success.

RATIONALE

- Turtles have used a variety of crossing structures under roads (e.g., Dodd et al. 2004, Aresco 2005, Caverhill et al. 2011)
- Several studies have demonstrated relatively high use of large (>1.5 m width) crossing structures by turtles:
  - A drainage culvert 1.8 m in diameter in Ontario that was approximately half full of water (Caverhill et al. 2011) was used regularly by Blanding's Turtles and was also used by an unknown number of Snapping Turtles
  - Multiple Spotted Turtles were confirmed to cross through a tunnel 1.8 x 1.8 m (Kaye et al. 2005)
  - Aresco (2005) documented over 200 turtle crossings through a 3.5 m diameter drainage culvert

SPECIFICATIONS FOR TURTLES

RATIONALE

- Wood Turtles continued to use a stream that passed through a culvert that was 3 m in diameter and 26 m long (Parren 2013).
- In a simulated tunnel experiment, more turtles crossed through a tunnel that let in at least 75% ambient light through the top (Yorks et al. 2011).
- Turtles will cross through tunnels 25 m long (Caverhill et al. 2011), although crossing success may be lower as length increases (Yorks et al. 2011).
- Turtles have used closed-top tunnels (e.g., Dodd et al. 2004, Aresco 2005, Kaye et al. 2005, Caverhill et al. 2011) and Wood Turtles (Photo 54) and Snapping Turtles (Whitelock 2014) have crossed through open-top tunnels in Ontario).
- Substrate type may not be as important in terrestrial tunnels for turtles as with other taxa. Blanding's and Spotted Turtles have been documented to cross through tunnels with natural substrates (e.g., Kaye et al. 2005, Caverhill et al. 2011), but in a simulated crossing structure experiment, Painted and Snapping Turtles did not demonstrate a substrate preference (Woltz et al. 2008).

Photo 54. Wood Turtle using open-grate tunnel © A. Mui

SNAKE AND LIZARD SPECIFICATIONS				
Structure type and minimum size based on tunnel length				
Tunnel Length	**Box Tunnel (w x h)**	**Arch/Round Tunnel (w x h)**	**Round Tunnel (diameter)**	**Overpass**
15 m	1.0 x 1.0 m	1.5 x 0.75 m	1.0 m	NA
15-25 m	1.5 x 1.0 m	1.8 x 0.9 m	1.5 m	NA
> 25 m	NA	NA	NA	Yes

ADDITIONAL DESIGN CONSIDERATIONS

- Open and closed-top tunnels have been used by snakes; open-top tunnels may increase crossing success.
- Open-top tunnels should not be used for lizards because they may be able to crawl onto the road surface.
- Aquatic tunnels will likely be used by highly aquatic SAR, such as Eastern Ribbonsnake, Queensnake, and Lake Erie Watersnake; however, they are unlikely to be used by other snake and lizard SAR and are not recommended for those species.

RATIONALE

- Snakes (e.g., Taylor and Goldingay 2003, Laidig and Golden 2004, Roberts 2010, Eads 2013) and lizards (e.g., Taylor and Goldingay 2003, Painter and Ingraldi 2007, Arizona Game and Fish 2010) have used a variety of crossing structures under roads. However, compared to other taxa, there is less certainty about crossing structure design preference for snakes and lizards, particularly for the species that occur in Ontario.
- Snakes have crossed through tunnels as small as 0.25 m in diameter (Roberts 2010), but tunnels 1.0 m in diameter had a greater crossing success than smaller tunnels for the Eastern Gartersnake and Eastern Ribbonsnake in an experimental set-up (Eads 2013).
- Both closed-top (Taylor and Goldingay 2003, Laidig and Golden 2004, Roberts 2010, Eads 2013) and open-top (Pagnucco et al. 2011, M. Colley pers. comm.) crossing structures have been used by snakes.
- Open-bottom box tunnels with cross-sectional dimensions of 1.0 x 1.0 m in Killbear Provincial Park were used by many (11) Massasaugas and 2 Eastern Foxsnakes in 2014 (M. Colley pers. comm.).
- Timber Rattlesnakes have crossed through concrete-bottom structures without natural substrate bottoms (Laidig and Golden 2004), but natural substrate or habitat conditions may enhance use (Laidig and Golden 2004; M. Colley pers. comm.).

SALAMANDER SPECIFICATIONS				
Structure type and minimum size based on tunnel length				
Tunnel Length	**Box Tunnel (w x h)**	**Arch Tunnel (w x h)**	**Round Tunnel (diameter)**	**Overpass**
15 m	1.0 x 1.0 m	1.5 x 0.75 m	1.0 m	NA
15-25 m	1.5 x 1.0 m	1.8 x 0.9 m	1.5 m	NA
> 25 m	NA	NA	NA	Yes

ADDITIONAL DESIGN CONSIDERATIONS

- Terrestrial tunnels should be used for salamanders; high moisture content and even small pools of standing water may be beneficial but the tunnel should not be flooded with water.
- Open or closed-top tunnels can be effective. Open-top tunnels allow more light into the tunnel and may increase moisture levels; the latter being important in longer tunnels where salamanders are at risk of desiccation. Consequently, open-top tunnels may offer suitable conditions for salamanders even when the dimensions are smaller than those listed above.
- Despite the potential advantages of open-top tunnels, they may result in higher levels of road salt and other pollutants in the tunnel, but these may be washed away with storm events.
- Soils and leaf litter substrates should be used as opposed to larger gravel or stone substrates.
- Mole salamanders make focused migrations to breeding ponds, and it is important to have multiple tunnels where migration paths cross roads. Tunnels for salamanders should not be more than 50 m apart (Schmidt and Zumbach 2008) as salamanders will not follow a fence for long distances (e.g. Pagnucco et al. 2012).

RATIONALE

- The best size of tunnel to encourage crossing by Jefferson Salamanders is not known, although there have been studies of crossing structures used by other salamanders in the same family (mole salamanders), which share similar life history traits.
- All documented use of tunnels by salamanders has been in terrestrial tunnels.
- Both closed-top (Patrick et al. 2010, Beasley 2013, Bain 2014) and open-top (Jackson and Tyning 1989, Allaback and Laabs 2002, Pagnucco et al. 2012) crossing structures have been used by other mole salamanders.
- Rectangular box culverts with local damp soil conditions are recommended for amphibians (see Jackson 2003, Smith 2003, Schmidt and Zumbach 2008, Amphibian and Reptile Conservation 2009, Beasley 2013).

SALAMANDER SPECIFICATIONS

RATIONALE

- Other mole salamanders have crossed through round tunnels as small as 0.25 m in diameter (Bain 2014) and 0.2 m wide; however, salamanders demonstrate hesitancy entering into small tunnels (Jackson 1996) and the percentage of salamanders that successfully cross through small tunnels may be low (e.g., Allaback and Laabs 2002, Pagnucco et al. 2012). Larger tunnels are required to ensure there is space for natural substrate and cover objects. In general, tunnels for amphibians are recommended to be at least 1 x 1 m in size (Schmidt and Zumbach 2008).
- Salamanders will cross through tunnels with or without natural substrate, but fewer individuals cross through bare concrete tunnels (Patrick et al. 2010). Natural soil substrate will retain moisture longer, lessening the risk of salamanders dehydrating or not entering structures.

FROG AND TOAD SPECIFICATIONS

Structure type and minimum size based on tunnel length

Tunnel Length	Box Tunnel (w x h)	Arch Tunnel (w x h)	Round Tunnel (diameter)	Overpass
15 m	1.0 x 1.0 m	1.5 x 0.75 m	1.0 m	NA
15-25 m	1.5 x 1.0 m	1.8 x 0.9 m	1.5 m	NA
> 25 m	NA	NA	NA	Yes

ADDITIONAL DESIGN CONSIDERATIONS

- Terrestrial tunnels should be used for frogs and toads; high moisture content and even small pools of standing water may be beneficial but the tunnel should not be flooded with water.
- Open or closed-top tunnels may be used.
- Open-top tunnels will provide moisture and air flow in the tunnel; however road salt or other pollutants may also enter into the tunnel but are most likely washed away during storm events.
- Soils and leaf litter substrates should be used as opposed to larger gravel or stone substrates.

RATIONALE

- There is no documented information available for crossing structure preferences for Fowler's Toads, however there is literature available for other species of toads and amphibians. Frogs and toads have used a wide variety of crossing structures under roads (reviewed in Schmidt and Zumbach 2008; Puky et al. 2013).
- Wide crossing surfaces with local soil are recommended for amphibians (e.g., Jackson 2003, Smith 2003, Schmidt and Zumbach 2008, Amphibian and Reptile Conservation 2009, Beasley 2013).

FROG AND TOAD SPECIFICATIONS
RATIONALE
• Although toads have been documented to use tunnels <1.0 m wide (e.g., Lesbarrères et al. 2004, Ottburg and van der Grift 2013, Puky et al. 2013, Wind 2014), larger tunnels tend to be more effective (e.g., Puky et al. 2013). There was very high toad crossing rates through tunnels 1.8 m wide (Biolinx (2013). • Guidelines for road crossing structures in England have been developed for the Common Toad (*Bufo bufo*). These guidelines recommend a rectangular crossing structure at least 1.0 x 0.75 m (w x h) for tunnels up to 20 m long and 1.5 x 1.0 m (w x h) for longer tunnels (Amphibian and Reptile Conservation 2009). • Both closed-top (Biolinx 2013, Puky et al. 2013, Wind 2014) and open-top (Pagnucco et al. 2012, Ottburg and van der Grift 2013) crossing structures have been used successfully by other toads.

4.2 Fencing for Reptile and Amphibian Crossings

Fencing in conjunction with crossing structures serves two purposes: 1) directing animals towards structure entrances and 2) providing a barrier to exclude animals from the road. Fencing can be used with crossing structures or as a stand-alone measure to prevent mortality along roads where connectivity is not a concern; this may include situations such as when suitable habitat is adjacent to, but not bisected by the road, or where animals are unlikely to cross successfully due to high traffic volumes (Jackson et al. 2015).

The following BMPs are divided into fencing design, placement, and maintenance considerations and are applicable to all amphibian and reptile SAR. For additional best practices for amphibian and reptile exclusion fencing, refer to Reptile and Amphibian Exclusion Fencing: Best Practices (OMNR 2013).

4.2.1 Fence Design

The primary objective of a fence design is to minimize fence breaches because animals that get through a fence can be trapped on the road and killed (e.g., Wilson and Topham 2009). Therefore these BMPs focus on providing recommendations for designing and installing a gap-free, permanent fence. Permanent fencing may have higher initial costs; however, when ongoing maintenance of temporary fencing is considered, permanent fences are less expensive in the long-run. A number of projects have experimented with fencing effectiveness for amphibians and reptiles (e.g., Woltz et al. 2008; Langen 2011; Smith and Noss 2011), and it is important to recognize that new cost-effective designs are continually being engineered and tested, and are strongly encouraged.

Fencing design should consist of a solid durable framework (stakes, posts, and sheeting) that is able to withstand weight and impact from snow removal and effectively exclude the target species. Recommended durable fencing materials include hardware cloth, chain link fencing, concrete barriers, and heavy-duty plastic fencing designed for wildlife (Table 2; Photos 38-44). Light-duty geotextile fence (lifespan up to 1 year; Photo 45), heavy-duty geotextile fence (2-3 years), or wood lath snow fencing (< 3 years), are not recommend for long-term use.

Standard chain link large animal fencing (e.g., 2.5 m high wildlife exclusion fencing with 4" mesh) does not work for many amphibians and reptiles as individuals can pass through the large mesh holes. In locations requiring guide or barrier fencing for both large animals and amphibians and reptiles, additional fencing material, such as hardware cloth at the appropriate height, can be attached to the base of the large animal fencing (Photo 25). When more than one species is targeted for mitigation, fencing height should be the tallest height recommended for all target species.

Table 2: **Summary of fence materials that have been used for long-term projects to exclude amphibians and reptiles from the road and/or guide animals to tunnels. For additional fencing specifications, refer to OMNR 2013.**

Fence Type	Benefits	Drawbacks	Considerations
Hardware mesh cloth (Photos 38 and 39)	Relatively durable; relatively low maintenance; allows drainage; available in rolls.	Susceptible to rust in seasonally wet areas unless heavy gauge wire used.	Use ¼" or smaller gauge to reduce the risk of small snakes getting stuck; requires attachment to post at regular intervals to avoid collapse.
Chain link fence (Photo 40)	Very durable; low maintenance; allows drainage; available in rolls.	Mesh size typically larger than species specifications.	Use buried hardware cloth with recommended mesh at the base of the fence to provide multi-species use for large and small animals (Photo 25); lip extension may increase effectiveness for some species (Photos 39 and 40).
Concrete (Photo 41), corrugated steel (Photo 43), aluminum sheeting (Photo 44), or vinyl walls	Very durable; low maintenance; vertical smooth surfaces prevent climbing.	Inhibits drainage and may cause pooling.	Aluminum sheeting and vinyl walls are less durable than concrete; corrugated steel can be obtained from corrugated steel pipes cut in half and are curved providing lip extension.

Fence Type	Benefits	Drawbacks	Considerations
Prefabricated plastic sheeting fence (Photo 42)	Very durable designs available, e.g., ACO fencing, available in 1 metre sections OR Animex fencing, available in rolls depending on thickness.	Inhibits drainage and may cause pooling.	Back-fill at road-side of fence to provide escape route for animals (Photo 49); fencing best suited for flat dirt terrain such as in drainage ditch (Photo 42); 1 m sections may not be suitable for long fences greater than 1 km.

Photo 38. Animex plastic sheeting made from post-consumer products ©K. Gunson

Photo 39. Hardwire cloth with ¼ inch mesh, wood frame, and top lip © K.Gunson

Photo 40. Chain link guide fencing and lip extension, Terry Fox Extension, Ottawa, Ontario © D. Seburn.

Photo 41. Concrete wall in Aurora, Ontario © K. Gunson

Photo 42. ACO fencing on highway near, Oliver, B.C. © R. Guse

Photo 43. Angled fence for salamanders at Waterton Lakes National Park© K. Gunson

Photo 44. Example of aluminum sheet fencing © K. Gunson

Photo 45. Fence end U design to deter animals following fence line from entering roadway in Haliburton County © K. Gunson

General considerations for fence design are as follows (see Figure 4 for further illustration):

- Steel posts will not break with snow load.
- Posts that are closer together (e.g., between 2-3 metres) will prevent fence sag and collapse during severe weather events and snow removal along roads.
- Stakes or posts should be placed along the road-side of the fence to deter climbing and be buried 30 cm into the ground (OMNR 2013).
- Use of materials that allow drainage at wet sites to avoid pooling at or near a crossing structure (Smith and Noss 2011; Photo 46).
- Mesh size needs to be appropriate for the target species (Photo 47). Refer to Table 3 for species-specific fence types. Many snakes can pass through ½" mesh fencing and some small snakes can even pass through or get stuck in ¼" mesh (Smith and Noss 2011, S. Marks pers. comm. 2014). A mesh size of ¼" or smaller should be used to help reduce the risk of small snakes getting stuck in the fence (Photo 47). The fence should be buried to deter animals from digging; the recommended depth is 10-20 cm where feasible. If rock cannot be avoided, the bottom of the fence can be folded and covered with gravel to hold it in place (Photo 48).
- The fence height should be higher than the high water level in spring.
- For reptiles, the fence should include an overhang lip extended away from the road to deter climbing (Photo 40).
- Backfill on the road-side of the fence can be used as escape ramps to assist trapped animals to climb to the safe side (e.g., ACO wildlife fence; Photo 49).
- Nylon mesh fencing or erosion materials should not be used along the right-of-way as snakes can become entangled and die in this material.
- Fence end treatments can be used to deter amphibians and reptiles from accessing the road at the fence ends:
  - The fence can be extended away from the road in a curved or 90 degree U design (Photo 45; Figure 4) to redirect animals away from the road
  - The fence should extend along the entire habitat and end at a point where habitat types transition (e.g., wetland-forest edge)
  - Rocks or other inhospitable materials at the fence end can help deter movement onto the road.

Photo 46. Pooling at culvert entrance that should be avoided at terrestrial wildlife tunnels © K. Gunson

Photo 47. Snake caught in ½ inch wire mesh; © M. Patrikeev

Photo 48. Fence along rock with gravel used to hold bottom of fence in place © K. Gunson

Photo 49. Backfill along ACO wildlife fence that can provide an escape ramp for animals on the roadside of the fence © V. D'elia

Table 3: **Fence design specifications for SAR reptile and amphibian species are based on OMNR 2013, Woltz et al. 2008 and expert advice.**

Taxonomic Group	Species	Fencing	
		Fence/wall Material	Minimum Height (above ground)
Salamanders, Frogs, Toads	Jefferson Salamander	• Hardware cloth with ¼ " mesh or smaller, concrete, aluminum, prefabricated plastic fence, or vinyl wall. • Salamanders are generally poor climbers (T. Bain pers. comm.) so a small mesh fence will work and also allow some drainage.	30 cm
	Fowler's Toad	• Solid, permanent material (e.g., cement, plastic panels), or hardware cloth with ¼" mesh or smaller. • Avoid using netted fencing because they can climb (Smith and Noss 2011).	50 cm
Lizards	Five-Lined Skink	• Aluminum flashing; skinks can easily climb most other fencing materials.	50 cm

Taxonomic Group	Species	Fencing: Fence/wall Material	Fencing: Minimum Height (above ground)
Snakes	Eastern Foxsnake, Gray Ratsnake	• Concrete, aluminum, or vinyl wall.	200 cm
	Blue Racer, Milksnake	• Hardware cloth (¼″ mesh or smaller), concrete, aluminum or vinyl walls.	100 cm
	All other snake species	• Hardware cloth (¼″ mesh or smaller), concrete, aluminum or vinyl walls.	60 cm
Turtles	All species	• Hardware cloth, chain link fence (½″ mesh or smaller), concrete, aluminum, vinyl wall, or prefabricated plastic wildlife fence • Combining chain link and hardware cloth will be effective for adults, juveniles, and hatchlings. • When fencing is used for both turtles and snakes, mesh size larger than ¼″ is discouraged as snakes can become entrapped.	60 cm

4.2.2 Fence Placement

Right-of-way considerations:

- Fencing should be placed as far as possible from the road edge to minimize impacts from snow removal, mowing or other road-side maintenance practices.
- Fencing cannot interfere with road interchanges or driveway access.
- Permissions and permits must be obtained from the road authority.
- When the fence will extend beyond the right-of-way, permission must be obtained from property owners, or in the case of Crown land, from the Ministry of Natural Resources and Forestry.

Fence Length and Placement:
Fence length depends on the species' movement abilities as well as the interface of the surrounding habitat with the road. Spatial analyses of where species are found on the road, in the road shoulder and in the road verge can help determine how much fencing is required and where it should be placed (Gunson and Teixeira 2015). However, when roads bisect continuous expanses of SAR habitat, fencing is often required along the entire stretch of a road to prevent mortality. The following should be considered when evaluating fence and crossing structure placement:

- Data collected from field and on-road surveys, expert opinion and other sources such as the NHIC to understand species presence, habitat use, and movements in relation to the road (see Appendix A).
- Maximum and mean movement distances of the target species should be used to inform fencing length. For example, salamanders generally will not move distances greater than a couple hundred metres, while turtles and snakes may move several kilometers (see Appendix A). Some species will move considerable distances along the fence and access the road at the fence ends; this can only be avoided if the fence is longer than the distances that the species will move.
- Gullies, uneven terrain and solid rock areas should be avoided when possible; if rocky areas cannot be avoided, gravel can be used to hold fence in place (Photo 50).
- When multiple crossing structures are used, fencing should span between structures (and angle away from the tunnel opening in a 'V' pattern: Photo 43 and Figure 4).
- To be effective, fencing must connect to the tunnel entrances without gaps (Photo 51) or go over top of the tunnel (Photo 52) in a 'V' pattern (Photo 53; Figure 3).

Photo 50. Fence with gap at bottom due to erosion from water draining under fence © K. Gunson

Photo 51. Fence tying into tunnel at Rice Lake Trail, Note shadecloth not recommended for permanent fencing © K. Gunson

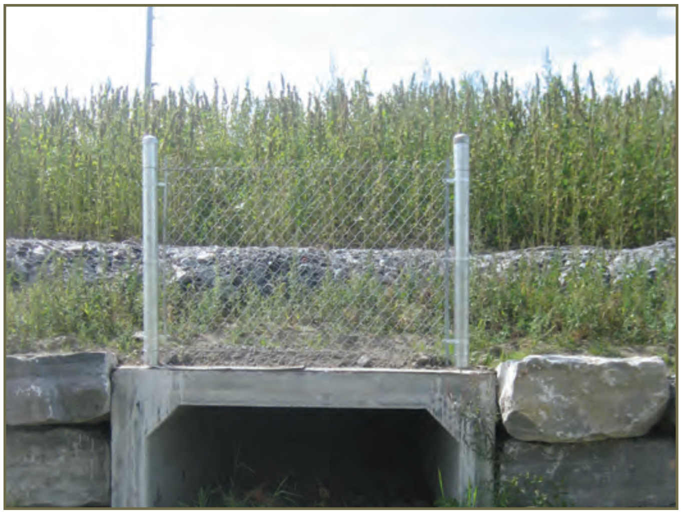

Photo 52. Fencing above tunnel, Terry Fox Drive extension © K. Gunson

Photo 53. Fencing approaching tunnel entrance in a 'V' pattern © K. Gunson

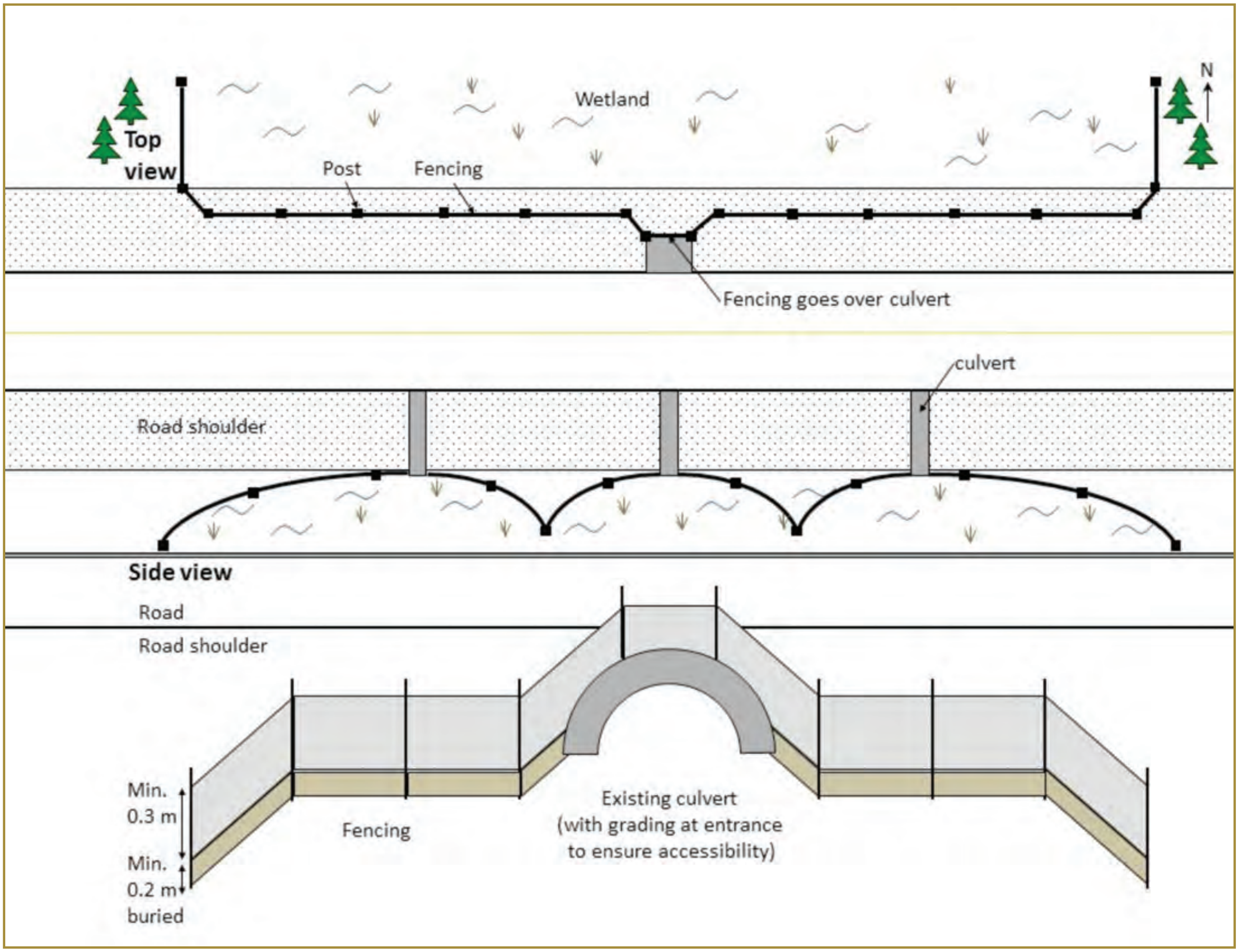

Figure 3. **Top view and side view of fencing design and siting options along the right-of-way. Figure adapted from Nature Conservancy Canada schematic.**

4.2.3 Fence Maintenance

All fencing requires routine survey checks and subsequent maintenance repairs and this should be planned and budgeted for. The frequency of maintenance checks and repairs will vary with the durability of the fence. After snowmelt, a thorough survey and follow-up fence repairs are essential prior to animals emerging from hibernation. The following are recommended considerations for fence maintenance:

- Woody vegetation, leaves, thick grasses, and other debris that pile up along fence may provide a `ladder` or puncture the fence allowing animals access to the road. Regular maintenance is required to clear vegetation from all fences.
- Fences should be marked with long posts and flagging tape to warn maintenance crews about its presence, especially where mowing will occur.
- Routine fence surveys should be done using a checklist approach to identify where repairs are required, including a description of the damage and the location. Checklist items should include that the fence has not collapsed, fence is still in the ground, fence abuts crossing tunnels, vegetation is not near the fence, and that there are no holes in the fence. Repair crews need to fix the fence in a timely manner to minimize fence breaches during the active season for amphibians and reptiles.

5 SUPPLEMENTARY MEASURES

Specifically designed crossing structures, combined with fencing, are the most effective mitigation strategy to reduce road mortality and enhance habitat connectivity (Dodd et al. 2004, Aresco 2005); however supplementary mitigation measures may be used in association with crossing structures and fencing (i.e., installing signage or reduced speed zones at fence ends). In addition, supplementary measures may be used as temporary measures during construction, or prior to road upgrade and rehabilitation projects, or on existing roads where there would otherwise be no mitigation. The effectiveness of some of these strategies at reducing road mortality and improving connectivity is difficult to measure and largely unknown; therefore implementation of these measures should proceed with caution using an adaptive management approach.

This section classifies each measure as those that influence driver behaviour, and those that influence wildlife movement as defined by Huijser et al. 2007. The following list of measures is not exhaustive, but instead summarizes what has been used in Ontario and elsewhere, with specific consideration for how each strategy may be applied to amphibians and reptiles.

5.1 Influencing Driver Behaviour

The strategies outlined in this section have relatively low effectiveness when used in isolation and several of these approaches should be used concurrently whenever possible. For example, a good strategy may include a reduced speed limit, traffic calming measures to reinforce the low speed limit, high quality signage to warn drivers, and a public education program to help drivers understand the measures that have been put in place.

With the exception of road closures, strategies that influence driver behavior rarely result in a significant reduction in road mortality. This is in part because, despite these measures, many reptiles and amphibians are small and difficult to see and/or avoid. Further, Ashley et al. (2007) found that approximately 2.7% of drivers intentionally ran over reptiles, and such behavior severely limits the success of these strategies.

Reduced speed zones allow drivers more time to react to an animal on the road, and subsequently safely avoid a collision. They have been implemented in Banff National Park to reduce collisions with larger wildlife, such as Grizzly bears (Banff National Park, unpublished data 2011-2014). Speed limits may be reduced seasonally and/or at specified times of day. This methodology is only suitable for amphibians and reptiles on low volume roads or roads in protected areas. A reduced speed zone is typically combined with a public awareness strategy and/or signage to educate motorists about the need to minimize road mortality for amphibians and reptiles. Enforcement or traffic calming mechanisms (see below) are usually necessary for the effective implementation of lower speed limits. This strategy can have a high cost given the need for regular enforcement.

Seasonal road closures offer an effective mechanism for reducing road mortality by eliminating vehicles from a road. Although this is a very effective solution, such closures are typically only feasible for a few days per year and they must be timed precisely to coincide with amphibian and reptile migrations. This method is most easily implemented in protected areas, on low volume roads where access to residences or businesses is minimal, or on roads where alternate access exists. A good example is King Road on the Niagara escarpment (Photo 55), where a seasonal road closure has been implemented for several years for the endangered Jefferson Salamander. Salamanders typically move across a defined road segment within a 2-3 week time period in early spring during a warm, rainy period. This type of strategy requires both buy-in from the road authority as well as the community using the roads. A public relations campaign is a useful tool to inform and gather support from local residents. This strategy has a relatively low cost.

Traffic calming refers to the installation of road features designed to decrease vehicle speeds without interfering with the flow of traffic. Some traffic calming methods, such as speed bumps (Photo 56), traffic circles, and raised medians, can only be implemented on low speed roads; whereas other methods, such as narrow lane widths, and rumble strip patches may be used on moderate to high speed roads. In some cases, speed bumps may interfere with snow removal; however installations can be used seasonally. This strategy has low to moderate costs dependent on the measure used.

Signage is a low-cost, widespread method of road-side messaging that is relatively easy to implement (Photo 57). The key objective for sign use is to instill awareness so motorists can avoid hitting wildlife along roads where the signs are placed. Effectiveness may be improved with a well thought-out strategy that avoids driver habituation and includes the following criteria (see Gunson and Schueler 2012; Kintsch et al. 2015):

- Seasonal placement of signs, or use of text indicating when target animals are likely crossing;
- Enhancement of signs with flags, flashing lights, or unique art work (Pojar et al. 1975, Hardy et al. 2006);
- Use of science and data to inform effective placement;

- Use of signs on moderate to high volume roads to deter theft;
- Strategic placement of signs and at the ends of exclusion fencing;
- Use of signs as temporary measures and markers in advance of more permanent mitigation measures (Ontario Ministry of Transportation 2012).

As with all of the other measures in this section, the effectiveness of signage can also be increased by combining it with other measures (e.g. reduced speeds, traffic calming). Benefits of signage for SAR amphibians and reptiles include driver awareness of wildlife on the road and heightened understanding of the importance of conservation efforts when used with a public awareness and education campaign (see example in Joyce and Mahoney 2001). In Ontario, signage has commonly been used on municipal and provincial park roads (Photo 58), and more recently on provincial roads (Ontario Ministry of Transportation 2012; Photo 59).

Public awareness and education campaigns are designed to inform drivers about wildlife and road issues and how they can help minimize or avoid wildlife road collisions. For amphibians and reptiles, public awareness campaigns typically target local communities near known high-risk road mortality locations, such as at Heart Lake Road in Brampton, Ontario. Local media attention generated awareness of the issue from local residents and subsequently a volunteer task force of 20-40 individuals was used to conduct on-road mortality surveys in 2011 and in 2013 (TRCA 2014).

While it is difficult to draw a direct correlation between heightened driver awareness and a decrease in road mortality, this strategy has the potential to improve effectiveness and public acceptance of other mitigation efforts, such as signage, reduced speed zones, or traffic calming measures. The cost of conducting a local-based public awareness campaign is comparable to that of the other strategies discussed; however, a regional, coordinated, long-term strategy (i.e. similar to the well-known Drinking and Driving Campaign) would entail greater funding and long-term commitment.

5.2 Influencing Wildlife Movement

Ramped curbs and escape gaps are used along roads (typically local, municipal roads) to replace vertical curbs that are too high for amphibians and reptiles to climb over. A good example is in Waterton Lakes National Park, where right-angle curbs were replaced with sloped curbs to allow Long-toed Salamanders to successfully escape the road (Photo 60). Additionally, escape gaps can be used where the structures meet the road (e.g., Banff National Park; Photo 61). Escape gaps would work well along high volume roads where continuous sections of jersey barriers divide opposing lanes of traffic and animals that enter the right-of-way cannot cross the road (e.g. Highway 401 and 417). This strategy has a relatively low cost.

Assisted migration can be used where a concentrated amphibian migration crosses a defined stretch of road. Temporary traps (typically drift fencing and buckets) may be used to prevent animals from crossing the road, which are then collected and moved across the road by volunteers. Alternatively, volunteers can survey the road during peak times and move any animals that are encountered. This strategy is labour-intensive and relies on having local volunteers to monitor traps during a migration event, and it requires safety precautions for the volunteers. However, if timed and coordinated effectively, facilitated migrations can be effective in reducing road mortality for amphibians (Photo 62).

Habitat creation can be used to reduce the need for individuals to access habitat close to the road or cross the road to access habitat on the other side. Since reptiles and amphibians often show high fidelity to specific habitats, many individuals will continue using historical habitat features and a population-level transition to the new habitat can take decades. Consequently, road-side barrier fencing is still necessary to prevent dispersing animals from accessing the road. The cost, feasibility and effectiveness of creating new habitat is variable and will be site and species specific (B.C. Ministry of Forests, Lands and Natural Resource Operations 2004).

New habitat creation may include wetlands as breeding sites for amphibians (e.g., Merrow 2007), artificial nesting sites for turtles; (Clarke and Gruenig 2002; Paterson et al. 2013); or gestation sites (Rouse 2005; Parent and Black 2006) and hibernacula (Willson 2005) for snakes. The B.C. Ministry of Forests, Lands and Natural Resource Operations BMP document (2004) describes the applicability of habitat restoration (or creation in this case) for amphibians and reptiles. General recommendations are as follows:

- A thorough understanding of the habitat use and movements of the target species is necessary.
- New habitat should be in close proximity and on the same side of the road as other habitat used by the target species.
- The created microhabitat should be suitable for the target populations.
- Other important habitats should not be manipulated to create new habitat.

Photo 55. Road Closure on King Road, Halton Region. © N. Finney

Photo 56. Speed bumps used to reduce speed on Cyprus Lake Road, Bruce Peninsula, Ontario. ©K. Gunson

Photo 57. Awareness sign on provincial park road in Point Pelee National Park. ©K. Gunson

Photo 58. Turtle signs used on municipal roads in Ontario. ©K. Gunson

Photo 59. Provincial Wildlife Habitat Awareness Sign on Highway 654. ©K. Gunson

Photo 60. Sloped curve in Waterton Lakes National Park, ©B. Johnstonh

Photo 61. Jersey barrier with gaps at the road surface ©K. Gunson

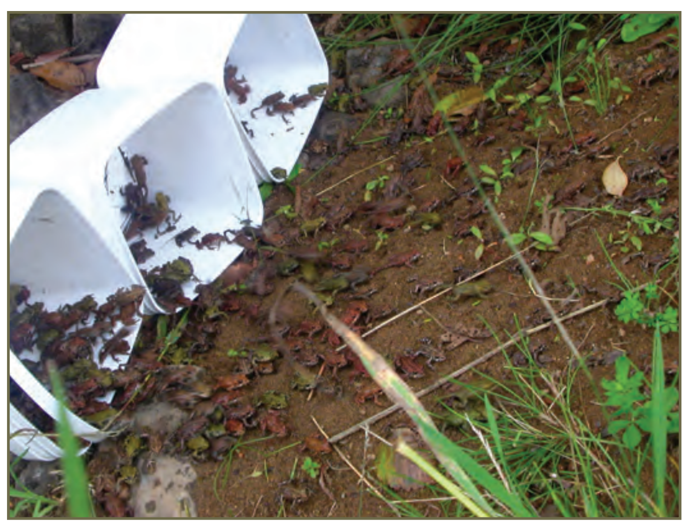

Photo 62. Assisted migration of toadlets in British Columbia. © E. Winde

6 TEMPORARY MITIGATION DURING ROAD CONSTRUCTION

This section provides general considerations for mitigation during construction when working in areas with SAR amphibians and reptiles. The following considerations address two components, timing construction activities to avoid construction-related impacts, and installing mitigation measures to minimize interactions with amphibians and reptiles and their habitat during construction.

Effective implementation of construction mitigation BMPs requires both oversight and consultation with experts. Regular consultation with local species experts is strongly recommended because active times for the target species will vary annually with changing climatic conditions and is site-specific especially in a landscape as large as Ontario.

6.1 Timing of Construction Activities

When road construction will occur within or near amphibian and reptile habitat, some impacts can be minimized by carefully scheduling the timing of the work to avoid habitats when they are occupied or during sensitive periods. Construction during the overwintering periods should avoid wetlands and other sites that are used for hibernation. This includes direct disturbance as well as indirect disturbance such as decreasing water levels in overwintering wetlands. Construction during the active season should avoid key habitat features or times when the species is most sensitive (see Appendix A). For example, avoiding work at breeding wetlands being used by Jefferson Salamander and Fowler's Toad in late March to June. Amphibian and reptile populations are active from March to October in southern Ontario and this time period lessens for more northern populations (Appendix A). Consultation with a local species expert and the district MNRF office may be required to assess annual variations of site-specific movements for the target species during construction activities.

6.2 Mitigation Measures for Construction Activities

On-site, temporary measures for all road projects that occur within, or adjacent to amphibian and reptile habitat help to avoid harming or killing individuals. BMPs for temporary measures include:

- Installation of exclusion fencing between the road construction zone and SAR habitat;
  - Use fencing that will last the duration of the road construction project (i.e., light-duty geotextile fence with a lifespan of up to one year)or, for longer projects, heavy-duty geotextile fence should be used (see section 5.2, OMNR 2013);
  - If permanent fencing is going to be installed as part of the mitigation plan (i.e. along roads), the permanent fence can be installed instead of temporary construction fence to avoid extra costs (Photo 63);
  - Fencing should be inspected and repaired daily to maintain effectiveness and avoid potential breaches; and
  - Fencing should be installed so that construction sediment does enter into wetlands or aquatic systems.
- When possible, alternative measures (e.g., rock barriers) should be integrated to create a sufficient barrier between construction sites and adjacent SAR habitat;
- Blast mats and other measures to control blast size and vibrations should be used within or adjacent (up to 250 m) to snake habitat (OMNR 2011);

- A qualified species expert should be present or available at all times to conduct searches, handle encounters, and translocate animals during construction;
- Searches should be conducted daily prior to and during construction activities;
- When SAR amphibians and reptiles are found on a construction site, proper handling, translocation and reporting protocols should be followed. Specific protocols for SAR encounters are available in the Ontario Species at Risk Handling Manual in addition to the Georgian Bay Biosphere Reserve BMP document (Clayton and Bywater 2012); and
- Project-specific reporting and handling protocols should be developed in coordination with the appropriate agency personnel. Observation records should include the observer's name, date and time, species, location (descriptive and georeferenced), photographs, and action taken.

Photo 63. Temporary fencing installed prior to installation of more permanent fencing along highway 69, note permanent fencing completed in Photo 48. © W. Kowbasniuk

7 MONITORING

Substantial research has been conducted to monitor the effectiveness of mitigation for large animals (e.g., Ford et al. 2010; Dodd et al. 2007); however, there exists a significant knowledge gap for amphibians and reptiles, and many mitigation projects have had no monitoring at all (Paulson 2010). This section provides recommendations for monitoring the effectiveness of road mitigation projects.

7.1 Study Design

Most studies that have evaluated the effectiveness of mitigation structures to-date are of low inferential strength due to poor study design, and this has resulted in results with high uncertainty (van der Grift et al. 2013). This uncertainty impedes implementation of mitigation measures and leads to inefficient use of limited financial resources.

Many monitoring plans only consider whether a specific species uses a structure at a specific location. However it is essential to monitor the viability of populations affected by a mitigated road (Figure 4). For example, if particular individuals, such as breeding females do not use a crossing structure to access breeding sites, this will lead to reduced breeding success and population declines, even though traffic mortality has been reduced and some individuals were observed using the tunnel.

Ideally, the population size (or density) of the target population should be measured at or near the road mitigation project to assess how the species responds (van der Grift et al. 2013). The population may increase, decrease or show no change in abundance after the road construction project (Rodenbeck et al. 2007). For example, Torres et al. (2011) performed visual census surveys for the Great Bustard

(*Otis tarda*), a globally threatened bird in Spain, and compared population trends in a Before-After-Control-Impact (BACI) design (see description below).

When it is not possible to measure a change in population size, the research questions should ask, “Is the current rate of road mortality sufficiently low, and/or is the rate of crossing sufficiently high to ensure a viable population?” If the answer to that question is no or possibly not, the next question is, “Which parameter of the road, traffic, or mitigation structure should be modified to improve viability to an acceptable level?” This question is more easily answered by assessing crossing and road mortality rates at different mitigation designs while controlling for habitat and road conditions.

Up to three years of monitoring data (from both before and after a road mitigation project) is likely necessary to measure changes in the ecological response (e.g. population size or road mortality rate) of the target species and reduce the influence of random, one-time events. The appropriate time-frame will depend on the ecological response and target species characteristics (e.g. longer-term monitoring for species that have longer generation times). This requires an understanding of the research goals among both the road planners and monitoring team early in the planning process to ensure the study design is adequately implemented in the road construction phase.

The optimal study design consists of data collected before and after the impact at sites where the impact has occurred and at control sites which have not been affected by the impact (Rodenbeck et al. 2007). This study design is referred to as a Before-After-Control-Impact (BACI) design and provides the highest level of inferential strength to measure the ability of the study to detect a change in the parameter of interest (e.g. population size, and rate of wildlife mortality on roads). A properly implemented BACI design allows the monitoring objectives to change from, “Are animals using crossing structures?” to “Has the mitigation prevented population decline?”.

Other considerations for a study design are to select specific mitigation treatments at each monitoring site as well as carrying out consistent and repeatable sampling to ensure results are broadly applicable (van der Ree et al. 2015). Design elements are described below as well as in Figure 4:

- Treatments that can be manipulated allow for different structural features to be assessed (e.g. open-top vs. closed-top or varied fencing type and length) while controlling for other variables.
- Replication of treatments and controls among sites is important, as is monitoring each treatment in more than one location.
- Treatments that are randomly assigned will help to reduce bias and allow for a rigorous statistical analysis.
- Appropriate covariates need to be selected and controlled for. Examples of covariates include spatial and temporal variability in road design and traffic levels, mitigation structure design and the features of the surrounding landscape (van der Grift et al. 2013).
- Sampling and field protocols that are repeatable and consistent at monitoring locations before and after road mitigation help to ensure unbiased data collection.
- Inclusion of impact (mitigated) and control sites is essential to ensure that the apparent effects of mitigation (reduced mortality or increased permeability) are due to the mitigation and not a confounding variable such as weather, differences in habitat or road and terrain conditions.
- The variables being monitored (e.g. relative abundance) should be clearly identified prior to the commencement of the project.

Research Questions

Monitoring Goal
1. Maintain and restore population viability
   a. Measure trend in population size/density

Fencing
1. Reduce road mortality
   a. Ask is the reduced mortality sufficient to maintain or restore population viability?

Crossing Structures
1. Crossing use by population (e.g. male and females)
   a. Ask is use enough to maintain or restore population viability?

Planning

Long-term Monitoring
1. Multiple seasons
2. Multiple years (3 or more) prior to AND after mitigation measures have been installed or modified, e.g. Beofre, after and control impact (BACI studies).
   a. To reduce influence of random, one-time events

Expertise & Collaboration
1. SAR biologist
2. Road authority
3. Road developer
4. Monitoring team

Other
1. Obtain funds
2. Obtain permits
3. Start collaborating early!

Study Design

Treatments
1. Measure trend in population size/density
2. Vary crossing structure design
3. Combination of both

Site Selection
1. Obtain pool of potential treatment and control sites
2. Random assignment of treatment at impact sites
3. Replication of treatments and controls among sites
4. Include before, after, and control sites

Sampling
1. Repeatable
2. Consistent

Figure 4. **Study design recommendations for developing research questions, and a rigorous study design that will inform road mitigation effectiveness for amphibians and reptiles.**

7.2 Monitoring Techniques

This section outlines monitoring techniques that are used to evaluate crossing structure and fencing effectiveness for amphibians and reptiles. All techniques may be combined in a monitoring plan depending on budget, timelines, and the specific objectives.

7.2.1 Road Surveys

Road surveys are the most common method used to evaluate where amphibians and reptiles road mortality and interactions occur along roads (see Langen et al. 2007 for a description of methods). This information can be used to evaluate road impacts on wildlife, where animals are interacting with roads, and the effectiveness of crossing structures and fencing systems.

Data is collected by driving, cycling, or walking along a selected length of road looking for alive or dead individuals. The sampling method will vary depending on the objectives, road conditions, and the degree of detectability desired (Langen et al. 2007, Collinson et al. 2014). Driving surveys allow greater distances of road travelled over a sampling period, however the detectability of small vertebrates may be underestimated (Slater 2002; Langen et al. 2007).

General monitoring considerations for documenting amphibian and reptile SAR on roads include the following:

- Surveys should be conducted at least three years prior to the construction phase of a road improvement or rehabilitation project:
  - When a species is common, road surveys may generate a lot of data in 1 or 2 seasons (Ashley and Robinson 1996), however for SAR that are inherently rare, more time will be required to understand movements in relation to the project area.
- Surveys should take place during the active season or movement period for the target species (Appendix A).
- The frequency of surveys will depend on the goal of the study, the target species, traffic volume, rates of scavenging, carcass persistence, and when the species is moving (Slater 2002; Barthelmess and Brooks 2010; Santos et al. 2011). When the goal is to survey the majority of species on a road in an active season, the following recommendations should be considered for each taxon:
  - For species that move in well-defined time periods such as salamanders and toads that migrate to breeding ponds, surveys should be timed during peak movements (e.g., rainy, warm spring nights) because carcasses will be obliterated with rain and from traffic in a few hours even on low traffic roads.
  - Greater than 50% of snake carcasses will disappear in 24 hours so surveys should be conducted daily during peak movements in spring and fall (Antworth et al. 2006).
  - Dead turtles persist the longest on roads, so surveys two to three times a week during nesting season are recommended.
- Weather conditions, time of day and traffic volumes will all impact detectability of carcasses. For animals that move on rainy nights, such as the Jefferson Salamander, surveys must be conducted at night before rainfall and morning traffic obliterates carcass remains.
- Note that road surveys may not detect rare species where road mortality has already depleted the number of individuals adjacent to the road (Fahrig and Rytwinski 2009), or species that avoid crossing roads all together (Andrews and Gibbons 2005):
  - Other visual encounter survey techniques may be required to detect rare and elusive animals surrounding roads (Konze and McLaren 1997). Examples include cover boards for snakes (Patrick and Gibbs 2009), pit-fall traps for amphibians and toads (Gibbs and Shriver 2005), and hoop-net traps for turtles (Beaudry et al. 2009).
  - When information is lacking for rare species, data from common species (e.g. Painted Turtles) may supplement sample size.
- Surveys should be conducted with consistent and repeatable methods so the road can be surveyed the same way in a before and after mitigation design. Smith et al. (2015) discusses methods as well as how to avoid observer bias.
- Each specimen should be carefully examined and photographed to determine the species and, if possible, the sex and length of the animal should be recorded (e.g. plastron of a turtle, total length of snakes) (Photos 82 and 83). Depending on the project, it may also be important to collect a DNA sample or to mark live individuals.

Photo 64. Identifying amphibian specimen peeled off the road. ©K. Gunson

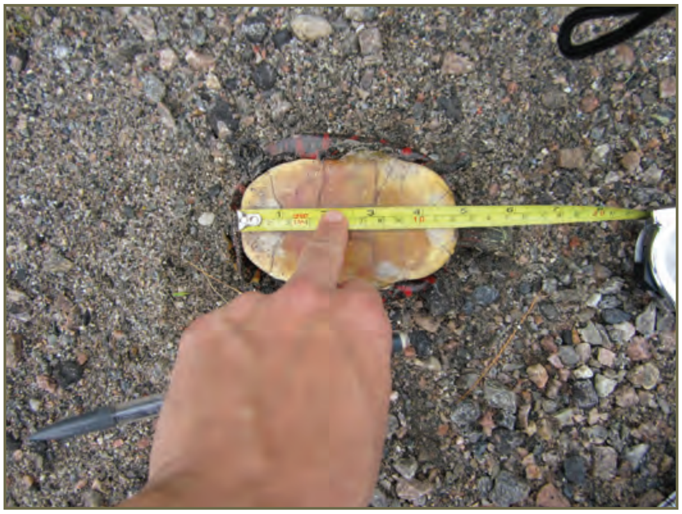

Photo 65. Measuring mid-plastron length for dead Painted Turtle found on the road. © K. Gunson

7.2.2 Crossing Structure and Fencing Effectiveness

This section focuses on monitoring techniques for measuring whether crossing structures and fence designs are effective at providing connectivity across roads. Previously the majority of studies that have monitored crossing structures have assessed use of tunnels by amphibians and reptiles (see review in Appendix C). Studies that assess fence-efficiency (proportion of animals encountering the fence that enter into the tunnel) and tunnel-efficiency (proportion of animals that enter tunnels and go through them) are needed to better inform mitigation designs (Jackson and Tyning 1989).

Smith et al. (2015) offer information for developing a monitoring plan to measure mitigation effectiveness for small vertebrates including reptiles and amphibians, and Clevenger and Huijser (2011) provide information on monitoring techniques based on mark-recapture methods. Further information regarding methods for surveying amphibians and/or reptiles can be found in Heyer et al. (1994), Konze et al. (1997) and McDiarmid et al. (2012). The Canadian Council on Animal Care (CCAC 2004) provides an excellent manual for handling and capturing amphibians and reptiles that can be integrated into the following monitoring techniques (http://www.ccac.ca/Documents/Standards/Guidelines/Add_PDFs/Wildlife_Amphibians_Reptiles.pdf)

Digital cameras are currently the most commonly used technique for measuring crossing structure use for animals in Ontario. Motion-activated cameras work well for large and medium-sized animals; however, they are not very effective at capturing pictures of ectothermic animals, such as amphibians and reptiles. This is because motion-triggered cameras only take a photograph when there is a temperature differential between the animal and the ambient temperature (Reconyx 2010). For example, Pagnucco (2012) found Reconyx infra-red motion triggered cameras only documented approximately 19% of salamanders in a 0.5 m by 0.5 m ACO tunnel. Since the motion-activated feature is not effective, the time lapse setting should be used instead to take pictures at regularly spaced intervals (e.g. every minute). Approximately 20,000 images are taken in a two week period with a one-minute interval and camera detection software can help to efficiently find wildlife in images (Dillon et al. 2011). Setting the camera to take photos over shorter intervals (e.g. every 10 seconds) will improve the quality of the data but would require the cameras to be checked more regularly. Cameras should be placed at both ends of the tunnel, securely fastened and locked to the undersurface of the tunnel top (photo 84). At larger tunnels, cameras can be mounted close to the ground to capture snakes and turtles.

Pitfall Traps: Pitfall traps consist of buckets, cans, or other containers that are buried flush with the ground and are set up along a fence that directs animals to the traps. Pitfall traps need to be large enough so that the target species cannot climb or jump out of the containers. In addition, once traps are set they need to be checked regularly (at least every day) to avoid drowning, desiccation or predation of individuals. They can be used at or near amphibian habitat to assess where animals are moving in relation to a road. For example, Gibbs et al. (2005) used metal cans

Photo 66. Camera securely fastened to top of culvert; note difficult to capture animals when water in culvert or tunnel. © K. Gunson

Photo 67. Using hand-held receiver to locate Blanding's turtles around highway 24 © K. Gunson

Photo 68. Blanding's turtle with radio transmitter on back of shell. © K. Gunson

Photo 69. Passive data logger receiver used to record turtle passage at culvert on highway 24. ©K. Gunson

50 cm deep and 7.5 cm in circumference to assess movements of salamanders across a road. Furthermore, pitfall traps have been used at entry and exit points of crossing structures to assess use of structures (Pagnucco et al. 2012). This also provides a useful technique to capture and mark individuals.

Mark-recapture: This technique involves capturing, marking and recapturing animals to determine if they cross the road. Several methods exist for marking amphibians and reptiles, including inserting Passive Integrated Transponders (PIT), notching scutes on turtles, marking salamanders with visible implant elastomer (e.g., MacNeil et al. 2011) and using image-recognition software. Some of these techniques are discussed in more detail in the CCAC (2004) manual. Mark-recapture methods for turtles are discussed in detail in Robertson et al. (2013) and for all reptiles in McDiarmid et al. (2012).

Radio-Telemetry and passive data loggers/ PIT tag readers: Radio-telemetry can be used to monitor animal movements using a hand-held receiver (photos 85 and 86) without the need to recapture the animals. Further, passive data loggers (photo 87) or PIT tag readers can be mounted near crossing structure entrances (James et al. 2011; Caverhill et al. 2011) to record the movement of marked individuals through them.

Table 4 provides a comparison of the advantages and disadvantages of these methodologies. A combination of several methods will provide the most robust data set and eliminate most of the disadvantages of any one method. For example, using both hand-held radio telemetry and passive receivers mounted in the crossing structures will provide high quality data on crossing events as well as the detailed movements of the individuals in relation to the crossing structures/road.

Table 4: **Advantages and disadvantages of the techniques used to monitor road crossing structures**

Technique	Advantages	Disadvantages
Mounted digital cameras	• Provides information on the time and date of the crossing event • Provides direct evidence that the structures are used • Should detect most individuals using the crossing structure if cameras are set to take photos regularly (e.g. every minute)	• Does not provide information on the individuals using the structure (e.g. sex) • Effective cameras are expensive, and there is a risk of theft • It can be very time-consuming to review photographs and maintain cameras (downloading pictures, adjustments, batteries, water levels, etc.) • Cameras typically do not work under aquatic conditions

Technique	Advantages	Disadvantages
Pitfall traps	• Provides information on the individuals using the structure (e.g. sex) and the date of the crossing event • Provides direct evidence that the crossing structures are used • Should detect most individuals using the crossing structure • Can use trapped animals for genetic sampling and mark-recapture	• Labour-intensive for set up and sampling as the traps should be checked a minimum of every day • Risk of animals dying in traps • Method is less suitable for reptiles
Mark-recapture	• Provides information on the individuals using the structure (e.g. sex) • Allows for estimates of population abundance (with enough sampling)	• May not provide information on the time and date of crossings • Does not provide direct evidence that animals used crossing structures (e.g. it is not possible to rule out crossing through holes in fence or at fence ends) • Detection of individuals crossing the road is limited to the number of animals captured and subsequently recaptured
Radio-telemetry and passive data loggers	• Provides information on the individuals using the structure (e.g. sex) and the time and date of crossing • Passive data loggers and PIT tag readers in the structure provide direct evidence that the structures are used • Hand held radio-telemetry receiver can track movements in relation to the road (e.g. home range size, etc.) • Will work under aquatic conditions	• Considerable field time, effort and cost can be required to capture, handle and monitor animals • Detection of individuals crossing the road is limited to the number of animals that are captured and tagged or tracked • Radio-telemetry with a hand-held receiver is unlikely to provide direct evidence that the structure is used, so it is ideal to combine this with passive readers mounted in the structure

7.2.3 Population Estimates

Monitoring that measures changes in population abundance, animal distribution, and genetic relatedness before and after a road mitigation project can answer questions related to how new road mitigation maintained or improved the long-term persistence of wildlife populations, especially when used in a BACI design. This section generally outlines inventory and survey techniques to measure whether a population is stable, increasing or decreasing as a result of the road mitigation measures and road construction project.

Mark-recapture studies may be used to estimate population size, but a large number of individuals need to be marked to produce statistically significant estimates.

Relative Abundance surveys are carried out using standardized methods, such as timed searches, grids or transects, that allow for comparisons over time or between sites. In addition to free searches, these surveys may consist of cover boards for snakes and salamanders or pit-fall traps for toads and frogs along. Abundance surveys (counts of animals per area and standardized by search effort) require a systematic study design with regular surveys by the same trained volunteers to reduce observer bias.

Call surveys may be used to collect relative abundance data for toads and frogs near roads, and do not require direct observation of the animals (Eigenbrod et al. 2008b). With respect to SAR amphibians and reptiles in Ontario this monitoring technique would only be applicable to the Fowler's Toad.

Genetic Sampling involves taking from blood or tissue samples from live or dead individuals to compare genetic relatedness and structuring (e.g. sex and age ratios) before and after a road mitigation project (e.g. James et al. 2011). For example, Clark et al. (2010) found roads have an effect on the genetic structure, connectivity and gene flow on Timber Rattlesnakes. In another study, Row et al. (2010) genetically analyzed blood samples from Eastern Foxsnake populations bisected by highways in Ontario, Ohio and Michigan. Notably, some populations bisected by Highway 401 were not genetically distinct, possibly because of underpasses that allowed snake passage.

7.3 Adaptive Management

Adaptive management consists of using the results from monitoring to inform decision making with regard to planning and designing subsequent phases of a project (Holling 1978). The Environmental Impact Assessment (EIA) process is meant to be a flexible, iterative and adaptive process that can adjust for uncertainty and preferences that emerge during the process (Lawrence 2003). With this in mind, and the typical long-term nature of road projects, there is an opportunity to integrate long-term and adaptive monitoring into the road planning processes.

Road construction and the implementation of mitigation strategies typically occurs in phases. The phased construction process allows for mitigation designs to be implemented in the initial section of highway so that lessons learned via monitoring can be integrated into subsequent phases of the road project. For example, the improvement of the Trans-Canada Highway in Banff National Park was conducted in 4 phases over 30 years, and long-term monitoring of crossing structures enabled lessons learned to be applied in each subsequent phase to improve crossing structure designs (Ford et al. 2010). Adaptive management of the project design based on monitoring results requires regular and close communication between the people conducting the monitoring and the transportation agency. Ongoing communication will permit timely changes to design plans that reflect the most current results from monitoring activities (Clevenger and Ford 2010).

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9 APPENDICES

Appendix A: SAR Amphibian and Reptile Habitat Use and Movements

General summary of seasonal habitat use, general movement distances within and between habitat and when this occurs for species at risk amphibians and reptiles in Ontario. Bold text indicates high risk of road mortality for the species during months indicated. Summary based on review of COSEWIC reports, Recovery Strategies, ESA Habitat Regulations, and ESA Habitat Descriptions. All of the COSEWIC reports that were used to inform this table are listed in the references section of the document. In some cases information was obtained from other sources and is indicated. More detailed summaries should be conducted for each target species on a project specific basis.

Species	Scientific name	Habitat		Home range	Movement	When movement occurs
		Spring and Summer	Winter			
Salamander						
Jefferson Salaman-der	*Ambystoma jeffersonia-num*	Spring Breeding habitat: ephemeral ponds or other ponds without fish (Helferty 2002); Summer: Deciduous or mixed upland forest	Deep rock fissures and burrows below the frost line in upland forest habitat	Generally within 300 m of wetland	Adults may move up to 1 km, usually 300 m from breeding habitat; Juveniles up to 100 m	Explosive adult breeding migration from late March to late April; juvenile dispersal in July and August
Toad						
Fowler's Toad	*Anaxyrus fowleri*	Spring Breeding habitat: shallow ponds, sandy lakeshore bays and wetlands, ephemeral ponds, bedrock pools; Summer: Sand dunes, sand bars and beaches along Lake Erie shore	Burrows in moist sand along Lake Erie shore to just above water table and below frost line	Within a few hundred metres of of Lake Erie shoreline	Usually only move a few hundred metres during summer; seasonal migrations up to 1 km are typical	Adult breeding migration in May and June; juvenile dispersal in August and September
Turtles						
Blanding's Turtle	*Emydoidea blandingii*	Eutrophic, shallow lakes, ponds, slow-flowing rivers, streams, marshes, bog, open fens with basking sites and thick vegetation, upland woods; nest in loose soils (including road shoulders)	Permanent wetlands and other bodies of water, occasionally temporary ponds (Glenside Ecological Services 2011)	Up to 3 km^2	Typical adult movement to and from hibernation and nesting sites is 2 km, although longer migrations have been documented; hatchlings move 400m to water (M. Gartshore, F. Schueler pers. comm.)	Spring migration from hibernation sites to summer habitat (April – early May); Adult nesting migration from late May to early July; Inter-wetland movements in the summer; hatchling and adult overwintering movements in fall months

Species	Scientific name	Habitat: Spring and Summer	Habitat: Winter	Home range	Movement	When movement occurs
Eastern Musk	*Sternotherus odoratus*	Shallow water with abundant floating and submerged vegetation; nest near water in direct sun	Similar to summer; buried in 30 cm of mud	Confined to single bodies of water	Overland movement limited; tend to nest at shorelines	Adult nesting migration from June to early July
Snapping Turtle	*Chelydra serpentina*	Slow-moving water with soft mud substrate and dense vegetation; nest on sand and gravel banks, roads (Patrick et al. 2012, M. Karch, F. Schueler pers. comm.)	Under floating vegetative mats, logs, overhanging banks in streams and lakes, or buried in mud	Up to 0.09 km^2	Adults move from 0.5km up to 5 km to and from hibernation site and in search of nesting sites	Spring migration from hibernation sites to summer habitat in April – early May; Adult nesting migration from late May to early July; hatchlings move to water in early fall
Spiny Softshell	*Apalone spinifera*	Rivers or lakes with shallow water and muddy or sandy substrate, deep pools, riffles, and inlets; nest in sunny areas with fine gravel or sandy substrate close to water	deep pools in rivers (>1 m in depth)	Confined to one body of water	Rarely leave water; nest close to water	Adult nesting from June to early July
Spotted Turtle	*Clemmys guttata*	Slow-moving or still shallow water wetlands with aquatic vegetation (fens, bogs, marshes and rocky pools); upland woods used for aestivation and movement; Mate in woodland pools connected to hibernacula; nest in sunny upland locations (Glenside Ecological Services 2011, Patrick et al. 2012)	Rock caverns in lakes, under hummocks and in burrows in sphagnum-rich wetlands, and in root cavities in swamps	Home range: 0.04 km^2	Adults can move on average 1120 m to and from hibernation site, in search of nesting site, and during inter- wetland movements; move on average 250 m from wetland to nest (Joyal et al. 2001).	Adult nesting migration from late May to June; inter-wetland movements in summer; spring and fall migration from and to hibernation sites

Species	Scientific name	Habitat: Spring and Summer	Habitat: Winter	Home range	Movement	When movement occurs
Northern Map Turtle	*Graptemys geographica*	Well-oxygenated, shallow rivers, streams, creeks, and lakes with basking sites adjacent to deep water; nest in soft sand beaches or soil in full sun	Bottom of lakes or rivers in deep hollows	Home range: 1.2 – 13.5 km^2 (usually within waterways)	Travel inland in search of nesting sites 35-100 m from water	Adult nesting season in early June – late July; Migration to and from hibernation sites in April - early May and late August - October
Wood Turtle	*Glyptemys insculpta*	Clear-water streams with sand or gravel substrate, alder thickets, upland forested areas; nest on sand or gravel-sand beaches and farm fields, road shoulders (Glenside Ecological Services 2011)	Bottom of deep pools in streams	Home range up to 1.5 km^2	Female adults move to nesting sites; typical home range length of 2 km; extensive movement in upland habitats throughout active season, typically within 300 m of water (K. Barrett pers. comm.)	Adult nesting migration from late May to early July
Snakes						
Blue Racer	*Coluber constrictor foxii*	Edge habitat, open fields, woodlands with sunny vegetation piles or rocks; nests in decaying organic matter, logs and under rocks in full sun	Crevices in Pelee Island's limestone plain and in piles of rock and soil	Confined to Pelee Island	Adults travel up to 2.7 km from hibernacula to find mates, nesting locations; hatchlings cross roads from nests	Adult mating season in April and May; neonate dispersal in July and August; movement to hibernaculum in September and October
Butler's Garter-snake	*Thamnophis butleri*	Open prairies, grasslands, old fields and other open habitats; bask on roads; live birth under cover	Small mammal burrows, ant mounds, rocky dikes, possibly crayfish burrows (M. Gartshore pers. comm.)	Within specialized habitat confined by roads	Most adults only move a few hundred metres from hibernacula in active season, but some move > 1 km	Adult mating season in April and May; neonate dispersal in July and August; movement to hibernaculum in September and October

Species	Scientific name	Habitat: Spring and Summer	Habitat: Winter	Home range	Movement	When movement occurs
Eastern Foxsnake, Georgian Bay population	*Pantherophis gloydi*	Open rock barrens, coastal meadow marshes, woodlands and forest clearings; nest in decaying vegetation piles, rock crevices	Granite or limestone fissures	3.5 km linear home range	Move extensively throughout active season to foraging, nesting and hibernation sites; Carolinian snakes move through vegetated corridors to find habitat	Adult mating season in April and May; neonate dispersal in July and August; movement to hibernaculum in September and October
Eastern Foxsnake, Carolinian population	*Pantherophis gloydi*	Wetlands complexes, unforested, early successional lands, hedgerows, riparian zones, woodlands; nest in decaying vegetation piles and fallen trees, road-side burrows, under concrete slabs	limestone bedrock fissures, mammalian burrows, tree root crevices, various man-made features	Up to 1.5 km linear home range, but varies with extent of habitat available		
Eastern Hog-nosed Snake	*Heterodon platirhinos*	Sandy areas or well-drained soil in open forests, forest edges or brushy habitats; sometimes wetlands close to conifer plantations; nest in south-facing open areas, under driftwood, or rock crevices in Shield (Glenside Ecological Services 2011)	Hibernate in upland burrows excavated by the snake, root cavities or abandoned mammal burrows (Glenside Ecological Services 2011)	Home range > 1 km^2	Very mobile throughout season; adults can move >4 km from hibernacula; max. adult movement 6.2 km	Adult mating season in spring and late summer; neonate dispersal and movement to hibernaculum in fall
Eastern Ribbon-snake	*Thamnophis sauritus*	Wetlands, shorelines, sloughs, and swamps. Sometimes give birth or seek cover in upland areas. Live-bearing.	Underground animal burrows and cracks and crevices ranging from well-drained to completely	Home range small, e.g. < 0.007 km^2 within their wetland	Typically found within 10 m of water; may move up to 200 m from water for birthing and hibernation	Adult mating season in spring, and birthing in July and August; neonate dispersal and movement to hibernacula in September and October

Species	Scientific name	Habitat: Spring and Summer	Habitat: Winter	Home range	Movement	When movement occurs
Gray Ratsnake	*Pantherophis spiloides*	Forest edge and open forests; hide in hollow logs and trees, under rocks and in rock crevices; Gravid females prefer large trees; nest communally in standing snags, stumps, logs and compost piles (S. Thompson pers. comm.)	Moist hibernacula (rock fissures) below the frost line	On average 0.18 km^2	Adults move up to 4 km to and from hibernacula	Adult mating season late May to early June; neonate dispersal and movement to hibernacula in fall
Lake Erie Water-snake	*Nerodia sipedon insularum*	Limestone shorelines with ledges and cracks, cobblestone beaches, gravelly or sandy areas with debris. Will also use flooded quarries and drainage ditches in summer. Live-bearing.	Inland communal hibernacula are used: cavities and crevices in quarries, soil and rock piles, cracks in bedrock, tree root masses and animal dens	Generally found along shorelines	Generally restricted to the shoreline during the active season, but may travel several hundred metres inland to hibernacula	Adult mating season early May to early June; neonate dispersal and movement to hibernacula in fall
Massa-sauga, Great Lakes population	*Sistrurus catenatus*	Habitats with low canopy cover (rock barrens, forest clearings, alvars, beaver meadows, fens, bogs and shorelines); Live-bearing: gestation sites are in open habitat (e.g. rock barren), often with large table rocks and low vegetation	Forested areas on the Northern Bruce Peninsula; Wetlands on the Eastern Side of Georgian Bay; mammal burrows, old roots and rock crevices that extend below the frost line with access to the water table	Home range: 0.25 km^2	Can move >1 km to and from hibernacula; max. adult movement: 4 km; max. juvenile movement: 400 m	Mating season from July - August; Neonate dispersal in July - August; Movement to and from hibernacula in early May and September
Massa-sauga, Carolinian population	*Sistrurus catenatus*	Open shrubby areas and man-made piles of woody debris. Will also use grassy, prairie-like fields, wetlands and hedgerows in summer. Live-bearing.	Mammal burrows tree root cavities below the frost line with access to the water table			

Species	Scientific name	Habitat: Spring and Summer	Habitat: Winter	Home range	Movement	When movement occurs
Milksnake	*Lampropeltis triangulum*	Forests, woodlands, fields, rocky outcrops, forest clearings and edges of wetlands	Mammal burrows, old foundations, old wells, gravel and dirt banks, hollow logs, rotting stumps	Home range up to 0.02 km^2	Adult movement: 400 m or more within the active season	Mating season in the spring; Neonate dispersal in July and August; Movement to hibernacula in September and October
Queen-snake	*Regina septemvittata*	Rocky streams, rivers and lake shorelines, wetlands, ponds, meadow marshes with full sun exposure	Underground and close to water	Linear home range (along waterways) 250m	Movement along waterways typically no more than 250m, but longer dispersal movements of > 1 km may occur; found within 15m of water during active season, but inland movements to hibernacula may be several hundred metres	Migrate to and from hibernacula in early April - mid-May and again in fall
Lizard						
Five-lined Skink	*Plestiodon fasciatus*	Great Lakes: open rocky areas in forests Carolinian: woody debris-strewn stable sand dunes, open forests, wetlands	same as spring, hibernate in rock crevices or buried in soil	Home range 270 – 578 m^2	Generally move short distances and adults move up to 210 m and juveniles up to 110 m	Breed in May or early June

Appendix B: Definitions

Connectivity - the degree to which the landscape facilitates or impedes movement among resource patches (Taylor et al. 1993)

Corrugated Steel Pipe (CSP) - round or elliptical culvert made with corrugated steel

Crossing Structure - general term for mitigation measures placed in roads to allow wildlife to cross safely

Culvert - general term for underpass structure type, traditionally used for conveyance of water under a road; in context of this document can be box or round

- **Arch Culvert** - portion of round culvert that allows natural bottom
- **Drainage Culvert** - a drain or pipe that allows water to flow under a road or railroad

Field-based information - Information measured within or near (few hundred metres) the road corridor used to inform impacts

Landscape scale - larger study area that may include an entire jurisdiction where information is available for an entire jurisdiction that is typically available in a GIS and informs broader level impacts of roads

Major road improvements - include road extensions, new alignments, and upgrades such as twinning from two to four lanes.

Population viability - the ability of a population to persist and avoid local extinction

Range length - maximum distance within animal's home range

Regional assessment - Integrate all multi-jurisdictional stakeholders and landscape information within the impact study area to develop a mitigation plan

Road-habitat interface - suitable habitat used by target species that is adjacent to the road

Road rehabilitation project - includes replacing bridges and pavements which are done under our capital program as opposed to our maintenance program

Skylight - structure on tunnel that permits ambient light to enter the structure

Target species – the species that the road mitigation measures are designed for; may include one, two or several species that are impacted by roads

Tunnel - type of crossing structure that is placed under the road surface for wildlife passage; in context of this document specifications are < 3 m width

- **Closed-bottom tunnels** - tunnel bottom is structural material
- **Open-bottom tunnels** - tunnel bottom is not structural material, provided by 3-sided concrete structure, arch pipe aluminum or corrugated steel
- **Open-grate tunnels** - provide ambient light through traditional metal grate structure that is placed on footings
- **Open-top tunnels** - provide ambient light through openings or slots at the top of the tunnel; openings must be at grade with road surface
- **Terrestrial tunnels** - dry tunnels installed for amphibians and reptiles undergoing overland movements

Underpass - general term for structural measures, e.g., culverts, bridge, viaducts, placed under roads to allow wildlife to cross safely

Appendix C: Crossing Structure Summary from Literature

Mole Salamander Crossing Structure and Fencing Review			
Species	**Comments**	**Crossing Structure**	**Crossing Structure Reference**
Projects with confirmed crossings			
Long-toed Salamander (*Ambystoma macrodactylum*)	No salamander >16 m from a tunnel was confirmed to cross. Tunnels ~200 m apart. Fences not angled to tunnels.	Six structures installed, two monitored. Two sizes of open-topped ACO Polymer tunnels: 0.47x0.32m (WxH); 0.23 x 0.21 (WxH). Did not indicate which size they monitored. Tunnels 11.1 m and 12.0 m long.	Allaback and Laabs 2002
California Tiger Salamander (*Ambystoma californiense*)	Salamanders readily used tunnels. Some individuals showed hesitancy to enter tunnels.	Three 0.25 m dia steel pipes, ~20 m long. Tunnels ~35 m apart.	Bain 2014
Northwestern Salamander (*Ambystoma gracile*), Rough-skinned Newt (*Taricha granulosa*), and Western Redback Salamander (*Plethodon vehiculum*)	Known Red-legged Frog (Rana aurora) migration route but also used by these spp. Juvenile newts and Redbacks could climb fence.	Concrete box culvert 1.8 x 0.9m (WxH). Half filled with soil and downed woody debris.	Beasley 2013
Spotted Salamander (*Ambystoma maculatum*)	At least 76% of salamanders that reached the tunnel entrances successfully crossed. Dark tunnel entrances may keep some salamanders from entering tunnels.	Two ACO open-topped tunnels, size not specified. Tunnels 7m long and ~60 m apart.	Jackson and Tyning 1989, Jackson 1996

Species	Comments	Crossing Structure	Crossing Structure Reference
Long-toed Salamander	More than 100 salamanders caught in tunnel exit traps in 2009, but only 23% of salamanders marked at the drift fence were caught exiting the tunnels.	Four open-topped ACO tunnels, 0.5 x 0.33m (WxH) and ~12 m long. Tunnels 80-110 m apart.	Pagnucco et al. 2011, 2012
Projects with no confirmed crossings			
Jefferson Salamander (*Ambystoma jeffersonianum*)	Not detected crossing through tunnels. Very few detected away from roads as well. Guidewalls not angled toward tunnel entrances.	5 tunnels installed. Four 1.2 m diameter CSP or concrete, and one 1.7m wide elliptical culvert. Tunnels 25-31 m long.	Gartshore et al. 2005
Spotted Salamander	Three years of monitoring failed to confirm usage by any amphibians. Migration routes not confirmed before construction.	2 bridges, 1 concrete box culvert 1.2 x 1.2m. Structure 17 m long and lined with soil.	Merrow 2007
Outdoor lab experiments			
Spotted Salamander	Found no major statistical differences in culvert crossing comparing the lengths, diameters and substrates tested. Thirty percent more salamanders crossed through the largest tunnel compared with the smallest.	Experimental culverts along migration route, not under road. Tested 0.3, 0.6, and 0.8 m diameter corrugated PVC pipes, 3, 6, or 9 m long. Also tested three kinds of substrate: bare plastic, sand/gravel and concrete.	Patrick et al. 2010

Toad Crossing Structure and Fencing Review			
Species	**Comments**	**Crossing Structure**	**Crossing Structure Reference**
Projects with confirmed crossings			
Western Toad (*Anaxyrus boreas*)	Tunnel used by 1700-7000+ toadlets leaving breeding pond. Significant road kill at fence ends.	One semi-circular, closed-topped culvert with earthen floor. 1.8 x 0.5 m (WxH) x 3.7 m long.	Biolinx 2013
American Toad (*Anaxyrus americanus*)	Confirmed tunnel crossing by American Toads.	5 closed-topped tunnels, mainly 1.2 m diameter CSP or concrete, but one 1.7 m wide elliptical culvert; 25-31 m long.	Gartshore et al. 2005
Common Toad (*Bufo bufo*)	Marked all toads. 40% used tunnels, 27% got around fence, 33% did not cross.	2 ACO open-topped concrete tunnels, ~0.5 m wide on bottom, 0.33 m high. No soil on bottom.	Ottburg and van der Grift 2013
Western Toad Common Toad (*Bufo bufo*) Western Toad	7 caught in exit traps. Greater usage of larger rectangular culverts than smaller round culverts. Dispersing toadlets from breeding pond crossed through culverts in the thousands.	4 ACO open-topped box culverts, 0.5 m wide and 0.33 m high and ~12 m long. Slots along the top. Tunnels 80-110 m apart. 4 types. 0.4 and 0.6 m diameter concrete culverts; box culverts 1.6 and 1.7 m high (width not given, but appears variable in photos). 2 CSP culverts, both 0.4 m in diameter.	Pagnucco et al. 2012 Puky et al. 2013 Wind 2014
Outdoor lab experiments			
Frogs and Toads of France	Toads showed no difference in use of tunnels with or without soil.	0.5 m diameter concrete culvert. Compared bare concrete with layer of soil.	Lesbarrères et al 2004

Turtle Crossing Structure Research			
Species	**Comments**	**Crossing Structure**	**Crossing Structure Reference**
Projects with confirmed crossings			
Florida Cooter (*Pseudemys floridana floridana*), Slider (*Trachemys scripta*), and Florida Softshell (*Apalone ferox*)	Primarily Cooters and Sliders crossed through culvert.	Drainage culvert 3.5 m in diameter (46.6 m long).	Aresco 2005
Blanding's Turtle (*Emydoidea blandingii*), Snapping Turtle (*Chelydra serpentina*)	Individual Blanding's Turtles used culvert up to 13 times. Snapping Turtles also crossed using the culvert, no numbers provided. Virtually no roadkill (2 in 2 years).	1.8 m diameter corrugated steel culvert, 25 m long, pre-existing, with sediment and year round water.	Caverhill et al. 2011
Spotted Turtle (*Clemmys guttata*)	At least 7 turtles confirmed to cross through tunnel. Other turtles likely crossed as well.	1.8 x 1.8m concrete box tunnel, ~13m long; 0.1-0.15 m organic substrate in culvert.	Kaye et al. 2005
Blanding's Turtle	Blanding's Turtles showed no strong preference for culvert size. Turtles more apt to cross through culvert when light visible at end of culvert.	Tested 1.0 and 1.2 m diameter corrugated steel culverts and 1.1 m diameter arch culverts; length unspecified. Culverts tested in pairs along known in outdoor lab.	Lang 2000
Snapping Turtle	Crossed through culvert. No details on amount of usage. Fence end roadkill. Hatchling could get through 5x10cm mesh fence. Effectiveness of fence increased after first yr or two, as vegetation held bottom of fence better.	1.3 m diameter corrugated steel culvert.	Langen 2011

Species	Comments	Crossing Structure	Crossing Structure Reference
Wood Turtle (*Glyptemys insculpta*)	Long term study found turtles moved along a stream that passed through the culvert .	3 m diameter culvert, 26 m long.	Parren 2013
Wood Turtle	At least one Wood Turtle observed to cross through tunnel.	Open-top (grate) tunnel ~1.5 x 1.0 m (WxH) on dirt logging road.	Steinberg pers. comm.
Projects with unconfirmed crossings			
Painted Turtle (*Chrysemys picta*), Snapping Turtle	6 Painted Turtles, 1 Snapping Turtle photographed in culverts. Plus Snapper tracks in culverts observed but no photos. Crossing not confirmed.	3 crossing structures, each consisting of 2 culverts connected with fenced open area between. Size: 3.4 x 2.4 m box culvert, 24.1 m long, then 15.3 m fenced opening and then another culvert 24.1 m long.	Baxter-Gilbert 2014
Snapping Turtle and Painted Turtle	No turtles detected in dry culvert with trail camera.	1 dry culvert 1.2m diameter CSP; 2 wet culverts, one was 4m wide concrete box culvert, second unspecified.	Buchanan and Basso 2007
Blanding's Turtle, Painted Turtle	Turtles could climb over 0.2 m high curb. Tunnel used by at least 1 Painted Turtle.	Three 4.6 x 0.9m (WxH) and 17.1 m long, open-top, 3-sided box culverts.	Compton and Seivert 2002
Blanding's Turtle, Snapping Turtle, Painted Turtle	Blanding's Turtles commonly observed in dry and wet culverts. Snapping Turtles used wet culverts mainly, but one dry. Only 1 Painted found in a wet culvert.	4 dry and 6 wet culverts, multiple sizes, with skylights. Minimum size 1.8 x 0.9m (WxH) and ~50 m long.	Dillon 2011, 2013
Eastern Musk Turtle (*Sternotherus odoratus*), Florida Softshell	1 Musk Turtle and 3 Softshells detected in 0.9m culvert. No turtles detected in other tunnels.	3 sizes of tunnels: 0.9m diameter; 1.8x1.8 m box culvert, with 3 light boxes; 2.7 x 2.7m box culvert. All tunnels 44 m long.	Dodd et al. 2004

Species	Comments	Crossing Structure	Crossing Structure Reference
Turtles	Monitored culverts in area with little roadkill before mitigation. Turtle roadkill went from 1 to 0. No turtles photographed in culverts.	1 and 2 m diameter culverts (although described as square sometimes).	Garrah 2012
Painted Turtle	No sex difference in climbing ability. In trials ~4% of turtles climbed over 0.45m tall fence with no flashing, while no turtles climbed fence with flashing.	n/a	Griffin 2005
Eastern Box Turtle (*Terrapene carolina carolina*)	At least 3 turtles used pre-existing drainage culverts.	No details.	Hagood and Bartels 2008
Snapping Turtle, Painted Turtle	Snapping Turtle photographed in both 0.8 and 0.9m culverts. Painted Turtle photographed in 0.8 m culvert.	Two culverts: 0.8 and 0.9 m diameter CSP.	Gunson et al. 2013
Spotted Turtle	Review of other crossing structures. Reported Spotted Turtles using an arch culvert and a box culvert at two sites in Mass.	Arch culvert: 11 x 3.4m (WxH) and 12m long; Box culvert: 1.8 x 1.8 m and 16.8 m long.	Paulson 2010
Blanding's Turtle	No mitigation. Studied roadill hotspots and movement patterns. Suggested crossing structures be an average of 500 m apart and no more than 1.5 km apart.	n/a	Riley et al. 2013

Species	Comments	Crossing Structure	Crossing Structure Reference
Snapping Turtle	Detected by trail camera in at least one tunnel. No details on which tunnel.	4 sizes, from 1.5 x 0.9m (WxH) to 2.7 x 1.8m. ~5 cm soil spread in bottom of culverts.	Rogers et al. 2009
Snapping Turtle and other herps	Pooled use of all frogs, snakes, lizards and turtles. Most use of culverts 1.5m or more in width and 0.6-1.5m high.	Variety of existing culverts.	Smith 2003
Snapping Turtle, Painted Turtle, Map Turtle (*Graptemys geographica*)(?)	At least 7 Snapping and 1 Painted Turtle used culverts. Map Turtle may have been seen swimming in one culvert. All but one reptile detected in ACO tunnel.	1.8 m x 0.9 m concrete box culvert; 0.5 x 0.48 open-top ACO tunnel.	Whitelock 2014
Outdoor lab experiments			
Painted Turtle	Tunnel placed on path of females on nesting forays. All turtles that reached the tunnel crossed through. Mean crossing time 113 sec (range: 60-197 sec).	0.6 x 0.6m wooden tunnel, ~6 m long in field.	Jackson and Marchand 1998
Painted Turtles	>85% of turtles used all tunnels. Largest tunnel had highest success rate and fastest crossing times. Turtles more hesitant to enter tunnels below grade.	Outdoor lab with 3 types of culverts: 0.6 x 0.6m, 0.6 x 1.2m, 1.2 x 1.2 m all 12.2 m long. Plywood with soil bottom.	Paulson 2010
Snapping Turtle, Painted Turtle	Outdoor lab. No turtle climbed 0.6m fence. Turtles more apt to use tunnels at least 0.5m dia. All substrates used about equally. Longest tunnel had slightly less usage. Light did not affect usage.	Black PVC pipe culverts. Varied length (3-9.1 m), aperture size (0.3-0.8 m), substrate (bare, soil, gravel, concrete) and light permeability (0-4%).	Woltz et al 2008

Species	Comments	Crossing Structure	Crossing Structure Reference
Painted Turtle, Blanding's Turtle, Spotted Turtle	Outdoor lab. Increased light increased crossing success. In closed-topped tunnels, the percentage of turtles crossing increased with increased culvert size. Low crossing rate (54% or less) with 80' culverts.	3 tunnels sizes: 0.6 x 0.6m, 1.2 x 1.2m, 2.4 x 1.2m; two lengths: 40' and 80'. Varied light through ceiling (0, 75, 100%).	Yorks et al. 2011
Snake Crossing Structure Research			
Projects with confirmed crossings			
Eastern Massasauga (*Sistrurus catenatus*)	4 snakes detected under crossing structures (likely crossing) in 2013.	4 open-grate crossing structures. ~1 x 1m (WxH) under 2-lane gravel roads.	Colley pers. comm.
Eastern Garter Snake (*Thamnophis sirtalis sirtalis*), Ribbon Snake (*Thamnophis sauritus sauritus*)	Outdoor lab. At least 70% of Ribbons and 90% Garters crossed at all widths. All Garters crossed whether substrate was soil or water. In 1.3m culvert >90% of Ribbons crossed regardless of substrate. In 0.33 m culverts Ribbons had lower crossing success with soil (50%), compared with water (70%). In real culverts, Ribbons had low crossing success (<30%) in small culverts but high success (~80%) in large culverts.	Outdoor lab box culverts 0.66 m high and variable width (0.33-1.33m) and 5 m long. Also examined crossing of real culverts ~1 m and ~0.5 m in diameter and 10 m long. Some culverts dry (soil bottom) and some with liner with ~7 cm of water.	Eads 2013
Northern Watersnake (*Nerodia sipedon sipedon*)	>80% crossing success with both size culverts.	0.5 and 1.0 m culverts. No other detail.	Eads et al. 2012

Species	Comments	Crossing Structure	Crossing Structure Reference
Timber Rattlesnake (*Crotalus horridus*), Ratsnake (*Pantherophis spiloides*)	Two radio-tracked rattlesnakes used one culvert during the culvert's first year. Snakes spent 10-14 days near fence before crossing through culvert. Some snakes went around fence and others used gaps in fence. 1 possible Ratsnake (or Racer) was also detected in one culvert.	5 concrete closed-top box culverts 0.91 x 0.41 m (WxH) and 15 m long.	Laidig and Golden 2004
Eastern Garter Snake	Tunnels used commonly. Fence end roadkill, some snakes got over fence.	0.25-0.30 m diameter steel pipe.	Roberts 2010
Unidentified snakes	3 crossings by a snake detected in sand tracking.	Concrete box culvert 2.74 (W) x1.83 (H)m and 30.5 m long.	Rogers et al. 2009
Snakes	Used sand tracking to detect usage. 1 snake crossing over 8 days in spring, and 1 crossing over 8 days in summer.	9 concrete box culverts, 2.4 x 1.2m and 18 m long. Culvert bottoms scattered with small stones and a thin layer of silt.	Taylor and Goldingay 2003
Milos Viper (*Macrovipera schweizeri*)	No snakes found on roads in areas with barriers. Snakes crossed through underpasses. Mean of 77% of snakes that encountered an underpass crossed through.	6 underpasses, 4 types. No details.	Yannis 2011

Species	Comments	Crossing Structure	Crossing Structure Reference
Projects with unconfirmed crossings			
Various species	Snakes found in both sizes of round culvert.	looked at use of existing culverts: 0.6 m and 1.0 m diameter CSP, concrete box culverts (size not given).	Arizona Game and Fish 2010
Snakes and lizards pooled; no species named	In general, reptile use of culverts was negatively correlated with culvert length.	Existing drainage culverts, no specs provided.	Ascensão and Mira 2007
Northern Watersnake, Red-bellied Snakes (*Storeria occipitomaculata*)	3 Watersnakes photographed in culvert, 1 juvenile Red-bellied observed in culvert.	3 crossing structures, each consisting of 2 culverts connected with fenced open area between: 3.4 x 2.4 m box culvert, 24.1 m long, then 15.3 m fenced opening and then another culvert 24.1 m long.	Baxter-Gilbert 2014
Eastern Garter Snake	No confirmed crossing by any snake, and very few captures away from road.	2 bridges, 1 culvert 1.65m wide.	Bellis et al. 2007
Unspecified species of Garter Snake	20 detected under bridge via sand tracking. Culverts not well monitored.	Bridge 5-9'aboveground, 400' long; multiple size tunnels, as small as 0.5m diameter culverts.	de Rivera and Bliss-Ketchum 2010
Unidentified snakes (likely Garter and Northern Watersnake)	39-50 snakes per yr (3 yr) in wet and dry culverts. Largest percentage in dry culverts, but may have been easier to photograph in those culverts. Snakes photographed basking in light from skylights.	4 dry and 6 wet culverts, multiple sizes, with skylights. Smallest tunnel 1.8 x 0.9m (WxH).	Dillon 2011, 2013

Species	Comments	Crossing Structure	Crossing Structure Reference
Eastern Racer (*Coluber constrictor*), Eastern Ratsnake (*Pantherophis alleghaniensis*), Eastern Ribbonsnake, plus other non SAR spp	1 Racer, 1 Ratsnake and 4 Ribbonsnakes detected in 1.8 x1.8m tunnels but crossing not confirmed. Not detected in other size culverts.	3 sizes of tunnels: 0.9m diameter; 1.8 x 1.8 m box culvert, with 3 light boxes; 2.7 x 2.7m box culvert. All tunnels 44 m long.	Dodd et al. 2004
Snakes	Monitored culverts in an area with little road kill before mitigation. No change in roadkill. Snakes not photographed in culverts.	1 and 2 m diameter culverts (although described as square sometimes).	Garrah 2012
Northern Watersnake, Eastern Gartersnake, Black Ratsnake	Watersnake found in association with 6 culverts, Ratsnake with 3, and Gartersnake with 2 (sizes of culverts not given).	Monitored 265 culverts of various sizes.	Gates and Sparks 2011
Timber Rattlesnake	Used by some snakes.	~0.3m diameter culvert.	Jacobson pers. comm.
Snakes	To prevent snakes getting through fence attached a fine mesh (0.6x0.6 cm) to turtle fencing. 30 cm high mesh did not prevent all passage, but 60 cm high mesh was more successful. No monitoring of culvert for snakes.	1.3 m diameter corrugated steel culvert.	Langen 2011
Northern Watersnake, Eastern Gartersnake	Watersnake entered and turned around in 0.9 m culvert. Gartersnake observed in 0.9 m culvert.	Two culverts: 0.8 and 0.9m diameter CSP.	Lesbarrères Gunson et al. 2013

Species	Comments	Crossing Structure	Crossing Structure Reference
Massasauga	No proof of crossing, but no DOR snakes in 4 years of monitoring road.	6 open-topped structures, with rock substrate, ~1.0 x 1.5m (WxH) and ~6 m long.	Lewis pers. comm.
Wandering Garter Snake (*Thamnophis elegans vagrans*)	Photographed in tunnels 48 times.	4 ACO box culverts, 0.5 m wide and 0.33 m high and ~12 m long. Slots along the top. Tunnels 80-110 m apart.	Pagnucco et al 2011, 2012
Grass Snake (*Natrix natrix*)	Detected in culverts. Believed to be hunting frogs in wet culvert.	Three 1m dia concrete culverts, 34 m long. Opening in middle of culvert to allow in light and water.	Puky et al. 2007
Grass Snake	Shed skins found in tunnels.	Eight 0.6-0.9 m diameter culverts, 8-9 m long. Five culverts had light shafts.	Puky et al. 2007
Massasauga, Eastern Hog-nosed Snake, Milksnake (*Lampropeltis elapsoides*), Northern Ribbonsnake (*Thamnophis sauritus septentrionalis*)	Milksnake and Northern Ribbonsnake confirmed in tunnels. Possible Hog-nosed, but photo blurry.	Concrete box culvert 1.8 x 1.2 m (WxH).	Rouse 2005
Eastern Garter Snake and other herps	Pooled use of all frogs, snakes, lizards and turtles. Most use of culverts 1.5m or more in width and 0.6-1.5m high.	Variety of existing culverts.	Smith 2003
Eastern Garter, unidentified snakes	At least 2 Garter and 2 unidentified snakes used culverts. All but one reptile detected in ACO tunnel. May have been more use but trail cameras set to shoot every 15 min.	1.8 m x 0.9 m concrete box culvert; 0.5 x 0.48 open-top ACO tunnel.	Whitelock 2014

Species	Comments	Crossing Structure	Crossing Structure Reference
Outdoor lab experiments			
Small (<20g) and medium-sized (75-250g) snakes	No snake able to climb over any fence. Medium-sized snakes could escape through ½" mesh. Small snakes could escape through ½ and ¼" mesh. Some snakes got caught in ½" mesh and had to be cut free.	n/a Tested fencing types.	Smith and Noss 2011
Lizard Crossing Structure and Fencing Review			
Projects with confirmed crossings			
Various lizards (no skinks)	Lizards found in all 3 types of culverts. More spp in smallest size culvert. Highest crossing rate (0.4) in box culverts.	looked at use of existing culverts: 0.6m and 1.0m dia CSP, concrete box culverts (size not given).	Arizona Game and Fish 2010
Flat-tailed Horned Lizards (*Phrynosoma mcallii*)	Experimental tests of simulated culverts. 12 of 54 lizards crossed. All size tunnels used, but the 1.0m CSP without skylights was used by more lizards. Dark culverts were used more frequently than culverts with skylights.	tested 3 sizes of tunnel: 0.6 m and 1.0 m CSP, and 2.6 x 1.3m (WxH) plywood box culverts. Two of each culvert size, one with skylights and one without. All tunnels were ~13 m long and had 2.5-7.5 cm of sand in the bottom of the tunnels.	Painter and Ingraldi 2007
Lace Monitor (*Varanus varius*) and other unidentified lizards	Australian study. 11 crossings by lizards during limited monitoring.	9 concrete box culverts, 2.4 x 1.2m and 18 m long. Culvert bottoms scattered with small stones and a thin layer of silt.	Taylor and Goldingay 2003

Species	Comments	Crossing Structure	Crossing Structure Reference
Projects with unconfirmed crossings			
Snakes and lizards pooled; no species named	In general, reptile use of culverts was negatively correlated with culvert length.	Existing drainage culverts, no specs provided.	Ascensão and Mira 2007
Five-lined Skink (*Plestiodon fasciatus*)	Skinks observed around the entrance of 5 culverts (sizes not given). Apparently used culvert entrances for basking and foraging but did not appear to cross through culverts.	Monitored 265 culverts of various sizes.	Gates and Sparks 2011
Northern Fence Lizard (*Sceloporus undulatus hyacinthinus*)	Detected in culverts 12 times during two month period.	5 concrete closed-topped box culverts 0.91 x 0.41m (WxH) and 15 m long.	Laidig and Golden 2004
Sand Lizard (*Lacerta agilis*)	Lizards lived on overpasses, using them for hiding places, basking sites and foraging habitat.	Wildlife overpass. Details not provided. Shrubs planted at side of overpass.	Puky et al. 2007
Five-lined Skink and other herps (pooled all amphibians and reptiles)	In general, amphibians and reptiles made most use of culverts 1.5m or more in width and 0.6-1.5m high.	Variety of existing culverts.	Smith 2003
Outdoor lab experiments			
Five-lined Skink	Skinks able to crawl through ¼ mesh fence. The aluminum flashing was the only fence that stopped all skinks from escaping.	n/a Tested fencing types.	Smith and Noss 2011

Appendix D: Links and Other Resources

Applicable Legislation and MNRF policies

General Regulation under the Endangered Species Act, 2007: Ontario Regulation 242/08

https://www.e-laws.gov.on.ca/html/regs/english/elaws_regs_080242_e.htm

Permits under the Endangered Species Act

http://www.ontario.ca/environment-and-energy/endangered-species-permits-and-authorizations

Overall Benefit Permit

http://www.ontario.ca/environment-and-energy/endangered-species-act-overall-benefit-permits

Step-by-step guide to applying for an overall benefit permit

http://www.ontario.ca/environment-and-energy/endangered-species-act-overall-benefit-permits (click link on right side of above page: "How to apply")

Streamlined approvals under the Endangered Species Act

(also known as Registering online for Natural Resources activities)

https://www.ontario.ca/environment-and-energy/natural-resources-registration-guide

Development and infrastructure projects and endangered or threatened species

http://www.ontario.ca/environment-and-energy/development-and-infrastructure-projects-and-endangered-or-threatened-species

Ontario Species at Risk Information

Ontario Species at Risk website

http://www.ontario.ca/environment-and-energy/species-risk

Species at Risk Reference Toolbox

http://www.ontario.ca/environment-and-energy/species-risk-guides-and-resources

Best Practices and Guidance

Reptile and Amphibian Exclusion Fencing: Best Practices

http://files.ontario.ca/environment-and-energy/species-at-risk/mnr_sar_tx_rptl_amp_fnc_en.pdf

Passage Assessment System for Evaluating the Permeability of Existing Structures

http://www.wsdot.wa.gov/research/reports/fullreports/777.1.pdf

Design Examples

Amphibian Tunnel Project in Waterton Lakes National Park, Vancouver

http://naturevancouver.ca/sites/naturevancouver.ca/VNHS%20files/Amphibian%20Tunnel%20Project.pdf

Appendix E: Sample Tunnel Costs Table (2014)

Tunnel type	Model Number	Provider	Size of culvert	Length (m) (estimate)	Cost	Installation costs (very approximate)	Cost/m (culvert only)
Terrestrial concrete box culvert	Reinforced non-standard concrete box culvert	M-CON Pipe and products Inc.	1.8m x 0.9m	16.3	$25,000	$15,000	$1,533
Terrestrial open-top culvert	ACO AT500	ACO Systems Ltd.	0.50m x 0.48m	16.2	$13,000	$11,000	$802
Hydraulic Concrete Box culvert	Reinforced non-standard concrete box culvert	M-CON Pipe and products Inc.	3.0 m x 2.1m	18.3	$65,000	$45,000	$3,551
Concrete Box culvert	Includes all materials	MTO	1.8m x 1.8m	48	$225,000		$4,687
Concrete Box culvert	Considered a structure, so includes only the cost of culvert	MTO	3.3m x 2.8m	48	$375,000	$325,000	$7,812
Concrete Box culvert		MTO	1.0m x 1.0m	48	$150,000		$3,125

Cost/m (installed)	Comments (installation limitations)	Additional information:	Source
$2,453		Additional fixed costs associated with each mobilization, special environmental precautions and insurances -Soil conditions play a crucial part in costs; -Generally, add 20% per project over $150,000, add 30% for smaller projects- Add $250,000 per site for special shoring-.	Rick Levick, Longpoint Improvement Committee
$1,481			
$6,010	Cost about 30% more than typical installation reflected in table due to digging to connect channels to marsh on one side and the bay on the other.		
		Actually for 2 culverts (= 1 eco-passage) for 4-lane hwy 69: each culvert is 24m long (spanning 2 lanes of highway, plus shoulders), and they're separated by a 15.3m gap (the median)	Andrew Healy, MTO
$14,583	True cost is much greater than structure alone due to blasting, footings etc., costs could be up to 700 K with installation		
$3,125	This is a guess and can range from 100 - 200 K		

Tunnel type	Model Number	Provider	Size of culvert	Length (m) (estimate)	Cost	Installation costs (very approximate)	Cost/m (culvert only)
Corrugated steel Pipe culverts		Atlantic Industries Ltd.	1.2 m round	16.5	$2,392	+	$145.00
Corrugated Metal Arch c/w metal footings		Atlantic Industries Ltd.	0.6 m rise x 1.22 m span	16.5	$16,360	+	$991.56
Corrugated steel Pipe culverts		Atlantic Industries Ltd.	3 m round	16.5	$9,240	+	$560.00
Corrugated Metal Arch c/w metal footings		Atlantic Industries Ltd.	2.99 m span x 1.45 m rise	16.5	$24,024	+	$1,456

Cost/m (installed)	Comments (installation limitations)	Additional information:	Source
+	Minimal assembly required.	Various coatings available. Price based on a coating common on low volume roads. Pipe material is subjective to enviornmental conditions. Reference Ontario Gravity Pipe Study for more specific detail.	Kevin Williams, Atlantic Industries Ltd.
+	Available preassembled or assembled in place. Can be assembled by person (no hoisting equipment) for a rough estimated cost of $50/m.	Open-bottom which can be constructed to maintain a more natural environment. Pricing based on low to moderate covers (0.6 m to 2 m cover). Greater covers are permitted but price will vary.	Kevin Williams, Atlantic Industries Ltd.
+	Minimal assembly required.	Various coatings available. Price based on a coating common on low volume roads. Pipe material is subjective to environmental conditions. Reference Ontario Gravity Pipe Study for more specific detail.	Kevin Williams, Atlantic Industries Ltd.
+	Available preassembled or assembled in place. Can be assembled by person (no hoisting equipment) for a rough estimated cost of $50/m.	Open-bottom which can be constructed to maintain a more natural environment. Pricing based on low to moderate covers (0.6 m to 2 m cover). Greater covers are permitted but price will vary.	Kevin Williams, Atlantic Industries Ltd.

Tunnel type	Model Number	Provider	Size of culvert	Length (m) (estimate)	Cost	Installation costs (very approximate)	Cost/m (culvert only)
Corrugated Metal Arch c/w concrete footings and headwall	Includes headwall costs. Shorter lengths conduits required with headwalls.	Atlantic Industries Ltd.	2.99 m span x 1.45 m rise	10	$29,617	+	$2,961

Cost/m (installed)	Comments (installation limitations)	Additional information:	Source
+	Available preassembled or assembled in place. Hoisting equipment required for headwalls and footings.	Open-bottom which can be constructed to maintain a more natural environment. Price/m value is inflated by inclusion of headwalls but headwalls permit shorter length conduits. Pricing based on low to moderate covers (0.6 m to 2.5 m cover). Greater covers are permitted but price will vary. Headwalls are intended for more aesthetically pleasing requirements.	Kevin Williams, Atlantic Industries Ltd.