Guidelines for Amphibian and Reptile Conservation During Road Building and Management Activities in British Columbia

Version 1.0

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Ministry of Environment and Climate Change Strategy

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1 INTRODUCTION

1.1 Background

Amphibians and reptiles are the most at risk species assemblages in British Columbia (B.C.), with more than 50% of species in each group listed provincially and/or federally as species of conservation concern. Road mortality is identified as a significant threat to amphibians and reptiles, and mitigating this threat is identified as a priority action in the recovery planning documents for most of these species. To address this issue, the first Herpetofauna and Roads Workshop was held in Nanaimo, B.C. in 2011. It brought together qualified professionals (QPs) from within and outside government, academics, and conservation biologists to learn about road mortality issues, share unpublished research, and work together toward more effective solutions.

One of the most significant outcomes of this meeting was the creation of the B.C. Herpetofauna and Roads Working Group, a network for exchanging ideas. In the years since that first meeting in 2011, some members of the Working Group and others have conducted substantial new research, in both in mitigation project design and effectiveness evaluation. However, the results are not widely available and standard guidance is still lacking. This document fills that need by providing guidance at an overview level as well as specific details for project mitigation on the ground. This document is based on a similar document produced by the Government of Ontario in 2016 (Ontario MNRF 2016) and has been updated with B.C.-specific information from the most recent literature and information shared at the 2018 Herpetofauna and Roads Workshop held in Kamloops, B.C.

What is Mitigation?

The ***Procedures for Mitigating Impacts on Environmental Values*** defines a "mitigation measure" as a tangible conservation action taken to avoid, minimize, restore on-site, or offset impacts on environmental values and associated components, resulting from a project or activity (Government of British Columbia, Version 1.0, May 27, 2014).

"There is no universally accepted mitigation design that is effective for every socio-economic roadway situation or wildlife species. The effectiveness of mitigation depends on the level of commitment and dedication of all stakeholders." (Colley et al. 2017)

1.2 Purpose

The purpose of *Guidelines for Amphibian and Reptile Conservation during Road Building and Management Activities in British Columbia* (hereafter referred to as Guidelines) is to provide comprehensive information on assessing, avoiding, minimizing, and mitigating road impacts on amphibians and reptiles in B.C. The information in this document follows the mitigation hierarchy set out in the Government of British Columbia's ***Procedures for Mitigating Impacts on Environmental Values*** and provides information on mitigating impacts arising from road building and upgrading, and from maintenance activities on existing roads.

1.3 British Columbia Legislative Context

The information and procedures described in this document do not create new legal requirements or supersede any statute. However, they are intended to serve as a decision support tool to inform the implementation of existing legislation and regulatory requirements, improve awareness and understanding of the best available science, and allow for flexible, well-informed, and balanced solutions. Some legislation that may have implications for road building and maintenance activities and their impact on herpetofauna is listed below.

Provincial Legislation

Wildlife Act, 1996

In B.C., native wildlife, including amphibians and reptiles, are protected or managed under the B.C. *Wildlife Act*. Under the Act, it is an offence to intentionally kill, harm, collect, transport, or trade in native wildlife species. An exemption permit may be issued when all avenues for avoiding impacts on wildlife have been examined and deemed not feasible.

Forest and Range Practices Act, 2002

The *Forest and Range Practices Act* provides for the management of forest and range practices on provincial Crown lands for the habitat of species at risk identified in the *Identified Wildlife Management Strategy* (see Appendix 1 for amphibians and reptiles listed as Identified Wildlife). Part of the protection for these species includes limited or no road building within designated Wildlife Habitat Areas. For a list of approved Wildlife Habitat Areas, visit http://www.env.gov.B.C..ca/wld/frpa/iwms/wha.html.

In addition to these laws, the Government of British Columbia is in the process of drafting B.C.-specific species-at-risk legislation. This document will be updated to include requirements under this Act once they become available.

Federal Legislation

Species at Risk Act, 2002

The *Species at Risk Act* provides the legislative framework for the protection of species at risk in Canada. The purposes of the Act are to prevent wildlife species in Canada from disappearing; to provide for the recovery of wildlife species that are extirpated (no longer exist in the wild in Canada), endangered, or threatened as a result of human activity; and to manage species of special concern to prevent them from becoming endangered or threatened. The Act provides for the development of recovery and management planning documents for species listed under the Act. These documents prioritize recovery and threat mitigation actions, including the identification of Critical Habitat—defined by the Act as “the habitat that is necessary for the survival or recovery of a listed wildlife species and that is identified as the species’ critical habitat in the recovery strategy or action plan for the species”—and the listing of activities likely to result in the destruction of Critical Habitat. For example, Table 3 of the *Recovery Strategy for the Western Rattlesnake (*Crotalus oreganus*), the Great Basin Gophersnake (*Pituophis catenifer deserticola*) and the Desert Nightsnake (*Hypsiglena chlorophaea*) in Canada 2017* lists road building and road maintenance as activities with the potential to result in destruction of Critical Habitat. This Guidelines document, along with recovery planning documents and others, provide guidance on preventing and mitigating the impacts of roads.

The location of approved Critical Habitats for species at risk that occur in B.C. can be found at http://donnees.ec.gc.ca/data/species/developplans/critical-habitat-for-species-at-risk-british-columbia/?lang=en.

1.4 Document Scope and Audience

Preventing the impacts of roads on amphibians and reptiles is a science that continues to evolve as new solutions are implemented and tested. As such, it is not possible at this time to provide specific or directive applications/practices that can be applied universally across the diversity of road projects. Instead, this document offers guidelines for developing site-specific mitigation based on current peerreviewed and grey literature (e.g., websites and conference proceedings), government documents, academic theses, and questionnaire-based surveys of experts in road ecology and other areas of relevance (e.g., engineering, species biology). When knowledge gaps are identified, the recommendations include a range of options based on the best available science and expert opinion, as well as interpretation based on species-specific needs and life history traits.

The intended audience of this Guidelines document is primarily the qualified professionals who advise the road authorities that build and maintain roads in B.C. We want to provide them with comprehensive information to support professional reliance and adherence to the precautionary principle. Road authorities include all levels of government, industry, and private landowners who build, manage, and maintain roads in B.C. This document is equally relevant to government staff who review development applications and provide advice to statutory decision-makers. Finally, this document will also be useful for academics who are interested in assessing the effectiveness of, and improving, mitigation measures, and in addressing knowledge gaps in current road ecology as it pertains to amphibians and reptiles.

This document presents current information, as of the date of publication. It is intended to be updated as new information becomes available. The members of the B.C. Herpetofauna and Roads Working Group will prioritize and guide the development and updating of this document going forward.

1.5 Document Outline

Much of the information in this document is subject to ongoing research and is evolving rapidly. It is strongly recommended that the services of a QP who has experience in the geographical region, and with the species of concern and the mitigation techniques required, are engaged to ensure that the most biologically sound and cost-effective solutions are considered and developed early in the project planning cycle. Citations and links for further information are provided throughout the document to enable QPs to access the latest developments, updates, and data from previous and ongoing projects.

This document is organized into the following sections:

Section 1 (Introduction) provides information on the purpose of the document in relation to regulations associated with the protection of amphibian and reptile species in B.C.

Section 2 (Why Mitigation Is Necessary: Impacts of Roads on Herpetofauna) provides background information on the diverse and complex impacts of roads on amphibians and reptiles that go beyond simple road mortality. Recent information on these more subtle and indirect effects provides the background against which to assess the need for, and development of, road mitigation measures.

Section 3 (Screening Tool – Assessing Project-Specific Level of Mitigation) provides step-by-step guidance on assessing whether mitigation is needed as a result of anticipated effects of a project on amphibians and reptiles and their habitats.

Section 4 (Guidance for Mitigation Planning and Design) describes how to develop a mitigation plan for new and existing roads, taking into account landscape-level considerations for habitat protection and connectivity. It provides details on road designs to reduce impacts, and on amphibian and reptile crossing structures and fencing systems. Options for influencing driver and wildlife behaviour to reduce impacts are also discussed.

Section 5 (Guidance for Road Construction Activities) provides considerations for reducing temporary and long-term impacts from road construction, including timing construction activities to avoid impacts.

Section 6 (Guidance for Road Maintenance Activities) outlines mitigation strategies to reduce the potential impacts of maintenance activities (such as dust control, de-icing, drainage, and roadside vegetation control) on amphibians and reptiles and their habitats. It also includes suggestions for maintaining roadside fences and tunnels that have been installed to reduce road mortality.

Section 7 (Monitoring) highlights the importance of filling knowledge gaps related to the effectiveness of mitigation measures for reducing road impacts on amphibians and reptiles. Monitoring requirements for compliance and maintenance and for evaluating the effects of mitigation on population viability are described. This section also describes study designs for crossing structures and fencing, and monitoring techniques for measuring their effectiveness to assist in adaptive management of the structures.

Literature Cited and Appendices summarize the resources used to develop this document, and provide more detailed information about the status, geographic location, home range, and dispersal distance of amphibian and reptile species in B.C.; road impact assessments for these species; and examples of amphibian and reptile crossing structures that have been implemented across B.C.

2 WHY MITIGATION IS NECESSARY: IMPACTS OF ROADS ON HERPETOFAUNA

Roads are a critical part of B.C.'s transportation infrastructure, underpinning a strong and vibrant provincial economy. In 2018, B.C. had approximately 719,000 km of roads (Environmental Reporting BC 2018). Most of these roads (92%) are unpaved, industrial roads (e.g., forestry, mining); the remainder are paved highways and municipal and local roads. While paved roads amount to only a fraction of the total road network in B.C., they may have a disproportional impact on herpetofauna because they are associated with higher traffic volumes and continuous, long-term use (as opposed to Forest Service Roads), and are often wide and have multiple lanes, which increase the risk of road mortality (Jochimsen et al. 2004). Decisions that affect road construction and maintenace need to consider many important factors, including public safety, cost, and timing. In recognition that the importance of roads needs to be balanced against their known impacts on wildlife, there is a growing field of study focused on mitigating the potential ecological impacts of road networks (e.g., Forman et al. 2003; Coffin 2007).

Reptiles and amphibians are particularly vulnerable to road-related impact because of their need to move between different habitats for their various life history requirements. Frogs, salamanders, and turtles migrate regularly between aquatic and terrestrial habitats as part of their annual life cycle. Their travel routes are often intersected by roads, which are commonly built along valley bottoms and follow the shorelines of water bodies. Most large snakes undertake long-distance seasonal movements, which brings them in contact with roads that crisscross their home range. Hobbs (2013) calculated that almost half (49%) of the 368 confirmed Western Rattlesnake dens in B.C.'s arid interior were within 1 km of a road.

Amphibians and Reptiles are Particularly Vulnerable to Roads

The threat to herpetofauna extends beyond B.C. and Canada:

- Globally, a higher proportion of amphibian and reptile species are declining compared to mammals or birds. Within B.C., 67% of native reptile and 55% of native amphibian species are at risk.
- Roads are a greater threat to amphibians and reptiles than to other vertebrates.
- Roads are assessed in the highest threat category in provincial and federal recovery documents.

(IUCN 2010; Rytwinski and Fahrig 2012; Environment and Climate Change Canada 2017; British Columbia Conservation Data Centre 2019 (see Appendix 1 and 2)

Roads can cause the following impacts on amphibians and reptiles (Figure 1):

- habitat loss
- barriers to movement, which leads to habitat fragmentation and isolation of populations
- road mortality of individuals that are hit by vehicles
- habitat pollution from runoff, which results in reduced fitness or increased mortality
- increased predation
- habitat degradation, which results in reduced survival and reproductive success
- attraction to poor-quality roadside habitats

These impacts can lead to a reduction in body condition, and in genetic diversity as populations become fragmented, and ultimately, to population declines and potential extirpation. Individual and population-level responses can occur more rapidly when impacts combine to produce a **cumulative effect** (see text box in Section 2.3).

An understanding of the various ways in which roads can impact herpetofauna is essential for planning avoidance and mitigation measures for future projects. In this section, examples of past projects in B.C. provide context and lessons learned, including what has worked and what has not. Drawing attention to both the positive and negative aspects of past projects helps reveal how impacts were assessed and solutions were implemented, where solutions were either too costly and/or logistically not feasible, and where adjustments are needed in the future.

Photo 1. Roads are cited as the most significant threat to Western Rattlesnake populations (COSEWIC 2015). Photo credit: Stephanie Winton (left) and Elke Wind (right)

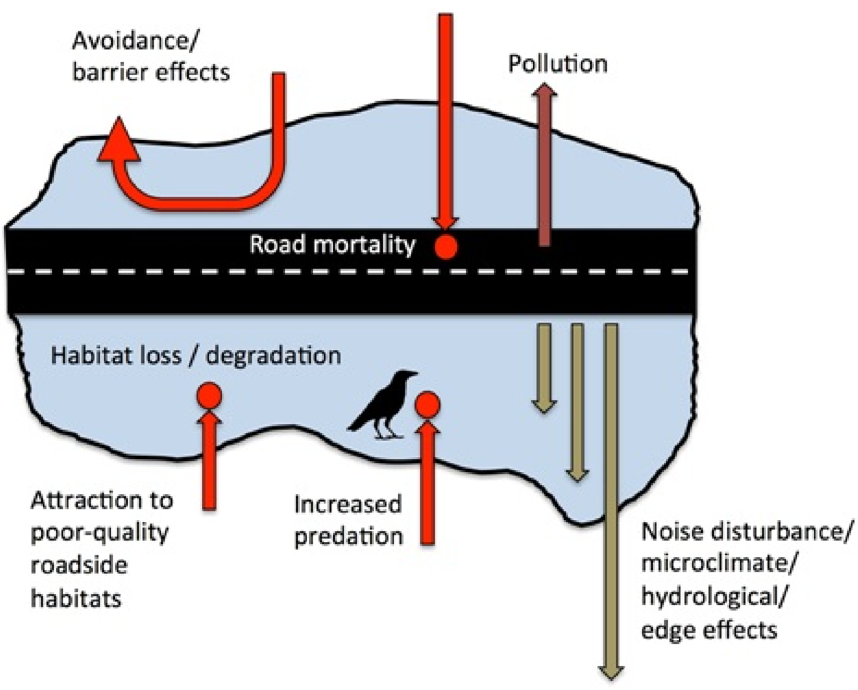


Figure 1. Effects of roads on amphibians and reptiles. Red arrows indicate animal movements; other arrows show the direction of influence of labelled effects (based on impacts outlined in Andrews et al. 2008; Beebee 2013; Langen et al. 2015; Marsh and Jaeger 2015).

2.1 How Roads Can Impact Herpetofauna Populations

2.1.1 Habitat loss

The construction and widening of roads may remove habitat that is important to amphibians and reptiles (Beebee 2013; Marsh and Jaeger 2015). The footprint of a road may destroy breeding sites, foraging areas, hydration sites, overwintering hibernacula, and migratory/dispersal routes. Habitat along the side of the road and/or downstream may also be lost or severely degraded by contaminants from the road and by compacted soil, altered hydrologic regimes, sedimentation, human garbage and disturbance, edge effects such as increased sun and wind exposure, altered plant and animal communities, and increased occurrence of exotic invasive species (Langen et al. 2015). The width of the habitat area impacted by a road, known as the “road-effect-zone,” may be many times the road’s actual width (Forman and Alexander 1998; Jochimsen et al. 2004).

Two recent road projects in B.C. attempted to mitigate habitat loss for amphibians and reptiles. The Highway 99 upgrades from Horseshoe Bay to Whistler, completed in preparation for the 2010 Winter Olympics to accommodate increased traffic volumes, resulted in a 1.9-km highway realignment through a wetland complex at Pinecrest. Several wetlands used by Northern Red-legged Frogs (*Rana aurora*) and other species were partially or completely filled, and a permeable retaining wall at the wetland–highway interface increased drainage that led to further wetland habitat loss (Malt 2012). The project implemented a number of mitigation and compensation measures, including the construction of new wetland habitats and the protection of an additional 260 ha within Brandywine Falls Provincial Park (Buckingham et al. 2009). Effectiveness of the mitigation and compensation is the subject of continued research (Bailey 2011; Isnardy 2015). Another example is the 2017 highway expansion near Williams Lake that inadvertently exposed a garter snake den when the snakes were in the den. The den was destroyed during construction, which led to an emergency salvage of hibernating snakes (Steciw 2018). A replacement den was constructed, but its effectiveness has yet to be assessed.

2.1.2 Barriers to movement

Roads disrupt normal movement patterns of amphibians and reptiles. Paved and gravel road surfaces and mowed right-of-ways have different microclimates and provide less protective cover from predators compared to the surrounding landscape (Langen et al. 2015). Amphibians have permeable skin, which makes them vulnerable to desiccation (drying out) while on paved roads, which rapidly lose surface moisture to evaporation. During dry weather, many amphibian species rarely cross roads, even though they continue to move through moist, vegetated habitats (Ervin et al. 2001; Gravel et al. 2012). Some snake species avoid crossing roads because the open space exposes them to predators (Shine et al. 2004; Andrews and Gibbons 2005; Kingsbury 2011). In some situations, roads include steep roadside verges, concrete barrier structures, and curbs that physically prevent some amphibian and reptile species from crossing (e.g., curbs on a road at Waterton Lakes National Park Reserve obstructed movements of Long-toed Salamanders [*Ambystoma macrodactylum*] [Pearson 2002]). In addition, collision with vehicles causes road mortality (see Section 2.3), which alters the abundance of animals moving across the landscape. When animals avoid or are prevented from crossing roads, their habitats can become fragmented into isolated patches. This can have detrimental impacts on individuals, populations, species, and ecosystems (see text box below) (Hocking and Babbitt 2014; Cosgrove et al. 2018).

Consequences of Roads as Barriers to Movement at Various Scales

- **Restricted home range and resource access** on a daily or seasonal basis can result in poor health and reduced survival and reproductive output, which can ultimately lead to population decline.
- **Impediments to dispersal affect demographics** because they make it more difficult for declining populations to be rescued via immigration and for unoccupied patches to be recolonized. Limited dispersal can also increase competition among individuals that would otherwise live farther apart to find resources.
- **Population isolation** over several generations results in low genetic diversity and higher risk of extinction (e.g., Timber Rattlesnakes [*Crotalus horridus*] in hibernacula that were isolated by roads had lower genetic diversity, which resulted in morphological abnormalities, low survivorship, and greater susceptibility to disease compared to non-isolated populations).
- **Blocked or restricted flow of energy and nutrients** may affect food webs within and across ecosystems (e.g., the high number of amphibians moving from land to water to lay their eggs can result in substantial energy subsidies to ponds).

(Regester et al. 2006; Marsh et al. 2008; Clark et al. 2010, 2011; Rouse et al. 2011; Robson and Blouin-Demers 2013; Hocking and Babbitt 2014; Cosgrove et al. 2018)

2.1.3 Road mortality

Amphibians and reptiles are forced to cross roads when they move between seasonal breeding, foraging, and overwintering habitats. Road mortality is primarily a function of traffic volume, regardless of road surface (paved or unpaved), road width, traffic speed, or other road characteristics. Roadkilled amphibians tend to be concentrated on roads near wetlands, usually during warm, rainy weather, as adults make seasonal migrations to and from breeding wetlands over late winter and spring, and as metamorphosed juveniles emerge and disperse over the summer and fall. On the coast, where temperatures are mild, the active period for amphibians can extend from as early as February to as late as November (e.g., Beasley 2006; Wind 2014); the active period is shorter in other parts of the province (e.g., Crosby 2014) (see Table 1). Hatchling turtles are killed as they disperse from nests in spring (beginning in March), and adult female turtles are killed in summer (June to July) when they leave the water and seek terrestrial nesting sites (Engelsoft et al. 2011; Killburn et al. 2011). Snake road mortality occurs mainly near dens and gullies during the active period (April to October); road mortality is especially high during summer and fall (July to September), when snakes are breeding and returning to hibernacula (Pickard et al. 2009; Winton 2017).

When herpetofauna cross roads, they are extremely vulnerable to being run over by vehicles for a variety of reasons:

- Most species cannot recognize and avoid the threat of oncoming vehicles (Bouchard et al. 2009).
- Many species are too small for drivers to see and avoid, especially amphibians, which are active at night (Beckmann and Shine 2012; B. Beasley, pers. obs.).
- Turtles, salamanders, and some snakes move very slowly and may immobilize (i.e., “freeze”) in response to passing vehicles, which increases their likelihood of being killed (Andrews and Gibbons 2005; Aresco 2005; Mazzerolle et al. 2005). For example, Gophersnakes use slower rectilinear movement (versus fast sinusoidal movement) in open areas such as roads, possibly to avoid detection by avian predators (M. Sarell, pers. obs.).

- Amphibians will linger on roads after rains in order to readily absorb water through their more permeable ventral skin.
- Snakes and toads can be attracted to paved roads for thermoregulation and will linger on the warm surfaces in order to raise their body temperature, which increases the time they are at risk of being run over (Waye and Shewchuk 2002; Wind 2018a).
- Some drivers deliberately run over reptiles. Ashley et al. (2007) reported that 2.7% of motorists in their study at Long Point, Ontario intentionally hit snakes and other reptiles on the road. Drivers have been observed deliberately targeting snakes in B.C. as well (M. Sarell, pers. obs.).

Species that move shorter distances or move less frequently are less prone to road mortality (Carr and Fahrig 2001). Several species in B.C. are infrequently found dead on roads (see Appendix 2). Terrestrial-breeding salamanders, tailed frogs, lizards, and some small snakes, including Sharp-tailed Snake (*Contia tenuis*) and Night Snakes (*Hypsiglena torquata*), have small home ranges and are therefore less likely to encounter roads unless the roads bisect their prime habitats. The few individuals that are killed on roads are potentially dispersing to other populations, and are therefore especially important for maintaining genetic diversity across populations.

Road placement within the surrounding landscape is one of the most important factors determining the severity of road impacts on amphibians and reptiles (Andrews et al. 2008).

2.1.4 Attraction to roadside habitat, and implications

Roads and roadside habitats often attract amphibians and reptiles, to their detriment. For example, turtles nest in gravel substrates on road shoulders (Evelyn 2018); frogs and salamanders breed in warm, shallow water in roadside ditches and stormwater ponds (Ostergaard et al. 2008; Karraker and Gibbs 2011); some snakes and toads bask on roadsides for thermoregulation (Waye and Sewchuk 2002; Andrews et al. 2008; Crosby 2014; Wind 2018a); Great Basin Spadefoots in B.C.'s arid interior have been observed hydrating themselves in puddles that form on roads after rain (P. Govindarajulu, pers. obs.); Western Toads have been observed on roads eating earthworms, which can be numerous on rainy nights (J. Dulisse, pers. obs.); and frogs are known to be attracted to road surfaces that have overhead streetlights, which attract abundant insect prey (Perry et al. 2008; Davies et al. 2012). Some species may also use roads as travel corridors (Deguise and Richardson 2009).

Roadside habitats may be of poor quality in many ways:

- Increased exposure to traffic, pedestrians, pets, and garbage or debris increases the chances of mortality from vehicles and maintenance equipment (e.g., mowing), and may lead to increased disturbance of breeding individuals and egg masses.
- Contaminants from the road, such as de-icing salts and dust control agents, accumulate in roadside ponds and reduce the survival of eggs and larvae of some species (Sanzo and Hecnar 2006; Collins and Russell 2009; Karraker 2008).
- Roadside ponds and ditches may have short hydroperiods that leave egg masses and larvae desiccated when the water recedes (Ostergaard et al. 2008).
- Traffic noise can disrupt choruses of breeding frogs (Nelson et al. 2017).
- Artificial light may interfere with navigational cues and the visual capabilities of some species (Perry et al. 2008).

Studies show considerable variation in the quality of roadside ponds: some potentially provide source habitat, while others act as sink habitats or ecological traps (McCarthy and Lathrop 2011; Le Viol et al. 2012; Gallagher et al. 2014). Source habitat produces a large enough number of juveniles that survive and increase adult populations, while sink habitats and ecological traps attract breeding adults but do not produce a sufficient number of juveniles to contribute to overall population stability or increase. Researchers suggest that roadside stormwater ponds may provide source habitat, especially in areas where natural wetlands are scarce, but caution that further study and management is needed to prevent them from becoming traps (Le Viol et al. 2012). For example, Karraker and Gibbs (2011) found that Spotted Salamander (*Ambystoma maculatum*) egg masses were smaller near roads than away from roads. Additionally, they found that road mortality shifted breeding populations toward smaller, younger individuals with lower reproductive capacity.

2.2 Long-term Impacts of Roads on Populations

Populations of amphibians and reptiles have been known to decline as a result of road mortality and population isolation (Aresco 2005; Eigenbrod et al. 2008a; Fahrig and Rytwinski 2009). Such declines usually take years to detect (Marsh and Jaeger 2015). Aquatic breeding amphibian species typically experience large annual fluctuations in population size, so long-term data collection over at least 10 years is needed to detect a trend (Pechmann et al. 1991). Similarly, it can take time to see a cumulative effect where annual mortality of reptiles is low (Pike et al. 2008). Researchers in Ontario (Findlay and Bourdages 2000) and British Columbia (Winton et al. 2020) have detected road-related losses of amphibians and/or reptiles decades after roads were built.

Modelling can be used to forecast the effects of road mortality on populations. Models require information about the probability of survival and reproduction, and the average number of offspring produced (i.e., fecundity) in a population that experiences road mortality. This information is used to calculate how the population size will change over time based on different levels of road mortality of various life stages. Models show that population declines vary among species and are based on the behaviour or life history traits that lead to increased exposure to traffic, the proportion and life stage of the population that encounters traffic, the volume of traffic, and the ability of the population to sustain high rates of mortality (Marsh and Jaeger 2015).

Species behavioural traits that increase exposure to traffic include:

- frequent long-distance movements (i.e., most individuals in the population make daily movements, migrate, and/or disperse versus being sedentary or territorial);
- attraction to habitats on or near roads; and
- slow road-crossing speed.

Road and landscape conditions that result in high road and traffic encounter rates include:

- high road density within home ranges;
- roads of any traffic volume that intersect migratory or dispersal paths;
- roads of any traffic volume that are immediately adjacent to important habitats (e.g., dens or breeding ponds); and
- consistently high volumes of traffic.

Traits of species that are most vulnerable to ongoing or high rates of mortality include:

- low fecundity and long generation times (long life spans and late sexual maturity), as among turtles and snakes;
- small population sizes, such as naturally/currently rare or endangered species (e.g., Sharp-tailed Snakes and Night Snakes);
- populations that fluctuate and experience periods of low population numbers (e.g., tiger salamanders during long-term drought);
- sex-specific behaviour or life history traits that cause adult females to be particularly vulnerable to road mortality (e.g., females may migrate longer distances than males)—the loss of reproductive females is more significant for population persistence than the loss of males or juveniles (Photo 2);
- isolated populations; and
- populations within which reduced competition for resources does not cause a rebound in population size (i.e., road kill is not like a “sustainable harvest” that is compensated by higher survival and/or reproductive rates among the survivors, or by immigration).

Examples of Population Models that Estimate the Impacts of Road Mortality

- Northern Red-legged Frogs (*Rana aurora*) along Highway 99 at Pinecrest, B.C. experienced a high rate of mortality because the highway bisected important wetland habitats. A population model predicted a high probability of local extinction within 40 years given the observed rate of 16–28% road mortality per year (Malt 2012).
- A model was used to assess the effects of road mortality on Blotched Tiger Salamanders (*Ambystoma mavortium*) at White Lake, B.C. based on 240 road killed juveniles in 2013 and an estimate that 7200 young were produced in 1997. The model indicated that the population would be able to sustain the annual loss of juveniles. However, the road mortality of only a few breeding females when population numbers were low could quickly lead to a population decline (Southern Interior Reptile and Amphibian Working Group 2016; Dyer 2018).
- Row et al. (2007) modelled the effects of roads on Black Ratsnakes (*Elaphe obsoleta*) in Ontario and predicted that the probability of extinction of the population would rise from 7.3% to 99% over 500 years (based on only 0.026 deaths per crossing), thereby illustrating the long-term effects of sustained, low rates of road mortality on a species with low reproductive output (fecundity).
- Winton (2018) used detailed population viability analysis (PVA) paired with refined road mortality estimates to evaluate the persistence of a Western Rattlesnake (*Crotalus oreganus*) population threatened by road mortality at White Lake, B.C. Overall, an estimated 6.6% of the population was killed on the road annually, and the PVA indicated that although the population was likely to persist for the next 100 years (provided traffic volumes did not significantly increase), it would be in continual decline as a result of road mortality. Any increases in road mortality rates resulted in increased probability of extinction.

Photo 2. Traffic kills female Western Pond Turtles more than males because females make overland movements to nesting areas. Photo credit: Elke Wind (left) and Purnima Govindarajulu (right).

2.3 Impacts of an Expanding Road Network and Increased Traffic in the Future

Between 2000 and 2005, the amount of paved and unpaved roads in B.C. increased by 23%, from an estimated 570,000 km to 702,574 km (Austin et al. 2008). Road expansion has been low since then; the total amount in 2018 was estimated at 719,000 km (Environmental Reporting BC 2018). As human populations grow, and as development and resource extraction continues, there will be further increases in traffic volume and pressure for road expansions and repair. B.C.'s population increased by 56% from 1986 (3 million) to 2015 (4.8 million) (B.C. Environmental Indicators), and it is expected to grow to nearly 6 million by 2031 (Austin et al. 2008). This population projection is important to consider because even if no new roads are constructed, traffic volumes on existing roads may increase with increasing population density and therefore lead to increased road impacts on amphibians and reptiles.

What Are Cumulative Effects?

The Government of British Columbia defines cumulative effects as "Changes to environmental [or other] values caused by the combined effect of past, present and potential future human activities and natural processes." The legacy and ongoing impacts of existing roads combine with the impacts of new road construction and present and future road maintenance to produce cumulative effects that amplify detrimental changes to herpetofauna population health and biodiversity in B.C. Therefore, it is important to assess and manage cumulative effects when mitigating the impacts of road management activities on herpetofauna (Government of British Columbia 2020).

Herpetofauna in B.C. are likely to be differentially impacted by paved and unpaved roads; however, there are no known studies to quantify the differences. Paved and unpaved roads may present similar levels of habitat loss and degradation, barriers to movement, and attraction of amphibians and reptiles to poor roadside habitats. Nevertheless, road mortality for many species is likely to be higher on paved, multi-lane highways than on smaller paved and unpaved roads because, for most species, the number of animals killed increases with traffic volume (Fahrig et al. 1995; Gibbs and Shriver 2002; Jochimsen et al. 2004; Mazzerolle 2004). In the case of expanding forestry roads and other unpaved resource roads, effects may be temporary because these roads may be decommissioned to reduce their long-term impacts.

2.4 Impact of Ongoing Road Maintenance Activities

In addition to the construction of new roads and upgrades to existing roads, roads need to be maintained in order to be safe and accessible. The cumulative effects of mandatory road maintenance activities on herpetofauna can be significant because they are continuous and occur across the entire road network. A number of road maintenance activities can have direct (e.g., mortality) or indirect (e.g., habitat loss/degradation) impacts on amphibians and reptiles. Ongoing road maintenance activities may disproportionately impact amphibians and turtles, which often breed in habitats adjacent to roads.

2.4.1 Road surface maintenance

Various chemicals are used to suppress dust and stabilize the base of the road surface. The chemicals commonly used are calcium chloride and magnesium chloride, although in some cases water or water mixed with oil or other agents is used (B.C. MOTI 2019; USDA n.d.). The larvae of some aquatic-breeding amphibians experience reduced survivorship when exposed to these chloride-based chemicals (Dougherty and Smith 2006; Harless et al. 2011). The effect of these chemicals on reptiles is not well understood, but impacts may occur on species that spend a significant amount of time in the water (e.g., turtles).

The objective of snow removal and ice control practices is to reduce accidents and benefit human safety, namely by removing winter accumulations from roadside, overhead, and pedestrian-accessed infrastructure, and by restoring traction (anti-icing, de-icing, and/or pre-wetting materials are used for this purpose). Inputs of meltwater that carries these chloride-based chemicals contaminate roadside aquatic habitat with sand, salt, and chemicals; amphibian larvae that are exposed experience reduced survivorship (Dougherty and Smith 2006; Collins and Russell 2009; Harless et al. 2011). Other issues include the disposal of accumulated snow into roadside aquatic habitats used by amphibians for breeding that may delay breeding or larval development due to cold water temperatures and temporary wildlife fencing can be crushed by snow plows or damaged under the weight of snow piles.

Roads are cleaned periodically to remove debris such as pieces of tire, discarded auto parts, and other garbage that could contribute to water contamination, destroy habitat structures, or affect the structural integrity of mitigation structures such as guiding fences for crossing structures.

2.4.2 Drainage maintenance

The objective of drainage maintenance is to provide effective drainage on and along road surfaces to maintain driver safety and protect roads and supporting infrastructure from erosion. Maintenance work in and along ditches that contain water and removal of obstructions such as beaver dams may strand eggs and impact larval amphibians. Direct impacts from machinery use may occur, while indirect impacts may result from changes in hydrology, such as a drop in water levels that strands eggs or larvae. Amphibians can inadvertently be captured in the spoil during roadside ditch cleanout work where standing water occurs.

Shore, bank, and watercourse maintenance is carried out (although relatively infrequently) to prevent scour and erosion damage to roadways at the shores and banks of watercourses. In some cases, rip-rap is installed to prevent water flow over road surfaces or to stabilize the shoreline. Depending on the size of the rip-rap boulders, the installation can impede the movement of amphibians and turtles. Debris and potential obstructions that raise water levels in ditches (e.g., beaver dams at culverts) are removed. This may inadvertently affect amphibians if the obstruction creates pooled water that is ideal for amphibian breeding. Removal of these obstructions when amphibian eggs and larvae are present could result in stranding or animals being washed away if the removal results in water draining or high flow volumes.

Chloride Contamination from Dust Control and Road De-Icers

(extracted from Copan 2016)

Canada applies 5 million tonnes of road salts annually (Environment Canada 2012). Chlorides are commonly used in de-icing agents due to their low price and abundance. Sodium chloride (NaCl) is the most frequently used. Some chlorides, such as magnesium chloride (MgCl) flakes are used for both road de-icing and dust control. Ecologists consider the application of chlorides to roads to be one of the leading anthropogenic factors affecting amphibians in northern climates (Environment Canada 2001, 2012). Amphibian species that breed early in the year are subject to the highest toxicity levels of road de-icers because their breeding season coincides with ice and snow melt (Collins and Russell 2009; Helmreich et al. 2010). Karraker et al. (2008) found that Spotted Salamander and Wood Frog egg mass density declined significantly with proximity to roads, with increased salinity having a small but detectable negative influence on egg mass density.

Environment Canada (2012) released a Code of Practice in response to concerns about road de-icers. The code seeks to regulate the use of salt-based de-icers, as well as to promote the use of “green” alternatives, such as urea, formates, and acetates, that are considered to be more environmentally friendly than the road salts currently used (Environment Canada 2012). However, some of these alternatives also create issues or have limitations (e.g., some cannot be applied at low temperatures and/or have corrosive effects on concrete and metals). Calcium-magnesium acetate (CMA) is of interest as an alternative de-icer because it has relatively low toxicity and is non-corrosive. However, it depletes oxygen levels in aquatic systems as it breaks down, which can be harmful to aquatic life, such as developing amphibians. Also, it is considered to be less effective and requires more frequent applications (approximately 1.2–1.6 times more) when applied alone to achieve the same results as sodium chloride (Manning and Crowder 1989; Transportation Research Board 1991). Currently, its primary use is to supplement salt-based de-icers (Fay and Shi 2012).

Copan (2016) compared acute toxicities of a traditional road de-icing chloride agent (NaCl) to a non-chloride alternative (CMA). She found that acute exposure to ecologically relevant levels of NaCl was detrimental to the survival of Wood Frog tadpoles. The 96-hour LC50 values for tadpoles (the concentration that causes tadpole mortality after 96 hours of exposure) ranged from 85.77 mg/L to 1406.96 mg/L depending on the tadpole’s site of origin and developmental stage. This response is a concern, given that Environment Canada (2001) reported higher chloride concentrations in ponds within 50 metres of roadsides, with many exceeding 4000 mg/L. In comparison, the 96-hour LC50 values for CMA toxicity were 2588.45 mg/L for Wood Frog tadpoles in aerated tanks and 465.17 mg/L in non-aerated tanks. These values are outside the typical 10–100 mg/L range for CMA found within roadside ponds and wetlands (Horner 1988; Transportation Research Board 1991); however, direct sampling of road runoff has yielded concentrations as high as 5000 mg/L (Horner 1988; Transportation Research Board 1991).

Photo 3. Road de-icers and dust control agents have been shown to be harmful to aquatic amphibians. Photo courtesy of TranBC website. (https://www.tranbc.ca/2019/11/28/your-most-popular-bc-winter-maintenance-questions-answered/).

2.4.3 Vegetation maintenance on roadsides

The objective of vegetation control along roadsides is to improve visibility for the safety of human road users and to facilitate drainage. This relatively exposed, open habitat with shorter vegetation may attract certain amphibian and reptile species and inadvertently put them at risk of predation and road mortality. Vegetation maintenance activities, such as mowing, can lead to direct mortality of amphibians and reptiles that are occupying the shoulder environment, especially during periods of migration. In addition, if mowers and other machinery are not properly cleaned between sites, invasive plants and disease agents (e.g., *Batrachochytrium dendrobatidis*, ranavirus) could be introduced into new habitats or wetlands and cause degradation of habitat for amphibians and reptiles. In some cases, herbicides may need to be used to control vegetation growth; however, some are known to be hazardous to amphibians and reptiles.

Wildlife fencing, including fencing to direct amphibians and reptiles toward a safe crossing structure, has been installed along some stretches of highways and other paved roads in B.C. Mowers and weed snippers used for vegetation control can damage fences by inadvertently slashing them; this creates gaps in the fencing, which is in place to prevent road mortality (B. Beasley, pers. obs; E. Wind, pers. obs.) (Photo 4).

Photo 4. Vegetation along barrier and directive fencing needs to be carefully and regularly cleared to avoid having amphibians and reptiles climbing over it. Photo credit: Elke Wind.

3 SCREENING TOOL – ASSESSING THE PROJECT-SPECIFIC LEVEL OF MITIGATION

The Government of British Columbia's ***Procedures for Mitigating Impacts on Environmental Values*** (2014) establishes the mitigation hierarchy for guiding the development and application of measures to mitigate impacts on environmental values and associated components. The levels of the mitigation hierarchy are (1) avoid, (2) minimize, (3) restore on site, and (4) off-set. Although the procedures are set out as a hierarchy with the expectation that all feasible measures at one level are considered before moving to the next, in practice, the levels within the mitigation hierarchy will often be considered as a whole. The feasibility of measures at each level of the hierarchy should be considered iteratively to reach the most cost-effective solution to achieving maximum ecological benefit.

The Screening Tool presented in this section enables the gathering of information and assessment of the first three levels of the mitigation hierarchy. The screening process may be used as a decision support tool that makes the process by which the final decision is made transparent and defendable. **It is expected that road authorities and QPs who are advising proponents on the project will use the Screening Tool** to gather and evaluate the scientific information needed to provide the rationale for the recommended mitigation level for amphibians and reptiles in the project area. The Screening Tool may also help QPs communicate with road engineers and planners about the need to use mitigation measures for herpetofauna in the project area. The Screening Tool can be applied to one-time projects, such as road construction and expansion, and to regular road maintenance activities.

The Screening Tool and mitigation planning process are outlined in Figure 2. The results generated from using the Screening Tool will guide proponents and their QPs to activity-specific guidelines in Sections 4, 5, and 6.

3.1 Step 1: Identify the Assessment Area

To identify whether amphibians and reptiles may be impacted by a project, it is necessary to identify the boundaries of the assessment area. This area needs to include the **project footprint** (physical works required; construction area; staging areas and borrow pits) and the **area of influence** of the project on the target species (e.g., important habitats such as dens or breeding sites, movement corridors, and movement distances of amphibians and reptiles; impacts of blasting can cause destabilization outside of the project footprint). Consideration of the impacts on amphibians and reptiles at local and landscape levels is a vital component of effective mitigation planning for transportation projects (Semlitsch 2008). Animals move within habitats to access resources (local scale), and move between habitats during migration (e.g., to breeding or overwintering habitat) and dispersal (landscape scale).

British Columbia's amphibian and reptile species vary in their home range size and dispersal distances (Appendix 3). Some species are relatively immobile (e.g., Wandering Salamander) (Davis 1991). Examples of highly mobile species in B.C. include Western Toads, which have been tracked dispersing over 7 km in less than 24 hours during spring migration on Vancouver Island (T. Davis, unpubl. data, cited in COSEWIC 2012), and Western Rattlesnakes, which have been tracked moving more than 3.5 km between summer foraging areas and overwintering dens (Gomez et al. 2015). Western Painted Turtles have been recorded travelling a straight-line distance of 2 km in the Lower Mainland, traversing four sloughs and ending at a small wetland (Kilburn and Mitchell 2011). In the early planning stages of all new developments, it is important to consider the risk of amphibian and reptile road mortality and isolation of habitat when determining road placement, in addition to several other factors (i.e., cost, engineering standards, geotechnical constraints, and cultural and archaeological resources).

Identifying the area of influence is not as straightforward as identifying the project footprint. In order to determine the area of influence of the project on amphibians and reptiles, first identify the species and important habitats that may occur within 3 km of the project footprint (or farther, when highly mobile species are recorded in the area). This distance is based on recorded movements of amphibians and reptiles away from dens, breeding sites, and hibernacula in B.C. or the Pacific Northwest (see Appendix 3). For road maintenance activities, the area of influence will be the area directly impacted by the activity (e.g., road surface and shoulders, roadside mowing swath) and the adjacent area that might be indirectly impacted by the activity (e.g., roadside ditches and wetlands that may be impacted by runoff of dust control and de-icing chemicals, herbicides, or sediment, or whose hydrology may be affected by drainage maintenance activities).

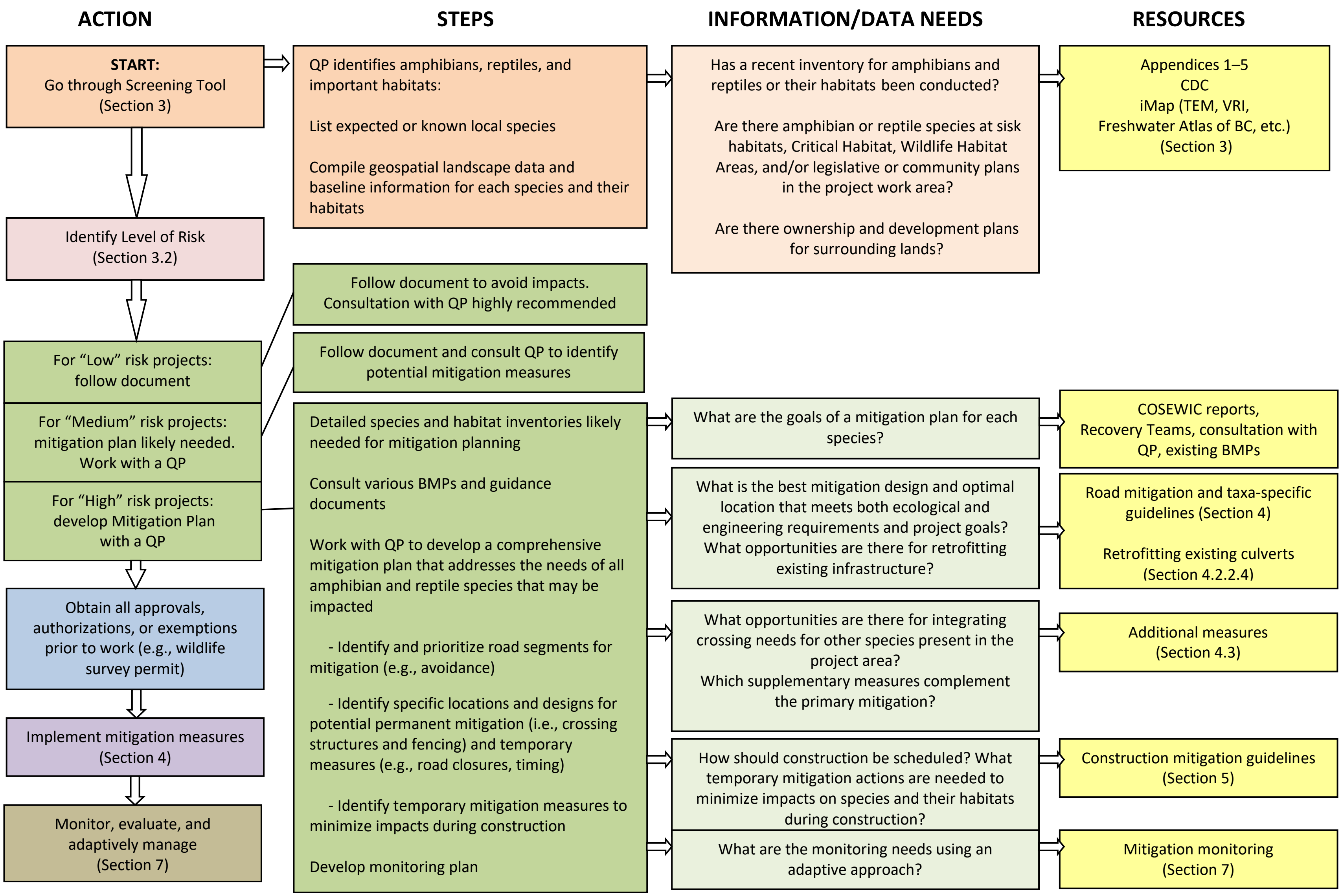


Figure 2. Use of the Screening Tool and development of a mitigation plan for road projects.

Provincial databases of amphibian and reptile occurrences provide a critical first step in assessing potential impacts. **For most herpetofauna species, existing data are rarely adequate for developing effective mitigation**. It may be necessary for additional baseline data to be obtained by a qualified professional biologist to meet provincial and federal environmental mitigation standards.

3.1.1 Identify and map species up to 3 km away from your project footprint boundary

A. Using Appendix 1, identify which species are likely to occur within the project footprint. Include confirmed or potential non-native species in order to factor them into the salvage/management plan (i.e., where details of humane euthanasia of American Bullfrogs, Green Frogs, and Pond Slider turtles may be needed).

B. Further refine your species list by consulting the government databases listed below to identify known and potential amphibian and reptile occurrences and important habitats in the project area. The provincial Wildlife Species Inventory (WSI) can also be queried for additional wildlife data and related information. Refer to Section 3.1.3 for project areas where there are few to no species records in government databases.

iMapBC

1) Go to https://maps.gov.bc.ca/ess/hm/imap4m/
2) Select the tab titled “Data Sources”
3) Click “Add Provincial Layers”
4) Select “Fish Wildlife and Plant Species”, under which you should search within the following data sources:
    - Amphibians - Incidental Observations – IO and Survey Observations - SO (Select all species in your region, based on Appendix 1)
    - Reptiles and Turtles - Incidental Observations – IO and Survey Observations – SO (Select all species in your region, based on Appendix 1)
    - Species and Ecosystems at Risk – Publicly Available Occurrences – Conservation Data Centre (includes publicly available data and masked secured data – see Data-sensitive species below)
    - Wildlife Species Inventory – Incidental Observation Points – Nonsensitive
        - WSI- IO – Reptiles and Amphibians – Nonsensitive
    - Wildlife Species Inventory – Survey Observation Points – Nonsensitive
        - WSI- IO – Reptiles and Amphibians – Nonsensitive
    - Wildlife Species Inventory – Telemetry Observation Points – Nonsensitive
        - WSI- TO – Gopher Snake - Nonsensitive

Note: Shapefiles can be requested from iMapBC (e.g., for use in ArcMap).

Data-sensitive species and ecosystems

Occurrence data are not made publicly available for elements that are considered “sensitive” (e.g., species at risk, den sites, hibernacula), and they are masked (buffered) in the iMapBC and CDC sites (i.e., presented as a polygon). This is to protect species from persecution or harm, for proprietary reasons, or to protect government interests. However, secured records are released on a need-to-know basis if a project location overlaps a secured element occurrence and the details of the element occurrence are relevant to decision-making. If the species of interest is included in the list of Species and Ecosystems Susceptible to Persecution or Harm, or if the mapping exercise above reveals the occurrence of masked secured data in the area of assessment, contact the Conservation Data Centre or Species Information Database (sometimes referred to as the Wildlife Species Inventory) using the information below; include your reasons for requiring the data, details related to project/activities, and the precise area of interest:

- all wildlife (including species at risk and WHAs): SPI_Mail@gov.bc.ca
- species and ecosystems at risk: cdcdata@gov.bc.ca

An online training module must be completed, and a Confidentiality and Non-Reproduction Agreement must be signed and submitted by all personnel that will have access to the data before secure data can be released. For more information on this process, consult the Species and Ecosystems Secure Data and Information Procedures.

Example of How to Further Refine Your Species List

Appendix 1 provides a species list for each region of the province. Additional information may be gleaned from biogeoclimatic (BEC) zones and elevations within 3 km of the project area. Species accounts can help determine if the project is likely to be within the habitat range of species listed in Appendix 1. For example, regarding the snake species listed for Region 3 (Appendix 1), if the road project is situated in the Montane Spruce BEC zone between 1100 and 1400 m elevation, the species account information states that some snake species possibly occur but are less likely to be present, and that the project is probably located at an elevation above any hibernacula. In that scenario, you are likely dealing only with possible summer habitat for snakes.

3.1.2. Identify and map habitat in your project area

Use Appendix 4 and the government databases listed below to identify and map important habitats for the amphibian and reptile species in your region/project area, such as breeding and hibernation sites, and corridors that connect important habitats (e.g., streams connecting forest patches, forests and meadows connected to wetlands) (see Section 4.1.1). In B.C., important habitats for amphibians and reptiles include, but are not limited to:

- old/mature forest stands and patches (e.g., terrestrial salamanders)
- grasslands/shrub-steppe (e.g., snakes, tiger salamanders, spadefoots)
- streams and creeks and associated riparian areas (e.g., tailed frogs, giant salamanders)
- rock outcrops (e.g., snakes, lizards)
- talus slopes (e.g., snakes, lizards)
- small, ephemeral (temporary) ponds and surrounding upland areas (e.g., aquatic-breeding amphibians)
- wetlands and lakes and associated riparian areas (e.g., turtles, aquatic-breeding amphibians)

Habitat databases and other habitat resources:

1) **iMapBC** (see Appendix 5 for instructions):
    - **Critical Habitat** for federally listed species at risk – posted;

For the most up-to-date information, mapped **Critical Habitat** (proposed and approved) for federal species at risk that occur in B.C. can also be found at http://donnees.ec.gc.ca/data/species/developplans/critical-habitat-for-species-at-risk-british-columbia/?lang=en

- **Wildlife Habitat Areas** – approved, proposed, and Forest and Range Practices Act (FRPA)
- **Terrestrial Ecosystem Mapping** (TEM)
- **Vegetation Resources Inventory** (VRI)
- **BC Freshwater Atlas**

2) Government of Canada **Species at Risk Public Registry** has links to up-to-date **Status Reports and Recovery Strategies**, including a description of Critical Habitat.
3) **BC Species and Ecosystem Explorer** provides reports and detailed information on the annual habitats used by each species in B.C.
4) **B.C. Species at Risk Recovery Planning** documents
5) Existing habitat **models** for amphibians and reptiles; for example:
   - South Okanagan (using TEM) – Warman et al. 1998 (updated version available)
   - Okanagan Valley (using SEI) – Iverson et al. 2008

   For more information, refer to the provincial Wildlife Habitat Mapping resources.

3.1.3 Inventory species and habitats in your project area

Do not consider the lack of records for a certain species as evidence that it is not present. If there is no information in the databases listed above, a field inventory by a qualified professional biologist (a QP with previous experience working with the species of interest) will be necessary to confirm whether amphibian or reptile species or their habitats are present. This is especially important if the project area is located within the range and habitat of amphibian and reptile species at risk and assessment and recovery documents have identified roads as a threat to them. A field inventory may not be necessary if recent and appropriate surveys indicate that no amphibian or reptile species have been detected in the area. "Recent" is suggested to be within the past five years and is based on the average lifespan of many herpetofauna. An "appropriate" survey is defined as one that follows provincial inventory guidelines (e.g., Resources Information Standards Committee (RISC) standards) in terms of the appropriate survey season(s), sampling techniques, and level of effort for the expected species in the area (Appendix 1). Surveys conducted within the project footprint and area of influence would be the most appropriate based on average home ranges and dispersal distances of herpetofauna (see text box).

Recommended procedure for species and habitat inventories for new road and road expansion projects:

1. *Within the project footprint area* – conduct intensive inventory of all habitat for reptiles and amphibians.
2. *Within 100 m of the outside of the project footprint area boundary* – conduct intensive inventory of potentially suitable habitat for reptiles and amphibians; conduct moderate inventory of all other habitats
3. *Within 500 m of the outside of the project footprint area boundary* – conduct moderate to intensive inventory of all suitable habitat
4. *Between 500 m and 3000 m of the outside of the footprint area boundary* – conduct desktop assessment of habitats and conduct field assessments/inventory if highly suitable habitat is identified.

3.2 Step 2: Identify the Impacts – Risk Assessment

For the purposes of this document, **risk** is defined as exposure to harm. The level of risk that a road project poses to amphibians and reptiles is influenced by two main components: (1) likelihood of harm, determined by the proximity of the project/road to amphibian and reptile species (especially species at risk), and/or their habitats; and (2) severity of harm, which considers short-term impacts (determined by factors such as the timing and duration of construction) and long-term impacts (determined by factors such as road width/number of lanes and traffic volume).

Severity of harm for amphibians and reptiles in relation to roads is influenced by:

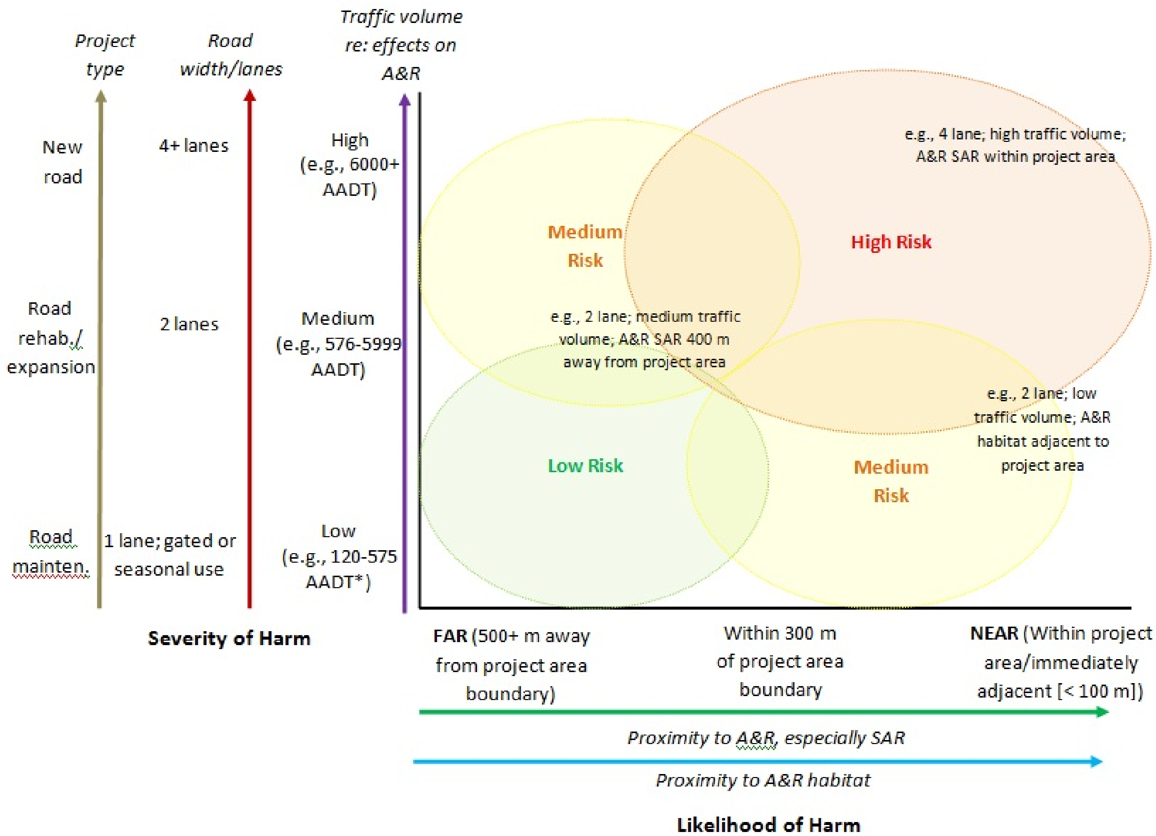
- **Project type:** Some projects result in habitat loss or degradation in addition to risk of collision/ mortality (e.g., new road construction).
- **Road width**: Wider roads expose crossing individuals to greater risk compared to narrower roads and may be a movement barrier for some species; traffic volume often increases with the number of lanes.
- **Traffic volume**: Traffic volume can affect the density of local herpetofauna populations, especially when amphibian and reptile migration/active periods coincide with peak traffic times daily or seasonally (e.g., in spring, summer, and/or after sunset).

Figure 3 shows the many factors that act together to determine the relative level of risk that a project poses to local amphibian and reptile populations.

Traffic Volume/Intensity

Traffic volume is considered to be the most significant risk factor for wildlife along roads (Charry and Jones 2009). Fahrig et al. (1995) found fewer frogs and toads (anurans), a higher proportion of dead anurans, and reduced anuran density (as measured by breeding chorus intensity) with increasing traffic intensity along two 2-lane roads near Ottawa, Ontario. Estimates of the potential effect of traffic volume on amphibians and reptiles should consider differences in their behaviour on both a daily and seasonal basis.

It should be noted that the need for action is not determined by the risk of the project alone but also by the vulnerability of the affected species/population, which may be increased due to the cumulative effects of road management activities in the area, other human activities (e.g., resource extraction, development), and natural processes (e.g., disease). For example, the presence of endangered species/populations might trigger the need to apply mitigation measures (i.e., if the proposed project overlaps federally designated Critical Habitat, and the activity is listed in a federal Recovery Planning document as an “Activity likely to destroy Critical Habitat”), even for low-risk projects, while mitigation may be minimal for medium-risk projects if species/populations are stable. The mitigation effort (as well as cost and technical feasibility) and due diligence required must be judged at a project-specific level, taking both risk and species vulnerability into consideration.



* AADT = average annual daily traffic; based on data compiled by Charry and Jones 2009 that related traffic volume to impacts on amphibians and reptiles (A&R) and species at risk (SAR). Note: Estimates of traffic volumes in spring and summer would be more accurate in terms of their impacts on amphibians and reptiles.

Figure 3. Relative level of risk posed by a road project for amphibians and reptiles based on likelihood of harm and severity of harm.

ACTIONS associated with relative level of risk:

- **All High Risk and Medium Risk New Road Projects – Mitigation is strongly recommended**
    1. Conduct further species and habitat inventories, if necessary, at a fine scale (i.e., field surveys) to determine exactly where mitigation is required.
    2. Consult this document and [Best Management Practices (BMPs)]() for guidance.
    3. Develop mitigation and follow-up monitoring plans in consultation with a QP who has appropriate species and local experience.
        - Provincial guidelines for mitigation planning can be found at https://www2.gov.bc.ca/assets/gov/environment/natural-resource-policy-legislation/environmental-mitigation-policy/em_policy_may13_2014.pdf
- **Medium Risk Existing Road Projects – Some mitigation is recommended**
    - Consult this document and BMPs and, if necessary, additional experts and QPs to identify the need for, and extent of potential mitigation measures.
- **Low Risk – Minimal mitigation recommended**
    - Consult this document and BMPs and, if necessary, additional experts and QPs to avoid and/or reduce impacts.

3.3 Step 3: Avoidance as a Strategy

Due to the sensitivity of herpetofauna to roads, avoidance of impacts is the most effective mitigation approach and should always be considered. Information and assessments from Step 1 and 2 can be used to follow the provincial guidelines for mitigation planning, with avoidance being the first step in the mitigation hierarchy.

Impacts can be avoided either spatially or temporally or by using both strategies. Spatial avoidance includes not working in important habitats and travel corridors. Temporal avoidance includes conducting work during periods when the animals are less vulnerable (e.g., not clustered at den sites or breeding ponds). Avoidance is often more feasible when the presence of amphibians and reptiles is considered early in the planning process (see Section 3).

Avoidance Challenges

Although measures can be taken to avoid important terrestrial habitats, such as known or potential hibernacula/dens, the locations of these habitats are largely unknown. Project managers should be aware that construction or maintenance work that involves removing or disturbing ground cover (e.g., large downed wood, stumps, or rocks), could uncover hibernating amphibians and reptiles (e.g., snake dens). See the BMPs for Amphibian and Reptile Salvages for actions required under this scenario.

For new road projects, overlay the proposed road location with the spatial data on species occurrences and habitats that were collected in Step 1. Where possible, alter the road alignment to avoid known occurrences and important habitat features, such as wetlands, rock outcrops, and talus slopes. Ideally, allow a buffer of at least 300 m around these important habitat features. Spatial avoidance may be much more challenging for road improvement projects, such as the widening of road, creation of medians, and installation of shoulder barriers. In these cases, temporal avoidance may be considered during the project. Road improvement projects may offer a valuable opportunity to retrofit mitigation measures where significant amphibian and reptile migration and dispersal routes have been identified (e.g., where occupied breeding sites or dens occur near the road alignment).

When possible, road maintenance and rehabilitation activities, such as culvert or bridge improvements/ replacements/removals, repaving, and ditch cleaning should be avoided at times of the year when herpetofauna are migrating or are clustered at roadside habitat features (e.g., when reptiles are at hibernation sites, or when amphibians are congregated at breeding ponds immediately adjacent to roads) (Table 1). When impacts are unavoidable, appropriate mitigation measures should be incorporated into the project design.

3.4 Step 4: Minimize and Restore On-site Using Best Management Practices and Expert Advice

If the project cannot avoid all impacts on amphibians and reptiles or their habitats, seek expert advice to develop a mitigation plan and implement the guidelines below in Section 4 for minimizing impacts, restoring habitat on-site, and where necessary, offsetting. Where complete mitigation cannot be implemented (i.e., avoid, minimize, restore on-site), offsetting is recommended by the B.C. Environmental Mitigation Procedures (B.C. MOE 2014). This may include restoring or creating habitat outside the project area, such as constructing a wetland or den in an area occupied by a species at risk. Additional monitoring and adaptive management requirements may be included in project-specific plans. In addition to the guidelines included here, the B.C. Environmental Mitigation Procedures, Guidelines for Amphibian and Reptile Conservation during Urban and Rural Land Development in British

Columbia, and Best Management Practices for Amphibian and Reptile Salvages in British Columbia provide a good foundation for developing a mitigation plan.

Table 1. General active/sensitive periods for amphibians and reptiles in B.C. Note: The timing of life history phases is species- and region-specific, varies annually with weather conditions, and must be confirmed with a QP.

Amphibian and Reptile Group	Breeding/Active Period (sensitive)	Migratory/Active Period (sensitive)	Relatively Inactive Period (hibernation, summer inactivity)
Terrestrial – breeding salamanders	Spring and fall (e.g., Feb.–June; Sept.–Nov.)	Not applicable	Winter; summer (on land/subsurface) (e.g., Dec.–Jan.; June–Aug.)
Pond-breeding amphibians	Later winter/ spring (e.g., Jan.–May on the south coast; Apr.–June in the interior and north)	(1) Late winter/spring and fall (e.g., Oct.–June on the south coast; Mar.–May in the interior and north) (2) Late summer/fall (metamorphs disperse; e.g., June–Sept., or later in interior)	Fall/winter (some on land/subsurface, some underwater) (e.g., Nov.–Jan. on the south coast; Oct.–Mar. in the interior and north)
Stream-breeding amphibians	Summer (e.g., June)	N/A	Fall/winter (in water and riparian areas) (e.g., Oct.–Feb.)
Turtles	Spring–summer (females nesting) (e.g., May–July)	Spring–fall (e.g., March–Oct.)	Fall/winter (underwater) (e.g., Oct.–Feb.)
Snakes and lizards	Summer (July)	Spring, summer, and fall (e.g., Apr.–Oct.)	Fall/winter (on land/subsurface) (e.g., Oct.–Mar.)

4 GUIDANCE FOR MITIGATION PLANNING AND DESIGN

Where the risk assessment that was conducted as part of the Screening Tool indicates a “high-risk” or “medium-risk”, then mitigation measures should be developed. A fully developed mitigation plan (e.g., for “high-risk” projects) includes a comprehensive design component for reducing impacts on amphibians and reptiles and an effectiveness monitoring component. While a fully developed mitigation plan may not be essential for “medium-risk” projects, assessing opportunities for reducing impacts on amphibians and reptiles is recommended.

4.1 Background Information for Developing a Mitigation Plan

The data compiled from the Screening Tool (Section 3), in combination with data collected during field inventory work (if applicable), will support the development of an effective mitigation plan, the steps of which are outlined in Figure 2. These data can be compiled into a geographic information system (GIS) that can be overlaid with georeferenced project layers. The following considerations and resources support project planning:

- Consider the local (daily or within-season) and landscape (from season to season between habitats) movement patterns of the species identified as confirmed and potentially present in the project area, and map these known and potential movement corridors.

- Consider a multi-species perspective to ensure that a strategy for an individual species does not create unintended negative impacts on other amphibians and reptiles or other wildlife species.
- In the case of larger road projects, the duration of the environmental assessment process can last for multiple years, especially if there are time lapses between the preliminary assessment, detail design, and construction. This provides opportunities for inventories to be conducted and other data to be collected within the project study area to better inform mitigation planning and provide important data for post-implementation effectiveness monitoring (Before-After-Control-Impact [BACI] design).
- Other useful data that may be available to support project planning include existing and future road network and other infrastructure, such as existing barriers (e.g., median and shoulder barriers) and passageways (e.g., culverts), and adjacent railroads and local or private roads.
- Identifying and considering existing and future land use, status, and ownership may also prove useful while designing a mitigation plan. For example, the condition and ownership of land adjacent to a project may provide opportunities for maintaining connectivity and protective buffers. Most Official Community Plans map environmentally sensitive areas and areas for development at a regional scale. Provincial and regional parks, ecological reserves, Wildlife Management Areas, Wildlife Habitat Areas, and other areas designated for conservation are mapped at a provincial scale (see Section 3.1, Step 1 for details).
- Effective communication is also important, from the planning to the implementation phase of mitigation measures. It is important for all individuals involved in construction and maintenance projects, including road crews, to be made aware of the mitigation measures to be implemented for the project (e.g., the need for additional, dry culverts with fencing; the need for fences to be buried properly, without gaps that allow animals to move through to the road). Coordinating with other jurisdictions (e.g., municipalities and conservation authorities) that own or manage adjacent infrastructure and land is also important.

4.2 Designing Crossing Structures

Specifically designed crossing structures (e.g., elevated roads, underpasses, overpasses) with fencing are often the most effective mitigation strategies for reducing road mortality and enhancing habitat connectivity (Dodd et al. 2004; Aresco 2005; Cunnington et al. 2014; Baxter-Gilbert et al. 2015; Rytwinski et al. 2016; Helldin and Petrovan 2019). This section summarizes current information on the best crossing structure and fence designs that allow amphibians and reptiles to move between habitats that are bisected by roads, with an emphasis on B.C. Different species preferentially use different types of crossing structures, and we are still learning about the requirements of many of B.C.'s species. This document provides the minimum and/or an acceptable range of recommended design specifications (e.g., height, length, and width of crossing tunnels and fencing) based on the best available information. Illustrations, relevant examples, photos, references, and caveats are provided throughout.

Most amphibians and reptiles do not naturally want to move through crossing structures. Specific designs and fences are needed to guide (encourage) them to move through these structures.

It is important to weigh the benefits of crossing structures and fences against their potential detrimental effects. Channelling animals through narrow crossing structures could increase predation pressure (Little et al. 2002) and disease transfer. Using fences to restrict movements across the landscape could slow the escape of animals from wildfire, introduce invasive plants by disturbing soil, and alter ecological processes that rely on open dispersal and movement (e.g., pollination, decomposition, germination).

Little research has been done to test these effects. For example, there is anecdotal evidence of predation events at some wildlife passages, but no studies have specifically examined predation rates in or near crossing structures compared to areas farther away (Little et al. 2002). Where traffic levels are low, some amphibians and reptiles are likely to cross the road without getting killed, and fencing may hinder their natural movement patterns. Thus, the decision to install crossing structures and fences depends on a combination of traffic intensity and the effectiveness of the structures (Helldin and Petrovan 2019). It is essential to assess the level of risk to aid in the decision-making process and to monitor the use of the fences and crossing structures to test their effectiveness and continually improve their design.

Elevated roads and bridges most effectively mitigate the impacts of roads on amphibians and reptiles for a variety of reasons (see Section 4.3.1). The next best option is to install a series of discrete crossing structures or underpasses, hereafter referred to as tunnels (see Section 4.3.2). Tunnels with associated fencing are the most common form of mitigation that have been applied within B.C. Wildlife overpasses that are used to connect habitats for larger wildlife species, such as deer, caribou, and bears, may also be used by amphibians and reptiles (van der Grift et al. 2009). Certain features that accommodate amphibians and reptiles must be incorporated into wildlife overpasses in places where this kind of multi-species approach is deemed appropriate (see Section 4.3.3).

Crossing structures alone are not sufficient for mitigating road impacts (Schmidt and Zumbach 2008; Rytwinski et al. 2016); they must be used in conjunction with fencing (see Section 4.3.4), which is essential for two purposes: guiding animals to the entranceways of crossing structures and preventing animals from accessing the road surface where they risk being killed. Fencing designs, in combination with crossing structures, must be tailored specifically to the terrain at mitigation sites and to the behaviour and movements of target species (see Section 4.2.5).

Installation of crossing structures and fencing during new road construction provides the greatest opportunity for creating functional underpasses because roads can often be designed to accommodate the recommended sizes of crossing structures (i.e., engineers can plan for appropriate grades and amounts of fill). Road improvement and rehabilitation projects are more challenging because the existing road profile often constrains what can be done. Despite these constraints, there are numerous examples in B.C. of the addition of new crossing structures to existing roads during upgrades (Appendix 6). There are also examples of retrofitting existing drainage structures to facilitate wildlife passage (see Section 4.2.2).

4.2.1 Bridges and elevated roads

Rivers and valley bottoms form natural movement corridors for amphibians, reptiles, and other wildlife. The best solution when a road cannot avoid crossing a river or wetland or following a shoreline for a long distance is to install a bridge or elevated road with an appropriate span to allow free water flow and maintain the continuity of the natural shoreline habitat (Beben 2016). These larger structures make it possible for various species to move freely under the road and access resources without being constrained to narrow crossing structures. Bridges and elevated roads are particularly important on wider roads (e.g., more than two lanes) because animals are more reluctant to move through long, narrow tunnels than under more open bridges of the same length (e.g., turtles) (Yorks et al. 2011).

A variety of frog, lizard, snake, and turtle species have been shown to cross under bridges (Smith 2003). Design details vary, but the width of the bridge crossing should be wider than the width of the stream at high water to allow terrestrial animals dry passage along its banks (Lesbarrères and Fahrig 2012) (Photo

5). Planting herbaceous vegetation and shrubs that extend from the edge of the road to beneath the bridge or adding other cover objects will provide safety cover. It is important to install ramps that allow animals to cross over abutments if they extend from the shoulder to the riverbank; otherwise, they form barriers for animal movement (Photo 6).

Photo 5. Bridge crossings need to be wide enough to allow dry passage for terrestrial animals along stream banks with vegetation to provide safety cover, Millstone River Bridge, Nanaimo. Photo credit: Richard Eliasen.

Photo 6. Bridge structure with connected guiding fences that guide animals around bridge abutments – Highway 4 Lost Shoe Bridge. Photo credit: Barb Beasley.

<table>
<tr><td colspan="2">Bridges and Elevated Roads</td></tr>
<tr><td colspan="2">Description
• Larger multi-span bridges, arches, viaducts, and elevated roads</td></tr>
<tr><td colspan="2">Advantages
• Maximize connectivity of migratory routes along creeks and shorelines, and throughout wetland habitats
• Maintain ecological and physical properties and processes
• Allow for the integration of terrestrial pathways at creek and river crossings (Photo 7)</td></tr>
<tr><td colspan="2">Disadvantages
• Expensive compared to smaller crossing structures</td></tr>
<tr><td>Application</td><td>• Deck on piles or columns</td></tr>
<tr><td>Engineering considerations</td><td>• Engineering measurements and road design will determine the best options for a bridge or elevated road</td></tr>
<tr><td>Maintenance considerations</td><td>• Natural substrate and cover objects must be maintained</td></tr>
</table>

Example Bridge and Elevated Road

Photo 7. Computer simulation of an elevated road with river and wildlife crossing underneath. Photo credit: Southwest Calgary Ring Road.

4.2.2 Tunnels

In this document, the term tunnel is used to distinguish crossing structures for amphibian and reptile use from culverts, which are designed to transport water under the road. Box tunnels, arch tunnels, and round tunnels (Figure 4) buried into the ground are the primary recommended tunnel types because they provide a natural, relatively flat or horizontal (versus rounded) crossing substrate, and sufficient air, light, and clearance for hopping amphibians (frogs and toads). If the edge between the ground and lateral wall is rounded or curved versus vertical, amphibians will attempt to climb the walls and are less likely to move through the tunnel (Schmidt and Zumbach 2008). However, curved or rounded lateral walls allow some amphibians to climb and escape flowing water in the culvert (B. Beasley, pers. obs.). The interior height of tunnels that are retrofitted to existing roads will be constrained by the depth of the ditch relative to the road height, but the minimum interior height should be at least 0.5 m. The interior width will vary with the tunnel design and species (see Section 4.2.2.1 below and Section 4.3.5). The tunnel should be as wide as possible within the constraints of the materials used to fit the road bed. Longer tunnels (i.e., under more road lanes) will need to be wider and higher to maintain ambient light and temperature throughout the span of the tunnel.

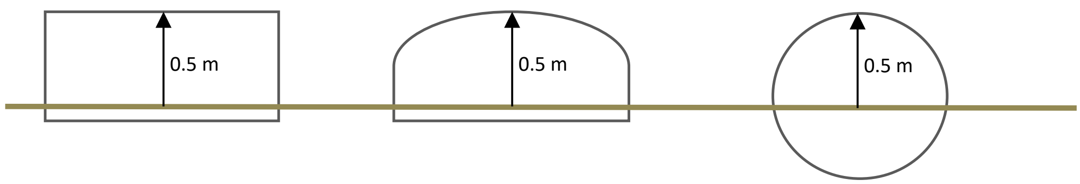


Figure 4. Box, arch, and round tunnels that are buried into the ground and provide an interior height of at least 0.5 m are recommended to allow amphibians and reptiles to move easily under roadways. The interior width will vary with the tunnel design and species (Section 4.3.5).

4.2.2.1 Tunnel design

Tunnels need to have particular moisture, temperature, and light conditions for amphibians and reptiles to readily use them (Andrews et al. 2008). In general, tunnels should have an interior width that is as wide as possible and an overall length that is as short as possible to allow airflow and keep temperatures inside the tunnel similar to those outside (Woltz et al. 2008; Yorks et al. 2011). For example, Smith (2003) noted that amphibians and reptiles in Florida used tunnels more often if they were at least 1.5 m wide and 0.6 m high internally, compared to smaller tunnels. In addition, amphibians prefer tunnels with high moisture levels due to their permeable skin and their vulnerability to water loss. Some species also tend to avoid structures that are too dark. Design elements can be used to create suitable microclimates in and near crossing structures (e.g., the use of natural substrates, inclusion of cover objects). For example, artificial (e.g., fluorescent lighting) and ambient lighting inside a tunnel has been shown to encourage use by turtles (Yorks et al. 2011) and speed up movements by an eastern species of salamander (Jackson 1996). However, artificial light may alter the vision of frogs and have other detrimental impacts (Perry et al. 2008).

General tunnel design recommendations for facilitating amphibian and reptile use (for tunnels < 3 m inner width) are outlined below based on the literature and expert opinion. Specific requirements for individual species or taxonomic groups are summarized in Section 4.3.5.

Design specifications

- Tunnels should be as open (internally wide and tall) as possible to maximize air flow and ambient light inside the tunnel.
    - Suitable microclimate and light conditions may be achieved by designing tunnels with larger (typically wider) openings (Photo 8), or with an open-top or partial open-top tunnel (Photos 9 and 10).
- When possible, include “skylights” or fenced gaps at medians and shoulders. Skylighted/grated tunnels can be used along roads that receive snow (e.g., they have been successfully used in Waterton Lakes National Park in Alberta, and in Bruce Peninsula National Park, Killbear Provincial Park and the Long Point Causeway in Ontario). The size of grating used for a tunnel in Bruce Peninsula National Park is 7.25 cm x 9 cm x 10 cm tall (Photo 11). The snow plow needs to slightly lift its blade so it does not catch anything as it passes over the grate. Another grated tunnel design made by ACO Ltd. (see Photo 9) does not have this issue but it is a smaller tunnel (T. Robins, pers. comm.)
- At locations where tunnels will be relatively long (e.g., under roads wider than two lanes), consider the following:
    - building a bridge or large underpass (> 3 m inner width)
    - elevating the road (especially when new highway alignments will bisect Critical Habitat for species at risk)
    - installing a wildlife overpass
    - using separate, shorter tunnels under each of the opposing traffic lanes with an open median between. On divided highways, crossing structures should never end in the centre median (Photo 12). Ensure the two tunnels are connected with appropriate fencing in the median (Figure 5).
- Where existing culverts are being replaced, increase the size of tunnels to at least minimum design specifications, and use the tunnel type guidelines summarized in Section 4.2.2.2; incorporate specific recommendations for each applicable species or taxonomic group (refer to Section 4.2.5).
- For all species, tunnel entryways should be flush with the terrain.

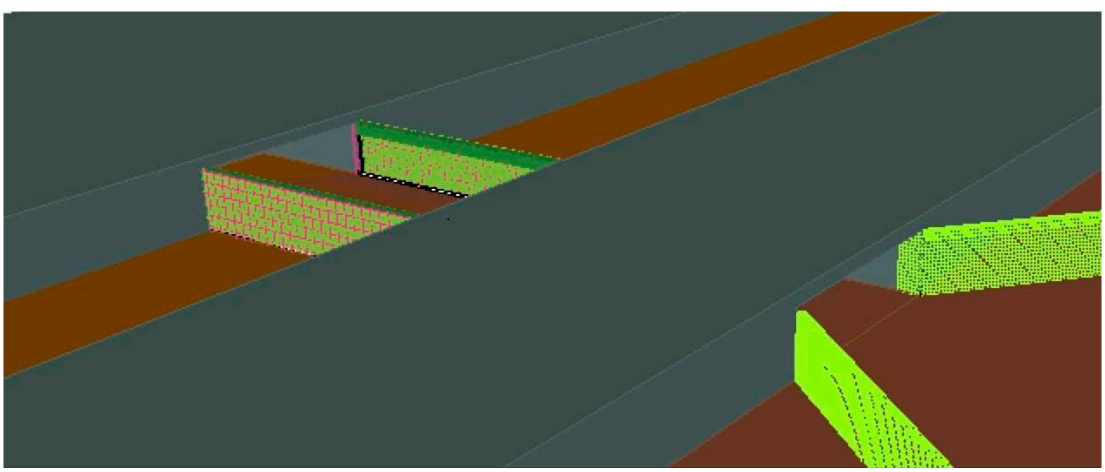


Figure 5. Fencing (green) leads animals into tunnel and then across opening between tunnels in the median of a divided road.

Microhabitat and cover

To encourage use by amphibians and reptiles, all terrestrial crossings should have a natural substrate on the tunnel floor that consists of soil, sand, branches and other natural materials (Photos 13 and 14). The use of local, moisture-holding soil (i.e., soil with high organic matter content, such as wood and humus, often referred to as "overburden") 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, Woltz et al. (2008) noted that fewer frogs crossed through tunnels that contained bare concrete or PVC compared to those with natural substrate. Substrate selection should be informed by the following considerations:

- Soils should be from the local area to maintain the composition of the local soil microfauna and avoid introducing invasive species.
- Soils that consist of large stones should be avoided because they typically have lower moisture-holding capacity. Soils should contain fines and with the largest stones no greater than 5 cm to have high moisture-holding properties and produce a level traveling surface.
    - Note: In the interior of B.C., researchers have experienced invasive plant issues in some tunnels. Large rocks or pieces of downed wood placed inside the tunnel can trap invasive plant fragments and seeds and make clean-out more difficult.
- Sediment baffles (e.g., open plate) may be used to "hold" the natural substrate in place if water flows through the tunnel (Photo 15). Ensuring that the tunnel is installed at ≤ 2% grade (except when there is an open grate top to the road) helps to ensure a sediment holding capacity.
- Cover objects (flat rocks and/or woody debris) should be placed throughout larger tunnels to provide security cover and shelter from predators. These cover objects should not block sightlines or impede individuals from crossing straight through the tunnel.
- Sufficient cover objects (e.g., one relatively large boulder/log or 2–3 cobbles/pieces of wood per 10 m) should be present near the entrances of all terrestrial crossing structures to provide shelter and safety cover.
- Retain as much natural vegetation at the entranceways as possible during construction; where needed, additional planting should occur after construction.

Other design considerations

- The amount of desired water within the tunnel will vary across the province depending on local species and conditions. Some species will use tunnels that contain water (e.g., turtles), while others will not (e.g., lizards). It may be desirable to allow rainwater to enter tunnels in drier interior locations, where precipitation is rare/low compared to wetter coastal environments, where precipitation can be heavy and can frequently flood tunnels. Where it is deemed suitable to have some water in wildlife tunnels (e.g., designed for aquatic amphibians or turtles), the water should be standing or have low flow rates. Except for tailed frogs and giant salamanders, few amphibian and no reptile species will move through tunnels filled with fast-flowing water. Wildlife tunnels should never be fully submerged (e.g., Caverhill et. al. 2011) (Photo 16) because amphibians and reptiles require access to surface oxygen.
- Terrestrial tunnels should be as level as possible for the entire their length so that any water that enters them will move through at a low flow rate. One exception to this is tunnels with grated tops, which can fill with water; these tunnels should be installed with a slight slope to allow for drainage and natural cleaning of the tunnel. The slope of tunnels with grated tops can follow the natural contour of the land or be highest in the middle and slope downward toward either end so that both tunnel entrances are level with the ground.

- Tunnel entrance bottoms (including the soil level inside the tunnel) should be at ground level so that animals do not need to “step up” or “step down” to enter the structure (Photo 17). If a slope leads to the entrance, it should not be steeper than 1:1 or 45˚.
- At terrestrial tunnels, drainage ditches or sloped excavation should be used to divert most runoff water away from the entrances (Photo 18). However, it is important to allow some rainwater to enter the tunnel to keep soils moist for amphibians (Malt 2012; B. Beasley, pers. obs.).
- If they are large enough, culverts that are intended for drainage and tunnels with water flow can be made suitable crossing structures for some species by creating a bench that allows dry passage through the tunnel. The bench can be integrated into the culvert or tunnel design (e.g., attached to the side wall), but it must be situated above the high-water mark and connected (extended) to dry ground at both tunnel entrances to be effective.
- When arch tunnels are used at road-stream crossings, terrestrial corridors should be retained along the stream riparian zone by using wider tunnels that extend beyond the high-water mark (Photo 19). 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 tunnel types and sizes should be provided. Structural diversity of tunnels can provide an experimental setting for testing species-specific crossing preferences (see Section 7).
- Many crossing structures become ineffective over time due to lack of maintenance (Iuell et al. 2003). Regular maintenance of all tunnels is required to ensure their long-term effectiveness and that the microhabitat is intact, passageways are clear of debris, and suitable substrate remains. Maintenance needs to be factored into the original design and budget of mitigation structures.

4.2.2.2 Types of tunnels for amphibians and reptiles

<table>
<tr><th colspan="2">Box Tunnels</th></tr>
<tr><td colspan="2">Description
Although traditionally used for drainage, concrete box culverts can be modified specifically to serve as tunnels for amphibian and reptile passage.
Tunnels up to 3 m wide or high are typically made from precast concrete.
The maximum recommended tunnel length is 25 m (i.e., to fit under a four-lane road) because amphibians and reptiles are reluctant to use longer structures.
Variations include open-top or open-grate, open-bottom, and variations of these.</td></tr>
<tr><td>Open-top</td><td>Achieved with slots or grooves along the top or open-grate, set upon two concrete footings.
Allow for internal moisture, light, and temperature conditions that are more similar to ambient conditions.
Possible concerns with influx of road debris, pollutants, or traffic noise.
Installation at a downward incline from the middle of the road to the edge of the road allows for drainage and natural cleaning of the tunnel.
The use of larger tunnel entryways in small tunnels facilitates maintenance.</td></tr>
<tr><td>Open-bottom</td><td>Three-sided structures.
Allow natural topography and substrate conditions to be retained (e.g., streambed or grass floor).</td></tr>
</table>

<table>
<tr><th colspan="2">Box Tunnels</th></tr>
<tr><td colspan="2">Advantages

Lower road cover requirements for concrete box tunnels compared to arches or round metal tunnels allows them to be set higher in the roadbed.
Provide more cross-sectional area, or openness, than round or elliptical tunnels of the same width. The amount of light and airflow (microhabitat conditions) in a smaller open-top tunnel may be equivalent to that of wider/taller tunnels that are enclosed.
Straight (vertical) walls are easy for animals to follow continuously from straight-walled fencing, and they may be perceived by target species as providing increased openness.
Can be ordered in sections, which allows them to be filled with appropriate substrate as they are placed.
Generally taller, which allows for easier access after they have been placed, and facilitates maintenance.
</td></tr>
<tr><td colspan="2">Disadvantages

Interior opening is smaller, darker, and potentially colder than passages under bridges and elevated roads.
Relatively expensive.
</td></tr>
<tr><td>Application</td><td>
Open-top grate tunnels (e.g., cattleguards) have previously been used on low-use roads or roads in protected areas (M. Sarell, pers. comm.).
The tunnel floor should be buried and covered with natural substrate and cover objects.
An open-top in the road shoulder and a closed-top along the road pavement may be more suitable for high-volume roads.
For divided highways with two structures that end in the median, tunnels should be connected with a fence.
Headwalls may be used at the entrance to shorten the length of the structure or to create a seamless join to a concrete guide wall.
</td></tr>
<tr><td>Engineering considerations</td><td>
Open-top tunnels must be at grade with the road surface.
Road must be constructed with a vertical road profile that will allow for the height of the tunnel and adequate cover for structural stability. The necessary elevational relief will vary depending on the size of box tunnel and road loading requirements. For a concrete box culvert with a vertical opening of 0.5 m, there will need to be at least 1 m between the elevation at the surface of the road and the elevation at the bottom of the ditch or where animals enter the tunnel.
Design variations may require special design drawings if the tunnel is not prefabricated.
</td></tr>
<tr><td>Maintenance considerations</td><td>
Natural substrate and cover objects must be maintained.
Open-top tunnels may have to be flushed with water periodically (e.g., with a fire hose) to clean out build-up of road pollutants.
Smaller tunnels will be more difficult to keep clear of debris.
Larger structures allow for better accessibility during maintenance, and have minor cost increases relative to narrower structures.
Open-top tunnels are thought to interfere with snow removal; however, this has not been the case in tunnel installations in cold countries (Langton 2014).
</td></tr>
</table>

Box Tunnels	
	• The top of the tunnel wears away at the same rate as the road surface (see review in Langton 2014).

Examples of Applications of Box Tunnels

Photo 8. Large precast concrete box culvert installed to provide a tunnel suitable for amphibians and larger wildlife at Highway 4 near Ucluelet. Photo credit: Barb Beasley.

Photo 9. Open top ACO tunnel for turtles and amphibians at Long Point Causeway, Ontario. Photo credit: Barb Beasley.

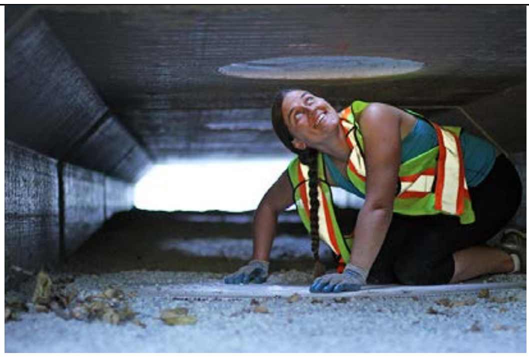


Photo 10. Open grate lets light in mid-way through the concrete box tunnel installed for Western Toads and other amphibians near Ryder Lake, Chilliwack. Photo credit: Fraser Valley Conservancy Land Trust.

Photo 11. Customized box tunnel with grate created for turtles in Bruce Peninsula National Park. Photo credit: Tricia Robins, Parks Canada.

Photo 12. Box tunnels in the median that should be connected with a fence when intended for wildlife passage. Photo credit: K. Gunson.

Photo 13. Filling sections of amphibian tunnel on Highway 4 with natural substrate during the installation. Photo credit: Barb Beasley.

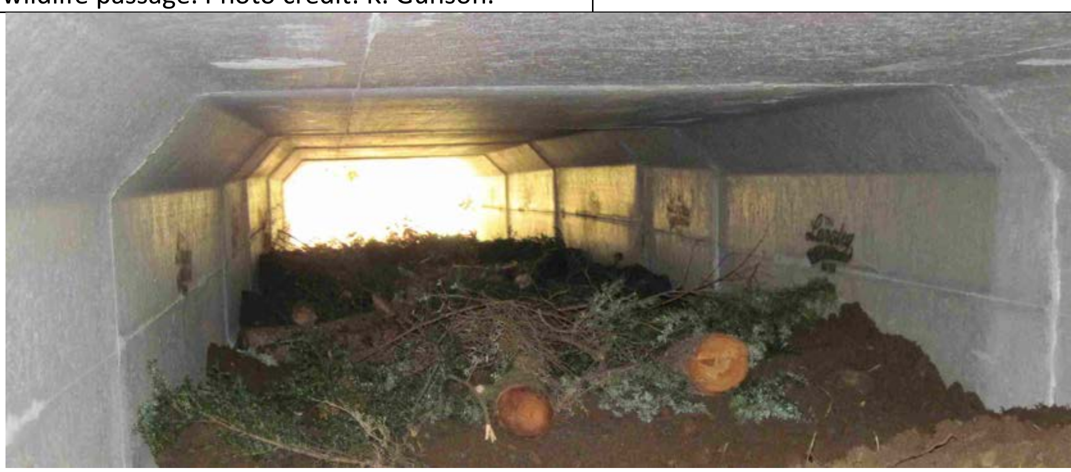


Photo 14. Soil and branches inside bottom of tunnel provide amphibians with moisture and places to hide from predators, Highway 4. Photo credit: Barb Beasley.

Photo 15. Sediment baffles hold natural substrate inside tunnels with water flow. Photo credit: B. Steinberg (left) and A. Mui (right).

a)

b)

Photo 16. Wildlife tunnels should never be a) fully submerged as amphibians and reptiles require access to surface oxygen or b) have strong currents (e.g., due to an undersized culvert). Photo credit: Barb Beasley.

Arch or Round Tunnels	
Description • Made of concrete, corrugated steel, aluminum, or plastic. • Arch tunnels have open bottoms and are recommended for tunnel widths greater than or equal to 1.5 m in diameter (common widths: 1.8 m, 2.4 m, and 3.0 m) (Photo 20). • It is also possible to make the shape of an arched tunnel by compressing a round pipe. • The maximum recommended tunnel length is 25 m because amphibians and reptiles are reluctant to use longer structures. • Recommended sizes for arch tunnels are slightly larger than those for box tunnels to compensate for the loss of openness due to tunnel shape.	
Open-top	• Slotted open-top or vertical skylight risers along the length of the tunnel are used to provide natural light (e.g., Photos 21 and 22).
Open-bottom	• Achieved by using an arch tunnel, or by placing sufficient natural substrates into the bottom of round tunnels to increase the floor width (at least 2 m in diameter).

<table>
<tr><th colspan="2">Arch or Round Tunnels</th></tr>
<tr><td colspan="2">Advantages
Round tunnels work well in aquatic conditions for turtles and semi-aquatic snakes.
Increasing the width of the tunnel allows terrestrial corridors to be retained alongside the stream or creek bed.</td></tr>
<tr><td colspan="2">Disadvantages
Provide less cross-sectional area or openness than box tunnels of the same width, so interior space is relatively small and dark and potentially cold.
Require higher road cover so need to be set lower in the roadbed.
Rounded vertical walls are not as easy for animals to follow continuously from straight-walled fencing.</td></tr>
<tr><td>Application</td><td>Arch structure may be preassembled and dropped in place or assembled at the site.
Corrugated steel arch or concrete side slabs are placed on footings.</td></tr>
<tr><td>Engineering considerations</td><td>Footings are required for arch tunnels.
In terrestrial conditions, round tunnels should be filled with local soil and debris to create a level crossing surface for amphibians and reptiles. The recommended tunnel substrate depth depends on tunnel diameter—0.1 to 0.2 m can be adequate as long as it raises the height of the bottom to a level that will not be flooded (Photo 23). The minimum diameter of a round tunnel is 1 m to compensate for the internal height lost with the addition of substrate material (Photo 24).
Buried tunnels may be more suitable when tall footings are required.</td></tr>
<tr><td>Maintenance considerations</td><td>Natural substrate and cover objects should be maintained.
Larger structures allow for better accessibility during maintenance, and have relatively minor cost relative to narrower structures.</td></tr>
</table>

Examples of Applications of Arch/Round Tunnels

Photo 17. Round concrete tunnel partially filled with material so that the entrance is even with ground level, Laburnum Road in Qualicum. Photo credit: Barb Beasley.

Photo 18. Water diverted down slope away from tunnel entrance at Highway 99 near Pinecrest, although too little water may make tunnels too dry for amphibians. Photo credit: Barb Beasley.

Photo 19. Arched tunnel with natural stream crossing. Photo credit: Sean Wong.

Photo 20. Aluminum arch culvert on metal footings. Photo credit: K. Williams.

 Photo 21. Pipe culvert with slotted top installed for Timber Rattlesnakes in Illinois, U.S. Photo credit: S. Ballard.	 Photo 22. Zoom-in of open-top pipe culvert installed at road for Timber Rattlesnakes in Illinois, U.S. Photo credit: S. Ballard.
 Photo 23. Round concrete tunnel with raised concrete strip and dirt to provide a bench for amphibians to use as water levels rise at Laburnum Road, Qualicum. Photo credit: Barb Beasley.	 Photo 24. Very large corrugated metal culvert crossing Sea to Sky Highway at Pinecrest. Photo credit: Elke Wind.

4.2.2.3 Location of tunnels, number and spacing

The following considerations will assist with the selection of sites to determine the optimal placement and number of crossing structures:

Location

In general, crossing structures should be placed where the road bisects habitat used by the target species (e.g., aquatic features and wetlands), where the road is between important, adjacent seasonal habitats used by a species (e.g., aquatic breeding habitat and upland overwintering habitat), and where the road bisects a movement corridor (e.g., natural linear pathway, such as a riparian area, hedgerow, or gully). Tunnels and fencing are best located where movement paths cross existing and proposed roads, as determined from field surveys and/or spatial analyses (see examples in Persello et al. 2011; Gunson et al. 2012; Beasley 2013; Grods and Garner 2018; Neilson 2018). Field surveys conducted over at least one year are likely needed to account for different species and seasonal differences in movements. Examples of predictable movements include annual spring migrations of adult amphibians between upland forests and breeding ponds (e.g., Wind 2014), snake migrations to and from overwintering hibernacula (e.g., Fortney et al. 2013; Winton 2017), and female turtle terrestrial nesting migrations and inter-wetland movements (e.g., Evelyn 2018). Road mortality hotspots, or areas where the highest number of animals are killed, are often used to guide the placement of crossings (which reinforces the need for comprehensive pre-construction wildlife surveys). For rare or long-lived species with low reproductive rates, any location with a roadkilled individual may be a site that requires long-term mitigation because even small numbers killed on the road each year may be unsustainable.

> In cases where past road mortality has reduced populations, road kill numbers may be low, even at sites with high traffic volume.
>
> **Priority should still be given to high-traffic locations where habitats are near or straddling the road.** These sites are particularly important for recovering depressed populations (Eberhardt et al. (2013).

Exact locations for crossing structures depend on the terrain at the specific site:

- Crossing structures should be integrated with the natural landscape. Gullies and ravines are often used as movement corridors, and are ideal positions for placing crossings under roads if there is sufficient elevational relief for installing a structure of appropriate height.
- Vertical alignment and location should be based on water level. For example, terrestrial tunnels should be placed in the roadbed just above the high-water mark defined by the maximum water level in the ditch during stormy periods.
- Hydraulic and engineering information should be used to predict the amount of water that will flow through the tunnel at its proposed location during migration and dispersal seasons. This can then be used to decide whether the proposed location is appropriate for the target species. Refer to taxonomic-specific recommendations for aquatic and terrestrial crossing types in Section 4.2.5, in addition to site-specific conditions measured in the field.
- Modify existing or planned human-made features (e.g., ditches, retaining walls) that can act as barriers to amphibians and reptiles that move along the right-of-way (parallel to) or toward (perpendicular to) roads so that they do not block animals from accessing crossing structures (Gartner Lee and Ecoplans 2009).

Number and spacing

The number of crossing structures and spacing between them will depend on the length of the section of road that animals interact with (preferably measured with road encounter data; see Section 7.2.1) and the distances that individuals of the species are willing to move along guiding fences to where they will encounter crossings. For example, Long-toed Salamanders moved an average of 29 m along fences monitored in Waterton Lakes National Park (Pagnucco et al. 2012). On this basis, Schmidt and Zumbach (2008) recommend that tunnels for amphibians be spaced no more than 50 m apart along the core road encounter length, but this distance will vary by species. In B.C., distances of up to 250 m between tunnels have been used for some snake species in some areas, although the ideal distance may be no more than 150 m apart within high road-encounter zones (M. Sarell, pers. comm.).

- Appendices 3 and 4 provide a general summary of movement distances, home range areas, and habitat used by each species, but more detailed species- and site-specific information gathered at mitigation locations should be used to inform the number and spacing of tunnels.
- When roads bisect large expanses of continuous habitat (e.g., forest), several small, evenly distributed crossing structures will increase connectivity more than a single, large crossing structure (Karlson et al. 2017).

The young of some species (e.g., Western Toads) and species in some locations in B.C. (e.g., dry interior habitats) may move en masse to or from important habitats (e.g., during infrequent rain events). On the coast, amphibians and reptiles typically move away from breeding sites or hibernacula individually and randomly in space and time to access resources in ways that reduce competition and predation (e.g., Figure 6). In this latter scenario, providing several crossing structures instead of a single structure will better maintain natural distribution patterns.

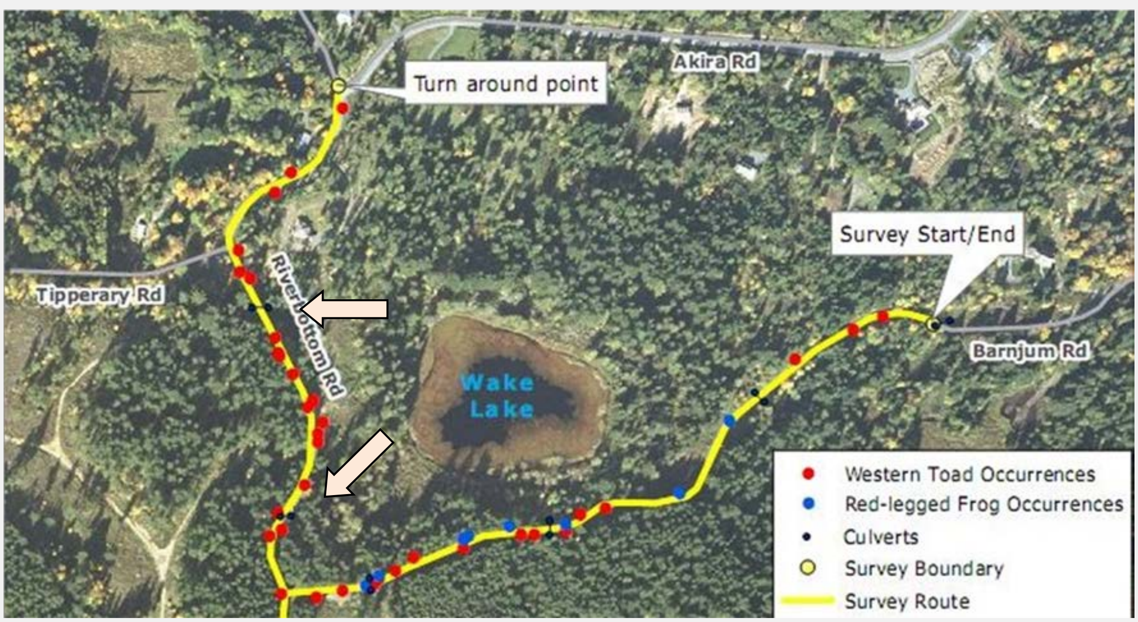


Figure 6. Road crossing locations of adult Red-Legged Frogs (blue dots) and Western Toads (red dots) in spring, adjacent to a breeding site on Vancouver Island. Adult movements were more random and widely dispersed than the relatively narrow corridors used by dispersing Western Toad juveniles (pink arrows) in summer after emergence from the breeding site (Source: Wind 2012).

4.2.2.4 Retrofitting existing drainage culverts

Some species of amphibians and reptiles use culverts that have historically conveyed water under roads (e.g., Caverhill et al. 2011). Road improvement and rehabilitation projects provide opportunities for retrofitting or enhancing existing drainage culverts to facilitate use by these animals. In some cases, existing drainage culverts may already be located and designed correctly for use by the target species and may require only guide fencing to facilitate crossing and reduce road mortality (Caverhill et al. 2011; Beasley 2012) (see Section 4.2.4 and Photo 25). Existing culverts need to be carefully evaluated for their potential as passages for the intended species before directional fencing is installed. If culverts become frequently inundated with water, some amphibians and reptiles may not be able to swim through them. Retrofitting water-carrying culverts with shelves (benches) attached to the inside of the walls, above the high-water line, can make them viable passageways (Photo 26).

Photo 25. Existing culvert retrofitted with temporary directive fencing. Photo credit: Elke Wind.

Photo 26. Existing culvert retrofitted with entryway ramp and inner shelf/bench. Photo credit: K. Foresman.

4.2.3 Wildlife overpasses

Overpasses are designed primarily for larger animals, such as large carnivores and ungulates, but they can serve as both passageways and intermediate habitats for amphibians and reptiles (Jackson and Griffin 2000; van der Grift et al. 2009) (Photo 27). Wildlife overpasses are sometimes referred to as "green bridges" because they are typically planted with vegetation to form a continuation of the natural landscape. Modifications for amphibians and reptiles include cover objects and ponds for hydration (e.g., in the Netherlands: van der Grift et al. 2009) (see Photo 28).

<table>
<tr><th colspan="2">Wildlife Overpasses</th></tr>
<tr><td colspan="2">Description
Large, multi-species crossing structures that are not usually prefabricated or precast.
Integrated as a multi-species strategy for both large and small animals.
Design includes a bridge deck that spans the road (Photo 29).
Require a natural landscape planting and drainage system on top of the structure.
The slope of approach ramps should be minimized for greatest visibility.
Overpass width varies from 20 m to > 70 m.</td></tr>
<tr><td colspan="2">Advantages
Less confining and relatively quiet compared to underpasses.
Maintain natural/ambient conditions of precipitation, air temperature, and light.
Serve as passageways for large and small wildlife (Glista et al. 2009).</td></tr>
<tr><td colspan="2">Disadvantages
Relatively expensive.</td></tr>
<tr><td>Application</td><td>Large structures offer a greater opportunity to provide cover objects, such as flat rocks, rock piles, or vegetated mounds composed of branches and logs, covered with sod (Photo 30).
Design enhancements for amphibians and semi-aquatic reptiles include small ponds as "stepping-stones" along the length of the structure. Natural or artificial substrate may be used to retain pond water or rainfall (van der Grift et al. 2009).
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 in Ontario has incorporated 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 fencing along the Highway 69 overpass in Ontario combines ¼" mesh with a 2.4-m high large animal mesh fence (Photo 31).</td></tr>
<tr><td>Engineering considerations</td><td>Overpass decks can integrate natural footings, such as rock cliffs (Photo 32).</td></tr>
<tr><td>Maintenance considerations</td><td>Maintenance checks for the initial establishment of vegetation on overpass structures are required.
Irrigation for pools and vegetation may be required.</td></tr>
</table>

Examples of Wildlife Overpasses

Photo 27. Wildlife overpass Groene Woud across motorway A2 in The Netherlands. Photo credit: E. van der Grift.

Photo 28. Wetland zone on wildlife overpass Groene Woud, consisting of a series of small ponds on loamy soils supplied by water pumped up to the top of the overpass. Photo credit: Rijkswaterstaat.

Photo 29. A 30 m-wide overpass installed near Sudbury on Highway 69 in Ontario. Photo credit: K. Gunson.

Photo 30. Brush piles on top of an overpass on Highway 69 in Ontario. Photo credit: K. Gunson.

Photo 31. Multi-species fencing guiding animals to overpass. Photo credit: K. Gunson.

Photo 32. Rock cliff footings on overpass on Highway 69. Photo credit: K. Gunson.

4.2.4 Fencing for reptile and amphibian crossings

Crossing structures are not likely to be used by amphibians and reptiles unless they incorporate fencing (Cunnington et al. 2014; Rytwinski et al. 2016). However, careful consideration must be given to the potential detrimental impacts of fencing on non-target species and the ecosystem (see Section 4.3). If the potential benefits to the target species outweigh the negative impacts for non-target species, then fences can be installed. The use of fencing should be limited primarily to mortality hotspots and sites between key habitats. Fence lengths will depend, in part, on the species, terrain, and number and spacing of crossing structures. Care must be taken to avoid leaving fencing and crossing structure gaps at amphibian and reptile movement hotspots because the gaps may have the adverse effect of funnelling animals onto the road (e.g., Baxter-Gilbert et al. 2015). It is important to provide a way over the fence for animals caught on the road side of the fence, where they would be exposed to traffic and experience greater risk of heat exposure and desiccation (Boyle et al. 2019).

Fencing serves two purposes: (1) directing animals toward structure entrances, and (2) providing a barrier to exclude animals from the road (e.g., Wilson and Topham 2009). Fencing can be used with crossing structures or as a stand-alone measure to prevent mortality along roads where connectivity is not a concern (e.g., 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 recommendations are divided into fencing design, placement, and maintenance considerations, and are generally applicable to all amphibians and reptiles. Species-specific details are provided in Section 4.3.5.

4.2.4.1 Fence design

These recommendations focus on designing and installing high-quality, gap-free fencing, which may have higher initial costs but will be less expensive in the long run compared to the ongoing maintenance required for lower-quality fencing. A number of projects have experimented with fencing effectiveness for amphibians and reptiles (e.g., B. Beasley, unpubl. data; Langen 2011; Smith and Noss 2011; Crosby 2014; Dulisse et al. 2017), and new, cost-effective designs are continually being engineered and tested.

Fencing should have a solid, durable framework (stakes, posts, and sheeting) to provide an effective barrier for the target species and to withstand the weight of snow and impact of snow removal. General considerations for fence design are as follows (see Figure 7 for further illustration):

- Posts
    - Steel posts will not break under snow loads.
    - Posts that are closer together (e.g., spaced 2–3 m apart) will prevent both fence sag and collapse during severe weather events and snow removal.
    - Stakes or posts should be placed along the road-facing side of the fence to deter climbing and should be buried at least 30 cm into the ground.
- Materials
    - The choice between recommended fencing materials listed in Table 2 depends on the target species.
    - Use materials that allow drainage through or beneath the fence at wet sites to avoid water pooling at or near a crossing structure (Smith and Noss 2011) (Photo 33).
    - Use opaque fence materials, especially where snakes or turtles occur.
        - Recent studies on the effects of hardware cloth fences on snakes (Eye et al. 2018) and chain link fencing on tortoises (Peaden et al. 2017) have shown that

these animals will repeatedly attempt to get through the fence if they can see the other side, which causes injury or death (Photo 34). In contrast, turtles were found to move more quickly along fences that were opaque (Yorks et al. 2011).

  - Fence material should not be flammable in areas that experience frequent wildfires.
  - Mesh should not be used as fencing material. Several species of amphibians can climb plastic ¼" mesh fences (B. Beasley, unpubl. data), and some small snakes can pass through or get stuck in ¼" mesh (Smith and Noss 2011; S. Marks, pers. comm.).
- Fence depth and height
  - The fence should be buried to a minimum depth of 10 cm, and have a fold 10–20 cm wide to create a lip that is directed away from the road (Figure 7). This is to deter animals from digging under the fence and to reduce the risk of the fence material being pulled out of the ground when bumped.
  - If fences could be inundated by spring runoff, their height should be at least 0.5 m higher than the high-water level in spring to prevent animals from jumping or climbing over the fence.
  - When more than one species is targeted for mitigation, fence height should be the tallest height recommended for all target species (Table 3). The use of an overhanging lip along the top of the fence can allow the fence to be shorter (see next point).
  - The fence should include an overhanging lip along the top (Figure 7). It should extend 6 cm outward, away from the road (horizontally), and then 4 cm downward (vertically).
- Additional requirements:
  - Fencing must connect to tunnel entrances smoothly and without gaps. There should be no rip rap or stepped ground that would deter or impede animals moving along the fence from entering the tunnel.
  - Escape routes are required for animals caught on the road side of the fence. They can be created in several ways:
    - On sloped right-of-ways, construct the top of the fencing at or below road level (Photo 35)
    - Backfill the road side of the fence with dirt to the height of the fence; e.g., ACO Systems Ltd. makes a curved fence product that is backfilled with dirt. It allows animals to cross over the backside of the fence along its entire length (Photo 36).
    - Install ramps every 3–5 m on the road side of the fence. Ramps should have a maximum slope of 1:1; they can be created in the shape of a half cone that tapers smoothly from a semi-circle on the ground to the apex at the top of the fence (Photo 37); adding fine plastic mesh or sticky fabric makes it relatively easy for animals to climb up the ramp.
  - Fence ends should be curved or installed in a 90° "U" design to direct amphibians and reptiles away from the road (Figure 8). This curved section should be a minimum of 200 cm long, though longer is better (D. Seburn, pers. comm.).

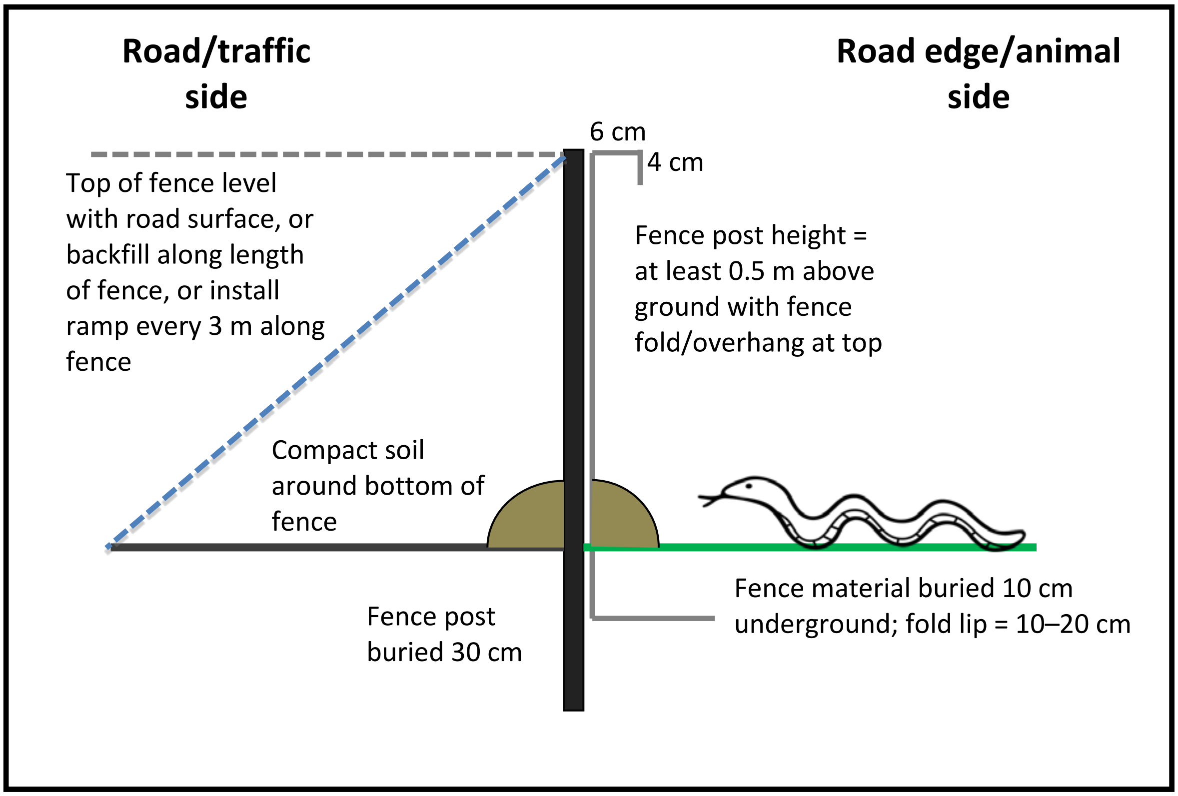


Figure 7. Design of fencing to exclude amphibians from roadways and/or guide them toward tunnels.

Table 2. Fence material options and considerations. See Section 4.2.5 for species group recommendations.

Material	Use	Recommended?
Rigid plastic mesh (1/4")	Durable fence material that allows drainage	No. Amphibians and reptiles can climb it. Use only if drainage is required. Never use for turtles or snakes (Photo 38)
Hardware cloth	Temporary fence material that allows drainage	No. It rusts after a few years, and is climbable. Never use for turtles or snakes (Photo 39)
Chain link fencing	Standard chain link used for large animals (e.g., 2.5-m high wildlife exclusion fencing with 4" mesh); does not work for many amphibians and reptiles because individuals can pass through the large mesh holes and get entangled (e.g., turtles; M. Sarell, pers. obs.).	Only if additional fencing material, such as heavy-duty plastic fencing, is attached at the base for amphibians and reptiles (Photo 40)
UV-treated hard plastic HDPE, straight-sided	Durable fence material	Yes, except not where wildfires are common; i.e., areas in the Interior where fires are expected at ≤ 10-year intervals (Photo 41)

Material	Use	Recommended?
UV-treated hard plastic HDPE, curved	Durable fence material	Yes, except not where wildfires are common, i.e., areas in the Interior where fires are expected at ≤10-year intervals (Photo 42)
Metal (e.g., sheeting)	Durable fence material that will not melt in fire	Yes, if installing on relatively flat terrain (Photo 43)
Wood	Durable fence material	Yes, except not where wildfires are common; i.e., areas in the Interior where fires are expected at ≤ 10-year intervals (Photo 44)
Concrete	Durable fence material	Yes, if installing on relatively flat terrain (Photo 45)
Heavy duty UV-resistant polypropylene fabric attached to wood posts and rails	Durable fence material easy to install over undulating terrain	Yes, except not where wildfires are common; i.e., areas in the Interior where fires are expected at ≤ 10-year intervals (Photo 46)
Light duty geotextile	Temporary fence material (lifespan up to 1 year)	Not for long-term use
Heavy duty geotextile fence	Temporary fence material (2–3 years)	Not for long-term use
Wood lath snow fencing	Temporary fence material (< 3 years)	Not for long-term use
Nylon mesh fencing or erosion materials	Should not be used because snakes and other species can become entangled and die in this material	No

Photo 33. Temporary fencing used along Highway 4 near Ucluelet included mesh fencing to allow for drainage and a slippery plastic cover (not buried) to impede climbing by amphibians. Photo credit: Barb Beasley.

Photo 34. Garter snake attempting to get through hardware cloth fence, Highway 99 at Pinecrest. Photo credit: Barb Beasley.

Photo 35. Rigid plastic fencing installed below road level along Highway 4, Vancouver Island. Photo credit: Barb Beasley.

Photo 36. Curved backside of ACO fencing allows animals to climb over along its entire length at Highway 97 Osoyoos (left) and Highway 6 near Summit Lake (right). Photo credit: Barb Beasley.

Photo 37. Mesh ramp on back/road side of exclusion fencing along Highway 4 near Ucluelet allows amphibians and other small animals caught on the road to escape. Photo credit: Barb Beasley.

Photo 38. Frog climbing ¼" plastic mesh fencing. Photo credit: Barb Beasley.

Photo 39. Hardware cloth torn off fence post 3 years after installation on Highway 99 at Pinecrest (left) and ungulate fencing on Highway 19 near Courtenay (right). Photo credit: Barb Beasley.

Photo 40. Amphibian and reptile fencing attached to the bottom of large animal chain link fencing. Photo credit: Elke Wind.

Photo 41. Animex UV-resistant HDPE straight-sided plastic with a scored top that can be bent over to form a top lip, Long Point Causeway, Ontario. Photo credit: Barb Beasley.

Photo 42. Waterton Lakes National Park's curved plastic fencing (sections of pipe) melted down after the 2017 fire. Photo credit: Kim Pearson, Parks Canada.

Photo 43. Metal curb sheeting used to replace plastic fence after it melted in the 2017 fire at Waterton Lakes National Park. Photo credit: Kim Pearson, Parks Canada.

Photo 44. Wooden fencing installed at Kentucky-Alleyne Provincial Park to keep Western Toads off road. Photo credit: Kristiina Ovaska

Photo 45. Concrete fencing guiding amphibians to tunnel under Highway 6, Summit Lake. Photo credit: Barb Beasley.

Photo 46. UV-resistant polypropylene fabric (pool cover fabric) installed with plastic wood posts and cedar rails over uneven terrain at Highway 4 near Ucluelet. Photo credit: Barb Beasley.

Table 3. Recommended above-ground heights and below-ground depths for fencing for each species group

Species Group	Recommended depth of buried fence, excluding bottom lip (10–20 cm; see Figure 6)	Recommended height of fence, excluding top lip (6 cm + 4 cm; see Figure 6)
Turtles	10–20 cm	60 cm
Frogs and toads	10–20 cm	50 cm
Snakes	10–20 cm	100 cm
Lizards	10–20 cm	Unknown
Salamanders	10–20 cm	30 cm

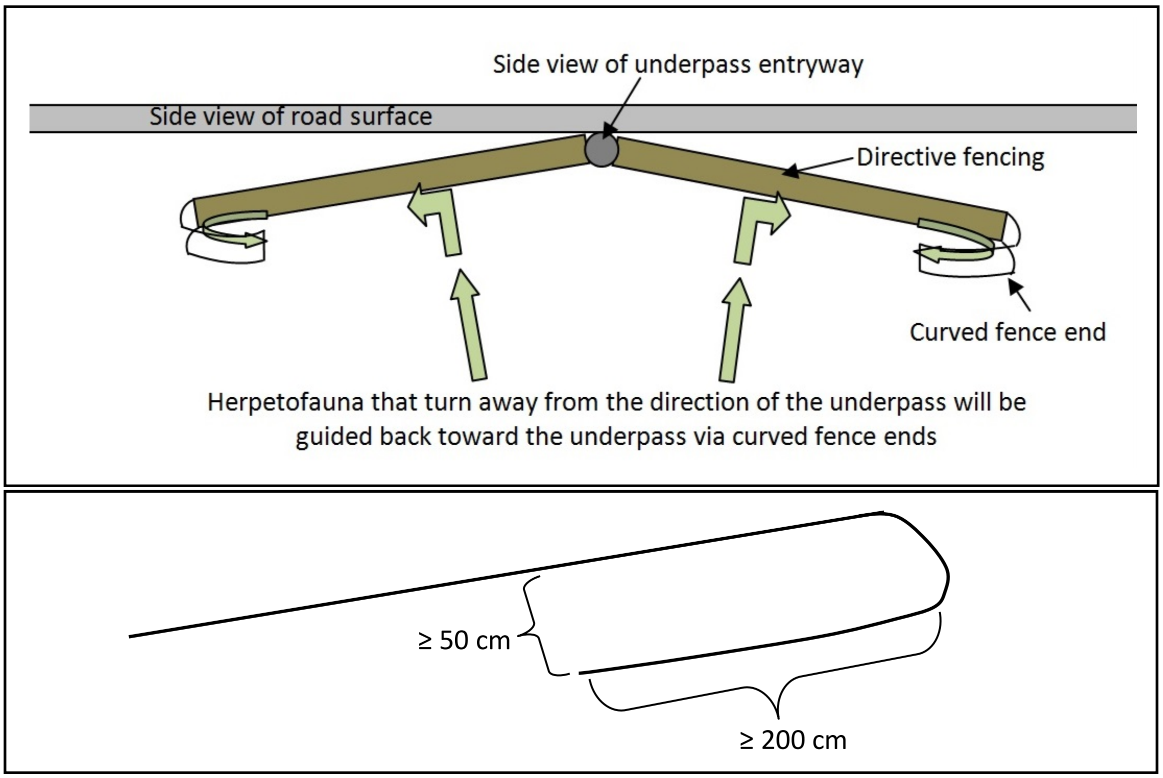


Figure 8. Fence ends should curve back, by a minimum of 200 cm, toward the shoulder side of the road to deter animals that are moving along the fence from continuing onto the road and, ideally, redirect them back toward the crossing structure. See Photo 51.

4.2.4.2 Fence length and placement

Fence length depends on the species' movement abilities and the interface of the surrounding habitat with the road. Spatial analyses of where species are found 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 habitat, fencing is often required along the entire stretch of road to prevent mortality. The following should be considered when evaluating fence and crossing structure placement:

- Data collected from inventory work, road surveys, expert opinion, and other sources should be used to understand species presence, habitat use, and movements in relation to the road (see Appendices 1–4).
- The target species maximum movement distances along fences should be used to inform fencing length. For example, salamanders generally will not move more than 50 m along fences (Schmidt and Zumbach 2008), whereas frogs, turtles, and snakes may move much farther (see Appendix 4). Some species will move considerable distances along the fence and access the road at the fence ends; this can be avoided only if the fence is longer than the distances the species moves, or if the fencing is extended back away from the road at each end (see Figure 8).
- Solid rock areas should be avoided when possible. If rocky areas cannot be avoided, dirt or mortar can be used to hold the fence in place and infill irregularities in the rock surface to create a seal (Photo 47).
- Wherever possible, the fence should direct wildlife, without impediment, toward the crossings.
- To be effective in guiding animals, fencing must connect to the tunnel entrances smoothly and without gaps (e.g., Photo 48).
- Connections should follow a “V” pattern (Figure 9a) or span between multiple crossing structures in a “W” pattern (Figure 9b) to funnel animals. Many factors, such as land ownership, terrain, limitations of the fencing material, road maintenance requirements, ditch drainage, must be included in the design. Where wildlife fencing is constrained by road right-of-ways and existing fencing, a “W” pattern may not be possible; in these cases, “V” patterns should be used near the crossings to funnel animals.
- Effective fencing requires regular, planned maintenance (see Sections 6.4 and 7.2).

To be effective, fences need to be the correct:
- ✓ Length
- ✓ Orientation
- ✓ Height
- ✓ Material

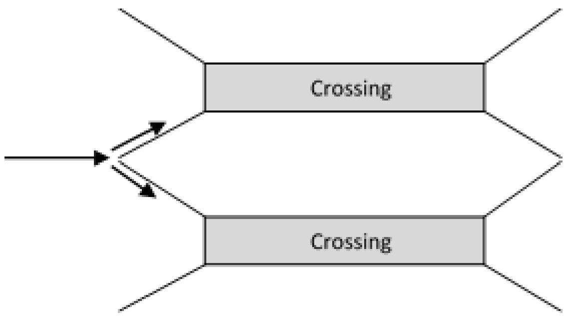
And they need to be:
- ✓ Buried
- ✓ Monitored/maintained

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 roadside maintenance practices.
- Fencing must not interfere with road interchanges or driveway access.
- Fencing must not interfere with ditch drainage or any watercourse flows that intersect the road.
- Permissions and permits must be obtained from the road authority.
- When the fence extends beyond the right-of-way, permission must be obtained from property owners.

Photo 47. Snake outcrop along a road. Dirt, gravel, or mortar can be used to help keep fencing in place along rocky areas such as this. Photo credit: Purnima Govindarajulu.

Photo 48. Pressure treated plywood was used to make a semi-permanent and low cost fitting for round and oval culverts to provide a firm and gapless attachment structure for direct fencing in a dry environment. Photo credit: Mike Sarell.

a. "V" formation of fencing is used to guide amphibians and reptiles toward a crossing structure.



b. "W" formation of fencing is used to guide amphibians and reptiles toward multiple crossing structures.

Figure 9. Fencing placement in relation to crossing entryways. Fencing should be continuous between multiple, adjacent crossing structures to increase the "capture" area of migrating individuals.

4.2.4.3 Fence maintenance

All fencing should undergo routine checks and maintenance, which should be planned and budgeted for (see Section 7.2). The frequency of maintenance checks and repairs will vary with the durability of the fence and the rate of vegetation growth, mammal activity, accidents, and vandalism. After snowmelt, a thorough survey of the fence and immediate repairs are essential before amphibians and reptiles emerge from hibernation. The following are recommended considerations for fence maintenance:

- Regular maintenance is required to clear vegetation and debris along a 1-m wide swath adjacent to the fence on both sides. Woody vegetation, leaves, thick grasses, and other debris that pile up along the fence may provide a "ladder" or may puncture the fence, which would allow animals to access the road. Clearing of vegetation and debris also helps reduce fuel loads and protect flammable fencing materials.
- Fences should be marked with tall posts and flagging tape to alert maintenance crews to their presence, especially where mowing and snow removal will occur.
- Routine fence surveys should be conducted using a checklist to identify where repairs are required, including the location and description of any damage (see Section 7.2). The checklist should include monitoring for carcasses along the fence and on the road during the active season (Table 1) to ensure that the fence materials and design are effective (not allowing animals onto the road) and not negatively affecting any local amphibian and reptile species (e.g., entangled snakes).
- Repair crews need to fix the fence in a timely manner (e.g., before and during the active season) to minimize fence breaches by amphibians and reptiles.

- Amphibian and/or reptile carcasses on the fence or adjacent road may indicate a failure in fence design, and signal a need for immediate fence repairs, modification, or replacement. If the fence has a gap, the crew should repair it immediately and search for amphibians caught on the road, but if there are no apparent gaps, the crew should consult a regional biologist. Mortality along fences may result from prolonged heat exposure (Boyle et al. 2019).

4.2.5 Recommendations by species group

In addition to the general design considerations for reptiles and amphibians outlined above, the following are specific recommendations that are unique to each group. The following recommendations are based on species that have been observed using tunnels. It is unknown how effective the specifications below are for under-studied reptile and amphibian species, or for overpasses, in B.C. This underscores the importance of conducting effectiveness monitoring for mitigation projects (Section 7).

In general, tunnel design recommendations are made based on the assumption that as tunnels get longer, an increase in width is more important than an increase in height in order to maintain suitable climatic conditions (see Box 1).

SPECIFICATIONS FOR TURTLES				
Type of structure and minimum size based on tunnel length				
Tunnel length	**Box tunnel (w x h)**	**Arch tunnel (w x h)**	**Round tunnel (diameter)**	**Other structure recommended**
15 m	1.5 m × 1.0 m	1.8 m × 0.9 m	1.5 m	
15–25 m	1.8 m × 1.0 m	2.0 m × 1.0 m	1.8 m	
> 25 m	Not recommended	Not recommended	Not recommended	Bridge/elevated road/overpass
Additional Design Considerations				

- Terrestrial and aquatic structures are suitable for most turtle species.
- Open- and closed-top tunnels have been used by turtles; however, crossing success may be greater through open-top tunnels because they provide more light.
- Installing shiny aluminum flashing at the end of tunnels may increase crossing success by reflecting more light into the tunnel (Wisconsin Public Radio 2019).
- Rip-rap should not be installed at entranceways, along footings, or leading into the crossing structure.
- Concrete fabric can allow turtles to climb into or out of culverts surrounded by steep hills.
- A minimum of 150 m (Appendix 4) of fencing (60 cm high, buried 10–20 cm into the ground) (Table 3) on either side of the crossing structure is recommended to funnel turtles to entranceways and keep them off the road/highway.
- Fencing should be opaque.
- Substrate type in terrestrial tunnels for turtles may not be as important as for other reptiles and amphibians.

Rationale
Western Painted Turtles in B.C. have been documented using culverts. For example, after a couple of years and several design modifications, turtles were observed going through a large culvert installed under Highway 97 where the road was expanded to four lanes, south of Williams Lake (Bings and Steciw 2018). Several studies have demonstrated relatively high use of large (> 1.5 m width) crossing structures by species of turtles outside of B.C.: o The Port of Portland Authority built turtle culverts for Western Painted Turtles, which, although not scientifically studied, appear to work (Kintsch and Cramer 2011). o In Ontario, a drainage culvert 1.8 m in diameter that was approximately half-full of water (Caverhill et al. 2011) was used regularly by Blanding's Turtles and was also used by Snapping Turtles. o In Massachusetts, multiple Spotted Turtles were confirmed to cross through a tunnel 1.8 m × 1.8 m (Kaye et al. 2005). o Aresco (2005) documented more than 200 turtle crossings (mostly Yellow-bellied Sliders and Florida Cooters) through a 3.5-m diameter drainage culvert in Florida. o Wood Turtles continued to use a stream that passed through a culvert that was 3 m in diameter and 26 m long in Vermont (Parren 2013). Caverhill et al. (2011) found that turtles will cross through tunnels 25 m long, although crossing success may be lower as length increases (Yorks et al. 2011). 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 have used closed-top tunnels (e.g., Dodd et al. 2004; Aresco 2005; Kaye et al. 2005; Caverhill et al. 2011), and Wood Turtles and Snapping Turtles (Whitelock 2014) have crossed through open-top tunnels in Ontario (Photos 49). Blanding's and Spotted Turtles have been documented crossing 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 49. Turtle crossing through a terrestrial tunnel. Photo credit: Jade Spruyt.

SPECIFICATIONS FOR SNAKES AND LIZARDS

Type of structure and minimum size based on tunnel length

Tunnel length	Box tunnel (w × h)	Arch tunnel (w × h)	Round tunnel (diameter)	Other structure recommended
15 m	1.0 m × 1.0 m	1.5 m × 0.75 m	1.0 m	
15–25 m	1.5 m × 1.0 m	1.8 m × 0.90 m	1.5 m	
> 25 m	Not recommended	Not recommended	Not recommended	Bridge/elevated road/overpass

Additional Design Considerations

- Open- and closed-top tunnels have been used by snakes. Some snake species may have greater crossing success through open-top tunnels, while others may access road surfaces through the open top of the tunnel (Photo 50).
- Depending on the tunnel material and shape, lizards may be able to access the road surface through open-top tunnels.
- Aquatic tunnels are not recommended for some B.C. snakes and all B.C. lizards. Existing culverts with intermittent flows are likely to be used by snakes and should be considered during project design.
- Rip-rap should not be installed at crossing entranceways in order to facilitate movement.
- A minimum of 250 m of fencing (1 m high, buried 15–25 cm into the ground) (Table 3) is required on either side of the tunnel, bridge or overpass (Appendix 4) to funnel snakes to entranceways and keep them off the road/highway.
- The fence should be at least 63 cm high, and the top edge of the fence should be strengthened with wire or top rails to prevent tearing (Photo 51) unless fence material is rigid and does not expand or contract with heat.
- Ramps or escape funnels can be used to allow snakes to move off the road side of the fence. Escape funnels can be made by rolling fence material into an open-ended cone. The edge is flared at the wider end to form a flange that can be secured to the fence. A hole can be cut in the fence to fit the flange where it joins. The bottom of the funnel should be elevated to allow animals to pass underneath as they travel along the outside of the fence. Short sections of fencing should be installed to divert snakes into the funnel as they travel along the fence line.
- Appropriate fence height and length are unknown for lizards.
- Fences should be opaque, and the tops and bottoms should be folded over as per Figure 7.

Rationale

Note: At the time of writing, few B.C.-specific data were available. These recommendations are adapted from the *Best Management Practices for Mitigating the Effects of Roads on Amphibian and Reptile Species at Risk in Ontario* (2016) and other publications and reports from outside the province. Modifications are expected as new projects in B.C. are monitored.

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) have used a variety of crossing structures under roads. However, compared to other taxa, there is less certainty about crossing structure design preferences for these species.

Snakes have crossed through tunnels as small as 0.25 m in diameter (Roberts 2010), but in an experiment by Eads (2013), Eastern Gartersnake and Eastern Ribbonsnake had greater crossing success through tunnels that were 1.0 m in diameter than through smaller tunnels.

Both closed-top (Taylor and Goldingay 2003; Laidig and Golden 2004; Roberts 2010; Eads 2013) and open-top (Pagnucco et al. 2011; Colley et al. 2017) crossing structures have been used by snakes.

Wandering Garter Snakes in Waterton Lakes National Park, Alberta moved through open-top tunnels manufactured by ACO Systems Ltd. that had interior dimensions that were 0.50 m wide × 0.33 m high (Pagnucco et al. 2011).

Open-bottom box tunnels with cross-sectional dimensions of 1.0 × 1.0 m were used by 11 Massasaugas and two Eastern Foxsnakes in Killbear Provincial Park, Ontario in 2014 (Colley et al. 2017).

Timber Rattlesnakes have crossed through concrete-bottom structures (Laidig and Golden 2004), but natural substrate or habitat conditions may enhance use (Laidig and Golden 2004).

Photo 50. Snake in terrestrial tunnel captured using wildlife camera mounted inside the tunnel mouth. Photo credit: Jade Spruyt.

Photo 51 Snake fencing in the Okanagan with curved ends to guide snakes back toward the tunnel entryway. Photo credit: Jade Spruyt.

SPECIFICATIONS FOR SALAMANDERS				
Type of structure and minimum size based on tunnel length				
Tunnel length	**Box tunnel (w × h)**	**Arch tunnel (w × h)**	**Round tunnel (diameter)**	**Other structure recommended**
15 m	1.8 m × 0.5 m	1.5 m × 0.75 m	0.6 m	
15–25 m	1.5 m × 1.0 m	1.8 m × 0.90 m	1.5 m	
> 25 m	Not recommended	Not recommended	Not recommended	Bridge/elevated road

Additional Design Considerations

- Salamanders prefer tunnels with high moisture content, and even small pools of standing water, 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 possibly have higher moisture levels, the latter being important in longer tunnels. The use of open-top tunnels may allow the dimensions to be smaller than those listed above.
- Open-top tunnels may allow higher levels of road salt and other pollutants into the tunnel; however, they may be washed away during storm events.
- Soils and leaf litter substrates should be used rather than larger gravel or stone substrates.
- Multiple tunnels should be used where migration paths to aquatic breeding sites cross roads. Tunnels for salamanders should not be more than 30 m apart (e.g., Pagnucco et al. 2012).
- Fencing must be buried at least 10 cm into the ground to prevent salamanders from burrowing beneath it, and the height should be at least 30 cm (Table 3).
- Fencing should have an overhanging lip to prevent salamanders from climbing over the fence (Figure 7).

Rationale

Northwestern Salamanders will swim through tunnels with slow-moving water (B. Beasley, unpubl. data) (Photo 52).

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) tunnels have been used by *Ambystoma* spp. (mole salamanders).

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).

In general, tunnels for amphibians are recommended to be at least 1 m × 1 m (Schmidt and Zumbach 2008). Some salamanders may pass through smaller tunnels (e.g., Long-toed and Barred Tiger Salamanders moved through open-top tunnels manufactured by ACO Systems Ltd. that had interior dimensions of 0.50 m × 0.33 m [Pagnucco et al. 2011], and *Ambystoma* sp. salamanders have crossed through round tunnels as small as 0.25 m in diameter and 0.2 m wide [Bain 2014]); however, salamanders demonstrate hesitancy about entering small tunnels (Jackson 1996), and the percentage of salamanders that successfully cross through may be low (e.g., Allaback and Laabs

2002; Pagnucco et al. 2012). Larger tunnels are required to ensure sufficient space for natural substrate and cover objects.

Salamanders will cross through tunnels with or without natural substrate, but Woltz et al. (2008) found that fewer individuals cross through bare concrete tunnels than tunnels with natural substrate. Furthermore, natural soil substrate will retain moisture longer, which lessens the risk of salamanders dehydrating or not entering structures.

Small Rough-skinned Newts and plethodontid salamanders (i.e., Western Red-backed Salamanders, Wandering Salamanders and Ensatina) are able to climb fences that do not have an overhanging lip (B. Beasley, unpublished data) (Photo 53).

Photo 52. Northwestern Salamander swimming against the flow in a retrofitted drainage culvert, Highway 4, Ucluelet. Photo credit: Barb Beasley

Photo 53. Juvenile Rough-skinned Newt climbing plastic fence. Photo credit: Barb Beasley.

SPECIFICATIONS FOR FROGS AND TOADS				
Type of structure and minimum size based on tunnel length				
Tunnel length	**Box tunnel (w × h)**	**Arch tunnel (w × h)**	**Round tunnel (diameter)**	**Other structure recommended**
15 m	1.8 m × 0.5 m	1.5 m × 0.75 m	0.6 m	
15–25 m	2.0 m × 0.5 m	1.8 m × 0.90 m	1.5 m	
> 25 m	Not recommended	Not recommended	Not recommended	Bridge/elevated road/overpass

Additional Design Considerations

- Frogs and toads prefer tunnels with high moisture content, or small pools of standing water, but the tunnel should not be flooded with water.
- Open- or closed-top tunnels may be used. Open-top tunnels will allow moisture into the tunnel and air flow through it, especially along long tunnels.
- Open-top tunnels may allow higher levels of road salt and other pollutants into the tunnel; however, they may be washed away during storm events.
- Soil and leaf litter substrates should be used versus larger gravel or stone substrates.
- Fencing should be at least 50 cm high to prevent ranid frogs from jumping over it, and should be buried 10–20 cm below ground to prevent frogs and toads from burrowing underneath it (Table 3). Juvenile Western Toads can be guided with very low fencing (25 cm high) as long as it is buried and has an overhang (Photo 54).

- Fencing should not be made of mesh because frogs and toads will attempt to climb it rather than follow it to tunnel entryways (B. Beasley, unpubl. data; P. Govindarajulu, pers. comm.) (Photo 55).
- Fencing should have an overhanging lip to prevent frogs and toads from climbing over it (Figure 7).

Rationale

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, moist soil are recommended for amphibians (e.g., Jackson 2003; Smith 2003; Schmidt and Zumbach 2008; Amphibian and Reptile Conservation 2009; Beasley 2013).

Northern Red-legged Frogs were reluctant to enter tunnels with dry soil (Malt 2012) but readily entered tunnels with moist substrates (Beasley 2013) (Photo 56).

Although toads have been documented using tunnels < 1.0 m wide (e.g., Lesbarrères et al. 2004; Pagnucco et al. 2012; 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) and are easier to maintain. Very high toad crossing rates have been documented at tunnels 1.8 m wide (Biolinx Environmental Research and Nicola Naturalist Society 2013, 2014). Newly metamorphosed toadlets, which disperse en masse, move more readily through tunnels—even narrower ones—than do adult toads (E. Wind, unpubl. data).

Guidelines for road crossing structures have been developed in England for the Common Toad (*Bufo bufo*). They recommend using a rectangular crossing structure at least 1.0 m × 0.75 m (w × h) for tunnels up to 20 m long, and 1.5 m × 1.0 m (w × h) for longer tunnels (Amphibian and Reptile Conservation 2009).

Both closed-top (Biolinx Environmental Research and Nicola Naturalist Society 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 toad species.

Photo 54. Young Western Toads guided 100 m to crossing structures using 10" PVC pipe cut lengthwise at Highway 31 A, Fish-Bear Lakes. Photo credit: Marcy Mahr.

Photo 55. Western Toad climbing 1/4" mesh fence. Photo credit: Purnima Govindarajulu.

Photo 56. Two Northern Red-legged Frogs (white arrows) moving through box tunnel installed on Highway 4 near Ucluelet. Photo credit: Barb Beasley.

4.3 Additional Planning and Design Mitigation Measures

Supplementary mitigation measures, such as installing signage or instituting reduced speed limits at fence ends, may be used with crossing structures and fencing to increase their effectiveness. In addition, supplementary measures may be used as temporary measures during construction, 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 monitoring and an adaptive management approach.

This section classifies measures as either those that influence driver behaviour or 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 elsewhere, with specific consideration of how each strategy may be applied to amphibians and reptiles.

4.3.1 Influencing driver behaviour

Temporary road closures are an effective mitigation tool where there is local support. Other strategies that may influence driver behaviour are presented below. They are appealing because they are often relatively inexpensive to implement. However, they rarely result in a significant reduction in road mortality, in part because many reptiles and amphibians are small and difficult to see or avoid. The success of these strategies is further limited by driver attitudes and behaviour; for example, Ashley et al. (2007) found that approximately 2.7% of drivers intentionally ran over reptiles on the Long Point Causeway in Lake Erie, Ontario.

The strategies outlined in this section have relatively low effectiveness when used in isolation, so several approaches should be used concurrently whenever possible. For example, a good strategy may include a temporary road closure, high-quality signage to warn drivers, and a public education program to help drivers understand the measures that have been put in place.

Seasonal road closures can reduce road mortality by eliminating vehicles from a road. Although this is a very effective mechanism, closures are typically feasible for only a few days or weeks per year (i.e., they may be dependent on providing alternative routes/detours for vehicles), and they must be timed precisely to coincide with amphibian and reptile migrations. Use of this method is particularly applicable at problem areas while more permanent measures are being considered or awaiting approval (see Case Study 1). 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 alternative access (i.e., a detour) exists. This type of strategy requires buy-in from both the road authority and the community that uses the roads. A public relations campaign is a useful tool for informing and gathering supporting from local residents. This strategy has a relatively low cost.

CASE STUDY 1 Road closure for the endangered Northern Leopard Frog

The Rocky Mountain population of Northern Leopard Frog (*Lithobates pipiens*) that occurs in B.C. is considered endangered and is genetically distinct from leopard frog populations elsewhere in Canada. Only one natural population of this species remains in B.C., in the Creston Valley Wildlife Management Area (CVWMA). Monitoring since 2009 has shown that the frogs are killed along the Duck Lake Dyke Road in the CVWMA during seasonal migrations. In fall 2016 and 2017, a seasonal, voluntary road closure was put in place, and patterns of vehicle use and frog migration and mortality were monitored nightly. Signage was used for the duration of the voluntary closures, and educational outreach (social media posts, newspaper articles, radio interviews, and an open house/information session) was provided. Researchers found that the voluntary road closure was ineffective because vehicles continued to use the road, and frog mortality was observed both years. In October 2017, the species' Recovery Team submitted a regulation change proposal under the *Wildlife Act* to enact a legal seasonal closure to motorized vehicles, which was approved in 2018. The motorized vehicle closure is in now in effect annually during the spring (March 15–April 30) and fall (August 15–October 15) migrations.

Photo 57. Road closure at Creston Wildlife Management Area to prevent roadkill of adult Northern Leopard Frogs. Photo credit: Lindsay Anderson (left) and Barb Houston (right).

Reduced speed limits allow drivers more time to react to an animal on the road, which makes it more likely that a collision will safely be avoided. This strategy has been implemented in Banff National Park to reduce collisions with larger wildlife, such as Grizzly Bears (Banff National Park, unpubl. data 2011–2014). Its use is best suited to sites where more visible slow-moving species, such as larger snakes and turtles, are likely to cross the road. Speed limits may be reduced seasonally and/or at specified times of the day. A reduced speed limit is typically combined with a public awareness strategy and signage to educate motorists about the need to minimize road mortality of amphibians and reptiles. Enforcement or traffic calming mechanisms are usually necessary to effectively implement lower speed limits. This strategy can have a high cost due to the need for regular enforcement.

Traffic calming involves installing road features that are designed to reduce vehicle speeds without interfering with traffic flow. As with reduced speed limits, this strategy is best suited to sites where more visible species occur. Some traffic calming methods, such as speed bumps, traffic circles, and raised medians, can be implemented only on roads with low speed limits. Other methods, such as narrow lane widths and rumble strip patches, may be used on roads with moderate or high speed limits. In some cases, speed bumps may interfere with snow removal. However, installations can be used seasonally. This strategy has low to moderate costs depending on the measure used.

Signage is a low-cost, widespread method that is relatively easy to implement but has low effectiveness (Photo 58). The key objective of posting signs is to raise awareness so that motorists avoid hitting wildlife. Effectiveness may be improved by using a well-thought-out strategy that discourages driver habituation to sign presence and messaging and includes the following criteria (see Gunson and Schueler 2012; Kintsch et al. 2015):

- promoting local education (e.g., public and school presentations, media articles);
- instituting the seasonal placement of signs with text indicating when target animals are likely to be crossing roads;
- enhancing signs with flags, flashing lights, or unique art work (Pojar et al. 1975; Hardy et al. 2006);
- using science and data to inform the effective placement of signs;
- limiting the use of signs to roads with moderate–high traffic volume to deter sign theft;
- ensuring the strategic placement of signs, such as at the ends of exclusion fencing; and
- using signs as temporary measures and markers in advance of more permanent mitigation measures (Ontario Ministry of Transportation 2012).

The benefits of using signage for amphibians and reptiles include raising driver awareness of wildlife on the road and, when used with a public education campaign, promoting greater understanding of the importance of conservation efforts (see example in Joyce and Mahoney 2001). In Ontario, signage has commonly been used on municipal and provincial park roads, and more recently on provincial roads (Ontario Ministry of Transportation 2012).

Photo 58. Example of signage used to make drivers aware of amphibians and reptiles on roadways. Photo credit: Elke Wind.

Public education campaigns are designed to inform drivers about wildlife and roads issues and how they can help minimize or avoid wildlife collisions. For amphibians and reptiles, public awareness campaigns typically target local communities near known high-risk road mortality locations and/or where volunteers are needed to help animals across roads (see Case Study 2).

While it is difficult to draw a direct correlation between heightened driver awareness and reduced road mortality, this strategy can improve the effectiveness and public acceptance of other mitigation efforts, such as signage, reduced speed limits, or traffic calming measures. The cost of conducting a locally 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 require greater funding and a long-term commitment.

CASE STUDY 2 Annual Toadfest generates awareness of road mortality

Toadfest is a free, family event held each year at Summit Lake Provincial Park, B.C. It is organized by the Fish & Wildlife Compensation Program to raise awareness about Western Toads (*Anaxyrus boreas*) and road mortality. An annual media release lets locals know when the event will take place based on the development rate and movement patterns of the toad tadpoles in Summit Lake. Participants learn about the toad's natural history, life cycle, and habitat needs. Toadlets migrate from Summit Lake to upland habitat in the summer, encountering roads along the way. Toadfest participants carry toadlets across the road (see table below). The event draws hundreds of visitors each year and is used as a model for other eco-fests. It has also prompted the addition of toad crossing tunnels in the area. Toadfest is supported by the Fish & Wildlife Compensation Program, BC Parks, the B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development, the Columbia Basin Trust, and the B.C. Ministry of Transportation and Infrastructure.

Toadfest results, 2010–2014 (from Dulisse 2015)

	2011	2012	2013	2014	2015
Estimated number of volunteer participants	400	500	500	400–500	300
Estimated total number of toadlets moved	5,000[a]	14,753	13,253	6,853	391

[a] The number of toadlets moved each year does not reflect population numbers, but rather the relative number of toadlets that were moving at the time of the educational event, the date of which was scheduled early in the season. In some years, the event was held earlier or later than the peak in toadlet migration.

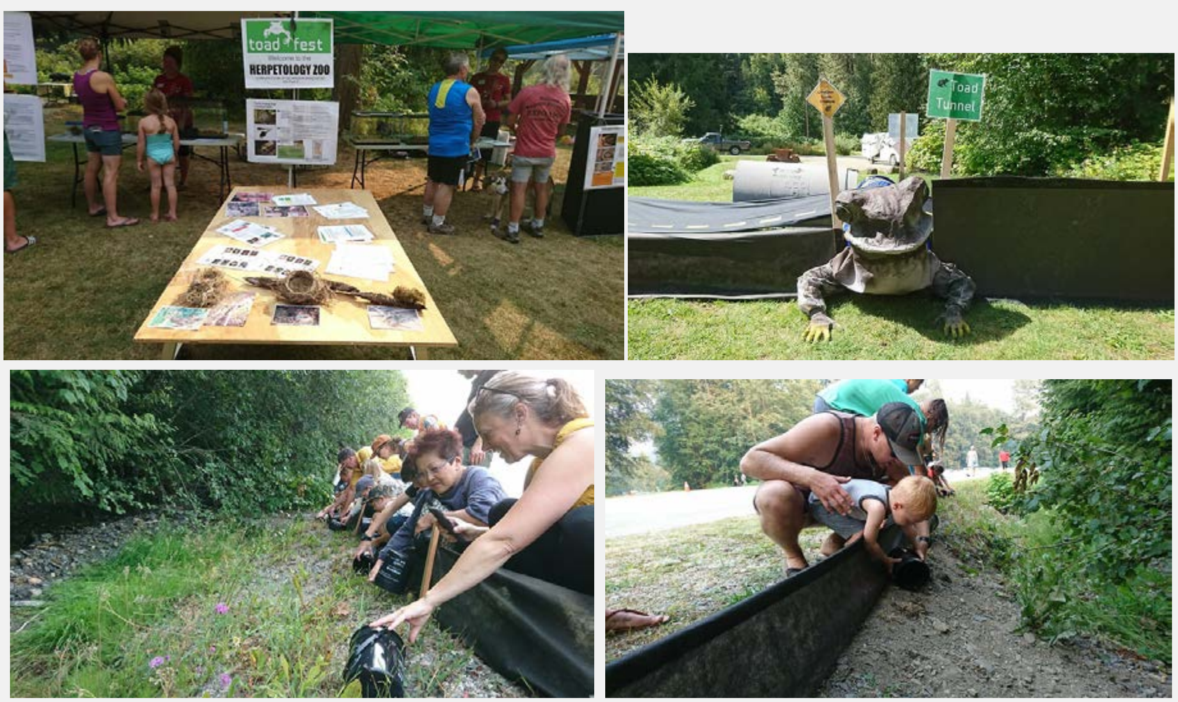


Photo 59. Volunteers at Toadfest learning about toad migrations and road issues. Photo credit: Irene Manley.

4.3.2 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. For example, in Waterton Lakes National Park, 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. Escape gaps work well along high-volume roads where continuous sections of precast concrete barriers divide opposing lanes of traffic and animals that enter the right-of-way cannot cross the road. For example, an unexpected mass migration of Western Toad metamorphs emerged onto Highway 19 on Vancouver Island during summer 2007 (Fyfe and Wind 2008). In addition to a bucket brigade salvage operation (see *Assisted migration* below), sections of precast concrete barriers were replaced with those with scuppers (i.e., gaps underneath) to allow toadlets that got onto the highway to get off the road (Photo 61). This strategy has a relatively low cost.

Photo 60. Angled curbs allow salamanders and other amphibians to climb off road. Photo credit: Peter Morenus/Uconn Photo.

Photo 61. Scuppers under precast concrete barriers placed in the middle of a divided highway allow toadlets to escape the road. Photo credit: Elke Wind.

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. The captured animals 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 requires a handling permit from the provincial government, is labour-intensive, relies on having local volunteers to monitor traps during a migration event, requires safety precautions for the volunteers, and poses some risks to the amphibians (e.g., disease transmission, stress). However, if timed and coordinated effectively, facilitated migrations can be an effective, temporary measure to help reduce road mortality for amphibians (Photo 62; see Case Study 2 for how this technique can also be used for educational purposes).

Photo 62. Volunteers assist amphibians across the highway. Photo credit: Elke Wind.

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

Newly created habitat may include wetlands as breeding sites for amphibians (e.g., Merrow 2007), artificial nesting sites for turtles (see Case Study 3) (Clarke and Gruenig 2002; Paterson et al. 2013), or gestation/basking sites (Rouse 2005; Parent and Black 2006) and hibernacula (Willson 2005) for snakes. General recommendations for habitat creation, based on the Guidelines for Amphibian and Reptile Conservation during Urban and Rural Land Development in British Columbia (2014), are as follows:

- A thorough understanding of the habitat use and movements of the target species is necessary.
- New habitat should be close to, and on the same side of the road as, other habitat used by the target species.
- The created habitat should be suitable for the target populations.
- Other important habitats should not be manipulated, degraded, or destroyed to create new habitat; e.g., check whether other wildlife depend on the area to be altered.
- Ongoing monitoring and maintenance of turtle artificial nesting habitat is required to avoid high egg/hatchling mortality due to invasive plants and predators (wild and domestic). Ongoing

monitoring and maintenance of suitable hydroperiod at artificial aquatic breeding habitat for amphibians is also required to avoid stranding and mass egg/larval mortality.

CASE STUDY 3 Creating nesting habitat for the endangered Western Painted Turtle

On the Sunshine Coast, human-related development has reduced available nesting habitat for Western Painted Turtles (*Chrysemys picta*). Each year, female turtles are killed on roads as they search for suitable nesting habitat or attempt to nest on road shoulders. Because the life history of this species relies on high adult survival and longevity, the loss of each reproductive female from the population can be devastating. To mitigate this threat, the Sunshine Coast Wildlife Project built turtle nesting beaches at six sites where turtle road mortality was a concern. In general, this approach has been extremely effective, but results vary from population to population. At North Lake, Lily Lake, and Ruby Lake Lagoon, turtles immediately used the beaches, road mortality declined dramatically, hatchling success rate was high, and population monitoring through time showed an increase in juvenile age classes. At Sakinaw Lake, Trout Lake, and Garden Bay Lake, it took several years before turtles started using the new beaches.

Photo 63. Female Western Painted Turtles will nest in roadside habitat putting them and newly hatched nestlings at risk of being hit by vehicles. Nesting areas have been created to keep turtles off of roads. Photo credit: Kym Welstead (left) and Purnima Govindarajulu (right).

5 GUIDANCE FOR ROAD CONSTRUCTION ACTIVITIES

This section provides general considerations for mitigation during road construction in areas with amphibians and reptiles. The considerations address two components: (1) timing construction activities to avoid construction-related impacts, and (2) implementing mitigation measures to minimize interactions with amphibians and reptiles and their habitats during construction.

Consultation with local species experts is strongly recommended because activity times for target species vary annually with changing climatic conditions and can be site- and region-specific.

5.1 Timing of Construction Activities

When road construction occurs within or near amphibian and reptile habitat, some impacts can be minimized by carefully scheduling the timing of the work to avoid impacts on habitats when they are occupied or impacts on animals during sensitive periods (i.e., migration, breeding, and overwintering). Construction during the overwintering period should avoid lakes, ponds, streams, wetlands, underground burrows, large downed wood, potential snake hibernacula, and other sites that are used for hibernation. This includes direct disturbance as well as indirect disturbance, such as reducing water levels in overwintering wetlands, and noise and vibration disturbance near potential hibernacula. The timing and duration of amphibian and reptile seasonal activities vary across the province. For example, amphibian and reptile populations are active from February to November along south-coastal B.C., but the duration of activity decreases as one moves northward (see Appendix 3 and Table 1). Also, the onset and end of the period when amphibians and reptiles are active on the surface can vary by almost two months depending on the weather. For example, most Western Toads that were radio-tracked on Vancouver Island went into hibernation in November during each year of a three-year study, but the timing of emergence from hibernation varied from year to year, occurring in February 2015, January 2016, and March 2017 (Wind 2018b). Local QP species experts, provincial Ministry of Environment and Climate Change biologists, and the regional Ministry of Forests, Land, Natural Resource Operations and Rural Development office may be able to provide information on annual variations in site-specific movements of target species during construction activities.

5.2 Mitigation Measures for Construction Activities

Temporary mitigation measures can be implemented on-site at all road projects that occur within or adjacent to amphibian and reptile habitat to avoid harming or killing individuals. The following are guidelines for temporary measures:

1) **Consult** Guidelines for Amphibian and Reptile Conservation during Urban and Rural Land Development in British Columbia (2014). This document discusses measures such as maintaining hydrological features; preventing the introduction of non-native species; reducing pollution in aquatic breeding habitats by, for example, developing erosion and sediment control plans and having an emergency response plan in place to contain and clean up oil and fuel spills safely and quickly; communicating measures to construction workers; avoiding compaction and/or disturbance of loose soils, the litter layer, coarse woody debris, and sensitive habitats, such as rocky slopes; and considering opportunities for habitat enhancement and restoration (e.g., taking advantage of heavy equipment that is already on-site, as well as any surplus woody debris, rocks, gravel, and soil to save time and money compared to doing the work post construction).
2) **Develop an amphibian and reptile salvage and relocation plan**. Assess and plan for the probability that amphibians and reptiles will be encountered during construction. Any animals within the construction area will need to be moved to avoid their injury or death, and to avoid infractions under the *Wildlife Act*. Develop a salvage plan following the protocols outlined in the Best Management Practices for Amphibian and Reptile Salvages in British Columbia.

> **Salvage and translocation** should be used only when other measures fail; they **should never be used as a primary mitigation measure**.

3) **Submit an application to the Province to obtain a wildlife handling permit at least six weeks (longer if possible) prior to the onset of construction work**.
    - Applicants must submit a General Permit Application, detailed project proposal, and complete BC Animal Care Form to FrontCounterBC via mail, in person, or online at http://www.frontcounterbc.gov.bc.ca/Start/fish-wildlife/.
    - If an emergency salvage becomes necessary during construction because amphibians and reptiles are unexpectedly found on the project site, all construction that impacts the animals needs to be halted immediately and the regional Ministry of Forests, Lands, Natural Resource Operations and Rural Development office should be contacted for further direction. It is illegal, under the *Wildlife Act*, to knowingly harm or kill amphibians, reptiles, or other wildlife.
    - When amphibians and reptiles are found on a construction site, proper handling procedures should be followed. One of the permit requirements for salvage of amphibians is that all staff follow the Interim Hygiene Protocols for Amphibian Field Staff and Researchers (B.C. MOE 2008) to reduce risk of disease transmission between sites and among animals within a site.
4) **Consult with a QP**. A qualified species expert should be consulted to provide guidance on salvage needs and the permit application. The QP needs to be present or available at all times prior to and during construction to provide guidance on fencing design and installation, if needed (see below), and to conduct searches, handle encounters, and relocate animals.
    - Searches should be conducted daily prior to and during construction activities if work occurs in high-quality or designated amphibian habitat or during the activity period of the target species.
5) **Install exclusion fencing**. Where needed, install exclusion fencing between the road construction zone and amphibian and reptile habitats.
    - Use fencing that will last the duration of the road construction project (e.g., a light-duty geotextile fence for projects completed within one year or a heavy-duty geotextile fence for longer projects [see Section 5.2, Province of British Columbia 2014). If permanent fencing is going to be installed as part of the mitigation plan (i.e., along roads), it can be installed instead of temporary construction fencing to avoid extra costs.
    - Fencing should be inspected daily for animals trying to cross the landscape, especially during migratory periods, and for gaps or damage. Animals should be carried across the road and released on the opposite side if it is a known migratory route. Fences should be repaired daily to maintain their effectiveness and avoid potential breaches.
    - Fencing should be installed so that construction sediment does not enter 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 amphibian and reptile habitat.
6) **Control blast size and vibrations** within or adjacent (up to 250 m) to snake habitat by using blast mats and other approved measures (Ontario MNR 2011).
7) **Conduct reporting**. Project-specific reporting and handling protocols should be developed in compliance with the requirements of the salvage permit. Observation records should include the observer's name; the species observed; the date, time, and location (descriptive and georeferenced) of the observation; photographs; and action(s) taken. Conditions of the *Wildlife Act* permit require that data and associated reports be submitted to the Wildlife/Plant Data Information site.

6 GUIDANCE FOR ROAD MAINTENANCE ACTIVITIES

Road maintenance activities are undertaken to maintain user safety or address engineering and infrastructure concerns. However, as described in Section 2.4, these activities can have ongoing impacts on nearby amphibian and reptile populations and habitat. This section provides information on developing guidance for road maintenance contractors to safeguard amphibians and reptiles and their habitats.

6.1 Assessing and Prioritizing the Application of Mitigation Guidelines during Road Maintenance Activities

As with new road construction and expansion projects, road maintenance activities should be preceded by a screening exercise to assess activities that pose a risk to amphibians and reptiles. The steps outlined in Section 3 (Screening Tool) may be applied to road maintenance activities to create a map of potentially vulnerable habitats (such as wetlands and ditches) and conservation areas (e.g., identified Critical Habitat). High-risk maintenance activities (such as removal of a beaver dam, which may dramatically change hydrology) and vulnerable time periods for amphibians and reptiles (such as during breeding or migration seasons [Table 1]) should also be identified. The guidelines described below can be provided to road maintenance contractors to minimize the impacts of road maintenance activities on amphibians and reptiles.

6.2 Road Surface Maintenance Guidelines

Dust control and stabilization is used to minimize the impact of dust on road users, adjacent properties, and watercourses adjacent to dirt or gravel roads/highways, and is usually conducted early in the year. De-icers, aggregate, and salt/brine are applied on roads to proactively minimize the development of slippery conditions and restore traction.

The following guidelines can be used to mitigate potential impacts of road surface maintenance on amphibians and reptiles:

- Consider using alternative, non-chloride/“green” forms of dust control and de-icing agents, especially near sensitive habitats (e.g., adjacent to aquatic breeding sites and streams; see text box in Section 2.4.2).
- Minimize runoff of dust control agents into adjacent habitats, especially wetlands. Techniques might include pre-wetting surfaces to ensure proper adhesion, not applying dust control agents before, during, or immediately after rain, and minimizing spraying on the shoulder.
- Install silt fencing adjacent to wetlands to prevent treated dust and sediment from washing into the wetlands.
- Store hazardous materials, such as de-icing compounds, on impermeable surfaces to prevent their release into soils and groundwater.
- Where possible, avoid depositing large snow and ice accumulations that have been removed from roads into or immediately adjacent to roadside ponds, wetlands, and ditch habitats (where amphibians may breed). Mark locations of known ditch pond habitats with tall coloured stakes so that they can be avoided during snow removal.
- Reduce sediment runoff from aggregate storage piles into nearby watercourses (e.g., cover storage piles that contain de-icing compounds [road salt]).
- Consult the salt management plans outlined in the Transportation Association of Canada’s (2013) Syntheses of Best Practices - Road Salt Management.

6.3 Drainage Maintenance Guidelines

The objective of ditch maintenance is to provide unobstructed drainage for roads.

The following guidelines can be used to mitigate potential impacts of drainage maintenance on amphibians and reptiles:

- Ditches in known areas of concern, including Critical Habitat, should be surveyed for the presence of amphibians (all life stages) and reptiles before drainage maintenance activities are initiated.
- Culverts should be surveyed for the presence of amphibians (e.g., eggs and/or larvae in standing water) and reptiles prior to culvert maintenance activities.
- Salvage needs to be conducted at ditches that contain amphibians or reptiles prior to the onset of maintenance work, especially where water drainage and/or culvert replacement is occurring. The salvage plan should include monitoring spoil piles for emerging amphibians and reptiles, and a protocol for relocating individuals exposed during excavation (e.g., reptile eggs and/or adults that were underground). An amphibian and reptile QP should assess the likelihood of amphibians and/or reptiles living in the soils within ditches that require excavating and should develop an environmental work window and salvage program, if necessary.
- Refer to the Government of British Columbia's *Best Practices for Drainage Maintenance Works in Oregon Spotted Frog Habitat* (Government of British Columbia 2010) for BMPs for ditches that contain water and aquatic-breeding amphibians.
- Prevent the collection of standing water in ditches, which act as "sink" habitats, by facilitating drainage. (Sink habitats are aquatic sites that attract amphibians for breeding but dry prematurely, resulting in high egg or larval mortality.)
- Where maintenance activities occur within or adjacent to known amphibian or reptile habitats (e.g., snake egg laying and gestating sites, snake dens, aquatic amphibian breeding sites), avoid spreading spoil materials on the site; they may degrade amphibian and reptile habitats.
- If feasible, avoid using rip-rap where it might impede amphibian and reptile movements or impact habitats that amphibians and reptiles use seasonally. Instead, use interlocking blocks (e.g., Johnson et al. 2013) or re-seed/re-vegetate affected areas with fast-growing, native vegetation to reinforce and maintain shoreline bank stability and provide habitat and cover for amphibians and reptiles. Examples of alternative techniques to rip-rap bank stabilization are provided in FEMA's Engineering with Nature document (n.d.).
- If maintenance activities require in-stream work, schedule activities during environmental timing windows (see definition and website links in Sections 5 and 6, respectively). Consult with a QP because site-, species-, and season-specific plans may be required.
- Consult the B.C. Ministry of Environment's Beaver Dam Removal best management practices document.

6.4 Roadside Vegetation and Wildlife Fence Maintenance Guidelines

Roadside maintenance can include vegetation control and the maintenance of fences that prevent wildlife from entering the road surface. These activities are undertaken to increase visibility for drivers and to prevent mortality of wildlife on roads. Fences are often used to lead amphibians and reptiles to safe crossing structures, and in most cases, these fences require ongoing maintenance.

The following guidelines can be used to mitigate potential impacts of roadside vegetation and wildlife fence maintenance on amphibians and reptiles:

- The location of specialty fences needs to be clearly identified for maintenance workers, and guidelines on specific maintenance requirements should be provided. For example, specialty wildlife fences along some highways, such as the elk fencing along Highway 19 near Courtenay on Vancouver Island, have ¼" galvanized hardware cloth attached to the bottom to direct amphibians (Western Toads) and other smaller wildlife toward wildlife underpasses.
- Winter weather and snow removal can damage specialty fences designed to direct amphibians and reptiles toward underpasses. Flooding can erode soil at the base of the fences, especially where they attach to crossing structures, and can carry cover objects (e.g., logs) out of passageways. Over the spring and early summer, vegetative growth creates "ramps" that allow amphibians and reptiles to climb over fences. The fences should be regularly inspected and maintained by trained staff in order to repair holes and gaps (e.g., created by the removal of snow and debris from roads; tunnels created by mammals), and to clear away vegetation that can enable animals to climb over the fence (see Sections 4.2.4.3 and 7.2). Vegetation within 0.25 m of an amphibian/reptile fence needs to be cut at least annually. The timing of fence repair should coincide with inactive periods for amphibians and reptiles in the work area, where possible, and should occur before the seasonal movements of animals (see Table 1).
- Contractors need to be trained in vegetation maintenance along specialty fences adapted for amphibians and reptiles to avoid damaging the fence with mowing and trimming equipment (see Photo 4).
    - Specialty fences should be inspected immediately after maintenance work to identify any gaps and damage that may have occurred, and should be repaired as soon as possible.
- Consult with a QP to design a vegetation management plan for sites where specialty wildlife fences are installed.
- At this time, it is recommended that an adaptive management approach be taken regarding the use of allowable fencing material. Research on wildlife fencing materials is rapidly evolving as many materials are tested and modified.
- Limit the use of herbicides, including glyphosate-based herbicides, for vegetation management around aquatic habitats for amphibians because they can have toxic effects on aquatic and terrestrial life stages (Wagner et al. 2013) (see Table 1).

In addition to the guidelines above, some road authorities have developed documents that provide general environmental guidelines and safety specifications, such as the B.C. Ministry of Transportation and Infrastructure's Environmental Best Practices for Highway Maintenance Activities (2018).

7 MONITORING

British Columbia is in the early stages of developing ways to mitigate the impacts of roads on amphibians and reptiles. There is uncertainty about how well best management practices that were developed in other areas will work for B.C.'s unique set of species and physical landscapes. Adaptive management, or "learning by doing," uses monitoring to reduce uncertainty. **Monitoring is a systematic and long-term process** that involves gathering information about an implemented project and evaluating whether it has reached its goals and delivered what was expected. Monitoring is essential for improving our knowledge base and ensuring that we are using the most effective techniques.

There are various phases of road projects, including construction, retrofitting, and maintenance activities that require three different types of monitoring:

- **Compliance monitoring** – Did the contractor do as required as laid out in the service contract and as recommended in the BMPs/guidelines?
- **Maintenance monitoring** – Are the mitigation features (e.g., tunnels and fencing) being maintained so that they function as intended?
- **Effectiveness monitoring** – Are the mitigation features working effectively, keeping amphibians and reptiles off roads and/or allowing animals to pass safely, and are they helping maintain viable populations of amphibians and reptiles at the site?

Only compliance monitoring may be required as part of a development permit; post-construction maintenance and effectiveness monitoring are rarely stipulated under permits or regulation. Further, ongoing routine monitoring and maintenance of mitigation structures are not usually factored into annual budgets or contractor or staff scheduling. In a few cases, effectiveness assessments have been conducted when road construction proponents have collaborated with university or independent researchers (e.g., Crosby 2014; Winton 2018). These research projects contribute to improving the effectiveness of mitigation measures and to making implementation more cost-effective. Adoption of the three monitoring programs by road construction and management authorities would contribute to the effective assessment of efforts to mitigate the impacts of road management activities on amphibians and reptiles.

7.1 Compliance Monitoring

Compliance monitoring focuses on **quality assurance and adherence to the mitigation specifications** for each project. For example, routine quality checks are needed during the installation of directive and exclusion fencing to avoid small gaps or folds, which render the fences ineffective.

7.2 Maintenance Monitoring

Maintenance monitoring should be conducted at critical times throughout the year. Fences should be monitored at the end of the winter/storm season, prior to the active season for amphibians and reptiles (see Table 1; Photo 64). Fences should also be inspected during the summer to ensure that overgrown vegetation has been cleared away before the late summer and fall migration season.

Photo 64. Maintenance monitoring is required to check for storm damage to fencing such as this fallen tree at Highway 99, Pinecrest. Photo credit: Barb Beasley.

A monitoring checklist should be used to identify when key design features become degraded and need repair (Table 4). This information can easily be recorded and maintained digitally via a tablet or smart phone.

Table 4. Example checklist for routine maintenance monitoring of crossing structures with fencing.

Date checked	Maintenance issue	Y/N	Location (coordinate; UTM or Lat./Long.)	Description of repairs needed, and other comments	Photo #	Date fixed
	Fence collapse (partial or complete)					
	Holes or gaps through/under fence					
	Bottom of fence still buried					
	Vegetation growing along fence					
	Fence abuts crossing structure					
	Cover objects remain in crossing structure					
	Tunnel opening blocked by vegetation or debris					
	Carcasses along fence					
	Carcasses along roadway					

7.3 Effectiveness Monitoring

Where fences and crossing structures have been constructed, effectiveness monitoring should include, at a minimum, gathering data on whether the structures are keeping amphibians and reptiles off roadways and providing safe passage to ensure habitat connectivity. More intensive effectiveness monitoring involves assessing whether the target populations of amphibians and reptiles that are impacted by the road remain stable after mitigation measures are implemented.

A recent review of 50 studies on mitigation measures designed to reduce road mortality showed that there were insufficient data to answer many of the most pressing questions that road planners ask (Rytwinski et al. 2016). There were two main reasons for this. First, there was not enough variation in the mitigation measures used to test for effectiveness; e.g., fence heights were too similar across studies to determine an effect of fences on road mortality. Second, key information was not reported; e.g., the length of crossing structures and the distance between them was not reported in more than 65% of the studies. This highlights the importance of developing a rigorous effectiveness monitoring plan for mitigation projects that includes better research and data reporting.

7.3.1 Developing an effectiveness monitoring plan and study design

An effectiveness monitoring plan includes clear goals, objectives, and questions, and involves a team of experts and collaborators during the early stages of the project in order to develop a statistically valid plan for quantifying effectiveness (Rytwinski et al. 2015) (Figure 10). The plan involves collecting data in a way that will allow conditions to be compared (1) before and after mitigation, and (2) along sections of the road where mitigation measures have and have not been applied. This is referred to as a **Before-After-Control-Impact (BACI)** study design, which is the most reliable way to detect a change in the variable(s) of interest (e.g., rate of road mortality, movements through crossing structures, population size) (see Case Study 4).

Goals and Questions

Overall Monitoring Goal:
Maintain or restore population viability
- Measure or model trends in population size/density

Goal – Fencing:
Reduce road mortality
- Is the reduced mortality sufficient to maintain or restore population viability?

Goal - Crossing Structures:
Crossing(s) used by all life stages and sexes
- Is use enough to maintain or restore population viability?

Planning

Long-term Monitoring
1. Multiple seasons or multiple years (can be 5 or more)
2. Prior to AND after mitigation measures have been installed or modified (e.g., BACI design)
   - to reduce the influence of random, one-time events

Expertise and Collaboration
1. Amphibian and reptile biologist
2. Statistician
3. Road authority
4. Road developer
5. Monitoring team

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

Study Design

Treatment(s) vs. Controls
Types of mitigation/ treatment(s)
- Vary fencing design
- Vary crossing structure design
- Combination of both

Site Selection
1. Obtain pool of potential treatment and control sites
2. Randomly assign mitigation/treatments at impact sites
3. Replicate treatments and controls among sites

Sampling Protocols
1. Repeatable
2. Consistent

Figure 10. Key elements for planning a rigorous study to assess the effectiveness of road mitigation for amphibians and reptiles.

Several seasons of monitoring data from both before and after mitigation is applied are recommended to measure changes. Rytwinski et al. (2016) recommended using a minimum of 4 years or four sites in a BACI study design; however, the appropriate time frame and number of sites used should be determined by consulting with experts, including a statistician and a biologist who has knowledge of the species' movement patterns at the site(s) of interest. A collaborative partnership that includes the road developer, the road authority, a monitoring group, and experts should be established early. The team will need to work together to obtain funding and permits to conduct multi-season sampling and, ultimately, to use the monitoring results to improve mitigation in the future.

CASE STUDY 4 Before-After-Control-Impact Study on the effectiveness of fencing

The Association of Wetland Stewards for Clayoquot and Barkley Sounds (2014) installed a fence at a known hotspot along Highway 4 near Ucluelet, B.C. It was created using plastic materials (UV-treated HDPE "puckboard") and the top edge was bent to create a rigid overhanging lip (6 cm across and 4 cm down) to make it difficult for amphibians, especially Pacific Treefrogs (*Pseudacris regilla*), to climb over the fence onto the highway (See Photos 6 and 36). Before the fence was installed, a simple Before-After-Control-Impact (BACI) study was set up to test the effectiveness of the new fence design in reducing road mortality. Surveys for dead amphibians on the surface of the road were conducted in the morning after rainy nights in fall 2012 (N = 11 surveys before installation) and 2013 (N = 16 surveys after installation). The amount of road mortality before and after the fence was installed was compared at both fenced (150 m) and unfenced sections (200 m) of the highway. The number of amphibians killed in the fenced section was reduced to 19% of that recorded before the installation (see Figure 10). Mortality in unfenced areas changed by < 1%. Mapping of carcasses before and after the fence installation showed that there was no major increase in the numbers killed at each end of the fencing. Thus, the BACI comparison revealed that the new fencing was 80% effective in reducing amphibian road mortality.

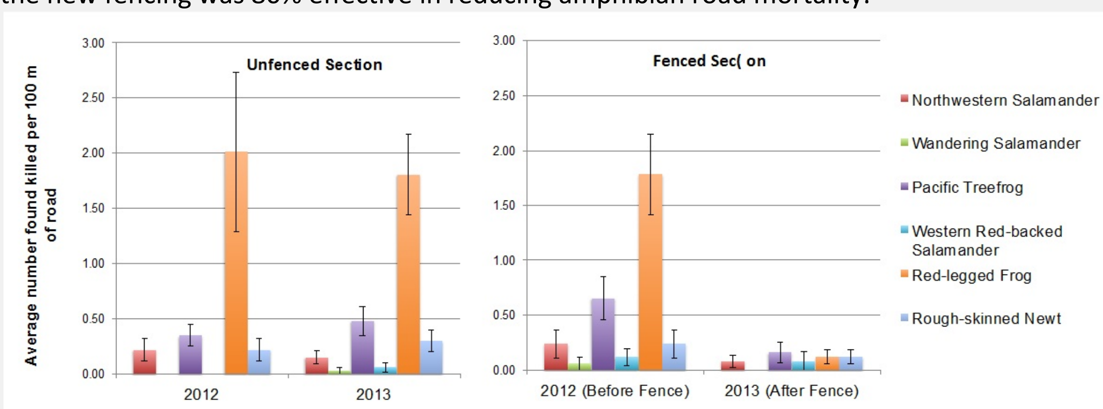


Figure 11. Average (± SE) number of amphibians killed per 100 m of road before and after fencing in unfenced (control) and fenced (impacted) sections of the road.

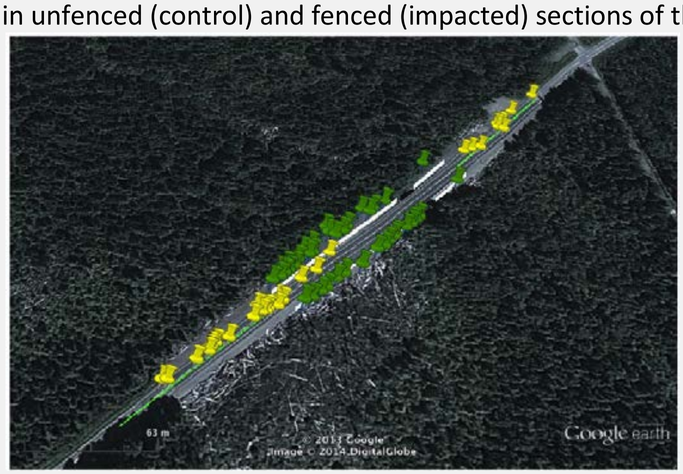


Photo 65. Distribution of live and dead amphibians on the highway (yellow pins) and live amphibians along the barrier fences (green pins) during four night surveys in Oct-Nov 2013. White lines are fences and green lines are unfenced sections of the survey area.

7.3.2 Sampling protocols and techniques for effectiveness monitoring

A variety of sampling protocols and techniques can be used independently or collectively to monitor the effectiveness of mitigation structures. The combination of protocols will depend on the questions being asked:

- Road Surveys – The numbers of dead and alive amphibians and reptiles on the road surface are counted to **assess reductions in road mortality** (e.g., relative number killed at/near underpasses versus away from underpasses).
- Fence and Crossing Structure Surveys – The movements of individuals are followed to determine if the animals travel along guiding fences and through crossing structures in order to **assess habitat connectivity**.
- Population Surveys – The number of individuals in a population is repeatedly counted over the long term to **assess population viability**.

The protocols and techniques must be repeatable and consistent over time and across sites (Figure 10). In general, less time, effort, and technical skill are required for protocols that involve sampling road mortality than those used to sample habitat connectivity or population viability (Figure 12). For example, measuring population viability requires a much greater time investment—at least 5 years before and 5 years after mitigation.

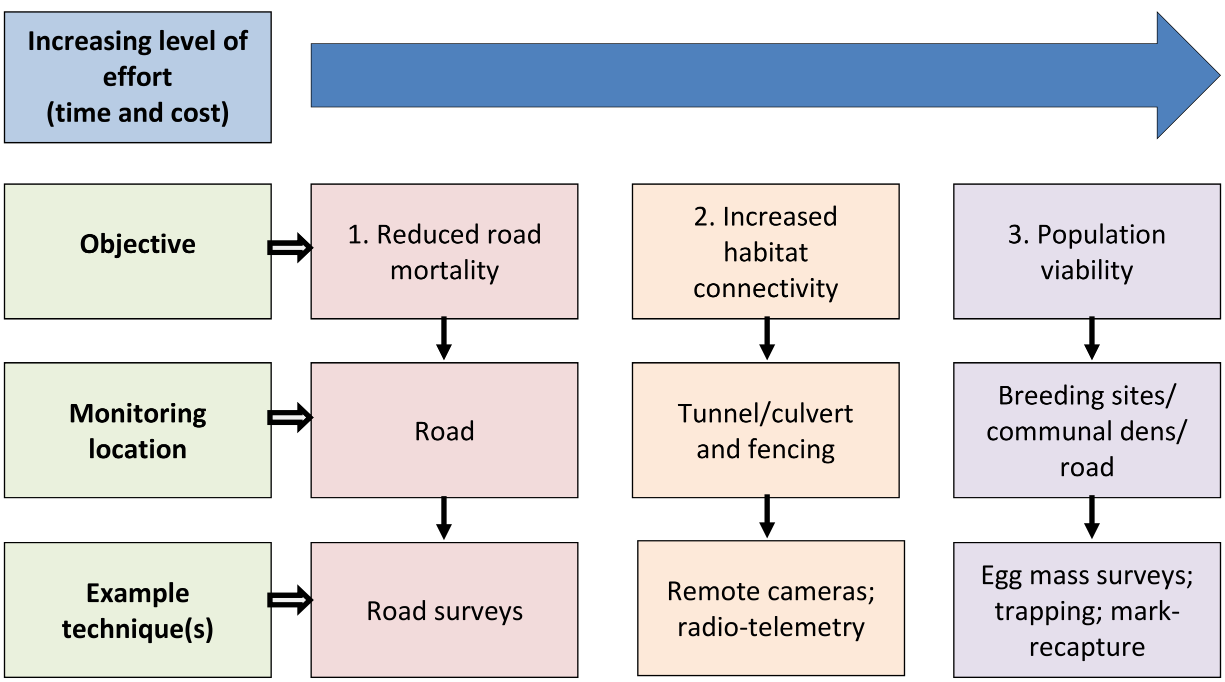


Figure 12. Relative level of effort required to collect data to meet different monitoring objectives, including where the monitoring occurs and example sampling techniques.

7.3.2.1 Road surveys

Methodical road surveys quantify road mortality rates more accurately than opportunistic/incidental monitoring of roadkill (Winton 2018). Road surveys involve gathering baseline data on the number and location of amphibians and reptiles that cross and are killed on the road. Data gathered before mitigation is applied help inform where mitigation structures should be placed and allow before-after comparisons to be made to determine if mortality has been reduced.

Data are collected by driving, cycling, or walking along a selected length of road while looking for alive or dead individuals. Driving surveys allow surveyors to cover a greater distance of road over a sampling period; however, the detectability of small amphibians and reptiles is much lower from vehicles than when surveying on foot (Langen et al. 2007). Surveys should be conducted using consistent and repeatable methods so that the road can be surveyed the same way before and after mitigation.

Important considerations:

- When a species is common, road surveys may generate adequate data in one or two seasons; however, for rare species, more time may be required.
- Surveys should be conducted during the active season or movement period for the target species (Table 1).
- Weather conditions, time of day, presence of scavengers, and traffic volumes will impact detectability of carcasses. Data for these factors need to be recorded, at least during the duration of the road survey. Traffic counters should be installed to count the number of vehicles on an hourly basis each day throughout the active migration season (traffic counters may not be necessary where road authorities are already collecting and reporting traffic volume data: http://www.th.gov.bc.ca/trafficData/). Data on temperature and the amount of rainfall throughout the day and night can be obtained from local weather stations.
- For animals that move on rainy nights (i.e., most amphibian species), surveys should be conducted at night before rain, runoff, and morning traffic obliterate carcass remains (Hels and Buchwald 2001; Langen et al. 2007). The use of bright lights positioned low to the pavement will aid in detecting individuals more effectively at night, as will lowering light levels inside the vehicle (i.e., turning headlamps down/off).
- After mortality occurs, carcasses can disappear or not be detected for various reasons, such as predation. Detectability measures (see text box below) should be obtained by marking carcass locations and resurveying to assess the number of carcasses that remain, or at a minimum, use known detectability multipliers to estimate the number of undetected animals.
  - Amphibians are the most difficult to detect over time because their small, soft bodies are easily obliterated by traffic, and mortality surveys are best conducted at night during the movement period.
  - More than 50% of snake carcasses will disappear in 24 hours, so surveys should be conducted daily during peak movements in spring and fall.
  - Dead turtles persist on roads the longest, so a survey frequency of two to three times per week during the nesting season is recommended.
- Note that road surveys may not detect depleted populations (e.g., where road mortality has already depleted the number of individuals adjacent to the road) or species that avoid crossing roads.
  - If a population has declined due to road mortality in the past, the density of amphibians and reptiles killed on the road may be low. Focusing mitigation efforts only on roadkill hotspots may ignore sites that have had the greatest historical road impact on population size (Eberhardt et al. 2013). Check sites that have high traffic volumes and good habitat near the road, especially where it surrounds the road. These sites may be particularly important locations for mitigation to restore populations.

  - Other survey techniques may be required to detect depleted, rare, or elusive amphibians and reptiles in habitats surrounding roads. Examples include coverboards for snakes, pitfall traps for amphibians, and hoop-net traps for turtles.
  - When information on rare species is lacking, data from a similar but more common species may indicate where road mortality of the rare species occurred.
- Each individual found on the road should be carefully examined and photographed to determine the species, sex, and age class. If possible, the length of the animal should be recorded (e.g., plastrons of turtles, total length of snakes, snout-vent length of frogs and salamanders) (Photos 66 and 67).
- Record the direction of travel, but be aware that this information is not always reliable because the individual may have been redirected by traffic.
- Depending on the project, it may also be important to collect a DNA sample or mark individuals or their locations to avoid double counting when surveys are repeated.
- Estimates of road mortality rates should account for factors that might influence their accuracy. For example, the equation developed for road mortality rate in Winton (2018) can be applied to surveys of any frequency provided that survey effort, time between surveys, carcass persistence time/scavenger removal rates, and observer detection probability are all taken into account.

Photo 66. Snout-vent length of a Pacific Treefrog can be estimated by placing a ruler beside the animal on the road. Photo credit: Barb Beasley.

Photo 67. The length and width of a turtle carapace is recorded. Photo credit: Purnima Govindarajulu.

Why should "detectability" be considered?

Numerous factors affect the ability to detect dead amphibians and reptiles on roadways, including observer characteristics (e.g., skill level, mode of travel, fatigue), presence of scavengers, traffic volumes, and variability in carcass deterioration rates. Species that are more vulnerable to scavengers and/or have carcasses that degrade rapidly may be detected less often, which results in their population numbers or their likelihood of being hit by vehicles appear lower compared to other species. For example, after marking amphibian carcasses and then having different observers survey for them, < 7% of salamander carcasses and 32–67% of frog carcasses were detected by surveyors during walking road surveys (Hels and Buchwald 2001). Using planted snake carcasses, Winton (2018) investigated the rate of carcass removal by scavengers and the probability of observer detection during road surveys. Fifty-two percent of carcasses were removed by scavengers in 2 days, while 11% remained for > 14 days. The mean observer detection probability was 0.76 for a team of two observers conducting walking surveys.

Correcting for detectability during road surveys

To account for missed detections, the number of roadkilled amphibians and reptiles found on the roadway can be multiplied by a compensation factor. In Hels and Buchwald's (2001) study, the number of detections made during walking surveys had to be multiplied by 1.5 and 15 for frogs and salamanders, respectively. The compensation factor for driving surveys would been 30 and 300, respectively, because the probability of detection is much lower from a vehicle than on foot (Beebee 2013). Winton (2018) estimated the true number of rattlesnake deaths as 2.7 times the number detected by all road surveys and incidental observations combined. Note that compensation factors are specific to the species, traffic levels, and scavengers at each site and should not be applied across studies.

There is a great deal of uncertainty in detectability factors, which makes it challenging to accurately relate road kill numbers to actual deaths, but it is possible to calculate relative changes over time at the same place with repeated use of standard methods (Beebee 2013).

7.3.2.2 Monitoring crossing structures and fencing

Amphibians and reptiles observed along fences and not on the road are evidence that the fences are helping reduce road mortality; likewise, animals observed moving through tunnels indicate that crossing structures are providing safe passage and habitat connectivity. Assessments of the **proportion of animals that encounter the fence AND enter into the crossing structure**, and the **proportion of animals that enter crossing structures AND go through them**, are needed to best inform mitigation designs.

Various monitoring techniques are used for following the movements of amphibians and reptiles along fences and through crossing structures (see Appendix 5 for examples of crossing structures that have been monitored in B.C.):

Camera traps: The use of remote digital cameras is a non-intrusive sampling technique that does not require a wildlife sampling permit. The time lapse setting is used to take pictures of ectothermic (cold-blooded) animals, such as amphibians and reptiles, at regularly spaced intervals (e.g., every minute). In this scenario, approximately 20,000 images can be taken over a 2-week period. In some cases, camera detection software can help find wildlife in images (Dillon Consulting Limited 2011). Setting the camera to take photos over shorter intervals (e.g., every 10 seconds) will improve the quality of the data, but the batteries and SD cards would have to be replaced more regularly. Some researchers have experimented with using a standard digital camera and a light beam aimed across the bottom of an underpass, which triggers the shutter when the beam is broken by a passing animal (Dulisse et al. 2017). Cameras should be placed at both ends of the underpass, securely fastened, and locked to the underpass structure (Photo 68). At larger underpasses, cameras should be mounted closer to the ground. Cameras can also be mounted outside the entrance ways of an underpass to monitor whether animals actually enter the structure (Photo 69).

Photo 68. Digital camera mounted and locked to crossing structure. Photo credit: Elke Wind.

Photo 69. Digital camera mounted outside the entrances of crossing structure to monitor the effectiveness of the fences in leading amphibians into the tunnel at Highway 4 near Ucluelet. Photo credit: Barb Beasley.

Sand pits, ink pads, and fluorescent powder: Surfaces at the entrance of crossing structures or inside them can be set up to record tracks. Sand, cleaned and free of plant seeds, can be laid down on top of existing soil and litter and raked smooth after each inspection. Sticky ink or fluorescent powder can be placed in a shallow well or on a card adjacent to blank cardboard where animals will leave prints after they have moved across the ink/powder. These techniques rely on being able to identify the tracks of species. It may be challenging to distinguish tracks if a number of animals are moving across the track pad.

Pitfall traps with fencing: Pitfall traps are buckets, cans, or other containers buried flush with the ground along a fence. The fence directs moving animals toward the traps. The use of pitfall traps requires a wildlife sampling permit from the provincial government. Pitfall traps need to be large enough 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 twice per day, and as frequently as every 6 hours in some areas) to avoid drowning, desiccation, or predation of individuals. Traps can be set at the entryway and exit of a crossing structure to assess how many animals are moving to and through the crossing structure. Traps can also be set in arrays within nearby habitats to assess the number of animals in the vicinity of the road. This technique provides an opportunity to capture, mark, and recapture individuals.

To prevent disease transmission among amphibians and between habitats, it is important that all fieldworkers utilizing techniques that involve capture and handling of amphibians follow the hygiene protocols developed by the B.C. Ministry of Environment (B.C. MOE 2008) and the decontamination protocols developed by the Canadian Herpetofauna Health Working Group (CHHWG 2017).

Capture-mark-recapture: Capturing, marking, and recapturing animals can be used to determine if individuals are crossing a road, and as a method of assessing population levels. There are several methods for marking amphibians and reptiles, including inserting passive integrated transponders (PIT), notching scutes on turtles, marking salamanders and frogs with visible implant elastomer dye (e.g., MacNeil et al. 2011), and using image recognition software. Some of these techniques are discussed in more detail in the Canadian Council on Animal Care (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: Amphibian and reptile movements can be monitored using radio-telemetry and a handheld receiver (Photos 70 and 71), while passive data loggers (Photo 72) or PIT tag readers can be mounted near crossing structure entrances (Caverhill et al. 2011; James et al. 2011) to record the movement of marked individuals.

Table 5 lists the advantages and disadvantages of these techniques. A combination of several methods will provide the most robust data set and eliminate most of the disadvantages of using any one method. For example, using both handheld radio-telemetry and passive receivers mounted in the crossing structures will provide high-quality data on crossing events and detailed movements of individuals in relation to the crossing structures and the road.

Photo 70. Toads have been fitted with transmitters in order to track their movements towards hibernacula. Photo credit: Elke Wind.

Photo 71. Radio telemetry requires the use of a hand-held receiver and antenna to track amphibian and reptile movements. Photo credit: Elke Wind.

Photo 72. Passive data loggers installed in (one at the mouth and one 15 m inside; black arrows) and outside of culverts to compare internal versus ambient air temperature. Photo credit: Elke Wind.

Table 5. Advantages and disadvantages of techniques used to monitor road crossing structures

Technique	Advantages	Disadvantages
Mounted digital cameras	• Provide information on the time and date of the crossing event • Should detect most individuals using the crossing structure if the cameras are set to take photos regularly (e.g., every minute)	• Do not provide detailed information on the individuals using the structure (e.g., sex) • Effective cameras are expensive, and there is a risk of theft • Reviewing photographs and maintaining cameras (e.g., downloading pictures, making adjustments, changing batteries, monitoring tunnel water levels) can be very time-consuming • Cameras typically do not work under aquatic conditions
Pitfall and funnel traps	• Traps within a crossing structure provide information on the individuals using the structure (e.g., sex) and the date of the crossing event • Trapped animals can be used for genetic sampling to assess genetic mixing across roads	• Labour-intensive and costly for set up and sampling because the traps should be checked at least twice per day • Risk of animals dying in traps • Risk of attracting predators to crossing structures
Capture-mark-recapture	• May be possible to capture and recapture marked individuals from one side of the road to the other • Is the best way to obtain estimates of absolute population abundance using a crossing structure (with enough sampling)	• Does not provide direct evidence that animals used the crossing structure (e.g., cannot rule out crossing through holes in the fence or at fence ends) • May not provide information on the time and date of crossings • Detection of individuals crossing the road is limited to the number of animals captured and subsequently recaptured • Labour- and time-intensive
Radio-telemetry and passive data loggers	• Provide information on the individuals using the structure (e.g., sex) and the time and date of crossing (PIT tags only) • Passive data loggers and PIT tag readers in the structure provide direct evidence that the structures are used (if placed at each end of the tunnel) • Radio-telemetry can track movements in relation to the road (e.g., home range size) • Will work under aquatic conditions	• Considerable field time, effort, and cost may be required to capture, handle, and monitor animals • Detection of individuals crossing the road is limited to the type and number of animals that are captured and tagged or tracked (e.g., only larger adults of some species are large enough to be tagged) • Radio-telemetry is unlikely to provide direct evidence that the structure is used, so it is ideal to combine it with passive readers mounted inside the structure

7.3.2.3 Monitoring population trends

The best sampling protocol for monitoring population sizes over the long term depends on the species' life cycle. It may be most efficient to conduct annual surveys at communal breeding sites or hibernacula. Road survey data for species that move in large numbers all at once can also be used to estimate population trends; however, possible changes in traffic volume or animal movement patterns due to habitat loss over time need to be considered. For a few species of amphibians in B.C., it is possible to measure relative abundance by counting the number of egg masses laid in ponds near roads or by conducting auditory surveys of breeding calls. For many species, however, more time-intensive sampling or capture-mark-recapture projects are needed to monitor changes in relative abundance and population size.

A variety of sampling protocols can be used to monitor population trends of amphibians and reptiles:

Capture-mark-recapture techniques may be used to estimate population size, but a large number of individuals need to be marked and recaptured to produce statistically significant estimates. Population trends (decreasing, increasing, or stable) can be observed if capture-mark-recapture sampling is repeated over time.

Relative abundance surveys (counts of animals per area and standardized by search effort) require a systematic study design with regular surveys conducted by trained individuals to reduce observer bias. Surveys are carried out using standardized methods, such as timed searches, grids, or transects, that allow for comparisons over time or between sites. Visual searches (especially on road transects), coverboards, and/or pitfall traps may be employed. Two effective measures of relative abundance for certain species of amphibians are counts of egg masses during visual surveys or adults during call surveys.

Counts of egg masses provide an efficient way to obtain non-invasive measures of the relative abundance of breeding amphibians. This technique can be used only for species in which individual breeding females lay single egg masses that are easy to detect and distinguish. Protocols should follow provincial standards (RISC 1998a). Egg mass identification guides are available (Corkran and Thoms 2020; Salt Spring Island Conservancy 2018). In B.C., it is possible to count egg masses of Northern Red-legged Frogs (*Rana aurora*), Oregon Spotted Frogs (*Rana pretiosa*), Columbia Spotted Frogs (*Rana luteiventris*), Wood Frogs (*Lithobates sylvaticus*), Northern Leopard Frogs (*Lithobates pipiens*), and Northwestern Salamanders (*Ambystoma gracile*).

Call surveys may be used to collect relative abundance data for toads and frogs at breeding ponds near roads, and do not require direct observation of the animals. Data logger monitoring devices can also be employed. However, in B.C., this monitoring technique is limited because few frog and toad species produce audible (surface detectable) calls. This technique can be used for the Great Basin Spadefoot Toad (*Spea intermontana*), Wood Frog (*Lithobates sylvaticus*), Boreal Chorus Frog (*Pseudacris maculata*), and Northern Pacific Treefrog (*Pseudacris regilla*). Northern Red-legged Frogs produce calls underwater, which can be detected with the aid of a handheld hydrophone.

Genetic sampling involves taking blood or tissue samples from live or dead individuals. It can be used to compare genetic relatedness and structuring (e.g., sex and age ratios) across a landscape that is bisected by a road before and after a mitigation project has been implemented (e.g., James et al. 2011).

Further information on methods for surveying amphibians and reptiles is provided in Heyer et al. (1994), Thoms et al. (1997) and McDiarmid et al. (2012). RISC (1998b) and the Canadian Council on Animal Care (CCAC 2004) provide excellent manuals on handling and capturing amphibians and reptiles.

7.3.2.4 Population viability modelling

If it is not feasible to measure population size or relative abundance, population viability modelling can be used to analyze the effect of mitigation on population levels (Section 2.2). **This approach integrates data on life history traits with changes in road mortality and movements across roads**.

Life history traits are quantified as "vital rates", and include:

- average female fecundity (number of eggs laid / live young per year per female);
- hatching success (number of eggs that hatch);
- juvenile survival (number of juveniles that grow from hatchling to subadult);
- subadult survival (number of subadults that reach adulthood); and
- adult survival (annual survival rates of adults from one breeding season to the next).

Vital rates for the female component of the population are necessary, and models improve with information about males. It can take years to measure vital rates of local populations; therefore, estimates from the literature are often used. Overall, this approach is useful for predicting relative, long-term changes in populations with and without mitigation. The accuracy of the model depends on the accuracy of the data used.

Data that need to be monitored for modelling purposes include:

- sex, reproductive status, and age classes of individuals killed on the road;
- sex and age classes of individuals moving through crossing structures in each direction; and
- proportion of individuals, by sex, reproductive status, and age class, killed on the road.

If particular individuals, such as breeding females, do not use a crossing structure to access breeding sites, it will lead to reduced breeding success and population declines. This would be true even if overall traffic mortality for the species has been reduced because some individuals, such as juveniles, use the crossing structure.

How differences in life history traits influence populations affected by roads

The results from population viability models show that differences in life history traits across species are important when considering population responses to road mortality. Finding many dead animals of a specific species on a road does not necessarily reflect greater population impacts for that species. Species with lower reproductive output (e.g., some snake species) suffer more by the loss of only a few individuals than species with high reproductive output (e.g., some frog and toad species). In addition, the loss of only a few reproductively mature individuals has a greater impact on the population than the mortality of hundreds of subadults that attempted to cross a road. For more information, see Section 2.2.

7.4 Communication Needs for Adaptive Management

Adaptive management involves using monitoring results to inform decision-making. Monitoring, research, and open communication among project partners (e.g., people conducting the monitoring, the road authority, contractors, experts) and across projects facilitate this process. The B.C. Herpetofauna and Roads conferences and working group provide an opportunity for sharing information and bringing together a group of experts who are working in this field. Ongoing communication through the B.C. Herpetofauna and Roads Working Group's annual conference calls and face-to-face workshops once every five years will ensure that the guidelines in this document are kept up-to-date and that road impacts on amphibians and reptiles are prevented and mitigated using the most current science and adaptive management techniques available.

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APPENDICES

APPENDIX 1 Amphibian and reptile species, their status (federally SARA listed species are highlighted in bold), and the TRAN region(s) where they occur (current to June 2018; check the SARA registry and BC Species and Ecosystem Explorer for updates).

Scientific Name	English Name	COSEWIC[a]	B.C. List	Identified Wildlife	SARA[a]	MOE Region(s)[b]	TRAN Region(s)
TERRESTRIAL-BREEDING SALAMANDERS							
Aneides vagrans	**Wandering Salamander**	**SC (2014)**	**Blue**		**1-SC (2018)**	**1**	**1,2,3 (some Georgia Strait islands - 3 or 5?)**
Ensatina eschscholtzii	Ensatina	NAR (1999)	Yellow			1,2,5,6	1,2,3,4,5,6
Plethodon idahoensis	**Coeur d'Alene Salamander**	**SC (2007)**	**Yellow**	**Yes (2004)**	**1-SC (2003)**	**4**	**9,10**
Plethodon vehiculum	Western Red-backed Salamander	NAR (2001)	Yellow			1,2	1,2,3,4,6, south end of 5
STREAM-BREEDING AMPHIBIANS							
Ascaphus montanus	**Rocky Mountain Tailed Frog**	**T (2013)**	**Blue**	**Yes (2004)**	**1-T (2018)**	**4**	**11**
Ascaphus truei	**Coastal Tailed Frog**	**SC (2011)**	**Yellow**	**Yes (2004)**	**1-SC (2003)**	**1,2,3,5,6,8**	**4,5,6,7,17,26**
Dicamptodon tenebrosus	**Coastal Giant Salamander**	**T (2014)**	**Blue**	**Yes (2004)**	**1-T (2003)**	**2**	**7**
POND-BREEDING AMPHIBIANS							
Ambystoma gracile	Northwestern Salamander	NAR (1999)	Yellow			1,2,5,6	1,2,3,4,5,6,7,17,26
Ambystoma macrodactylum	Long-toed Salamander	NAR (2006)	Yellow			1,2,3,4,5,6,7,8,9	1-21, 23-28
Ambystoma mavortium	**Blotched Tiger Salamander**	**E (2012)**	**Red**	**Yes (2004)**	**1-E (2018)**	**8**	**8,9**
Anaxyrus boreas	**Western Toad**	**SC (2012)**	**Yellow**		**1-SC (2005)**	**1,2,3,4,5,6,7,8,9**	**1-28**
Lithobates pipiens	**Northern Leopard Frog**	**E (2009)**	**Red**	**Yes (2004)**	**1-E (2003)**	**1,4,8**	**10,11**
Lithobates sylvaticus	Wood Frog		Yellow			3,4,5,6,7,9	11,12,15-26, 28
Pseudacris maculata	Boreal Chorus Frog		Yellow			7,9	21,22
Pseudacris regilla	Northern Pacific Treefrog		Yellow			1,2,3,4,5,6,7,8,	1-18,20,27
Rana aurora	**Northern Red-legged Frog**	**SC (2015)**	**Blue**	**Yes (2004)**	**1-SC (2005)**	**1;2;5;6**	**1-7,17**
Rana luteiventris	Columbia Spotted Frog	NAR (2000)	Yellow			2,3,4,5,6,7,8,9	4-27,28
Rana pretiosa	**Oregon Spotted Frog**	**E (2011)**	**Red**		**1-E (2003)**	**2**	**6,7**
Spea intermontana	**Great Basin Spadefoot**	**T (2007)**	**Blue**	**Yes (2004)**	**1-T (2003)**	**3,5,8**	**8,9,13-15**
Taricha granulosa	Roughskin Newt		Yellow			1,2,3,5,6	1,2,3,4,5,6,7,17,26
Lithobates catesbeianus	American Bullfrog		Exotic				1,2,6,7
Lithobates clamitans	Green Frog		Exotic				1,2,3,4,5,6,7,8

[a] SC - Special Concern; NAR - Not at Risk; T - Threatened; E - Endangered

[b] MOE Region: 1 - Vancouver Island; 2 - Lower Mainland; 3 = Thompson-Nicola; 4 - Kootenays; 5 - Cariboo; 6 - Skeena-Bulkley Valley; 7 - Omineca; 8 - Okanagan; 9 - Peace

Scientific Name	English Name	COSEWIC[a]	B.C. List	Identified Wildlife	SARA[a]	MOE Region[b]	TRAN Region(s)
TURTLES							
Chrysemys picta pop. 1	**Painted Turtle - Pacific Coastal Population**	**T (2016)**	**Red**		**1-E (2007)**	**1,2**	**1,2**
Chrysemys picta pop. 2	**Painted Turtle - Intermountain-Rocky Mountain Pop.**	**SC (2016)**	**Blue**		**1-SC (2007)**	**3,4,5,8**	**south part of 5, 8-11, 13**
Trachemys scripta	Pond Slider		Exotic				1,2,4,6,8,9 (in lakes & ponds in many cities and towns)
LIZARDS							
Elgaria coerulea	Northern Alligator Lizard	NAR (2002)	Yellow			1,2,3,4,5,8	**1-11,13,14**
Plestiodon skiltonianus	**Western Skink**	**SC (2014)**	**Blue**		**1-SC (2005)**	**3,4,8**	**8-10**
Podarcis muralis	Common Wall Lizard		Exotic				1
SNAKES							
Charina bottae	**Northern Rubber Boa**	**SC (Apr 2016)**	**Yellow**		**1-SC (2005)**	**2,3,4,5,8**	**4-11,13-16**
Coluber constrictor	**North American Racer**	**T (2015)**	**Blue**	**Yes (2006)**	**1-SC (2006)**	**2,3,4,5,8**	**8,9, 13-16**
Contia tenuis	**Sharp-tailed Snake**	**E (2009)**	**Red**		**1-E (2003)**	**1,2,3**	**1,4**
Crotalus oreganus	**Western Rattlesnake**	**T (2015)**	**Blue**	**Yes (2006)**	**1-T (2005)**	**3,8**	**8,9,13-15**
Hypsiglena chlorophaea	**Desert Nightsnake**	**E (2011)**	**Red**		**1-E (2003)**	**8**	**8**
Pituophis catenifer	**Gopher Snake - *deserticola* subspecies**	**T (2013)**	**Blue**		**1-T (2005)**	**1,2,3,4,5,8**	**8,9, 13-16**
Thamnophis elegans	Terrestrial Gartersnake		Yellow			1,2,3,4,5,6,7,8,9	1-17
Thamnophis ordinoides	Northwestern Gartersnake	NAR (2003)	Yellow			1,2,3,5	1-7
Thamnophis sirtalis	Common Gartersnake		Yellow			1,2,3,4,5,7,8,9	all

[a] SC - Special Concern; NAR - Not at Risk; T - Threatened; E - Endangered

[b] MOE Region: 1 - Vancouver Island; 2 - Lower Mainland; 3 = Thompson-Nicola; 4 - Kootenays; 5 - Cariboo; 6 - Skeena-Bulkley Valley; 7 - Omineca; 8 - Okanagan; 9 - Peace

APPENDIX 2 Impacts of roads on amphibians and reptiles (federally listed species are highlighted in bold)

NOTE: Actual numbers of amphibians observed are not presented in most cases. There is limited value in listing numbers because they have not been corrected to length of road surveyed and number of surveys conducted. Listing the locations gives a sense of the scope of the problem for each species.

Species	Examples of Documented Road Mortality Occurrences in B.C.	Other Documented Impacts of Roads
TERRESTRIAL-BREEDING SALAMANDERS		
Wandering Salamander	Few reported at any site. Highway 4 Ucluelet–Tofino: 21 dead over 6 years, < 1% of the population adjacent to the highway killed each year (B. Beasley, unpubl. data); Lazo Rd., Comox: 1 live, 2 dead in 2011; Nanaimo Lakes Rd.: 1 dead from 2007 to 2011 (Wind 2012). Ross-Durrance Rd., Highlands (CRD): 1 dead adult in 2015 (< 1% of roadkilled amphibians that could be identified to species) (HAT 2015).	Genetic divergence found in several populations of terrestrial-breeding salamanders bisected by large highways (Marsh et al. 2008).
Ensatina	Few reported at any site. Lazo Rd., Comox: 1 live, 1 dead in 2011; Laburnum Rd., Qualicum: 12 dead 2006 to 2013 (Materi 2013); Nanaimo Lakes Rd.: 97 dead, 33 live from 2007 to 2011; Riverbottom Rd. at Wake Lake near Duncan (Wind 2012). Highlands and Saanich (CRD): 33 live, 8 dead from 2015 to 2018 (< 1% of roadkilled amphibians that could be identified to species) (HAT 2015; Ovaska and Engelstoft, unpubl. data).	
Coeur d'Alene Salamander	Mt. Revelstoke National Park road: numerous adults and juveniles on wet paved road surface, Sept. 2010 (Ovaska and Sopuck, unpubl. data). Rangewide: found clinging to rock walls and venturing onto the gravel shoulder of highways on rainy nights (Ohanjanian 2003).	A threat to at least 20 of the 56 known species sites is highway widening and maintenance (COSEWIC 2007a). Planned widening of the Trans-Canada Highway near Revelstoke would cause direct mortality and habitat disruption (B.C. MOE 2015a). Rock-scaling, ditch-cleaning, culvert repair and replacement, blasting, vegetation clearing, dumping of spoil, and salt application will cause mortality/harm.
Western Red-backed Salamander	Highway 4 Ucluelet–Tofino: 26 dead, 25 live from 2001 to 2006 (Beasley 2006); Nanaimo Lakes Rd.: 57 dead, 13 live from 2007 to 2011; Riverbottom Rd. at Wake Lake near Duncan; Lazo Rd., Comox: 1 live, 1 dead in 2011 (Wind 2012); Laburnum Rd., Qualicum: 24 dead 2006 to 2013 (Materi 2013); Highlands, Saanich, and East Sooke (CRD): 9 live, 4 dead from 2015 to 2018 (< 1% of roadkilled amphibians that could be identified to species) (HAT 2015; Ovaska and Engelstoft, unpubl. data).	

Species	Examples of Documented Road Mortality Occurrences in B.C.	Other Documented Impacts of Roads
STREAM-BREEDING AMPHIBIANS		
Rocky Mountain Tailed Frog	Not reported. Risk of road mortality may be low because of nocturnal habits and low traffic volumes at night.	Extensive road networks in the Yahk and Flathead areas are sources of chronic sedimentation that reduces tadpole abundance (Dupuis and Friele 2006). Full-round culverts are barriers to upstream movements; General Wildlife Measures within Tailed Frog Wildlife Habitat Areas specify the use of bridges or open-bottom (half-round) culverts for road crossings (B.C. Ministry of Water, Land and Air Protection 2004).
Coastal Tailed Frog	Not reported.	Sedimentation from constructed channel crossings (Ardea Biological Consulting Ltd. 1999; Dupuis and Friele 2004). Road use is a chronic source of sedimentation (Reid and Dunne 1984).
Coastal Giant Salamander	Not reported. Most roads in the region where this species occurs are in upslope habitats that are less occupied (i.e., not near and parallel to watercourses) (COSEWIC 2014).	Sediments and chemical pollutants from methods used to reduce road dust and to de-ice roads; fragmented forest habitats interfere with movement and dispersal of adults and juveniles (COSEWIC 2014).
POND-BREEDING AMPHIBIANS		
Northwestern Salamander	Highway 4 Ucluelet–Tofino: 258 dead, 139 live (Beasley 2006); Lazo Rd., Comox: 6 dead, 3 live in 2011; Nanaimo Lakes Rd.: 14 dead, 5 live from 2007 to 2011 (Wind 2012).	
Long-toed Salamander	Lazo Rd, Comox: 5 dead, 5 live in 2011; Laburnum Rd., Qualicum: 89 dead 2006 to 2013 (Materi 2013); Nanaimo Lakes Rd.: 25 dead, 6 live from 2007 to 2011 (Wind 2012); Airport Rd. at Arrow Lakes Reservoir (Tuttle and Hawkes 2011); Highway 3A at Grohman Narrows Provincial Park: 16 dead, 10 live in Mar./Apr. 2015 (Dulisse 2015); White Lake: 23 dead from 2015 to 2016, though this is an underestimate (Winton 2017); Highlands and Saanich (CRD): 9 dead, 13 live from 2015 to 2018 (< 1% of roadkilled amphibians that could be identified to species) (HAT 2015; Ovaska and Engelstoft, unpubl. data).	
Blotched Tiger Salamander	Highway 97 Oosoyoos: 13 dead, 2 live from 2010 to 2012 (Crosby 2014); White Lake, Penticton: 240 dead juveniles in four surveys, Aug. 2–23, 2013 (Dyer 2018); White Lake: 13 dead from 2015 to 2016 (Winton 2017).	

Species	Examples of Documented Road Mortality Occurrences in B.C.	Other Documented Impacts of Roads
Western Toad	Vancouver Island sites: Sooke Mainline at Sooke Lake, Riverbottom Rd. in Duncan, Spruston Rd. in Nanaimo, Katherine Dr. in Port Alberni, Highway 19 near Courtenay, Railway Ave. in Merville, MU-55 near Gold River—all report high mortality of juveniles and some adults (Wind and Willmott 2012). Also at Nanaimo Lakes Rd. in lower numbers (Wind 2012). High numbers of juveniles on Toquaht Rd. (B. Beasley, pers. obs.). Mainland/Interior sites: Ryder Lake Rd. in Chilliwack (Clegg 2011), Allard Crescent in Langley, Lost Lake in Whistler (Wind and Willmott 2012), Airport Rd. at Arrow Lakes Reservoir (Tuttle and Hawkes 2011), Prince George (M. Thompson, pers. comm., 2011, cited in COSEWIC 2012), Dawson Creek (S. Kinsey, pers. comm., 2011, cited in COSEWIC 2012), Chilliwack, and Summit Lake (Dulisse et al. 2017), Kentucky-Alleyne Provincial Park 2011–2014 (Biolinx Environmental Research and Nicola Naturalist Society 2013, 2014), Highway 31A at Fish/Bear Lakes (McCrory and Mahr 2018), Highway 22A near the Waneta Dam. Most report both juvenile and adult mortality (Machmer 2012, 2015).	Irrigation ponds/borrow pits created during road construction provide poor larval habitat (Stevens and Paszcowski 2006). Beaver control, used to prevent road flooding, can result in loss and deterioration of breeding habitat (Stevens et al. 2007). Roadside culverts and verges of logging roads are used as movement corridors (Deguise and Richardson 2009).
Northern Leopard Frog	Dyke road at Creston Valley Wildlife Management Area: 1 adult and 1 young-of-the-year killed, with only two cars using the road (Houston 2010). Remain immobile at the approach of a vehicle (Mazerolle et al. 2005). A very small amount of road mortality impacts the very small population of Northern Leopard Frogs at Creston.	
Wood Frog	No data.	
Boreal Chorus Frog	No data.	
Northern Pacific Treefrog (a.k.a. Pacific Chorus Frog)	Highway 4 Ucluelet–Tofino: 315 dead, 69 live from 2001 to 2006 (Beasley 2006); Lazo Rd., Comox: 299 dead, 32 live in 2011; Laburnum Rd., Qualicum: 479 dead 2006 to 2013 (Materi 2013); Nanaimo Lakes Rd., Nanaimo, and Riverbottom Rd. at Wake Lake near Duncan (Wind 2012); Highway 97 near Oosoyoos: 279 dead, 148 live from 2010 to 2012 (Crosby 2014); Ryder Lake Rd. in Chilliwack (Clegg 2011); Airport Rd. at Arrow Lakes Reservoir (Tuttle and Hawkes 2011); Highway 3A at Grohman Narrows Provincial Park: 81 dead, 13 live in Mar./Apr. 2015 (Dulisse 2015); Highlands, Saanich, Metchosin, East Sooke (CRD): 1099 dead, 256 live from 2015 to 2018 surveys (74% of roadkilled amphibians that could be identified to species) (HAT 2015; Ovaska and Engelstoft, unpubl. data); White Lake: 114 dead from 2015 to 2016 (Winton 2017); Highway 22A near the Waneta Dam: 13 dead during the Waneta Expansion Project, 2011–2014 (Machmer 2012, 2015).	

Species	Examples of Documented Road Mortality Occurrences in B.C.	Other Documented Impacts of Roads
Northern Red-legged Frog	Highway 4 Ucluelet–Tofino: 330 dead, 37 live, 2001–2006, (Beasley 2006); Coombs (Blood and Henderson 2000); Nanaimo Lakes Rd (Wind 2012); Highway 4 within Pacific Rim National Park Reserve; Ryder Lake Rd. in the Fraser Valley (Clegg 2011); Laburnum Rd., Qualicum: 41 dead 2006 to 2013 (Materi 2013); Lazo Rd., Comox: 78 dead, 2 live in 2011 (Wind 2012); Wake Lake near Duncan (Wind 2012); Sea-to-Sky Highway at Pinecrest (Malt 2012); Highlands, Saanich, Metchosin (CRD): 30 dead, 10 live (2% of roadkilled amphibians that could be identified to species) (HAT 2015; Ovaska and Engelstoft, unpubl. data).	Road construction along Sea-to-Sky Highway 99 resulted in the removal of 4160 m^2 of wetland habitat and salvage of 1037 amphibians (including 683 Northern Red-legged Frogs) (Malt 2012). Roads are barriers to movement in dry conditions (B. Beasley, unpubl. data). Road de-icing salts and other pollutants from roads drain into ditches and wetlands where the species spends time, and sometimes breeds (B. Beasley, unpubl. data).
Columbia Spotted Frog	Highway 22A near the Waneta Dam: 3 dead during the Waneta Expansion Project, 2011–2014 (Machmer 2012, 2015).	
Oregon Spotted Frog	Not reported. Populations at Maintenance Detachment Aldergrove, Maria Slough, and Mountain Slough are close to roads, but road mortality is a knowledge gap (Canadian Oregon Spotted Frog Recovery Team 2012). Road mortality of this species is not anticipated because it does not spend substantial time out of water. Western Toads and Northern Red-legged Frogs have been found dead on the roads adjacent to the Maria Slough site. Oregon Spotted Frogs are thought to move through wetted culverts with low water flow.	At Maria Slough, improper timing of culvert maintenance and watercourse clearing resulted in the water level dropping and stranding eggs out of water. Ditch clearing and deepening alters the availability and suitability of habitat, causes direct mortality, and enables American Bullfrog (an invasive competitor/predator) occupation and breeding. Roads isolate populations and prevent new colonization.
Great Basin Spadefoot	Inkaneep Rd. near Oliver, July 1990 (R. Cannings, pers. obs. Cited in COSEWIC 2007b); Highway 97 near Osoyoos: 1648 dead, 1894 live from 2010 to 2012 (Crosby 2014); White Lake: 44 dead from 2015 to 2016 (Winton 2017); Douglas Lake Rd., Upper Nicola: 21 live adults and juveniles on road from 2011 to 2015 (Ovaska et al. 2016; K. Ovaska, unpubl. data).	Effects of using magnesium chloride for dust abatement during road maintenance need to be studied (R. Packham, pers. comm., 2014 cited in Southern Interior Reptile and Amphibian Working Group 2017).
Rough-skinned Newt	Highway 4 near Coombs (Blood and Henderson 2000); Nanaimo Lakes Rd.: 1781 dead, 81 live from 2007 to 2011 (Wind 2012); Highway 4 Ucluelet–Tofino: 65 dead, 6 live from 2001 to 2006 (Beasley 2006); Ryder Lake Rd. in the Fraser Valley (Clegg 2011); Lazo Rd., Comox: 313 dead, 14 live in 2011; Laburnum Rd., Qualicum: 502 dead 2006-2013 (Materi 2013); Wake Lake, Duncan: 11 dead, 2 live in 2011 (Wind 2012); Highlands, Saanich, Metchosin (CRD): 334 (14% of amphibians) dead, 28 live (22.5% of roadkilled amphibians that could be identified to species) (HAT 2015; Ovaska and Engelstoft, unpubl. data). Gulf Islands – numerous roads (B. Penn, pers. comm., 2018).	

Species	Examples of Documented Road Mortality Occurrences in B.C.	Other Documented Impacts of Roads
TURTLE		
Western Painted Turtle	Beaver Lake Rd. in Saanich (Ovaska and Engelstoft 2011); Sunshine Coast Highway (Kilburn et al. 2011); Arrow Lakes Reservoir (Tuttle and Hawkes 2011); White Lake: 2 dead from 2015 to 2016 (Winton 2017); Highway 3 in Cranbrook (Gillies and St. Clair 1997; Dulisse and Clarke 2018). Nesting females are killed when crossing these roads to nest in the fill material or exposed cutbanks along roadsides, or to nest at sites on the opposite side of the road.	Road construction immediately adjacent to wetlands destroys nests (Maltby 2000). Roadways lead to increased predation by raccoons, skunks, coyotes, and foxes (Frey and Conover 2006).
LIZARDS		
Northern Alligator Lizard	Creston: Not commonly found on roads even though 6 of 10 occupied sites within a study were bordered on one side by a road (Rutherford and Gregory 2003).	Not attracted to roads as heat sources, but it is possible that roads act as barriers between populations (Rutherford and Gregory 2003).
Western Skink	Creston: Not commonly found on roads even though 6 of 10 sites within a study were bordered on one side by a road (Rutherford and Gregory 2003).	Rock blasting may cause direct mortality and destruction of important basking sites, nesting sites, or hibernacula. Conversely, road and other corridor construction may enhance skink habitat through the creation and maintenance of open areas. Also, the presence of blast rock pieces that are created from the construction of roads, power lines, or pipelines may also increase available cover for skinks (Dulisse 2006).
SNAKES		
Northern Rubber Boa	Okanagan, Creston, Pemberton—Lillooet Highway (P. Gregory, pers. comm., 2014, cited in COSEWIC 2016).White Lake: 19 dead from 2015 to 2016 (Winton 2017). Highway 22A near the Waneta Dam: 18 dead during the Waneta Expansion Project, 2011–2014, and 1 dead prior to the Project in 2009 (Machmer 2012, 2015).	Bentley Rd. to Okanagan Lake Parkway Highway construction destroyed den and snakes (Summit Environmental Consultants 2010 cited in BC MOE 2015b).
Western Yellow-bellied Racer	Okanagan Connector: almost all suitable habitats are intersected by the road. White Lake: 128 dead from 2015 to 2016 (Winton 2017); Highway 22A near the Waneta Dam: 29 dead, 3 alive during the Waneta Expansion Project, 2011–2014, and 2 dead prior to the Project in 2009 (Machmer 2012, 2015).	Habitat loss and fragmentation.
Sharp-tailed Snake	North Pender and South Pender Islands: 6 dead (Spalding 1995; Engelstoft and Ovaska 1999; C. Engelstoft, pers. comm., 2008). Traffic at the busy ferry terminal on Saltspring Island poses a risk to snakes nearby and one site on Vancouver	Localities on Gulf Islands: habitat fragmentation hinders dispersal movements.

Species	Examples of Documented Road Mortality Occurrences in B.C.	Other Documented Impacts of Roads
	Island is bisected by a popular recreational trail, and mortality from collisions with bicycles is a possibility, although is undocumented (COSEWIC 2009).	
Western Rattlesnake (a.k.a. North Pacific Rattlesnake)	Osoyoos Indian Reserve: roadkills were 72–100% of known mortalities over the 3-year period reported (Snook and Blaine 2012); White Lake: 92 dead from 2015 to 2016 (Winton 2017), with 6.6% of the population killed on the road annually, and projected population decline (Winton 2018); Highway 97 between the U.S. border and Okanagan Falls: none detected from 2010 to 2013, though heavy traffic is incompatible with the species (S. Ashpole, pers. comm., 2014 cited in COSEWIC 2015). Across B.C. range: 50% of 106 dens were subjected to regular road mortality or damage from road construction (Sarell 1993); 86% of 368 confirmed dens were located within 2 km of a road (Hobbs 2013).	Snakes and hibernacula were destroyed by earth-moving equipment during road construction (M. Sarell, pers. obs.).
Desert Nightsnake	South-central British Columbia: Only about 20 Desert Nightsnakes have been reported in Canada, all from a small region that is under intense development pressure.	Habitat loss and population isolation.
Great Basin Gopher Snake	Highway 1 from Chase to Ashcroft, and Highway 97 from Summerland to Peachland: local extirpations/precipitous declines (J. Hobbs, pers. comm., 2013 cited in COSEWIC 2013). White Lake: 84 dead from 2015 to 2016 (Winton 2017). In British Columbia, Reed (2013) predicted a Gopher Snake population reduction over 24 years (three generations) of 40–50%, if road mortality affected adults only, and up to 90% if road mortality affected all age classes.	Habitat fragmentation. Highways 3 and 8 bisect prime habitat.
Terrestrial Gartersnake	Airport Rd. at Arrow Lakes Reservoir (Tuttle and Hawkes 2011). White Lake: 9 dead from 2015 to 2016 (Winton 2017). Highway 22A near the Waneta Dam: 8 dead, 2 alive during the Waneta Expansion Project, 2011–2014, and 1 dead, 1 alive prior to the Project in 2009 (Machmer 2012, 2015).	
Northwestern Gartersnake	No data.	
Common Gartersnake	Airport Rd. at Arrow Lakes Reservoir (Tuttle and Hawkes 2011); Highway 4 Ucluelet—Tofino (B. Beasley, unpubl. data); White Lake: 20 dead from 2015 to 2016 (Winton 2017). Highway 22A near the Waneta Dam: 5 dead, 1 alive during the Waneta Expansion Project, 2011–2014, and 3 dead, 1 alive prior to the Project in 2009 (Machmer 2012, 2015).	

APPENDIX 3 Migration, dispersal, and movement distances of amphibians and reptiles in B.C. (federally listed species are highlighted in bold)

Species	Migration/Dispersal Distances from Key Habitats	Distance between Captures, and Home Range Estimates
TERRESTRIAL-BREEDING SALAMANDERS		
Wandering Salamander	No seasonal migrations, but occasionally found on roads.	94% of movements between recaptures of marked individuals at Rosewall Creek were < 10 m; average distance between captures was 2.8 m; longest distance was 38 m (*N* = 176) (Davis 1991).
Ensatina	No seasonal migrations, but occasionally found on roads.	Most individuals were recaptured in the same location within a 50 m × 50 m sample plot in Maple Ridge; longest distance moved was 80 m (Maxcy 2000).
Coeur d'Alene Salamander	Annual fall migration from interior of a cave to outside is ~25 m (Ohanjanian 2000).	Longest distance moved was 52.8 m (Ohanjanian and Beaucher 2002).
Western Red-backed Salamander	No seasonal migrations, but occasionally found on roads.	In Goldstream Provincial Park, Vancouver Island, individuals showed high fidelity to particular cover objects on the forest floor, and their movements over several years were very small: mean distance between the two farthest captures was 2.5 m for adult males, 1.7 m for adult females, and 2.0 m for juveniles, and the longest movement by a male was 8.5 m based on capture-mark-recapture (Ovaska 1988).
STREAM-BREEDING AMPHIBIANS		
Rocky Mountain Tailed Frog	Seasonal migration follows mainly an elevational gradient along streams, but dispersal movements between streams are also likely.	Juvenile female moved 360 m over 1 year, 50% of reproductively mature adults had a maximum movement of 20 m/yr in Montana (Daugherty and Sheldon 1982).
Coastal Tailed Frog	No seasonal migration reported. Rapid recolonization of Mt. St. Helens following the 1980 eruption (Crisafulli et al. 2005) may indicate they are capable of occasional, long range dispersal.	Average daily distances moved on land were 23.3 m ± 7.8 m for females and 16.8 m ± 3.9 m for males in the B.C.'s South Coast region (Wahbe et al. 2004).
Coastal Giant Salamander	Johnston (1998) and Johnston and Frid (2002) found that 67% of locations of 18 radio-tracked adults in old-growth and mature second-growth forest were within 5 m of a stream bank. Longest distance moved by an adult from the stream bank was 66 m. Several studies in	Average movement distances for individual salamanders ranged from 3 to 21 m (Johnston and Frid 2002). Average adaptive kernel home range

Species	Migration/Dispersal Distances from Key Habitats	Distance between Captures, and Home Range Estimates
	Oregon have reported finding the Pacific Giant Salamander up to 400 m from stream edges (reviewed in Olson et al. 2007).	size for individual salamanders ranged from 3 to 35,321 m^2 (Johnston and Frid 2002).
POND-BREEDING AMPHIBIANS		
Northwestern Salamander	Migrate toward breeding ponds in fall and away from ponds in spring; some individuals crossed the road > 500 m from breeding pond (Beasley 2006, 2013).	Most individuals moved 30 m within 35 days in 50 m x 50 m sample plots in Maple Ridge; a single individual moved more than 1.25 km between sample plots over 1.5 years (Maxcy 2000).
Long-toed Salamander	Migrate from overwintering sites to breeding ponds in early spring and away from ponds after egg laying. An individual was captured 750 m from a breeding pond in Hinton, Alberta (Graham 1997).	Straight-line distances between capture sites ranged from 135 to 525 m in Hinton, Alberta (Graham 1997). Home range estimates per individual ranged from 115 to 282 m^2 in the Bow Corridor, Alberta (Sheppard 1977).
Blotched Tiger Salamander	Radio-tagged adults rarely moved more than 250 m from the wetland of capture (Richardson et al. 2000; Steen et al. 2006). Juveniles are more likely to disperse than are adults (up to 20% of juveniles vs. 3–6% of adults move between wetlands in any given year (Church and Wilbur, unpubl. data, cited in Church et al. 2007). There are anecdotal reports of salamanders found up to 3 km from the nearest wetland (Sarell and Robertson 1994).	Daily movements were generally constrained within a 5-m radius and were often centred on abandoned animal burrows (Richardson et al. 2000).
Rough-skinned Newt	Variation in migratory arrival/departure of males and females at breeding ponds across sites has been recorded (Efford and Mathias 1969; Neisch 1970; Oliver and McCurdy 1974). Adults have been found in underground retreats within 400 m of breeding ponds (Pimentel 1960), but there has been little research on the terrestrial phase.	Most individuals moved 40 m within 35 days in 50 m × 50 m sample plots in Maple Ridge; a couple of individuals moved 80 m (Maxcy 2000). Homing experiments showed that displaced newts travelled 5.6 km back to home ponds in 485 days and 0.4 km back to home ponds in 5 days (Darrow 1967).
Western Toad	On Vancouver Island (Davis 2000; Wind 2018b) and in east-central Alberta (Browne 2010), most Western Toads used terrestrial habitats within 2 km of breeding sites, although longer movements were occasionally reported. Near Duncan, telemetry research indicated that 7 non-breeders hibernated an average distance of 1438 m from a potential breeding site, and the maximum fall movement from the point of capture to the hibernaculum was 1979 m (Wind 2018b). Western Toads are capable of directional long-distance dispersal movements (up to 7.2 km in < 24 hours in spring on Vancouver Island	The longest straight-line movement of radio-tagged adult male toads released in an unfamiliar area in Maple Ridge was 1.48 km (Deguise and Richardson 2009).

Species	Migration/Dispersal Distances from Key Habitats	Distance between Captures, and Home Range Estimates
	[T. Davis, pers. comm., 2004]). Schmetterling and Young (2008) documented movements up to 13 km.	
Northern Leopard Frog	Recently metamorphosed Northern Leopard Frogs disperse in all directions and have been observed 1 km from natal ponds in Creston (Waye and Cooper 2001). In southern Alberta, adults may travel up to 1.6 km from hibernation sites to breeding habitats (Wershler 1991). Seasonal dispersal distances of 8–10 km have been documented in Alberta (Alberta Northern Leopard Frog Recovery Team 2005).	Adults maintain small home ranges that vary from 15 to 600 m^2 (Dole 1965). Adults may move up to 160 m on a single rainy night (Waye and Cooper 2000) but generally remain in the vicinity of breeding areas.
Wood Frog	Post-breeding movements of adults from breeding pools to nearby, closed-canopy, forested wetlands ranged from 102 to 340 m (median 169 m, *N* = 8) in a telemetry study conducted in Maine (Baldwin et al. 2006). Juveniles have been observed dispersing to non-natal breeding sites over distances that exceeded 1200 m (Berven and Grudzien 1990).	Activity was localized inside forested wetlands during the summer (*N* = 38 tracked frogs). Summer movements in Maine were generally short (median 2.8 m, *N* = 217) but included some longer, rain-associated movements (maximum 61 m) to nearby wetlands (Baldwin et al. 2006).
Boreal Chorus Frog	Mark-recapture studies in montane Colorado showed maximum movements up to 750 m from breeding ponds, and maximum juvenile dispersal was approximately 690 m, but most individuals moved < 300 m (Spencer 1964).	No information available.
Pacific Treefrog	Fall and winter habitats can be several hundred metres from breeding sites (Jameson 1957). Adults migrate and some juveniles disperse more than 500 m from natal ponds (B. Beasley unpubl. data 2014).	Displaced frogs travelled more than 1000 m from release sites to capture sites (Jameson 1957).
Northern Red-legged Frog	Adults appear to leave breeding sites relatively soon after the breeding period and move substantial distances (commonly 1.5 km to up to 4.8 km from breeding pools) (Hayes et al. 2001, 2007); an individual was radio-tracked travelling 312 m in straight-line distance away from a breeding site (Serra Shean 2002); some juveniles disperse more than 500 m from natal ponds (B. Beasley, unpubl. data, 2014).	Travelled > 190 m (straight-line distance) through clearcuts during 2–3 rainy days (Chan-McLeod 2003); in Washington, five adult females moved up to 80 m/day during the spring migration period (Serra Shean 2002).
Oregon Spotted Frog	Highly aquatic adults move through wet channels between shallow breeding sites and deeper pools during the non-breeding season; they rarely move overland (Watson et al. 2003).	In Washington, home ranges during the breeding and fall seasons averaged 2.2 ha within a mosaic of wetlands and upland pasture (Watson et al. 2003). The same study reported movements of 32–111 m/day for 2–18 days. The longest reported movement was made by an adult female along Jack Creek in Oregon: she moved 2799 m (stream distance) from her original capture

Species	Migration/Dispersal Distances from Key Habitats	Distance between Captures, and Home Range Estimates
		location (Cushman and Pearl 2007). In the same study, two juveniles moved 1245 m and 1375 m downstream from their initial capture location.
Columbia Spotted Frog	In a radio-tracking study in the mountains of Idaho, many males remained in breeding habitat and those that moved were usually found within 400 m of breeding pond, whereas females moved up to 1033 m from breeding ponds (Pilliod et al. 2002).	
Great Basin Spadefoot	Richardson and Oaten (2013) found two types of movement patterns in shrub–steppe habitat near Kamloops. Twenty-one of 32 (66%) telemetered adults stayed within 500 m of an aquatic breeding site; 10 (48%) of them were between 250 m and 500 m of the wetland. Ten individuals made longer movements (750–2350 m) away from wetlands. These longer movements may have represented the dispersal of non-breeding individuals to other wetlands or to more distant foraging areas.	Garner (2012) used telemetry to track 19 adults in grassland and open forest habitat near 70 Mile House. After breeding, animals moved a mean of 100 m from aquatic habitat (95% confidence interval = 85.3–111.7), with an average maximum of 135.9 m ± 98.2 m and a maximum of 371 m.
TURTLE		
Painted Turtle	Movements of several hundred metres overland between ponds are not uncommon (Matsuda et al. 2006). Females, in particular, make extensive use of the terrestrial environment, and lay their eggs up to 150 m or more from the water's edge. In Nebraska, this species often migrates several kilometres from shallow or dry marshes and basins to permanent water bodies during dry summer months (Ernst et al. 1994).	Daily movement of a radio-tagged turtle recorded in the Lower Mainland showed average movement of 97.8 m within 2 hours, with a maximum of 582 m traveled in a 2- hour period (Kilburn and Mitchell 2011). In the same study, from July to March, one individual moved a straight-line distance of 2 km, traversing four sloughs and ending up in a small wetland.
LIZARDS		
Northern Alligator Lizard	Do not make large movements between hibernation or summer sites, as far as is known.	Rutherford and Gregory (2003) found an average distance of 16 m between recapture locations in Creston. The maximum distance was 750 m.

Species	Migration/Dispersal Distances from Key Habitats	Distance between Captures, and Home Range Estimates
Western Skink	Rutherford and Gregory (2003) found high site fidelity over 3 years.	Rutherford and Gregory (2003) found that 25 recaptures of tagged Western Skinks in the Creston Valley Wildlife Management Area in B.C. were on average 8 m from the previous capture in the same year, and maximum movement was 61.4 m during a season. The authors estimated the home range to be roughly 0.01 ha (a circle with a 10-m diameter is 78 m^2 or approximately 0.01 ha), but it may be higher.
SNAKES		
Northern Rubber Boa	One hibernaculum was about 450 m from the general area that the snake used in summer (St. Clair, unpubl. data, cited in COSEWIC 2016). Lowcock and Woodruff (2014) noted that some rubber boas travel short distances (< 100 m).	Using telemetry data, St. Clair (unpubl. data) calculated home ranges of two Northern Rubber Boas, including the hibernaculum, as 0.298 and 1.203 ha (COSEWIC 2016).
Western Yellow-bellied Racer	In B.C., migration distances from dens are poorly known. In B.C., gravid females may travel more than 500 m to suitable egg-laying sites (Sarell 2004).	In Utah, radio-telemetry studies (Brown and Parker 1976) indicated that maximum movement distances from two den sites were 1.6 and 1.8 km, with an average straight-line distance of < 1 km (781 m for males; 663 m for females). Shewchuk and Waye (1995) found that daily movements on summer ranges in the Okanagan were usually < 200 m and sometimes followed a circuit that returned to a regular overnight roost.
Sharp-tailed Snake	There is no evidence to suggest that individuals migrate between seasonal habitats. Hibernation and aestivation might occur within habitats that are occupied year-round, but long movements are very difficult to document.	Within a rural residential area on North Pender Island, 16 recaptured adults were found within areas that were usually < 55 m apart (average = 25 m; range: 16–93 m) over a year (Engelstoft and Ovaska 1999). The longest movement was made by an adult male that moved a straight-line distance of 93 m within a 3-week period in March–April (Engelstoft et al. 1999). In relatively undisturbed habitat on Vancouver Island, 5

Species	Migration/Dispersal Distances from Key Habitats	Distance between Captures, and Home Range Estimates
		recaptured snakes moved straight-line distances of up to 32 m within one active season (Ovaska and Engelstoft 2005).
Western Rattlesnake (a.k.a. North Pacific Rattlesnake)	The migration distance between summer foraging areas and overwintering dens varies depending on habitat; distances of 290–3500 m have been reported in B.C. Gravid females do not migrate but remain within 400 m of the hibernacula, frequently at group basking areas termed rookeries (Macartney 1985; Bertram et al. 2001). The maximum migration distance of a mature male was 3568 m (Gomez 2007), but most males remained within 1400 m of the den (Macartney 1985; Bertram et al. 2001; Gomez 2007; Lomas 2013). Migration from dens in the Okanagan occurs along specific corridors (Macartney 1985).	The linear distance moved by 10 adults (non-gravid females and males) from five dens near Kamloops varied from 290 to 3000 m (Bertram et al. 2001). Bertram et al. (2001) reported home ranges of 0.12–103.5 ha based on radio-telemetry locations of 12 snakes near Kamloops, with the smallest range being that of a gravid female. Other B.C. estimates range from 1.2 to 171 ha (Macartney 1985) and average 23 ha (Lomas 2013).
Great Basin Gopher Snake	Females may travel long distances (> 2 km) to nest sites. The longest single-season movements (> 2 km) were generally made by females travelling to oviposition sites in summer and fall (Shewchuk 1996; Bertram et al. 2001). Brown (2006) reported that 2 females near Vaseux Lake oviposited 81.2 m and 40.2 m from their respective hibernacula. White (2008) noted that in the Okanagan Valley, males moved farther than females in spring (perhaps searching for mates), while females moved farther than males in summer and fall.	Average movement distances of 350–500 m have been reported from B.C. (Kamloops: average maximum of 453 m [Bertram et al. 2001]; Osoyoos: 934 ± 185 m [Shewchuk 1996]; 520 ± 25 m [Williams et al. 2012]), but occasionally longer distances up to 2360 m have been documented (Williams et al. 2012). After reaching their summer ranges, movements of snakes in Osoyoos were relatively short (average 153 ± 96.2 m/day for females; 124.8 ± 23.7 m/day for males) and were centred on a particular retreat site (Shewchuk 1996). Home ranges of 1.14–33.47 ha have been documented in B.C. (Bertram et al. 2001; Brown 2006; White 2008).
Common Gartersnake	Can travel several kilometres between foraging sites and dens when these habitats are widely separated. In Wood Buffalo National Park, radio-tracked females travelled more than 3.75 km to reach a foraging marsh, and one individual completed a round trip of > 15 km (Larsen 1987). Near Valemont, hibernacula were 1.48 km from summer habitat (range 148–2657 m, *N* = 8) (McAllister 2018). At Spectacle Lake, summer ranges did not seem to be in areas that were distinct from dens (Lawson 1991).	Average daily movements tracked by radio-telemetry in Creston ranged from 2.5 m/day (gravid females) to 29.5 m/day (non-gravid females), and the longest distance moved was 93 m over 2 days (gravid female) and 236 m in 1 day (non- gravid female) (Charland and Gregory 1995).

Species	Migration/Dispersal Distances from Key Habitats	Distance between Captures, and Home Range Estimates
Northwestern Gartersnake	No information available.	Adult males moved an average of 6.2 m/day and 43 m between captures; females moved shorter distances on average (Macartney et al. 1988). Female daily movements did not differ from those made by Common Gartersnakes tracked by Charland and Gregory (1995) (see above).
Terrestrial Gartersnake	Very few studies; work by Lawson (1991) suggested that they are non-migratory because there was no evidence of dens in areas that were distinct from summer ranges at Spectacle Lake.	Home ranges at Spectacle Lake varied between 0.014 and 0.33 ha, and averaged 0.178 ha (*N* = 9) (Lawson 1991). The longest straight-line distance travelled was 230 m in 25 days (Lawson 1991). A recaptured male moved 40 m in 23 days in a Saanich park (Dixon-MacCallum 2013).

APPENDIX 4 General habitat associations of amphibians and reptiles in B.C.

Scientific Name	English Name	**Forest** (moist/wet, mesic, dry, mixed, deciduous, Garry Oak coastal bluffs)	**Shrub** (natural, logged, sagebrush steppe, antelope-brush steppe, hedgerow)	**Meadow / Grassland**	**Rock** (cliff, sparsely vegetated rock, talus)	**Subterreanean** (subsoil, caves)	**Riparian** (forest, shrub, herbaceous)	**Seeps / streams** (stream, river, splash zone, gravel bar)	**Wetland / Lake** (bog, fen, swamp, marsh, lake, pond / open water, vernal pool)	**Built / Industrial** (urban, suburban)	**Agricultural** (pasture, old field, cultivated field, ditches)
TERRESTRIAL-BREEDING SALAMANDERS											
Aneides vagrans	**Wandering Salamander**	**X**	**X**			**X**	**X**				
Ensatina eschscholtzii	Ensatina	X	X			X	X				
Plethodon idahoensis	**Coeur d'Alene Salamander**	**X**			**X**	**X**	**X**	**X**			
Plethodon vehiculum	Western Red-backed Salamander	X	X		X	X	X				
STREAM-BREEDING AMPHIBIANS											
Ascaphus montanus	**Rocky Mountain Tailed Frog**	**X**				**X**	**X**	**X**			
Ascaphus truei	**Coastal Tailed Frog**	**X**				**X**	**X**	**X**			
Dicamptodon tenebrosus	**Coastal Giant Salamander**	**X**				**X**	**X**	**X**			
POND-BREEDING AMPHIBIANS											
Ambystoma gracile	Northwestern Salamander	X				X	X	X	X		X
Ambystoma macrodactylum	Long-toed Salamander	X	X	X		X	X		X		
Ambystoma mavortium	**Blotched Tiger Salamander**	**X**	**X**	**X**		**X**	**X**		**X**		
Anaxyrus boreas	**Western Toad**	**X**	**X**	**X**		**X**	**X**	**X**	**X**		
Lithobates pipiens	**Northern Leopard Frog**		**X**	**X**			**X**	**X**	**X**		
Lithobates sylvaticus	Wood Frog	X	X	X		X	X	X	X	X	
Pseudacris maculata	Boreal Chorus Frog	X		X		X	X		X		
Pseudacris regilla	Northern Pacific Treefrog	X	X	X		X	X	X	X	X	X
Rana aurora	**Northern Red-legged Frog**	**X**		**X**		**X**	**X**	**X**	**X**		**X**
Rana luteiventris	Columbia Spotted Frog						X	X	X		
Rana pretiosa	**Oregon Spotted Frog**						**X**	**X**	**X**		
Spea intermontana	**Great Basin Spadefoot**	**X**	**X**	**X**		**X**			**X**		**X**
Taricha granulosa	Roughskin Newt	X		X		X	X	X	X		
Lithobates catesbeianus	American Bullfrog						X	X	X	X	X
Lithobates clamitans	Green Frog			X		X	X	X	X		

Sources:
Jones et al. (2005); Matsuda et al. (2006); B.C. Conservation Data Centre (2019)

Scientific Name	English Name	**Forest** (moist/wet, mesic, dry, mixed, deciduous, Garry Oak coastal bluffs)	**Shrub** (natural, logged, sagebrush steppe, antelope-brush steppe, hedgerow)	**Meadow / Grassland**	**Rock** (cliff, sparsely vegetated rock, talus)	**Subterreanean** (subsoil, caves)	**Riparian** (forest, shrub, herbaceous)	**Seeps / streams** (stream, river, splash zone, gravel bar)	**Wetland / Lake** (bog, fen, swamp, marsh, lake, pond / open water, vernal pool)	**Built / Industrial** (urban, suburban)	**Agricultural** (pasture, old field, cultivated field, ditches)
TURTLES											
Chrysemys picta	**Painted Turtle**					**X**	**X**	**X**	**X**	**X**	
Trachemys scripta	Pond Slider					X	X	X	X	X	
LIZARDS											
Elgaria coerulea	Northern Alligator Lizard	X		X	X	X	X	X			
Plestiodon skiltonianus	**Western Skink**	**X**	**X**	**X**	**X**	**X**	**X**	**X**			
Podarcis muralis	Common Wall Lizard			X	X	X				X	
SNAKES											
Charina bottae	**Northern Rubber Boa**	**X**	**X**	**X**	**X**	**X**	**X**	**X**			
Coluber constrictor	**North American Racer**	**X**	**X**	**X**	**X**	**X**	**X**				
Contia tenuis	**Sharp-tailed Snake**	**X**		**X**	**X**	**X**					
Crotalus oreganus	**Western Rattlesnake**	**X**	**X**	**X**	**X**	**X**	**X**				
Hypsiglena chlorophaea	**Desert Nightsnake**	**X**	**X**	**X**	**X**	**X**		**X**			
Pituophis catenifer	**Gopher Snake**	**X**	**X**	**X**	**X**	**X**			**X**		**X**
Thamnophis elegans	Terrestrial Gartersnake			X	X	X	X	X	X		
Thamnophis ordinoides	Northwestern Gartersnake		X	X	X	X	X			X	X
Thamnophis sirtalis	Common Gartersnake	X	X	X	X	X	X	X	X	X	X

Sources*:*

Matsuda et al. (2006); B.C. Conservation Data Centre (2019); Thompson Rivers University and B.C. Ministry of Environment and Climate Change Strategy (2019)

APPENDIX 5 Instructions for navigating iMapBC

Visit https://maps.gov.bc.ca/ess/hm/imap4m/

Critical Habitat for Federally-Listed Species at Risk – Posted:
1) In iMap, select the "Data Sources" tab
2) Click "Add Provincial Layers"
3) Select "Fish Wildlife and Plant Species"
4) Select "Critical Habitat for Federally-Listed Species at Risk – Posted"

For the most up-to-date information, mapped **Critical Habitat** (proposed and approved) for federal species at risk that occur in B.C. can also be found at http://donnees.ec.gc.ca/data/species/developplans/critical-habitat-for-species-at-risk-british-columbia/?lang=en

Wildlife Habitat Areas – Approved, Proposed, and Forest Range and Practices Act (FRPA)
1) In iMap, select the "Data Sources" tab
2) Click "Add Provincial Layers"
3) Select "Fish Wildlife and Plant Species"
4) Select "Wildlife Habitat Areas" Approved and Proposed

Terrestrial Ecosystem Mapping (TEM)
1) In iMap, select the "Data Sources" tab
2) Click "Add Provincial Layers"
3) Select "Forest Grasslands and Wetlands"
4) Select "Terrestrial Ecosystem Mapping (TEM)"

Vegetation Resources Inventory (VRI)
1) In iMap, select the "Data Sources" tab
2) Click "Add Provincial Layers"
3) Select "Forests Grasslands and Wetlands"
4) Select "Vegetated Land Cover"

BC Freshwater Atlas
1) In iMap, select the "Data Sources" tab
2) Click "Add Provincial Layers"
3) Select "Base Maps"
4) Select "Freshwater Atlas"
5) Select all layers with Streams, Lakes, Rivers, Wetlands, and Manmade Waterbodies

APPENDIX 6 Examples of mitigation projects to reduce road impacts on amphibians and reptiles in B.C.

Species (main target listed first for each location)	**Location**	**Mitigation**	**Successes and Challenges**	**Reference**
Mitigation: Crossing Structures with Fencing				
Western Toad	Park road at Lost Lake Municipal Park, Whistler	A single tunnel (corrugated metal, 60-cm diameter culvert, ~8 m long) and more than 100 m of fencing (manufactured by ACO Systems Ltd.) were installed in 2014 to keep juvenile toads away from recreational areas that had high human use and to guide them upslope into forest. A portable ramp installed across a trail allows toads to crawl beneath it while people walk overtop.	ACO wildlife fencing works well to exclude juvenile toads from high human use areas as long as it is installed properly (dug in, with substrate covering the back side, and no gaps between panels). Toadlets safely move under the ramp and follow the fencing into the forest but do not use the tunnel, even though LED lights were installed. It is not possible to seal the migration path and lead toadlets to enter the tunnel; road closure was more effective in the past. In the future, new ACO fencing will be installed to guide toads to a creek that flows out of the park.	Beresford 2018; H. Williamson, pers. comm., 2018
Western Toad	Highway 6 at Summit Lake, near Nakusp	One plastic tunnel (0.86 m in diameter × 16.5 m long, 1.2 m depth of fill over culvert) was installed in 2006. One concrete box tunnel (1.2 m × 1.5 m wide × 21 m long, 0.58 m depth of fill over culvert) was installed in 2014. There is also one existing corrugated metal culvert (0.6 m in diameter × 25 m long, 2 m depth of fill over culvert) at the site. Approximately 1152 m of fencing (550-m ACO, 310-m mesh, 240-m polypropylene sheeting, and 60-m concrete wing walls) has been installed as a barrier to prevent toads from accessing the highway and to guide toads to the tunnels.	High use of both tunnels by adults (533) and juveniles (10s of 1000s) was recorded by camera traps between 2015 and 2018 in the plastic and concrete tunnels. Regular fence maintenance is required; portions of the fence may be replaced with a product made by Animex in the future.	Dulisse et al. 2017; J. Dulisse, pers. comm., 2019; K. McGlynn, pers. comm., 2019

Species (main target listed first for each location)	**Location**	**Mitigation**	**Successes and Challenges**	**Reference**
Mitigation: Crossing Structures with Fencing				
Western Toad	Park road at Kentucky-Alleyne Provincial Park, south of Merritt	A single, semi-cylindrical “half culvert” with an earthen floor (3.6 m long, 1.8 cm wide at ground level, 0.5 m high, 0.3 m from the top to the road surface) was installed in May 2013. In 2014, a temporary fence was replaced with wooden fencing (~20 cm high with a 5 cm lip) that has a 20-cm strip of landscape cloth stapled to the base of each board and is buried to prevent toads from burrowing under the fence. The fence extends 136 m on the pond side of the road and 34 m on the forest side. One-way ramps allow toads to move back toward the pond.	Road mortality was reduced at the crossing location. Thousands of post-metamorphic juveniles moved alongside the fence and through the tunnel; some spillover occurred at the fence ends.	Biolinx Environmental Research Ltd and Nicola Naturalist Society 2014; Ovaska et al. 2018
Western Toad	Wake Lake	Temporary directional fencing was attached to existing drainage culverts.	Post-metamorphic juveniles moved through the drainage culverts. Potential housing development plans in a hotspot location make it challenging to do permanent mitigation.	Wind 2012
Western Toad	Highway 19 Courtenay	Tunnels (of various sizes) and short sections of guiding fences and barrier fences (made of steel mesh hardware cloth) attached to elk barrier fences were installed.	Toads have breached the fencing when it has not been maintained (e.g., thick vegetation growth and holes and small mammal burrows allow toads to move over or through the fence).	Fyfe and Wind 2008
Western Toad and other coastal amphibians	Ryder Lake Rd., Chilliwack	A box culvert with natural substrate and 3 day-lighting openings in the road surface and temporary directional fencing made of landscape cloth fabric were installed.	Camera monitoring shows that amphibians are using the tunnel. Data are still being collected to examine changes in road mortality. Directional fencing is temporary in some locations due to land use. Fencing is the most challenging aspect to the long-term sustainability of the project.	Fraser Valley Conservancy 2018

Species (main target listed first for each location)	**Location**	**Mitigation**	**Successes and Challenges**	**Reference**
Mitigation: Crossing Structures with Fencing				
Northern Red-legged Frog and other coastal amphibians	Highway 4 at Lost Shoe Creek near Ucluelet	200 m of barrier roadside fencing was attached to a bridge that was installed next to a constructed salmon off-channel.	Road mortality of amphibians was reduced by 80%, but the frequency of movements under the bridge seems low. It appears that animals stay still at fences. We suspect that rip-rap under the bridge would be a deterrent to movement, so we are proposing to cover it in 2020 to make a smoother pathway.	Beasley 2018a
Northern Red-legged Frog and other coastal amphibians	Highway 4, between Ucluelet and Tofino	One concrete box tunnel (1.8 m × 0.9 m × 14.5 m) and directional fencing that was made of fabric/plastic wood/cedar and that extended for 150 m to a box tunnel and an existing drainage culvert were installed.	Road mortality has been reduced. Northern Red-legged Frogs and Northwestern Salamanders use the passage through both the new tunnel and existing drainage culvert. Some predation events in culverts have been observed and frequencies are being monitored. Fences require regular monitoring and maintenance, but maintenance costs are inexpensive.	Beasley 2018b
Northern Red-legged Frog and other coastal amphibians	Highway 99, Pinecrest	Eight tunnels and hardware cloth fencing were installed in 2009; new plastic mesh fencing was added in 2010.	The original fencing design did not reduce road mortality. Improved fencing has been added, but no effectiveness monitoring has been conducted since the addition, and maintenance is needed. Amphibians were hesitant to use the passageways: only 9% of anurans and 4% of salamanders observed at entrances passed through the culverts, possibly because of a lack of moisture.	Malt 2012; B. Beasley, pers. obs.

Species (main target listed first for each location)	**Location**	**Mitigation**	**Successes and Challenges**	**Reference**
Mitigation: Crossing Structures with Fencing				
Northern Red-legged Frog and other coastal amphibians	Laburnum Road, Qualicum	Five tunnels along with concrete roadside barriers were installed on 500 m of the 3-km road in 2004–2005. One tunnel is 75 cm in diameter and 28 m long; the others are 90 cm in diameter and 15–20 m long, and have a centreline grate for increasing light, and a raised strip and dirt along the base. Guiding fences, 15–30 m long, are positioned at the tunnel entrances where there is no roadside barrier.	Road mortality was reduced after the concrete roadside barriers were installed, although juvenile newts accessed the road at gaps between adjacent sections. Steep road banks did not deter amphibians from accessing the remaining 2.5 km of road. Rates of amphibian movements through the tunnels were very low based on numbers caught in traps at the culvert entrances; photo-monitoring of one 15-m long tunnel detected more movements, including those of Northern Red-legged Frogs.	Materi 2013; Goudreau et al. 2013
Great Basin Spadefoot, Blotched Tiger Salamander, Western Rattlesnake, Great Basin Gophersnake, Western Yellow-bellied Racer	Highway 97 South Okanagan	Tunnels and ACO fencing were installed in 2010.	Fenced areas covering both sides of the highway were associated with a 94% reduction in amphibian road occurrence (both crossings and roadkill) for 2 years post installation. Since 2003, data collected on species detection and reproductive success at adjacent wetlands demonstrate significant variability. Fence degradation by the sun, expenditures for fencing upkeep and repair have ranged from Can$2000 to $10,000 annually since installation.	Ashpole et al. 2018
Western Rattlesnake, Great Basin Gophersnake, Western Yellow-bellied Racer, Great Basin Spadefoot, Blotched Tiger Salamander	White Lake	Eleven pipe arch and three round corrugated steel culverts were installed in 2017, with directional fencing in development.	No monitoring results are available yet.	Olson 2018

Species **(main target listed first for each location)**	**Location**	**Mitigation**	**Successes and Challenges**	**Reference**
Mitigation: Artificial Habitat and/or Exclusion Fencing				
Western Toad	Highway 23 Mica Dam	An artificial pond was constructed to compensate for road mortality; a French drain was added to a parking lot where toads were breeding to avoid water collection and egg laying; no barrier fencing was installed at the original breeding site.	The terrain constrained options for installing a crossing structure, and road mortality was not high enough to warrant the use of exclusion fencing along the road that would restrict migration movements. Toads breed in the new artificial pond and continue to breed in the original pond.	Wind 2018c
Northern Red-legged Frog and other coastal amphibians	Laburnum Road, Qualicum	Artificial ponds with total maximum wetted area of 4670 m^2 were constructed to compensate for lost habitat.	Plantings of native aquatic emergent vegetation became well established in the artificial ponds after 7 years. The ponds support breeding by Northern Red-legged Frogs, Pacific Treefrogs, Rough-skinned Newts, and Long-toed Salamanders.	Materi 2013
Northern Red-legged Frog and other coastal amphibians	Highway 99 from Squamish to Whistler	Artificial ponds were constructed to compensate for habitat loss at Pinecrest.	Many of the constructed ponds are used for breeding by Northern Red-legged Frogs, Northwestern Salamanders, Long-toed Salamanders, and Pacific Treefrogs, but one set (W Brohm Creek) has been damaged by vegetation maintenance.	Bailey 2011; Isnardy 2015; B. Beasley, pers. obs., 2018
Western Rattlesnake	Osoyoos	Exclusion fencing (1/4" galvanized wire hardware cloth) was installed and extended at the campground; cover boards were placed as refuges along the fence.	Mortality due to heat stress occurred along fence; the cover boards did not help.	Eye et al. 2018

Species (main target listed first for each location)	**Location**	**Mitigation**	**Successes and Challenges**	**Reference**
Mitigation: Artificial Habitat and/or Exclusion Fencing				
Western Terrestrial and Common Gartersnakes	Highway 97, south of Williams Lake	An artificial hibernaculum (4 m × 4 m × 1.5 m) was constructed 650 m west of an original hibernaculum that was dug up during highway expansion in October 2016. In November, 150 salvaged snakes were released into the artificial hibernaculum, which had a fence around it. A portion of the fence was removed before spring 2017 to direct snakes away from the highway and toward the lake. There is still fencing along the backside of the hibernaculum; the fencing is winged out to either side to encourage the snakes to move in the opposite direction of the highway.	A few snakes were observed emerging in spring 2017. During the 2017 summer season, there was construction adjacent to the hibernaculum, and then wildfires dominated the landscape in the Williams Lake area. An approximately 600-m radius around the den did not burn. It is not known if the extreme smoke conditions and fire in the adjacent area affected snake movements and other life stages. Ongoing highway construction has been a major disturbance adjacent to the hibernaculum site, and has made it difficult to monitor the site.	Steciw 2018; J. Steciw, pers. comm., 2019
Western Painted Turtle	Swansea Bridge, Highway 3 west of Cranbrook	An artificial nest pad and 150–200 m of chain link fencing were installed in 2017.	No nesting occurred in 2017, but the installation was still under construction. No monitoring has occurred since.	Dulisse and Clarke 2018
Western Painted Turtle	Lower Sunshine Coast	Nesting beaches were installed at six sites on the lake side of the road to keep turtles from crossing a road. Sizes varied and were 15 m × 5 m × 0.5 m deep; 5 m × 5 m	Three of the sites were extremely effective in terms of successful nesting and reduced road mortality; progress has been slower at the other three sites because it took several years for turtles to start using the new nesting beaches. Lessons learned: it helps to use pure sand and orient beaches southward.	Kilburn et al. 2011; Evelyn 2018