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16. ABSTRACT

The main objective of this project was to develop this Best Management Practices (BMP) document for constructing and maintaining amphibian and reptile road crossing systems. U.S. Geological Survey (USGS) researchers collaborated with the project team by conducting studies on California tiger salamanders (CTS) in Stanford, CA and on Yosemite toads in the Sierra National Forest with respect to passage spacing, barrier fencing materials, and the effectiveness of turnarounds and jump-outs. The USGS researchers also evaluated the permeability of an existing amphibian tunnel systems and a novel pilot elevated road segment passage to inform this BMP document. The BMP document presents several measures that could be used by Caltrans and other practitioners to minimize the effects of roadways on herpetofauna. These measures, when implemented correctly, also present the best opportunity to reconnect bisected populations of rare species and to also reconnect habitats used for breeding, foraging, and sheltering. The tools presented here include the identification of 'Roads of Concern' which are maps of roadways in California that overlap with the habitats and known occurrences of the state's most sensitive and threatened species. The guide includes several figures and tables documenting mitigation strategies from around the world. Technical guidelines are presented here for the planning, design, and evaluation of wildlife passages, barriers and their associated measures that facilitate the safe movement of herpetofauna across roads. This BMP also describes how to increase the effectiveness of established designs and recommends ways to design for particular species groups in different California landscapes. The guidelines can be used for wildlife passages on roadways including but not limited to new or existing highways, highway expansion projects, and culvert retrofitting and reconstruction projects.

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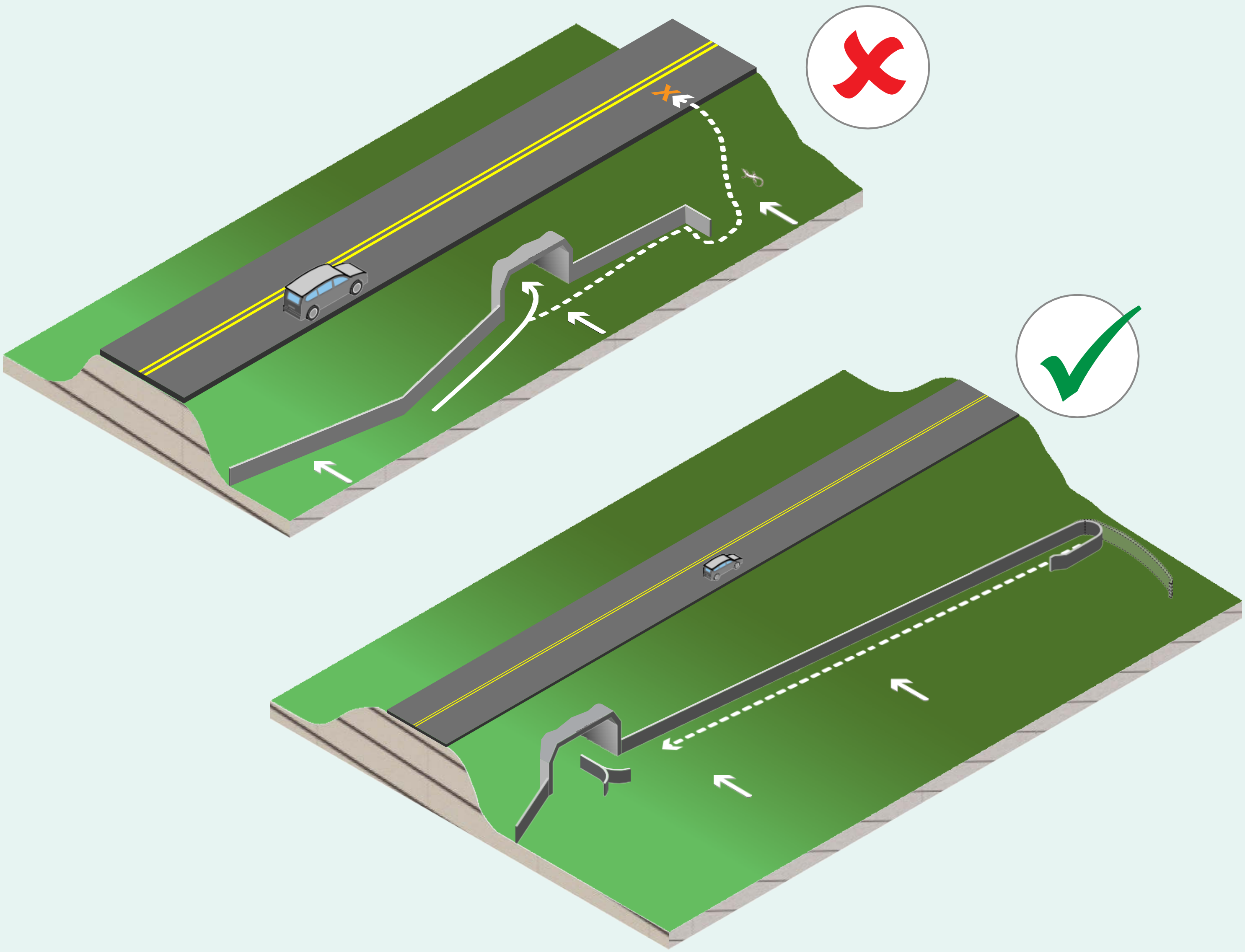
Best Management Practices and Technical Guidance

March 2021



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Measures to Reduce Road Impacts on Amphibians and Reptiles in California

Best Management Practices and Technical Guidance

Thomas E.S. Langton
HCI Research Consultant for WTI

Anthony P. Clevenger
WTI Research Ecologist

In collaboration with

Cheryl S. Brehme
USGS Supervisory Biologist

Robert N. Fisher
USGS Supervisory Research Biologist

Illustrations

Neil Hetherington
WTI

Western Transportation Institute
Montana State University

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We thank Cheryl Brehme (USGS) and Robert Fisher (USGS) who contributed to these WTI products, conducted a road risk analysis for California herpetofauna, and created a geodatabase of California highway segments of concern for at risk species. They also performed a number of research studies to help inform aspects of these recommendations.

Funding for this project was provided by Caltrans Agreement Number 65A0550, to Montana State University as part of the contract, "California Sensitive Amphibian and Reptile Highway Crossings Combined Tasks: Develop Roadway Crossings for Sensitive Amphibians, Develop Roadway Crossings for Reptiles."

From Caltrans, we would like to thank Harold Hunt (retired), Senior Environmental Planner, Division of Research, Innovation, and System Information (DRISI) for early on recognizing the need for Caltrans and other transportation agencies to mitigate the effects of roads on amphibians and reptiles along state highways. Harold's input and guidance put our project on firm footing from the outset. Loren Turner was instrumental in administering this project in the beginning. We would also like to thank James Henke, Amy Bailey, Amy Golden, Simon Bisrat, Lindsay Vivian, Luz Quinnell and Nancy Siepel (now retired). We thank many other Caltrans staff who provided input on this research and manual and a range of other independent external reviewers who generously provided comments. We would like to extend our gratitude to Tiffany Allen (WTI) for her help on the project in its first year and Rob Ament (WTI) who assisted with various administrative aspects of the project.

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Table of Contents

CHAPTER 1 Introduction

The mission of the California Department of Transportation (*Caltrans*) is to provide a safe, sustainable, integrated and efficient transportation system to enhance California's economy and liveability. Caltrans has 12 district offices throughout the state and a Headquarter office located in Sacramento (*Figure 1*). Caltrans employs nearly 20,000 employees, including engineers and environmental planners. Caltrans must comply with several regulatory requirements when planning, constructing, and maintaining the State Highway System (SHS). Caltrans is often required to mitigate for unavoidable adverse impacts arising from the construction, operation and maintenance of the SHS, including when projects affect threatened and endangered species.

In California, there are over 160 species and subspecies of herpetofauna (amphibians and reptiles). Herpetofauna are receiving increasing attention from conservation groups as many species have experienced precipitous declines in abundance globally and in the United States. Globally, it is estimated that 40% of amphibian species and 20% of reptile species are trending towards extinction. Herpetofauna populations face many threats, including habitat loss and degradation, habitat fragmentation, environmental pollution, introduced disease and the effects of a changing climate.

In California, 24 out of 154 herpetofauna species (16 %) are currently listed as endangered and threatened. Threats to these species include habitat loss and degradation, habitat fragmentation due to roadways, environmental pollution, introduced disease and the effects of a changing climate. Herpetofauna species occur in all eight ecoregions within the state (*Figure 2*). Herpetofauna species richness varies across the state, with the largest number being in the southwest portion of California (Figure 3). Those species considered to be at highest risk of roadway mortality tend to follow a similar pattern (see also Chapter 4 and maps in Appendix 1) and it is unfortunate that this is the most human populated area with most vehicles too.

For some years, transportation agencies and others have sought to mitigate road impacts by providing dispersal passage and barrier systems, often in an experimental manner. Although wildlife passages and barriers for herpetofauna have been constructed on roads, and to a limited extent for railroads, in many parts of North America and beyond, there are few technical guidelines that effectively summarize measures to prevent and reduce the effects of roadways on rare and vulnerable species.

Figure 1: *Caltrans Districts and State Highway System*

Figure 2: *California's Eight Ecoregions. Credit: Caltrans, California Department of Fish, and Wildlife and U.S. Department of Transportation.*

Figure 3: *Species Density Map for High Risk Reptiles and Amphibians in CA. Credit USGS, ESRI, NOAA*

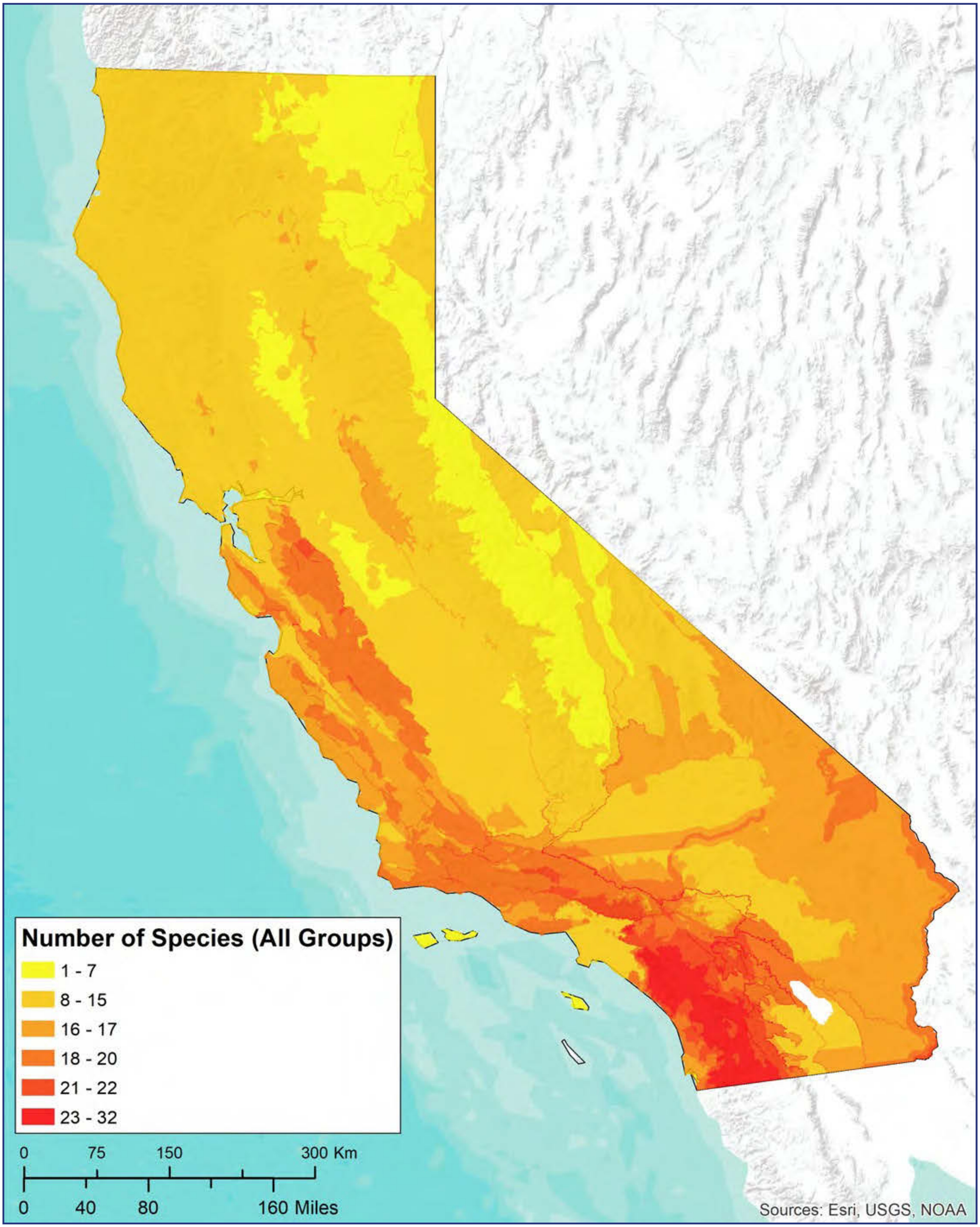
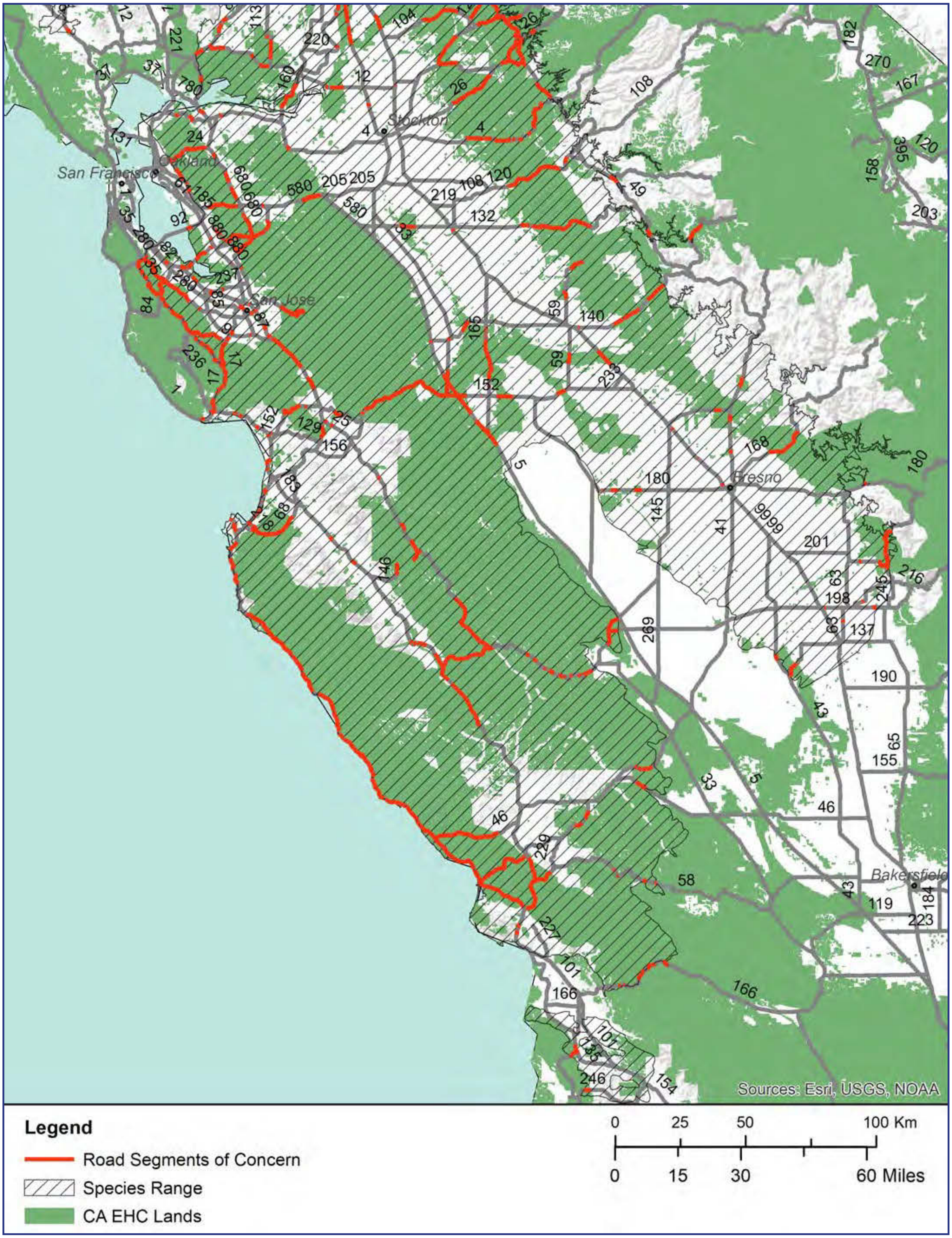


Figure 4: *Example of a Roads of Concern Map (USGS) using overlays of California Essential Habitat Connectivity layers (see this chapter and chapters 4 & 5) Here for the California tiger salamander (Ambystoma californiense) as an example. Credit USGS, ESRI, TANA*



How to use this guidance

This Best Management Practices and Technical Guidance (hereafter shortened to BMP) describes known best practices for retaining or improving habitat connectivity for amphibians and reptiles in the state of California. This guidance relates to the vulnerabilities of California herpetofauna species that are a function of their life cycle needs and behaviors (Chapter 4). It shares current understanding at the time of writing of the performance of various passage mitigation measures in California and elsewhere.

Road ecology research has increased over the years, but sufficient rigorously tested practices that are useful to transportation agencies are still largely lacking. The purpose of this BMP is to present several measures that could be used by Caltrans and other practitioners to minimize the effects of roadways on herpetofauna. These measures, when implemented correctly, also present the best opportunity to reconnect bisected populations of rare species and to also reconnect habitats used for breeding, foraging, and sheltering. The tools presented here include the identification of 'Roads of Concern' which are maps of roadways in California that overlap with the habitats and known occurrences of the state's most sensitive and threatened species (Figure 4). The guide includes several figures and tables documenting mitigation strategies from around the world.

Technical guidelines are presented here for the planning, design, and evaluation of wildlife passages, barriers and their associated measures that facilitate the safe movement of herpetofauna across roads. This BMP describes how to increase the effectiveness of established designs and recommends ways to design for particular species groups in different California landscapes. The guidelines can be used for wildlife passages on roadways including but not limited to new or existing highways, highway expansion projects (e.g., upgrading from a 2-lane to 4-lane facility) and culvert retrofitting and reconstruction projects.

This BMP synthesizes information gleaned from scientific literature and practitioner knowledge. It is not intended to be static as the body of knowledge on wildlife crossing designs and their efficacy continues to grow. The implementation and monitoring of crossings for amphibians and reptiles will serve to refine and advance understanding of the efficacy of different wildlife crossing designs around the world. At times in this document, the text shortens the terms 'amphibians and reptiles' and 'herpetofauna', to 'herp' and 'herps'. While terminology in this report refers mainly to roads, many aspects of this manual apply to railroads as well.

Key Points

- Amphibians and reptiles (herpetofauna) are receiving increasing attention as two groups declining globally and in the U.S. Globally, an estimated 40% of amphibian species and 20% of reptile species are trending toward extinction.
- In California, 24 out of 154 herpetofauna species (16%) are currently listed as endangered and/or threatened.
- The highest density of herpetofauna species in California including those species most at risk due to roadway mortality occurs in the south and west portion of the state.
- Technical guidelines and best management practices can help justify the implementation of protective measures, which are much needed for California's herpetofauna species and their habitats, as they are elsewhere.
- Many new management tools are being developed and include GIS applications, such as 'Roads of Concern' maps. Examples show how areas that are known or expected to bring traffic and the habitats of the most sensitive and threatened species into contact can be identified using the new systems.

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Chapter 2 Regulatory requirements

Federal and state transportation and natural resource managers have a broad range of federal and state laws and policies to consult. These provide support for the planning and design of wildlife passages, as deemed appropriate during transportation project planning and delivery (Ament et al. 2015). A large part of the wildlife passage assessments, planning, design, and actions are motivated by laws designed to protect wildlife and its habitats.

Example applicable laws that call for the implementation of measures: avoidance, minimization, and mitigation (including compensation) to protect and conserve wildlife and ecosystems includes federal laws such as the National Environmental Policy Act, the Endangered Species Act, and the Clean Water Act. Relevant state laws include the California Endangered Species Act (CESA) and California Fish and Game Code.

Various federal and state policies call on transportation agencies to consider pertinent environmental data during project planning. These references might include forest and resource management planning documents; general plans and land use plans; long-range, metropolitan and rural transportation plans and more. Published guidance includes FHWA's Eco-Logical: An Ecosystem Approach to Developing Infrastructure Projects, which is an ecosystem-based planning decision-support tool. Additionally, FHWA promotes the practice and implementation of Planning and Environmental Linkages, which enables transportation planners to consider environmental factors and resources early during project planning and scoping. Habitat Conservation Planning for federally-listed species calls for the inclusion of wildlife passage improvements. In California, the State Wildlife Action Plan and Natural Community Conservation Plans also include reference to the need to improve roadway connectivity for threatened and endangered herpetofauna.

Provided below is a short list of key references giving access points to illustrative federal and California state laws and policies surrounding aspects of the planning and design of herpetofauna passages during transportation planning and projects.

Key References

Policy and strategy

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- California Department of Fish and Wildlife (CDFW) Habitat Conservation Planning Branch website (https://www.wildlife.ca.gov/Explore/Organization/HCPB) summarizes state habitat conservation regulations, programs and plans governing activities that have the potential to adversely affect fish and wildlife species and habitats.
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Chapter 3 Impacts of transportation infrastructure on amphibians and reptiles

California has one of the largest road networks in the United States. Traffic and roadways in the state and elsewhere contribute to air and water pollution; fragmented farmland and habitat, and losses in wildlife and biodiversity. The construction and operation of roads have a suite of effects on wildlife, some of which are related to the level of use of a roadway. For roads, the density of the network, traffic volume, the extent of road surface and other engineered features all affect the extent of the effects of a road on wildlife.

Roads cut across California's landscapes and intersect with many local ecosystems. In doing so, roads can block or filter water flow, wind erosion, and the movement of animals. Roads may compromise a herp population by passing along the interface between a wetland and upland habitat. Common examples are salamanders or turtles moving to lay eggs in permanent or seasonal wetland areas. In some cases, road verges can function as linear habitat corridors. Some animals live in them and move through them and this may be the only refuge for them in intensive agricultural areas.

Impacts of roads and railways on herpetofauna

Impacts on population dynamics result from stressors ranging from habitat loss to direct mortality on roads. Responses to them result from three major potential exposures: changes to habitat; changes in species movement patterns; and direct mortality.

1) Changes to habitat

Loss of habitat: Road construction and expansion can result in habitat loss by transforming natural habitats to pavement and cleared roadsides. Some herpetofauna are more vulnerable to habitat loss than others by virtue of their larger home ranges, life history traits, degree of specialization and rarity.

Reduced habitat quality: Roads may cause a range of subtle or obvious alterations to microhabitats that result from the construction of new roads or lane expansion. These changes can cause a behavioural tendency for animals to avoid or move away from the road and near-road area.

Improved habitat quality: Some species can be attracted to road corridors or the physical surface of roads, road shoulders and slopes, for example for basking. The attraction may be the result of the proximity of adjacent habitat (spawning/nesting, living space) or to food resources.

2) Changes in movement patterns

Barrier effects: The home range sizes of herpetofauna vary considerably in size. Some species may travel hundreds of feet and up to several miles in one day. Individuals may travel large distances to access habitat used for breeding, feeding or sheltering. These areas can become bisected by roads. Animals may avoid roads causing a barrier effect or not avoid roads resulting in reduced survivorship from road mortality. When roads act as barriers, this results in habitat fragmentation effects.

Corridor function: Roads (and railroad routes) can limit movement for some taxa, but they can also potentially facilitate dispersal and range extensions of native and non-native species. Such changes may potentially bring significant onward impact over time. Vegetation changes along a road's edge may provide habitat corridors for migratory species, for example it may link up patches of degraded landscapes with a strip of navigable habitat, better enabling dispersal. This may however, also facilitate the spread and introduction of invasive species.

3) Mortality

The most obvious effects of roadways are direct mortality or injury to animals from vehicles. This is usually from contact with moving vehicles but can also result from rapid changes in air pressure under moving vehicles, including trains. Mortality and injury may result from the entrapment of individuals in road drainage systems or as a result of contact with chemical residues. Mortality can be dramatic and noticeable at certain times of year such as when, for example frogs or snakes migrate in large numbers in response to seasonal conditions, such as spring rains or emergence from seasonal dormancy. Many turtle populations are male-biased, partly because females travel larger distances and are more likely to cross roads. Increased mortality may result in decreased survivorship (a population sink), ultimately leading to population decline.

Road Effect Zone

The ecological effects of roadways can extend far beyond the roadway surface and road's edge. This area of impact is sometimes called the road effect zone (REZ). Areas of habitat near the roadway itself can be adversely affected by chemical or noise pollution, vibration, visual intrusion of moving traffic (Figure 5).

Road residues from tires and roadside chemical treatments such as herbicides may reach into adjacent habitat according to factors such as prevailing wind patterns and elevation, whereas pollution to waterways may travel long distances. Other effects along the roadway may include altered physical and chemical soil conditions that result from construction and ongoing maintenance activities. Changes in hydrology can result from the addition of impervious or porous surface and base materials to the landscape bringing potential drainage or flooding effects that may be undesirable.

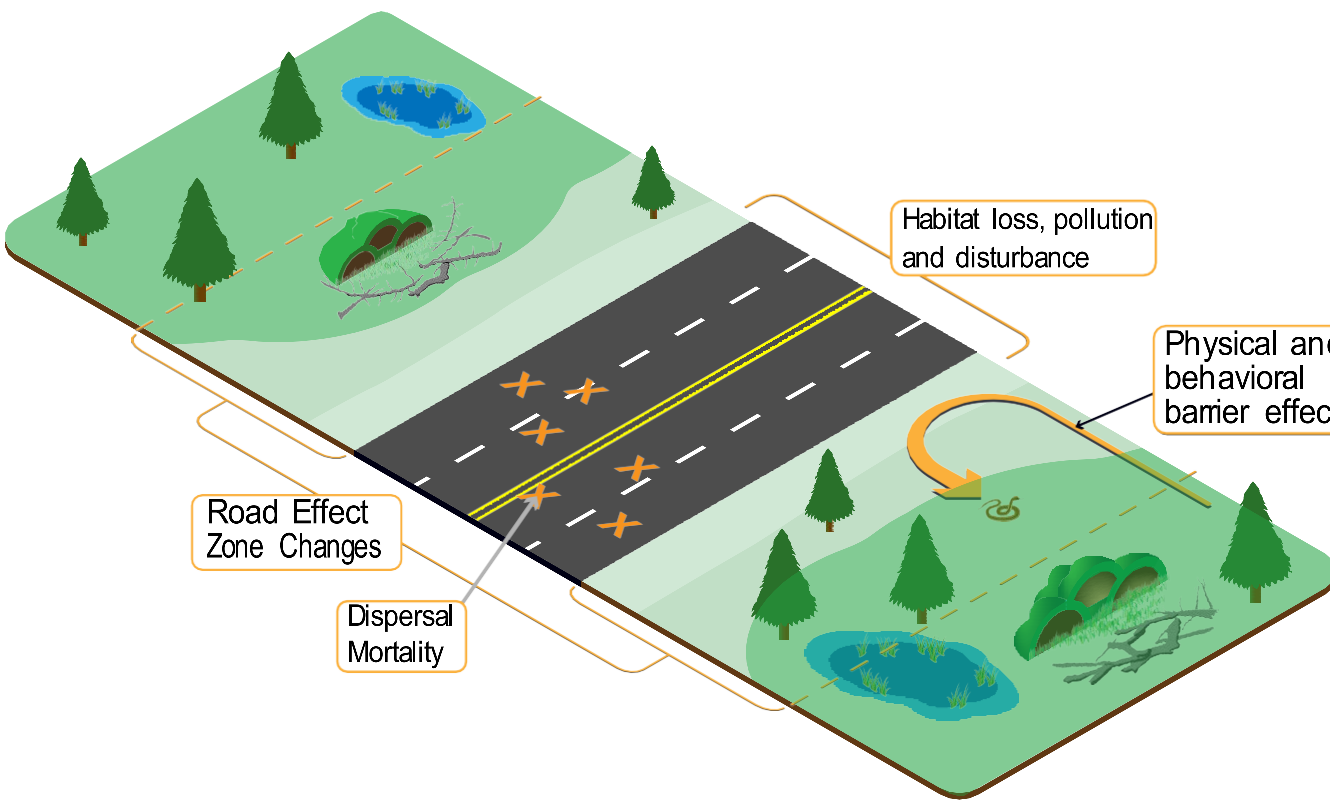

Figure 5: *Schematic representation of influences within the Road Effect Zone (REZ).*

Within the REZ, beyond habitat loss and fragmentation from road building, wildlife suffer from road mortality and injury. Some wildlife species may also be influenced by factors such as noise and light, resulting in avoidance of the road area, lower use of adjoining land and bring about population declines. The REZ can extend to considerable distance. With the desert tortoise (Gopherus agassizii), population depletion may be observed up to 0.25-mile (mi)/400 meters(m) from the edge of the road. Built passage and barrier measures together with habitat management can help remove, reduce or offset these potential impacts.

Reducing on-road mortality and maintaining connectivity across a transportation corridor may still be required to minimize negative effects. Example measures may include the following:

1. adding wildlife barriers to prevent mortality;
2. constructing purpose-built passages to maintain genetic flow and population-level connectivity; and
3. retrofitting existing drainage culverts to reduce on-road mortality and restore safe passage.

The siting of mitigation measures will be described in subsequent chapters. What is built or implemented should be determined following the completion of pre-construction population studies and analyses of the major risk factors facing a local population (potential mortality or fragmentation effects) and how best to mitigate those impacts. A range of specialists in herpetofauna ecology, passage design, engineering, and construction may be needed to achieve successful outcomes according to the species and habitats involved and the complexity of the built and natural landscape along the route.

Key Points

- Traffic and roads can be major stressors to California biodiversity and are strongly implicated in many of the major environmental problems in the State today
- Impacts of roads range from habitat loss and change to direct mortality on roads and population fragmentation.
- Many ecological effects of roads are spatially small or restricted. Most documented effects occur at the road-segment level, which includes the road and roadside described as the road effect zone. Population effects in this zone may be up to a quarter of a mile (400 m) or more from the road, for example for desert tortoise.
- Road right-of-ways can have the effect of creating a linear strip of vegetation either side that is different to that present before the road was constructed, and this may potentially bring beneficial and or harmful effects.

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CHAPTER 4 Endangered status focus and road risk appraisal

Passage and barrier structures built for wildlife or with accommodations for species in mind are important for maintaining the long-term viability of populations and natural communities. In order to prioritize these efforts for herpetofauna, species that are particularly threatened and most at risk of extirpation from road-related impacts should be highlighted early on in the planning process. With over 160 California herp species and a lack of detailed species-specific data for most species and areas, a quantified risk assessment method has been developed by USGS, based upon known road ecology science and life history documentation. While Caltrans focuses on the most threatened and endangered species for roads and railroads within their jurisdiction, the measures described in this BMP can be used to address concerns anywhere on California's road network. This may extend even beyond state highways, where measures for species may be warranted, including for less threatened species that may be experiencing increased mortality levels and declines.

Risk scores for the assessments were based upon a suite of life history, movement, and space-use characteristics associated with harmful road effects:

- movement distances
- movement frequency
- speed
- habitat preferences
- movement behavior (territorial, non-territorial vs. migratory)
- fecundity
- range size
- conservation status

All California herpetofauna species (and some subspecies) were ranked into five relative categories of road-related risk and assigned scores in 20-point increments for both aquatic and terrestrial connectivity ranging from "very high" to "very low".

Road risk assessment

For each species group, the percentage and number (in brackets) of reptiles and amphibians in California were assigned a score or ranking of "high" or "very high" risk due to the adverse effects of roads on herpetofauna populations:

- 100% or all turtle and tortoise species (4/4);
- 72% of snake species (36/50);
- 50% of frog and toad species (11/22);
- 18% of lizard species (8/38);
- 17% of salamander species (8/44)

Results were largely consistent with local and global scientific literature in identifying those species most at risk due to roadway mortality ("species of conservation concern"). Overall, turtles, tortoises and snakes had the highest percentage of species ranked as "high risk" of potential harmful impacts of roads. This was due to a range of factors such as their having longer movement distances than other species. For instance, turtles, tortoises and snakes tend to have larger home ranges and/or are more migratory than other species; they may lack road avoidance behavior; and have lower fecundity in comparison to other herp groups. This includes the desert tortoise *Gopherus agassizi*, a species that has been shown to suffer from high road mortality and reduced near-road abundance in for example the Mojave Desert. Western pond turtles may travel up to a mile or more within perennial waters and intermittent aquatic habitats to forage and find mates. In addition, female turtles nest and lay eggs in adjacent terrestrial habitats which make roads that parallel aquatic habitat a threat to both females and hatchlings.

Many large snakes and rattlesnakes were ranked as high risk. They may be attracted to paved road surfaces for thermoregulation (basking) but also have wide home ranges or move long distances between winter hibernacula and summer feeding grounds. Long foraging movements within aquatic habitats also contributed to the majority of garter snakes falling within the highest road risk categories.

Approximately 50% of California frog and toad species were ranked at high risk of negative road effects. These include bufonid toads (generally; rough skinned toads with a pair of large glands on the back of their heads) and California red-legged frog that may move large distances within and between both aquatic and terrestrial habitat to satisfy their annual resource requirements. This is also the case with newts and several Ambystomid (often heavy-bodied and short limbed) salamander species whose populations annually migrate between aquatic and upland habitat. Only a few lizard species scored in the highest risk categories including the Gila monster, leopard lizards, and two-horned lizard species. This may relate not just to their relative rarity but to them having smaller home ranges.

Within the range of a species there are populations that occupy areas with greatly differing road pressures. Therefore, the actual risk to local populations depends upon local road densities, road design, traffic levels, and road locations in relation to species habitat and movement corridors.

Threats from roads to both terrestrial and aquatic connectivity means that semi-aquatic species have two risk scores. Some species were ranked as high risk for both the aquatic and terrestrial life stages, while others may have scored high in only one. This is important when evaluating the need for underpasses and other crossing structures for terrestrial species or species with both aquatic and terrestrial habits compared to when planning for fish passage remediation projects and bridges. For example, passage and barrier structures (see Ch. 7 for full definition and purpose of barrier types) may be suitable for species with high terrestrial risk scores, such as tortoises, colubrid snakes, rattlesnakes and Ambystomid salamanders. Conversely, fish passage structures and bridges might be evaluated for species with high aquatic risk exposure; such as the giant gartersnake *Thamnophis gigas*, California red-sided gartersnake *Thamnophis sirtalis infernalis*, two-striped gartersnake *Thamnophis hammondii*, and Sonoran mud turtle *Kinosternon sonoriense*. Both terrestrial and aquatic crossings may be needed for species groups that ranked high in both categories; such as pond turtles, Bufonid toads, newts and California red-legged frog *Rana draytonii*.

Buffer distances for terrestrial and aquatic habitats were calculated to encompass 95% of population level movements of all species. This can be helpful when determining whether a population is close enough to a road (within buffer distance) to warrant measures to reduce mortality impacts including the possible need for crossing systems to retain connectivity.

Californian herpetofauna - high and very high road risk

Very High and High road risk California amphibians and reptiles are listed by species group in Tables 1.a-1.c. The detailed approach taken, methods used, complete rankings and buffer distances for all species are provided in Brehme et al. (2018).

Table 1a. High and very high road risk Californian amphibians, by species group.

GROUP	VERY HIGH RISK	HIGH RISK
Toads	Arroyo toad *Anaxyrus californicus*[F,SSC] Black toad *Anaxyrus exsul*[S] Sonoran desert toad *Incilius alvarius*[SSC] Yosemite toad *Anaxyrus canorus*[F,SSC]	Great plains toad *Anaxyrus cognatus* Western spadefoot *Spea hammondii*[SSC] Woodhouse's toad *Anaxyrus woodhousii*
Frogs	California red-legged frog *Rana draytonii*[F,SSC]	Cascades frog *Rana cascadae*[SSC] Northern red-legged frog *Rana aurora*[SSC] Oregon spotted frog *Rana pretiosa*[F,SSC]
Salamanders	California newt *Taricha torosa*[SSC] California tiger salamander *Ambystoma californiense*[F,S] Red-bellied newt *Taricha rivularis*[SSC] Sierra newt *Taricha sierrae*	California giant salamander *Dicamptodon ensatus*[SSC] Rough-skinned newt *Taricha granulosa* Santa-Cruz long-toed salamander *Ambystoma macrodactylum croceum*[F,S] Southern long-toed salamander *Ambystoma macrodactylum sigillatum*[SSC]

Table 1b. High and very high road risk Californian snakes, by species group.

GROUP	VERY HIGH RISK	HIGH RISK
Terrestrial snakes	Alameda striped racer *Masticophis lateralis euryxanthus*[F,S] Baja California coachwhip *Masticophis fuliginosus*[SSC] Baja California ratsnake *Bogertophis rosaliae*[SSC] California glossy snake *Arizona elegansoccidentalis*[SSC] Coachwhip *Masticophis flagellum* Coast patch-nosed snake *Salvadora hexalepis virgultea*[SSC] North American racer *Coluber constrictor* Panamint rattlesnake *Crotalus stephensi* San Joaquin coachwhip *Masticophis flagellum ruddocki* Striped racer *Masticophis lateralis*	California lyresnake *Trimorphodon lyrophanes* Nightsnake *Hypsiglena ochrorhyncha* Desert nightsnake *Hypsiglena chlorophaea* Mojave rattlesnake *Crotalus scutulatus* Red diamond rattlesnake *Crotalus ruberSSC* Regal ring-necked snake *Diadophis punctatus regalis*[SSC] Sidewinder *Crotalus cerastes* Sonoran lyresnake *Trimorphodon lambda* Speckled rattlesnake *Crotalus mitchellii* Spotted leaf-nosed snake *Phyllorhynchus decurtatus* Western groundsnake *Sonora semiannulata* Western diamond-backed rattlesnake *Crotalus atrox* Western patch-nosed snake *Salvadora hexalepis* Western shovel-nosed snake *Sonora occipitalis* Western rattlesnake *Crotalus oreganus*
Aquatic snakes	California red-sided gartersnake *Thamnophis sirtalis infernalis*[SSC] Giant gartersnake *Thamnophis gigas*[F,S] San Francisco gartersnake *Thamnophis sirtalis tetraaena*[F,S] Two-striped gartersnake *Thamnophis hammondii*[SSC]	Aquatic gartersnake *Thamnophis atratus* Common gartersnake *Thamnophis sirtalis* Northwestern gartersnake *Thamnophis ordinoides* Sierra gartersnake *Thamnophis couchii* Western terrestrial gartersnake *Thamnophis elegans*

Table 1c. High and very high road risk turtles, tortoises and lizards, by species group.

GROUP	VERY HIGH RISK	HIGH RISK
Freshwater turtles	Northwestern pond turtle *Actinemys marmorata*[SSC] Southwestern pond turtle *Actinemys pallida*[SSC] Sonora mud turtle *Kinosternon sonoriense*	
Tortoises	Mohave desert tortoise *Gopherus agassizii*[F,S]	
Lizards	Banded gila monster *Heloderma suspectum cinctum*[SSC] Blunt-nosed leopard Lizard *Gambelia sila*[F] Cope’s leopard lizard *Gambelia copeii*[SSC] Desert horned lizard *Phrynosoma platyrhinos* Flat-tailed horned lizard *Phrynosoma mcallii*[F,SSC]	Coastal whiptail *Aspidoscelis tigris stejnegeri*[SSC] Long-nosed leopard lizard *Gambelia wislizenii* Switak’s banded gecko *Coleonyx switaki*[S]

F= Federally Listed as Threatened or Endangered

S= State Listed as Threatened or Endangered

SSC= California Species of Special Concern

State and Federal Regulatory Requirements

Caltrans is required to safeguard state and federally listed herpetofauna species. The “California Species of Special Concern” list is updated by California Department of Fish and Wildlife from time to time and most recently in September 2020.

Federal Endangered Species Act

The Federal Endangered Species Act (FESA) provides a program for the conservation of threatened and endangered plants and animals and the habitats in which they are found. The law prohibits any action that causes “take” of any listed species of endangered fish or wildlife and generally prohibits import, export, interstate, and foreign commerce of listed species. Under the provisions of Section 7(a)(2) of FESA, a federal agency that permits, licenses, funds or otherwise authorizes a project activity must consult with USFWS to ensure that its actions would not jeopardize the continued existence of any listed species or destroy or adversely modify critical habitat. Pursuant to the Moving Ahead for Progress in the 21st Century Act (MAP-21), as described in the NEPA Delegation Pilot Program Memorandum Of Understanding between Federal Highway Administration (FHWA) and Caltrans, Caltrans has been designated the authority to conduct Section 7 consultation of the FESA.

California Endangered Species Act

The California Endangered Species Act (CESA) is administered by CDFW and prohibits “take” of plant and animal species identified as either threatened or endangered in the state of California by the Fish and Game Commission (Fish and Game Code Section 2050 to 2097). “Take” includes pursuit, hunt, kill, capture, or any other action that results in adverse impacts to listed species. Section 2091 and 2081 of CESA allow CDFW to authorize exceptions to the “take” of the State-listed threatened or endangered plant and animal species for purposes such as public and private development. CDFW requires formal consultation to ensure that its actions would not jeopardize the continued existence of any listed species or destroy or adversely modify critical habitat.

California Species of Special Concern

A Species of Special Concern (SSC) is a species, subspecies, or distinct population of an animal* native to California that currently satisfies one or more of the following criteria: 1) is extirpated from the State; 2) is listed as Federally threatened or endangered; meets the State definition of threatened or endangered but has not formally been listed; 3) is experiencing, or formerly experienced, serious (noncyclical) population declines or range retractions (not reversed) that, if continued or resumed, could qualify it for State threatened or endangered status; and/or 4) has naturally small populations exhibiting high susceptibility to risk from any factor(s), that if realized, could lead to declines that would qualify it for State threatened or endangered status. CDFW requires consideration of impacts to SSC species during the California Environmental Quality Act (CEQA) environmental review process.

Key References

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CHAPTER 5 Getting passage and barrier systems built

Roads and railways can affect herp populations in various ways, and many impacts are based on the type of transportation project involved. Project types may include new construction, road widening, lane expansion, road improvements (unpaved to paved; resurfacing), installation of solid barriers in medians and shoulders, and culvert or bridge retrofits.

Planning of connectivity measures can be triggered in several ways, but usually by regulatory requirement to protect species and their habitats (Chapter 2).

Project and system level planning

Funding for road impact reduction measures such as wildlife crossing structures is most likely to originate from transportation projects that address specific multiple transportation management concerns. Mitigating road impacts is most economical and likely when it arises from these project-level improvement projects.

Crossing systems may also emerge from a systems-level analysis of transportation management concerns and priorities over a much larger area than project-level improvements. It may be possible to develop 'early opportunity and enhancement tables' for key road segments thought to pose high risk to wildlife species. Risk assessments (see Ch. 4) identify species most vulnerable to road impacts. During appraisals if risk assessment maps are overlaid with State Transportation Improvement Program (STIP) data, road projects that may impact high and very high risk species can be identified. Further, for STIP short and long-range planning this information enables a proactive data collection approach to identify high and very high risk species potentially impacted by new projects.

The systems-level analysis is a broad-scale planning and construction process that addresses stakeholder concerns, prioritizes agency objectives, and incorporates landscape patterns and landscape processes.

Mitigation hierarchy

Transportation projects should be approached in a manner that fulfills the generally recognized international standards of the three distinct stages of the mitigation hierarchy (Figure 6). These are to (1) firstly avoid sensitive wildlife habitat, (2) take steps to mitigate impacts including actions that minimize impacts such as barrier and passage system development and (3) compensate for any loss of wildlife habitat, such as restoring equivalent (equal or greater) habitat or connectivity lost for the same species, as close to the impacted site as possible. This should be done in a way so that there is 'no net loss' of biodiversity and ideally 'net gain'. Compensation or biodiversity offsetting is the third stage, referred to as 'compensation mitigation' by Caltrans.

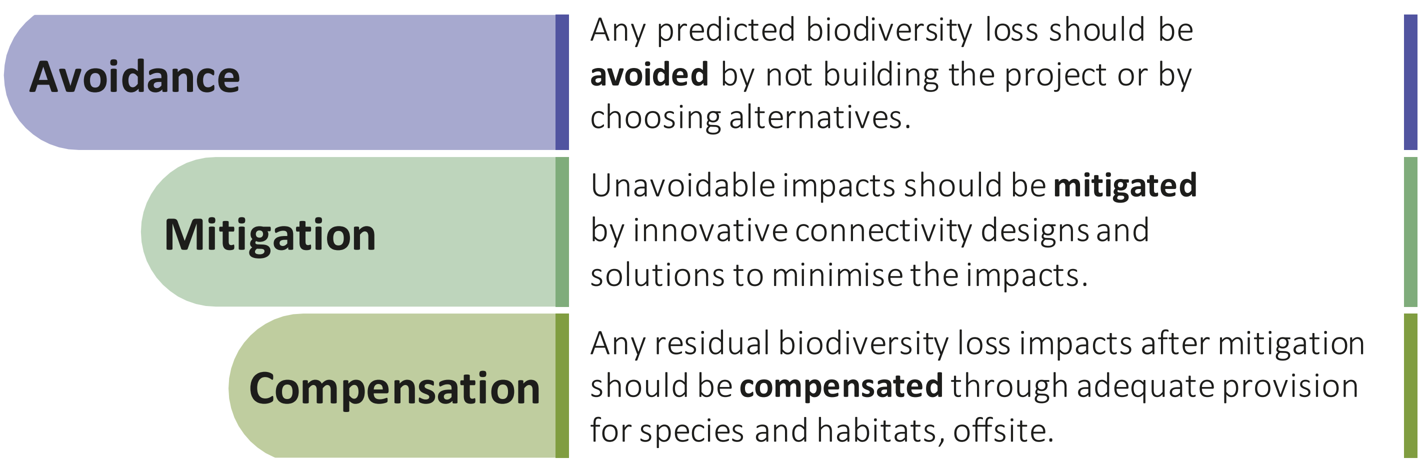

Figure 6: *Transportation practitioners should use the 'avoid, mitigate, compensate' hierarchy when planning for new infrastructure where threatened and endangered species occur. Minimizing impacts is the main aim of mitigation.*

Most road construction projects in California today are Operation and Maintenance or Safety projects and frequently involve lane expansions, so there may be limited opportunities to avoid sensitive wildlife habitats.

If projects are unable to avoid or mitigate impacts fully or sometimes at all, then the compensation principle is applied, so there is no net loss of biodiversity within the definition of this concept. This principle is commonly applied in transportation projects throughout North America; through the California Environmental Quality Act (CEQA) and also the National Environmental Protection Act (NEPA).

Resources

Identifying the most suitable sites for avoiding and mitigating road impacts requires tools and resources. Typically a variety of approaches are used, including site-specific information on species being impacted by roads, species distributions and connectivity, and local or expert knowledge. These can help define where herpetofauna are most impacted by roads and identify the most appropriate areas for measures.

Site-specific data are most valuable when rigorously collected, information on species rates of mortality, barrier effects and habitat loss/alteration guides planning and design. However, focusing planning on road-kill hotspots may ignore populations that have been reduced by past traffic-related mortality. Road-kill analyses should therefore be used with caution when evaluating options or proactive restoration of linkages. Further, small populations of local importance may not show up well or at all in road-kill surveys, yet even low rates of mortality may have big impacts on population viability.

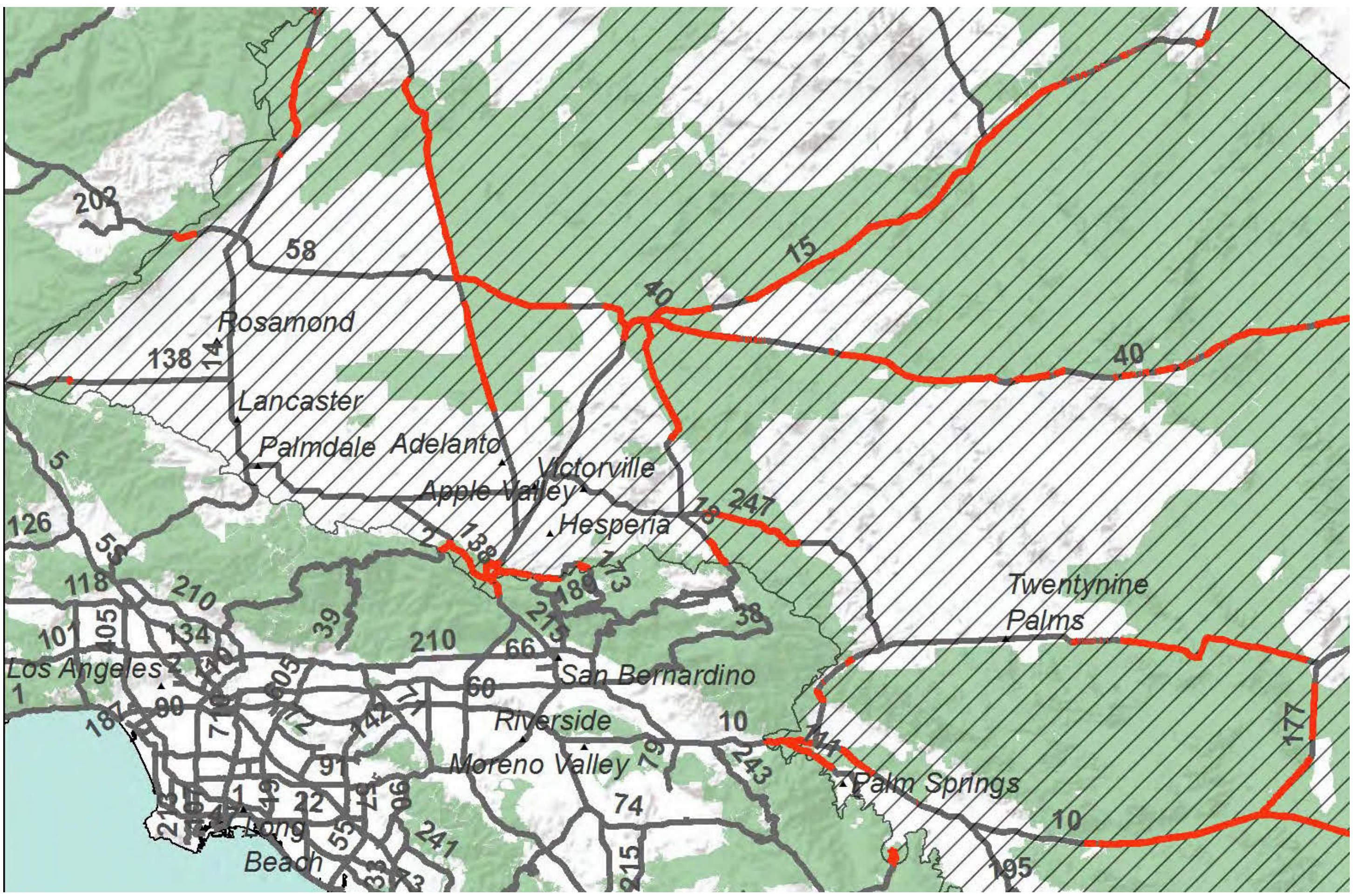

Figure 7: *Example of a data query from a USGS created geodatabase that users can use to identify where species most at risk of roadway mortality overlap with California highways.*

Transportation projects also may address connectivity over long distances and landscape scales, to meet *Wildlife Linkages* objectives such as those of the Caltrans and California Department of Fish and Wildlife commissioned *California Essential Habitat Connectivity Project*;

https://wildlife.ca.gov/Conservation/Planning/Connectivity/CEHC

As a part of the California Sensitive Amphibian and Reptile Highway Crossings project (2014-2020) a unique geodatabase was prepared by the USGS that identified where very high and high road-risk species (Chapter 4.) intersect with California Essential Habitat Connectivity Lands and Caltrans highways. An example of the output from this is shown at Figure 7 where, in this case occupied desert tortoise (*Gopherus agassizii*) habitat intersects (shown as red line) with roads within the California Essential Habitat Connectivity Project (areas shown in green) in southern California, east of Los Angeles. These highways cross areas that may be considered opportunities for preserving and enhancing remaining corridors of wildlife habitat supporting endangered species.

Mapping is also possible for medium and lower risk species. This planning tool will aid Caltrans in short and long-term planning of transportation projects and potential impacts to herps. Once road projects are identified that may impact species of risk, District biologists are then able to work proactively to drill down at the project level and investigate conditions and potential site-specific data that may be available.

Some basic map and data resources to initiate the planning of safe crossing systems for herpetofauna include:

- California herpetofauna road risk assessment
- California Department of Fish and Wildlife. 2014. Guidance Document for Fine-Scale Wildlife Connectivity Analysis.
- California Department of Fish and Wildlife. Areas of Conservation Emphasis ('ACE' depicts connectivity needs at a relatively fine scale). https://wildlife.ca.gov/Data/Analysis/ACE#523731769-overview
- Aerial and satellite photography and images
- Land cover-vegetation maps
- Topographic maps
- Land ownership maps
- Herpetofauna/other wildlife distribution and species-specific ecological data
- Herpetofauna/other wildlife road-kill and live observation data
- Road network data

Use of these resources enables consideration of how planned Caltrans road projects may impact herpetofauna. Combining multiple resources will provide greater accuracy in identifying where road project conflicts do, or may potentially occur.

Spotting opportunities and maximizing benefits

While this BMP manual is focused on amphibians and reptiles, it is important to investigate how roads may impact other wildlife (large and small) in these identified areas, as there may be synergies with other species needs and cost-sharing of project funding. For example, a road segment that blocks herp movement may coincide with a location where an underpass may be installed to reduce mule deer (*Odocoileus hemionus*) road-kill, or passing lanes installed, or where a bridge may be retrofitted. Such "piggy-backing" on larger transportation projects may be a low-cost means of mitigating roads for wildlife connectivity, particularly for herps and small mammals.

Sound planning should identify early the specific measures needed for any project. In broad consideration these tend to fall into three categories.

a) A large passage structure that enables movement across a road of all wildlife in an area;

b) Species-specific passages for one or more species, to enable high rates of seasonal movement with a population using habitat on both sides of a road;

c) Passages that allow for a lower level of movement that is nevertheless sufficient to prevent complete isolation (demographic and genetic) of a population that is divided by a road.

Failing to have clearly defined objectives and goals during the planning stages of a project can confound how well connectivity systems perform and how success or failure of a project is judged. Low levels of passage use (see above) may be sufficient in some situations where mass migration is not necessary. For such locations, if barriers are effective in reducing mortality, large passages may be a lesser priority. Measurement and evaluation of chosen objectives are addressed in Chapter 8.

Key Stages: please note these are generalized stages and specific Caltrans project planning and delivery are available elsewhere and may be subject to change.

Stage 1. Project planning and design. Although highly desirable, the occurrence of high and very high risk species may not always be flagged early on in most projects and may simply emerge as the output of specific pre-construction planning before work begins. Communication between biologists and transportation planners early in the planning phase will allow for wildlife crossing considerations as project scopes are being developed. During this stage, input should be obtained from species experts, such as local naturalists and university researchers. Resources and readily available data should be leveraged where possible, and all species of herpetofauna that occur in a project area should be considered. The ecological community as a whole should be addressed when planning for wildlife connectivity improvements. Initial passage system concept plans should be developed in collaboration with professional engineers. Timing of construction work in relation to seasonal behavior of species is important to minimize impacts on them and to establish lead-in periods prior to construction starting.

It is important to remember the temporal and spatial context of landscapes. Wildlife connectivity measures, including that completed to reduce the impact to herpetofauna and other wildlife, will often have a lifespan of decades or longer as culverts and bridges are generally designed to have a design life of 50 to 75 years. The planning of built measures for herps requires forecasting, visualization and understanding how to proactively integrate species-specific concerns into transportation projects and potentially rapidly changing landscape. Approaches need to ensure that crossing structures remain functional over time. Long-range planning needs to take into consideration not only likely future changes in land use but also how a changing climate may affect species and landscapes including increased fire risk.

Stage 2. Construction Stewardship and Monitoring. Road project planning should include measures to protect existing habitat and populations during construction. Measures might include the installation and maintenance of temporary fencing and protocols for relocating species out of harm's way. District biologists may work closely with resident engineers and construction workers to develop environmental avoidance measures and implement them. This results in reciprocal training and skill sharing that can be used on future projects. Environmental monitoring during construction is critical for ensuring that design meets reality on the ground.

Impact reduction measures can include a range of habitat manipulations and hard structure construction of varying type, size, and scale. In some cases, what is termed 'substitute habitat' may be created, replacing essential habitat features lost to road construction or confined to one side of it. This can be developed through careful habitat creation work. For example, artificial breeding ponds can be formed and placed on or near a new structure. Water drainage adjustments and features can be constructed to augment created ponds. Placing substitute habitats in proximity to a passage on one or both sides of a road may greatly enhance the level of their use, for example ponds at either side of a passage (see Ch. 6).

Stage 3. Post-construction monitoring and performance evaluation. Sometimes it is only an afterthought, but monitoring of population reaction to disturbance needs to be part of the planning process by setting an initial baseline of population size and distribution and recording of passage system use once built. Several years of

Figure 8: *Surveys and studies are often essential in order to update historic knowledge and to inform planning and assessment of outcomes. Credit: M Huijser.*

monitoring post-construction over 3-5 years or longer are necessary in order to determine whether investment in interventions is successful at meeting the pre-stated project objectives (Figure 8).

Monitoring post-construction will also identify problems or issues requiring attention (blocked passages, maintenance, fence repairs etc.). This ensures that built measures are functional and effective over the long term (see Chapter 9). Chapter 8 covers crossing system performance assessment.

Proactive and precautionary factors concerning herpetofauna

Invasive species and associated diseases should be a consideration when planning for wildlife connectivity improvements. Overall, consideration should be given to those invasive species that are, or could be expected to be present in a project area.

It has long been recognized that the spread of invasive species poses a significant threat to species biodiversity globally, including threatened and endangered herpetofauna. Consulting the *California Aquatic Invasive Species Management Plan* will help identify non-native algae, plants crabs, clams, fish, and amphibians. Amphibians such as American bullfrog *Lithobates catesbeianus*, (that displace native California red-legged frogs) and African clawed frog (*Xenopus laevis*), may impact native species populations. The non-native tiger salamander (*Ambystoma tigrinum*) may hybridize with the native California tiger salamander.

One example is on the lower Mad River in northern California where Caltrans built a permanent wetland feature that has become a bullfrog pond in the coastal zone. Efforts are underway to remedy this but it has been a very slow process. Features that facilitate invasive species spread should be a very early consideration in any potential project. Awareness of reptile disease pathogens such as Snake Fungal Disease (SFD) is also advised. Disease is a particular concern when temporary captivity, captive breeding and head-starting or translocation forms a part of a program.

When present, a strategy should be developed to ensure that non-native species status is not enhanced by road building or through impact reduction or compensatory activities. Actions should, in most instances, be taken to remove them. The *Declining Amphibian Task Force Fieldwork Code of Practice* should also be considered in relation to working with non-native species to prevent accidental spread of disease pathogens to amphibians or other species on equipment or clothing.

Key Points

- Generally, across a district, look out for synergies with all road-related construction and maintenance projects that impact wildlife to find places where herp connectivity measures may be applied. Studies may be made of long road segments to consider a range of needs and opportunities.
- A newly developed geo-spatial database that identifies road segments that may block the movement of herpetofauna is one tool available to transportation practitioners.
- Risk assessment is a valuable tool to identify road project impacts on herps in both short term and long-range transportation planning.
- Site-specific data are needed for new crossing structures. Protocols to get a reporting system for amphibian and reptile road mortality ‘hotspots’ should be encouraged. However, use road-kill data with caution as it may not always be the best indicator of mitigation need and opportunity.
- Required linkage retention or creation objectives need to be stated, agreed upon and recorded in the early planning stages of transportation projects. Environmental monitoring before and during construction is critical to ensure that design meets reality on the ground. Post-construction monitoring and research is the only way to determine whether performance objectives are met.
- Building passage and barrier structures on roads to protect amphibians and reptiles may be most economical when part of a larger transportation project.
- Build for multiple species or all resident wildlife species where possible, and as conditions and funding allow.
- Consult and follow the recommendations in the California Aquatic Invasive Species Management Plan to prevent and limit the introduction or spread of non-native species and/or disease.

Key References

Connectivity Initiatives

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Note: CDFW provided a list of specific connectivity data sources in the 2018 Regional Conservation Investment Strategies guidelines. See Section 4.2.9.6. Habitat Connectivity (pages 4-23 through 4-25).

- California Department of Fish and Wildlife. Climate science page (https://wildlife .ca.gov/Conservation/Climate-Science/Resources/Vulnerability) includes resources and the RCIS guidelines include climate change assessment guidance in section 4.2.9.8 Climate Change Vulnerability Assessment (pages 4-26 through 4-27)
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Caltrans Best Management Practices

Once project plans have been approved and objectives for the built system have been determined and agreed upon, work begins on detailed design. Because of the relatively small body size of amphibians and reptiles, past projects have focused mainly on smaller passage and barrier structures. Measures have been driven by regulatory requirements, often times geared toward a single endangered species.

Passage design types

Passages for animals mitigating roads and rails vary greatly in size and type, from large viaducts crossing canyons to small pipe and box culverts for small and medium-sized species. In the past, overpasses have been designed primarily for large wildlife in North America.

Herps and small mammals use wildlife overpasses also but there has been little monitoring of this. Ideally passage design should be holistic, serving the wider wildlife community and restoring severed ecological connections and natural landscape linkages.

Underpasses for the largest mammals that are involved in vehicle collisions are the most common purpose-built wildlife passage type in North America. Like overpasses, these structures often accommodate passage for herpetofauna, small mammals and invertebrates less able to cross highways. At the opposite end of the spectrum, small (<3.3 feet(ft)/1.0 meter (m) diameter) micro passages have been placed, in order to provide short-distance safe passage for target species. These are often in places where installation of a large structure over or under a road may not be technically feasible or achievable without large expenditure.

Design for climate change

In consideration of both a rapidly changing climate, climate adaptation needs and sustainable construction approaches, transportation agencies should consider developing less energy-intensive technologies. Alternatives to concrete and steel should be explored, that require less energy to manufacture and to build with such as lumber resources and recycled materials.

Innovative materials

Materials such as fiber reinforced polymers (FRPs) are increasingly being used for pedestrian bridges. FRPs are made of a fiber such as glass or organic material embedded within a plastic composite and have the potential to be used in the construction of wildlife passage structures. Overpasses have been over-engineered for decades, with load strengths designed for vehicles and trucks rather than wildlife. Currently there are investigations aimed at reducing costs through innovation in materials, processes and design and construction approaches.

Design criteria and variables

The main objective of wildlife passage design is to provide conditions that minimize species passage 'avoidance' responses. Because herps are 'cold blooded' and body temperature may be rapidly influenced by surroundings, they can be highly sensitive to temperature change. Physical features of a passage may appear unfamiliar. Light levels can play a role, even for nocturnal species (many amphibians and some reptiles). Related to this are temperature and moisture gradients that may also influence behavior. A small passage may mimic the entry to a burrow or cave and this may induce rejection responses. The extent of use of a passage may be a balance between instinct or stimulus for directional movement versus resistance brought about by behavioral reaction to unusual conditions. Some species may avoid going into and moving along passages that are darker, drier or cooler than the surrounding environment, while others may not. Species may 'explore' for different distances before turning back. Given the lack of research for most species, practitioners should aim to design structures that best match ambient environmental conditions (Figure 9).

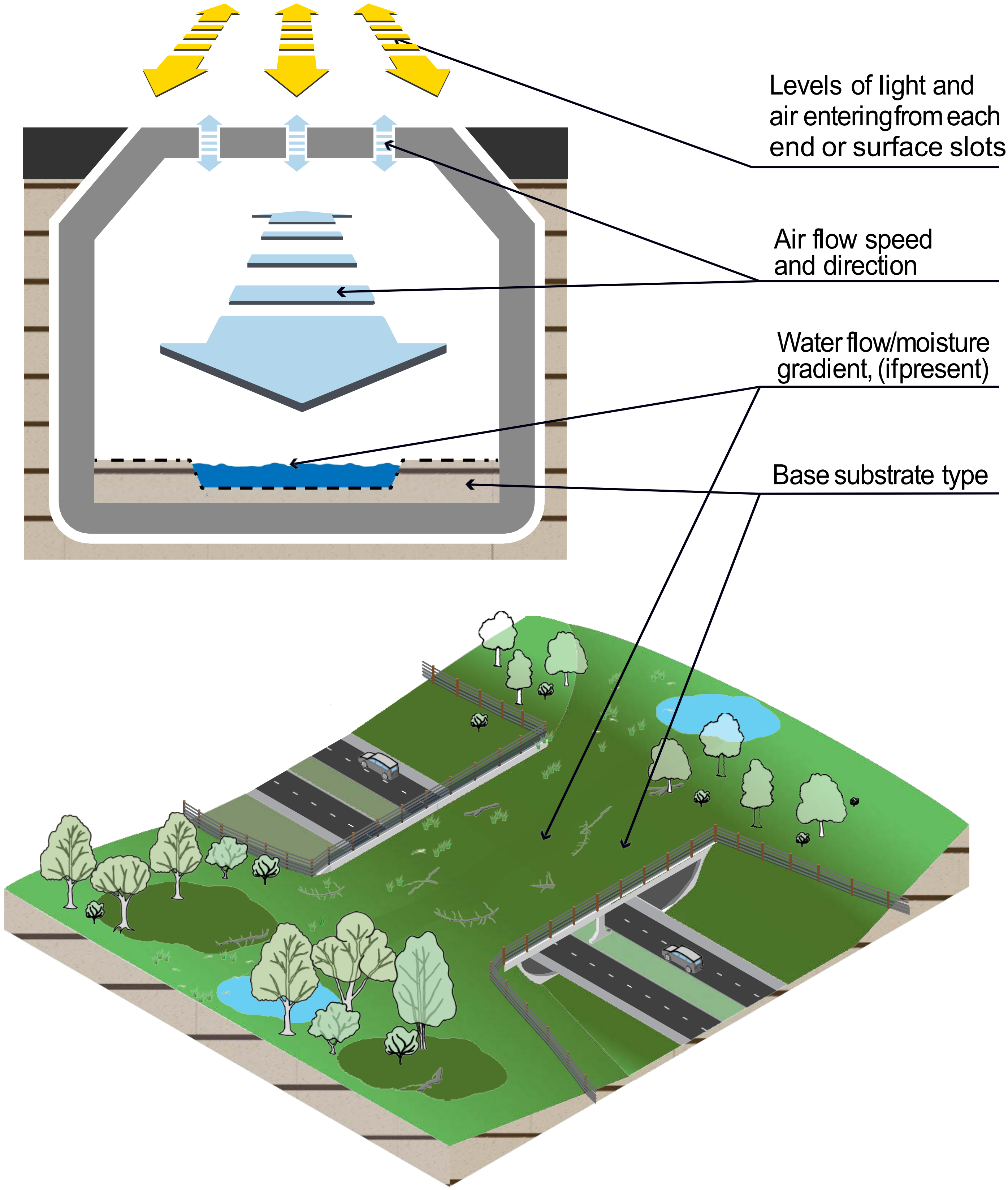


Figure 9: *Abiotic conditions that influence passage use. Air movement and light levels may influence passage temperature and humidity beyond the normal night and day fluctuations Soil or substrate type and near-passage drainage design influences water flow and passage base moisture levels.*

The type of substrate at the passage floor is important and should mimic the surrounding soil properties, including moisture and temperature. Untreated cast concrete can release efflorescence that can leach out and burn amphibian skin. A corrugated steel passage without a substrate base is uneven and hard for some species to easily traverse. In addition, as metal is a good thermal conductor, it can become much colder and hotter than the surrounding air temperature, this may be harmful in some circumstances at certain times of day. Care in design when using different materials is essential.

The maintenance of passage structures is an important consideration in the design process. Windblown soils, sand or debris such as leaves and roadside trash can accumulate inside. Vegetation may not grow far beyond the entrance in small to medium sized passages. Mammals that dig can disturb soil causing passage blockages. The cost of cleaning and maintaining structures in the long term should be factored into project planning and programming (see Chapter 9). Some of the smallest passages are designed with inert polymer surfaces and have no soil base. Passages may require assessment and adjustments in the early years following installation to provide attractive moisture levels. This may include adding drainage to reduce waterlogging or channeling rainwater to the passage to make it damper.

Wildlife Connectivity Structure Categories

The dimensions (length, width and height) of passages described in this BMP are as shown in Figure 10. Crossing structure types No. 1-5 (large to small) are illustrated in Figure 11 and Figure 12 and described in more detail below. For crossing structure type 6: prototype micro-bridge structures see the end of this chapter.

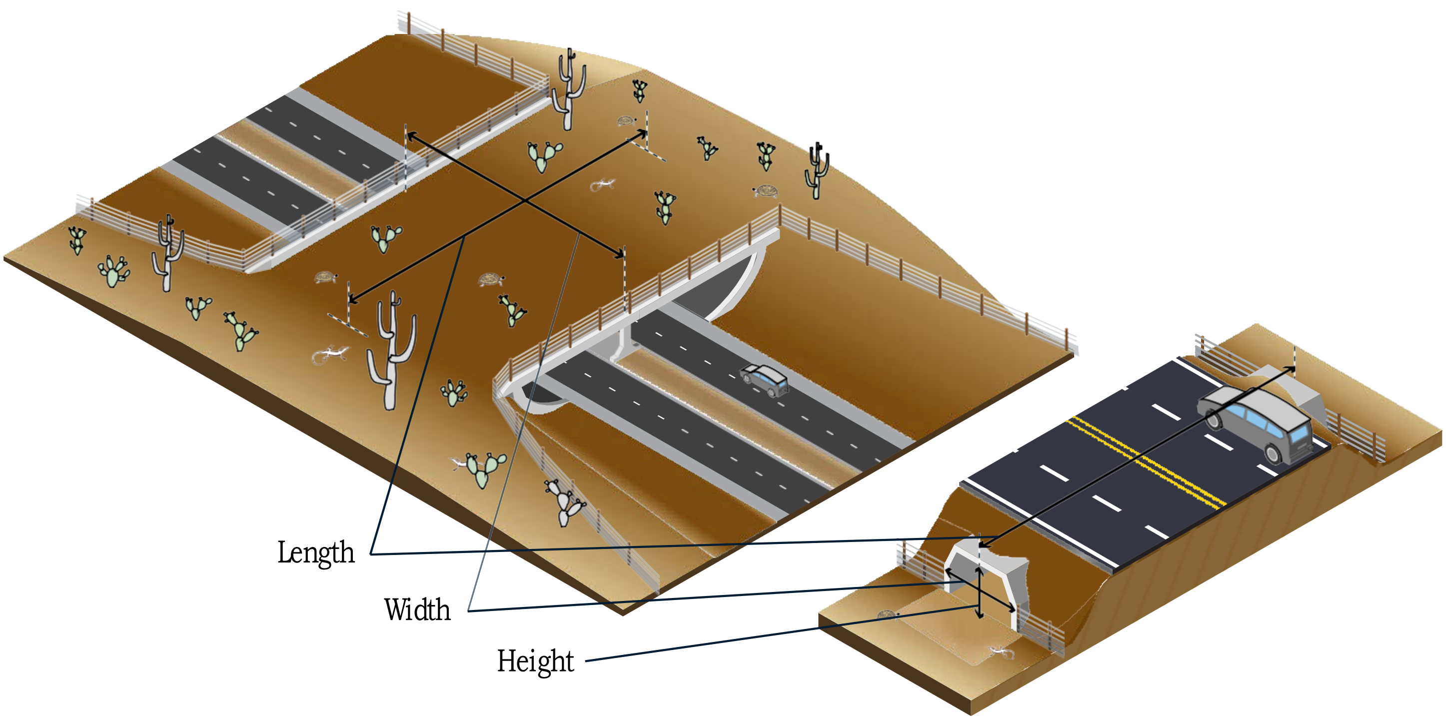
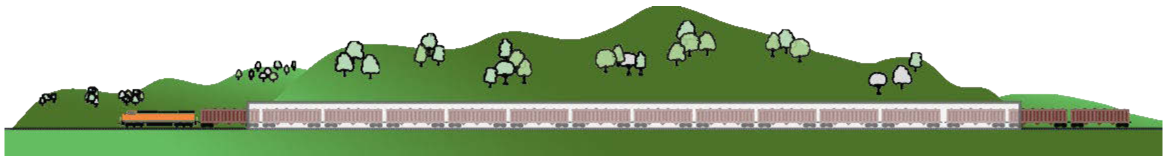
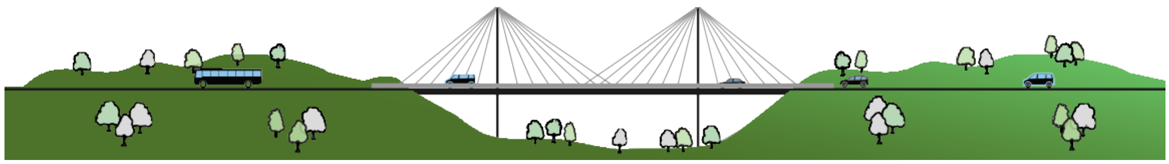


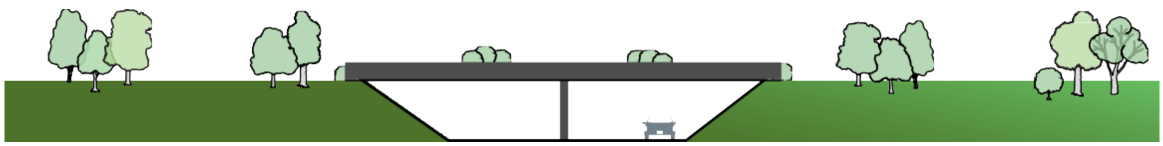
Figure 10: *Dimensions of length, width and height of passages referred to in this BMP*



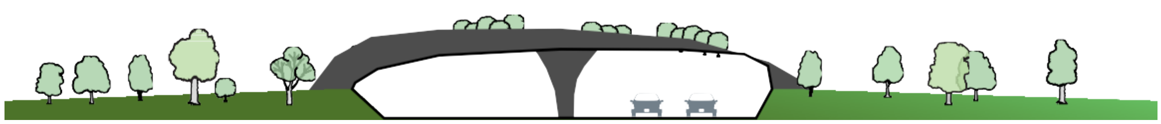
Type 1A
Mountain/
Hill Tunnel



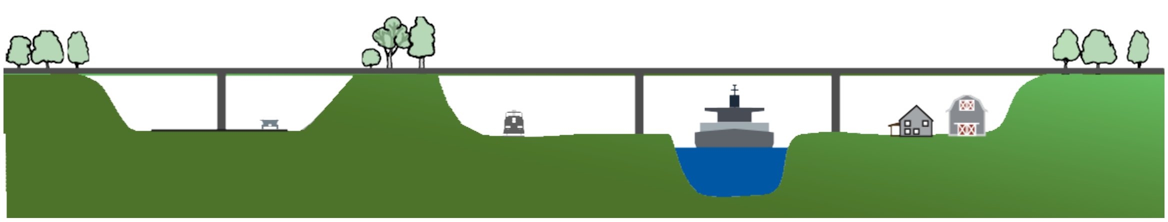
Type 1B
Viaducts/Open
Span Bridges



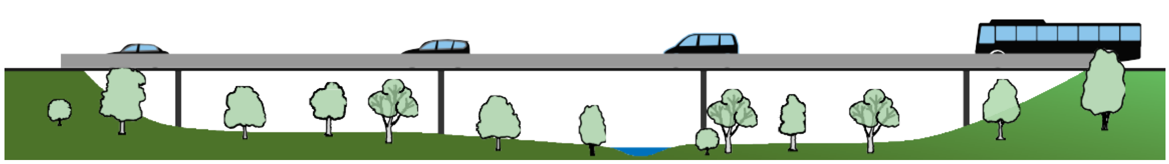
Type 1C
Wildlife
Overpass
at Grade



Type 1C
Wildlife
Overpass
Raised



Type 1C
Wildlife Overpass
Multi (road, rail,
canal, farm)



Type 2
Smaller Open
Bridges and
Viaducts less
than 120 ft

Figure 11: *Overview of passage categories Types 1-2*

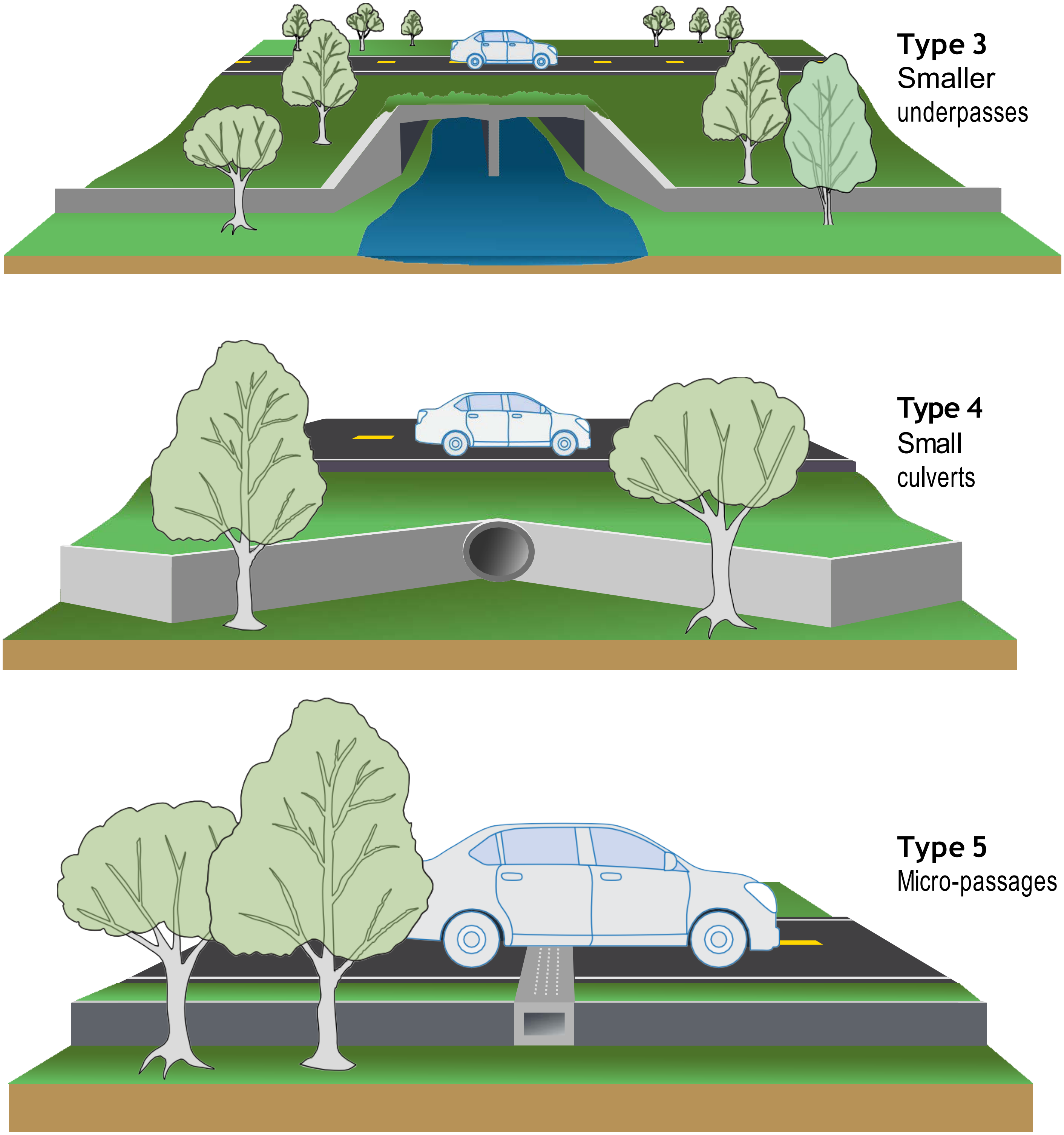


Figure 12: *Overview of passage categories Types 3-5*

Type 1A: Mountain/hill tunnel

There are many examples of road and rail mountain tunnels that have been constructed worldwide over the last 150 years or so. Mountain tunnels minimize the extent of above ground environmental disturbance and leave habitats virtually intact other than at their openings. They provide for the least disturbed wildlife passage in proximity to transport routes.

Roads entering mountains may block lateral (sideways) animal movement at the base of a steep or shear slope. Sometimes ledges, fences and strategically placed rocks and boulders are built around and along the top of the tunnel entrance to catch falling rocks and to provide access for lighting and ventilation equipment servicing. By extending tunnel entrances slightly with a 'portal structure' (Figure 13), greater wildlife provision may be made for wildlife moving around the base of a hillside. This is effectively a wildlife overpass along the side of a steep hill or cliff.

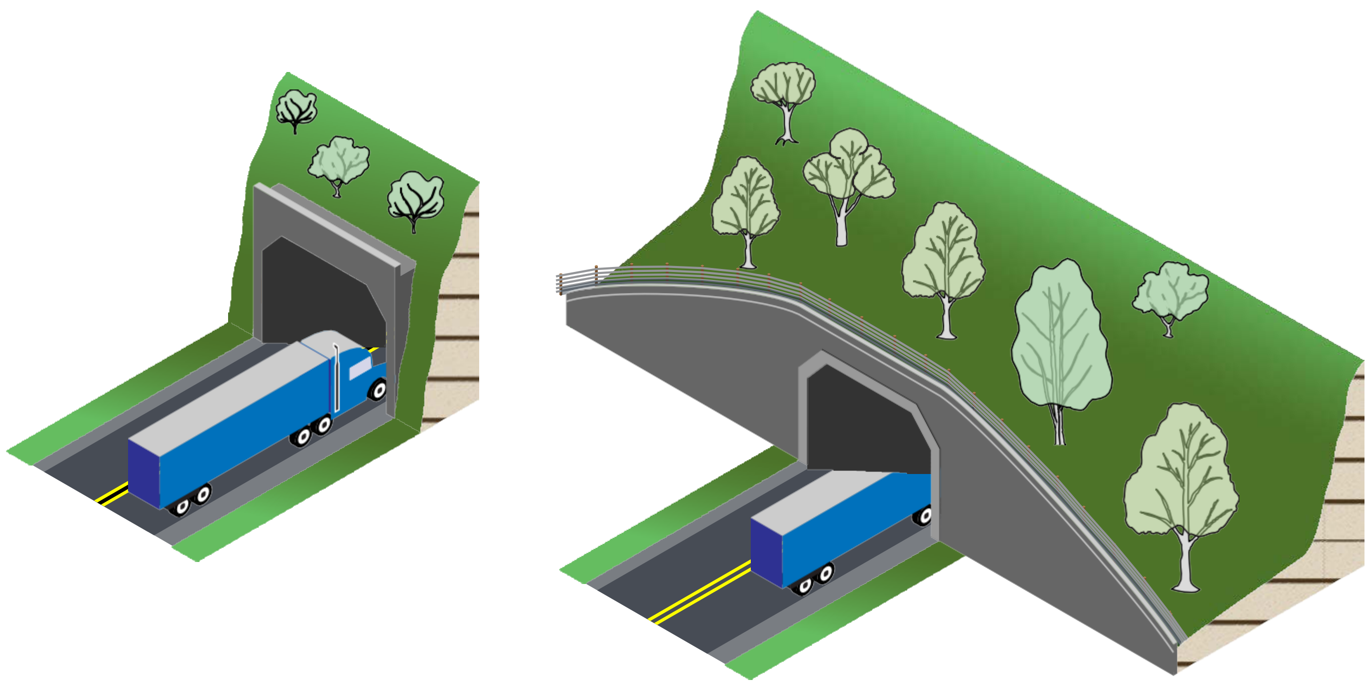


Figure 13: *'Portal structures' may be formed at transport tunnel entrances to help retain lateral wildlife movement at the base of steep mountain cliffs and slopes.*

Examples of mountain tunnels protecting biodiversity in California include the Devil's Slide Tunnel located on Highway 1 near Pacifica, south of San Francisco and the Caldecott Tunnel located on Highway 24, north of Oakland (Figure 14 to Figure 16).

At Devil's Slide, (District 4), a bypass route was built to alleviate an eroding section of coastal Highway 1. The project is located adjacent to McNee Ranch State Park in the Santa Cruz Mountains, San Mateo County and in an area of scenic coastal mountains. The area supports a patchwork of grassland and coastal scrub habitats and freshwater drainages. The shorter tunnel alternative left the area largely untouched and retained wildlife movements along a small valley where protected species are present compared to realigning the roadway inland and along a new overland route. The 4,600-ft twin road tunnel option that opened in 2013, provided an economically viable solution. The new tunnel is considered safer and shorter than a traditional winding road and the project resulted in less environmental damage. Amphibians and reptiles including California red-legged frog and San Francisco garter snake, both California Species of Special Concern, were factors in the environmental considerations and decisions.

Figure 14: *Devil's Slide bridge and tunnel entrance on Highway 1 near Pacifica, California. An amphibian breeding pond is just beneath the bridge (light colored triangle shaped feature). Image: Caltrans District 4.*

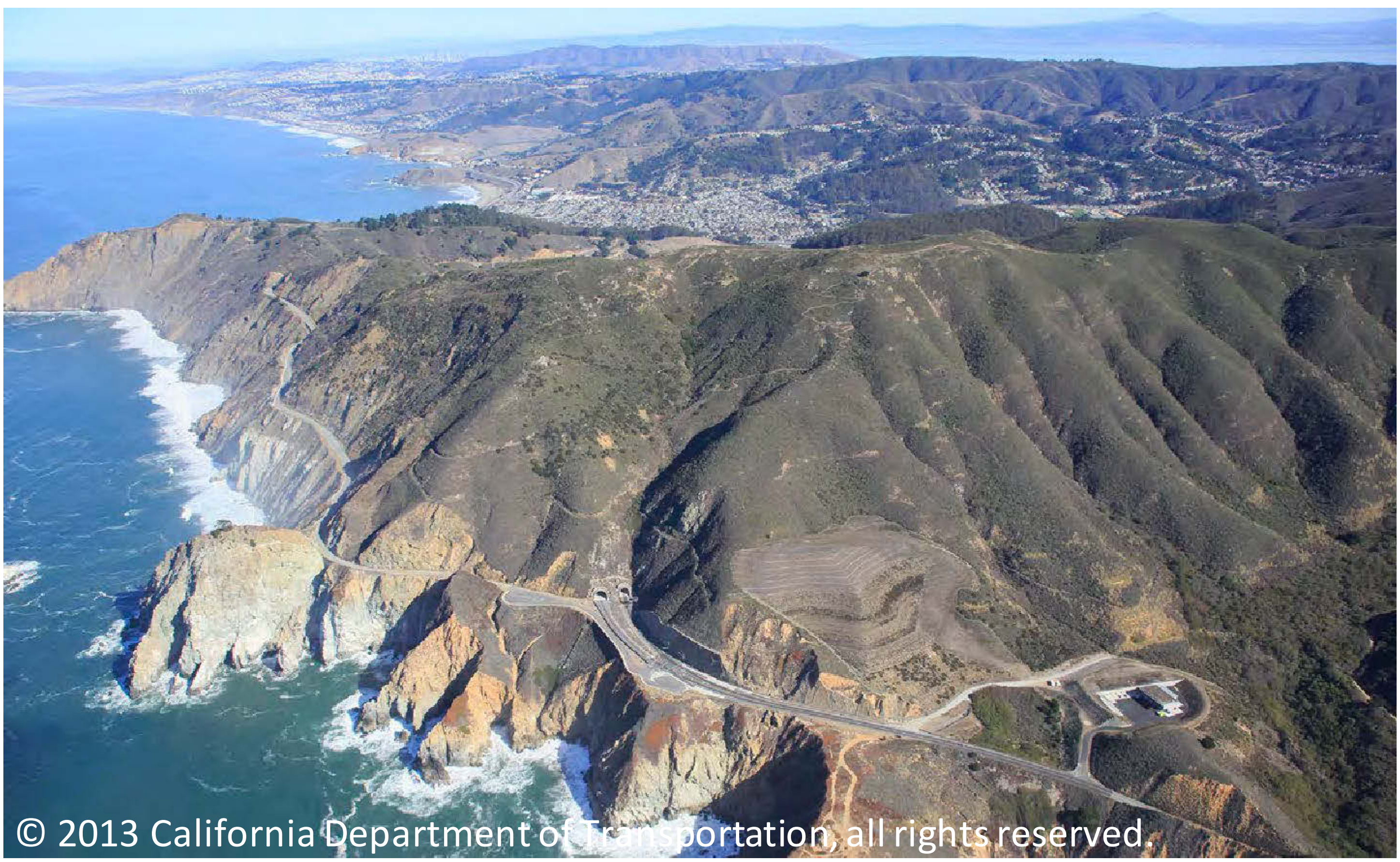


Figure 15: *Devil's Slide, Highway 1 near Pacifica, California. South entrance. Tunneling prevented the need for a longer, winding and more damaging overland route, while the old route is now a multi-use recreational cliff path. Image: Caltrans District 4.*

Figure 16: *The Caldecott Tunnel is located on Highway 24, near Oakland, Caltrans in District 4. Tunneling for about 3,300 ft/1000 m, helped to protect the area known as the Caldecott Wildlife Corridor (East Bay Regional Park District), preserving a movement corridor for wildlife between Oakland and Orinda. Image: Google Maps.*

Caltrans completed construction of the fourth bore of the Caldecott Tunnel in 2013. The threatened California red-legged frog and Alameda whipsnake were known to occur in the project area and the tunneling retained the above ground linkage for these protected species. Constructing a traditional highway would have blocked wildlife movement and interfered with foraging, mating, and dispersal. Loss of wildlife habitat was restricted to 0.56 acre.

Type 1B Viaducts and open span bridges

Viaducts are larger steel and concrete structures that span wide valleys, floodplains and canyons and are often many hundreds of feet long. They are optimal wildlife passages by virtue of their size, often completely bridging aquatic and terrestrial habitats or otherwise set on multiple stilt support structures. They provide relatively intact habitat and adequate space underneath for animals to move safely under the road corridor. These structures are rarely built specifically for wildlife, but in most instances, they retain wildlife connectivity underneath. An example is The Yolo Causeway; a 3.2-mile long elevated highway viaduct on Interstate 80.

Type 1C Wildlife overpass

Also called "green bridges" or "ecoducts", over 200 wildlife overpasses have been built in Europe as part of national nature "defragmentation" (landscape linkage) strategies. 'Cut and cover' road tunnels (Figure 17) are similar and allow extensive wildlife and side road movement above.

Today there are roughly two dozen wildlife overpasses in North America, varying from 15 – 200 ft/ 5.0 - 60 m in width, with plans for more in the future. None have been built with herpetofauna specifically in mind or as a major component. However, local soil and habitat components can be included in the design of overpasses so that these structures are conducive to all wildlife species, including amphibians, reptiles and even butterflies. Overpasses provide contiguous habitat for small species with smaller home ranges, as well as providing a movement corridor for wider ranging species.

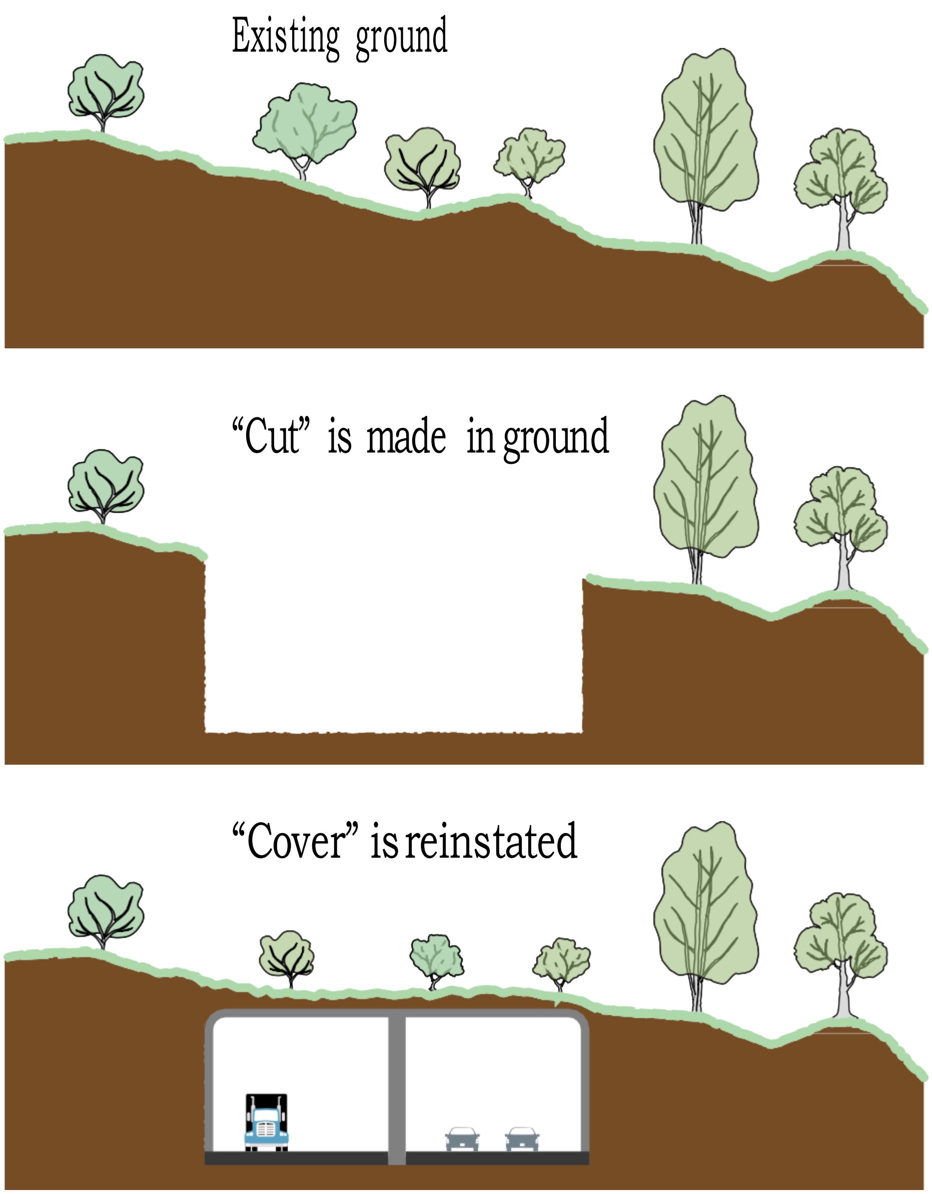


Figure 17: *Cut and cover vehicle tunnels are built by totally or partially excavating away the ground and a placing back a roof or 'false' cover to enable lateral movement above the new road.*

Figure 18 shows a design model for a proposed large Type 1C multi (two-road) wildlife over-pass crossing. This aims to re-join habitat between the Santa Monica and Sierra Madre moun-tains at Liberty Canyon (Agoura Hills, CA). The target species is mountain lion (*Puma concolor*); however, at least three species of herpetofauna considered high or very high road risk; coach-whip, striped racer and western rattlesnake may benefit from increased connectivity if the overpass is constructed.

Figure 18: *Design model for a large Type 1C multi-road wildlife overpass crossing at Liberty Canyon (Agoura Hills, CA). Image: Simulations: #SAVELACOUGARS & NATIONAL WILDLIFE FEDERATION*
Image: Tom Langton.

Figure 19: *Type 1C wildlife overpass that is 150 ft/46 m wide and was constructed specifically for mule deer on Highway 93 north of Elko, Nevada. Image: Nevada Department of Transportation*

Figure 20: *Type 1C wildlife overpass with emphasis on amphibian connectivity (Netherlands). Features include a narrow wet strip along the length of the passage connecting small ponds at each end. Image: Rijkswaterstaat.*

Figure 21: *Type 1C Wildlife overpass in forest area. Image Thibaud/Limba/FilmDroneProject*

Figure 22: *Root wads and tree branches are sometimes placed along the length of an overpass. These provide shelter for herps and other wildlife that show a preference for closed cover within their habitats. Image: Tom Langton*

Type 2: Smaller open bridges and viaducts less than 120 ft/36.5 m

This category spans gaps of 60-120 ft/20-36.5 m. Small road bridges are probably the most common structure bridging natural habitat. These structures are generally designed to cross smaller floodplains, rivers, streams, small dry valleys and upland habitats. They consist of pre-cast or cast on-site single or multiple span beam structures. These small open bridges can benefit a range of wildlife species, including herps. Amphibians and reptiles may cross underneath if suitable water and land surfaces for movement are present. Although animals will continue to use the riparian corridor or other linear feature, individuals may not actually cross under the structure. There can still be upticks in wildlife mortality at the bridge ends where wildlife crosses the road most often. Directional fencing should be incorporated into the design of new or renewal projects to reduce or prevent this.

Figure 23: *Image shows a Type 2 bridge that is about 120 ft/36.5 m in length. This bridge is located over a stream at the junction of Campo Road with Honey Springs Road and Otay Lakes Road, San Diego County. Image: Tom Langton*

Figure 24: *A Type 2 underpass in the Sonoran Desert in Arizona, constructed for passage by deer and bighorn sheep. The passage crosses under a 6-lane road with a median. It is a purpose-built, 50 ft wide, 12 ft high, and 190 ft long (15.2 m wide, 3.6 m high and 58 m long) structure is located at Oracle Road, near Tucson, Arizona. Image: Tony Clevenger.*

Type 3: Smaller road underpasses less than 60ft/20 m wide

Smaller underpasses include largely concrete and/or steel formed bridge structures. They can also be built of brick, rock or wood. Small bridges may be designed for wildlife only, but are mostly built to assist drainage with the additional benefit for wildlife. Small underpasses typically range from 10 to 60 ft /3.0-18.0 m in length and span waterways with ephemeral or intermittent water flow or those with permanent flows that also convey high flows during storm events. Other purposes for the construction of smaller underpasses may include access for pedestrians and recreationists; agriculture and livestock; and forestry access. Some Type 3 structures

Figure 25: *An adult garter snake is using a Type 3 structure on State Route 152 in California. This bridge spans Pacheco Creek near San Felipe Lake on the Pacheco Pass Highway near Gilroy. California quail (Callipepla californica) are also present. Image: Pathways for Wildlife, Santa Clara County, CA.*

Figure 26: *Image shows a 30 ft/9.1 m Type 3 concrete temporary stream bridge along Campo Road/Highway 94, San Diego County, south of San Diego. The bridge has three 10 ft × 10 ft concrete chambers and was built without specific wildlife goals. Image: Tom Langton*

Figure 27: *From the same structure shown in Figure 26, one of the chamber dividing walls. These chambers can be scoured out by seasonal heavy stream flow and flash flooding, but may also be used by nesting birds as well as mammals, such as the kangaroo rat (Dipodomys californicus) which has excavated soil in the base of this structure. Image: Tom Langton*

may be designed with herpetofauna connectivity as a factor, while others have been purpose-built for them, and these are usually under 20 ft/6.0 m wide. Examples are the larger drainage culverts built under desert roads that were adapted for use by Desert tortoise and other desert animals. Such structures, may be retro-fitted with wildlife fencing and other measures for safe-use passage.

Type 4: Culverts less than 10 ft/3.0 m wide

Type 4 passages used by herps are often drainage culverts made from concrete or galvanized steel, High Density Polyethylene (HDPE) and other plastics. In cross section the open space formed can be square, rectangular, arched, round, half or three-quarter round These structures can be adapted for use by wildlife. Some may be completely or partly permanently flooded and serve to help balance surface water levels on either side of

Figure 28: *A new culvert built under State Route 58 in southern California (Hinkley Highway Re-alignment Project, Caltrans District 8). Adjustments will be needed to join wire fencing to the entrance of the passages and to make the rip-rap safe, so desert tortoises do not get trapped in it.*
Image: Cheryl Brehme

Figure 29: *With a large median and easements under a four-lane highway, desert culverts can be extremely long (over 300 ft /90 m) and dark during the day. The view foreground here is lit by a camera flash.*
Image: Cheryl Brehme

Figure 30: *This is a Type 4 cast concrete 'bottomless' or 'stilt' passage with side walls built on foundations in the Netherlands. It is constructed below a two-lane road with cycle path, particularly to enable rare lizard dispersal. The sandy base substrate is in contact with the natural water-table. Image: Tom Langton*

Figure 31: *Located on the far side of the road shown in Figure 30 and either side of the cycle lane is a series of cast steel gratings placed within the roof of the wildlife passage to allow entry of light and moisture. Image: Tom Langton*

Figure 32: *Here two Type 4, 3 ft/90 cm concrete culverts are positioned to accommodate flood events at a desert drainage. Provisions like this might potentially be used by reptiles but many have not been built with directional fencing. They are potentially suitable for modification. Image: Cheryl Brehme*

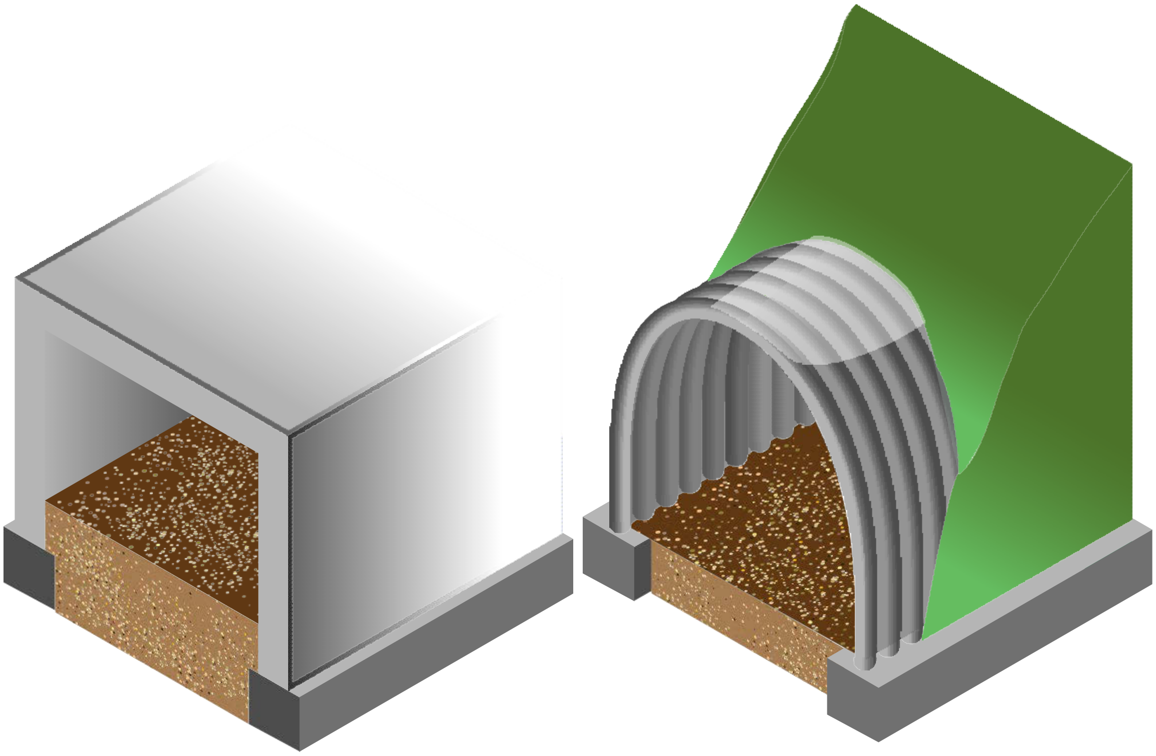


Figure 33: *Passages built on foundations are sometimes referred to as 'bottomless' or 'stilt' passages due to the open natural soil base and support on both sides. A free-draining interior may sometimes conform to moisture levels of the surrounding area more than a closed culvert.*

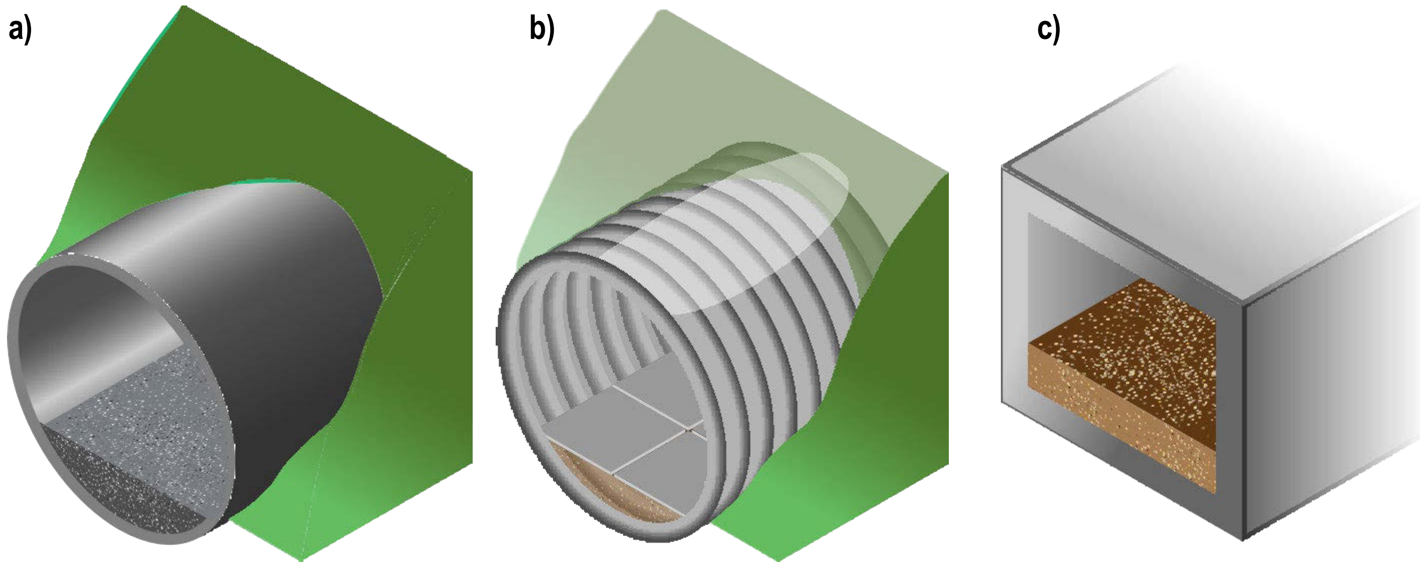


Figure 34: *Simulation of three Type 4 (round and rectangular) passages that can be designed with substrate placed at the base during construction. In Figure 34(a) concrete is poured in and sealed at the surface; in Figure 34(b) soil and moisture-inert heavy tiles are placed at the bottom; and in Figure 34(c) a shallow dirt floor may be sufficient for some species.*

a road. Most are seasonal and prevent water from building up, or the road area from becoming waterlogged and flooded by storms. These culverts may have a natural substrate or purpose-lain soil to provide a flat and more natural surface to encourage animal movement. Rocks or rip-rap may be placed to reduce scouring, but this can present an issue for tortoises and turtles as animals may become trapped between gaps and die. Designs that do not trap tortoises are being investigated out of state.

Passages can be designed with substrate placed at the base during construction. Examples are given in *Figure 34*, but there are multiple options for creating suitable passage floors. These are not always tied to the shape and size of the culvert. The behavioral needs of the target species involved may play a big part in passage floor design in particular moisture and humidity that can be extremely important where amphibians are being considered.

Water may be a necessary feature and an important component of a passage structure for some species. A drainage system to divert the right volume of rain water may be incorporated into the design of a culvert and its surrounding land to provide a damp or wet channel (*Figure 35*) in important seasons of animal dispersal.

Aquatic snakes and turtles will use a still or slow flowing aquatic environment. Project specifications will need to dictate how the drainage feature will be provided, such as through diverted surface water channels or 'leaking pipe' design. 'Leaking pipe', as used in horticultural situations, releases water slowly from a supply on higher ground, for example a rainwater drainage basin or pond or a stone surface trench with a perforated land drain that is placed along an embankment to intercept rainfall.

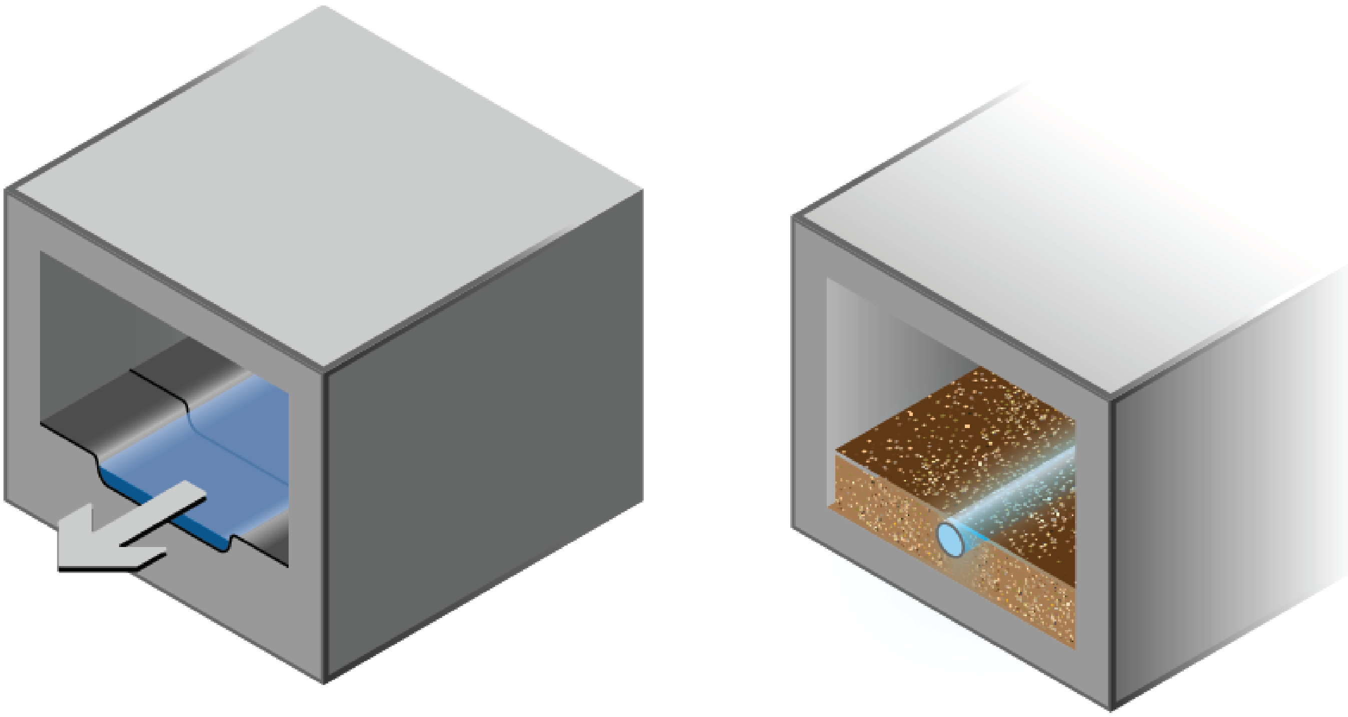


Figure 35: *Water flow or a drainage system may be incorporated into the design of a culvert passage to provide a wet channel or moist passage base.*

Figure 36: *A Type 4 sized passage with dry ledges, in addition to a central wet channel is suitable for a range of species, shown here at a wildlife crossing in central Europe. Image: Silvia Zumbach, KARCH*

Figure 37: A Type 4 purpose built passage with a light and air gap in the median and with wet and damp conditions suitable for amphibians and other wildlife that prefer damp conditions. Image: Andreas Meyer, KARCH

The sowing and planting of vegetation and placement of natural structural materials such as boulders, rocks and logs should be considered very carefully. These features may help encourage more secretive or closed habitat specialists animals to the passage openings and particularly larger passages that span greater than two lanes of traffic.

Without care, however, structure and vegetation may have the opposite effect and deflect animals away from the openings via effects such as altering the angle of approach to a barrier. For many, but not all species, a relatively open passage base boosts the speed of travel into and through a passage.

Vegetation that grows tall and creates shade may lower passage opening temperature. Designs should wherever possible avoid creating places that encourage higher numbers of predators than usual. For the larger passages over and under roads, structural cover, whether living or inert materials (e.g. native shrubs, rock and log piles) may be placed along one side of the entire crossing structure to provide cover to closed habitat specialists. The exact design will relate not only to passage size but the systems objectives, the main target species involved and habitat type/s present.

Passages under 6 ft/1.8 m span have restricted access for maintenance and closed-space regulations may prohibit entry without full safety training and equipment. The placement of cover items (e.g. rocks or logs) in a smaller passage may not hold an advantage as cover materials can shift and block light and air movement through a smaller passage. The topography and drainage characteristics of any passage location may dictate to some extent the potential for cover to be used. If a passage is installed both to convey drainage and provide for the safe passage of wildlife, the cover should be placed well outside the drainage area.

If a passage is there principally to enable rapid movement to either end, resting places may delay a journey and promote turn-arounds. Yet on the other hand they may provide shelter so that some species are more likely to use them. So great care is required in the use of cover items inside and close to passage ends, as they may strongly influence system performance. Cover is particularly suitable for larger passages to enhance the use for most herpetofauna.

Type 5: Micro passages less than 3 ft/0.9 m in diameter

Micro passages can include both the smaller water drainage culverts and purpose-built passages for the movement of small wildlife species. Most culverts under roads are associated with ditches and slopes and are installed for the purposes of conveying surface water flow after rain.

Figure 38: There are many small cross-road steel drainage culverts on California roads, such as this elliptical shaped steel culvert near San Diego. This culvert was built during the last century and is nearing time for refurbishment. This type of scenario offers an opportunity for culverts to be adapted for safe wildlife passage as well as for road drainage purposes. See also Chapter 9. Image: Tom Langton

Most micro passages are 30-60 ft/10-20 m in length and span the width of a two-lane road, to a ditch or base of the embankment. Some wildlife passages may also have a drainage function by design. The position of the road in relation to the surrounding terrain (on embankment, at grade or in cutting) may dictate the type of passage selected and the way in which materials are built.

There are approximately 50 crossing systems with over 150 passages in total that are designed exclusively or partly for amphibians or reptiles across the USA. Many are experimental and installed due to road and housing development impacts to try to retain movements across habitat. In California, few systems are part of the State Highway System. At 11 known locations in California there are a total of at least 52 amphibian passages installed, with between 1 and 12 passages per location. These passages are mostly Type 5; less than 3 ft/0.9 m in diameter. These were built for the following target amphibian species: Western toad, California red-legged frog, California tiger salamander and Santa Cruz long-toed salamander (Table 2a). For reptiles, purpose built passages could only be located for Desert tortoise in the Mojave desert (Table 2b.).

Table 2a. Provisional checklist of recorded passage and/or barrier systems in California for amphibians.

Target Species and Crossing Location; (Road and County)	Year/s installed	Approximate number & type of tunnels, barriers. General notes.
Western Toad Pole Line Rd, Davis, Yolo County	1995	1 no. ca. 12 inch/300 cm metal corrugated pipe, no fences. System not functional
Santa Cruz long-toed salamander Ventana Way, Seascape Uplands, Santa Cruz, Santa Cruz County	1999	5 no. ACO AT500 20 in/500 mm and 1.no. ACO Q200 8 in/200 mm polymer concrete slotted surface tunnel. Approximately 1000 ft/300 m of ACO plastic panels with 30 ft or so extensions to some barriers with silt fence on wood post. For monitoring See Allaback, M.L. & D.M. Laabs. 2003
Santa Cruz long-toed salamander Highway 1, Santa Cruz County	1999	Barrier only
California tiger salamander Junipero Serra Freeway (I-280), Stanford Hills near Lake Lagunitas, near San Jose, Santa Clara County	2001 & 2003	3 no. polymer concrete ACO 20 inch (500 mm) surface tunnel and 1 no. metal corrugated steel culvert. Plastic panel and mesh fence barriers. See Brehme et al. 2020.
California tiger salamander Stony Point Road near Cotati, Sonoma County	ca.2013	3 no. 10 in/25 cm steel pipes with plastic pipe entrances. One 20 in elliptical concrete pipe. Range of fence types. See: Bain, T. 2014.
California tiger salamander Portola Avenue, Cayetono Creek, Livermore, Alameda County	2013	11 no. 8 in polymer concrete slotted surface drains(ACO HD 200) with buried plastic mesh and solid sheet barrier.
California tiger salamander Wilfred Avenue, Graton Resort and Casino, Sonoma County	2014	12 no. polymer concrete slotted surface tunnels (20 and 8 in types) Each tunnel has a circular pipe spanning a ditch before entering the main passage. Circa 3280 ft/1000 m of in places very low (8 in) fence.
California red-legged frog California tiger salamander Vasco Road, Livermore, Contra Costa County	2015/16	8 no. concrete culverts 3x48 in 3x24 in round and 2x5 ft square, 98-132 ft long with wire mesh fencing on 1 mile segment. Use 2017/2018 by target species uncertain. Camera monitoring showed use by rattlesnake, kingsnake and gophersnake spp.
California tiger salamander State Road 246 between Buellton and Lompoc, Santa Barbara County	2017	A 64 ft viaduct with six 6 ft round concrete passages with 14 in high concrete fencing – Data needed on what exactly built. California red-legged frog also present.
Yosemite toad 9S09 Road: Sierras, Fresno County	2018	Elevated road segment 100 ft wide, 8 in high passage with 400 ft/120 m of barrier fencing at each end on both sides (polymer mesh and solid)
California tiger salamander Santa Cruz long-toed salamander San Andreas Road, Santa Cruz County	Not known	1 no. Passage and barriers. Data needed.
California Tiger Salamander Orcutt Rd, between Orcutt & Santa Maria, Santa Barbara County	Not known	Dry box culverts. Data needed.
Yosemite toad Highway 108, Humboldt-Toiyabe National Forest Mono County	2020*	*Experimental type 6. crossing and barrier systems recently constructed

Table 2b. Provisional checklist of recorded passage and/or barrier systems in California for Desert tortoise.

Target Species and Crossing Location; (Road and County)	Year/s installed	Approximate number & type of tunnels, barriers. General notes.
Desert tortoise Multiple culverts under Interstate 15 (I-15) Mojave desert San Bernardino County	1991-1996	Multiple steel and concrete culverts: round & rectangular, • Diameters: 3.0-11.0 ft/0.9-3.5 m • Lengths: 108-215 ft/33-66 m • Barrier: 15 mi/24 km of 24 in/60 cm high, 0.5 in/1 cm galvanized hardware cloth, with 6 in/15 cm buried in the ground. Held on 5 ft/1.5 m wire strand fence. See: Boarman and Sazaki 1996
Desert tortoise Mojave desert San Bernardino County	1994-1995	Corrugated metal pipe 215 ft/66 m long. 13 x 5 ft/4 x 1.6m. Metal aprons installed at entrances. Tortoises have been recorded passing through on 60 occasions. See Boarman et al. 1999
Desert tortoise Harper Lake Road (Solar Farm) Lockhart San Bernardino County	1997-2009	1 no. ca. 3 ft round pre-cast concrete culvert passage (2004) and 12 mi/19 km fencing http://www.tortoise-tracks.org/wptortoisetracks/projects/harp-er-lake-fencing/
Desert tortoise Interstate 58 near Hinkley Mojave Barstow Highway Between miles markers 22 and 31 San Bernardino County	2017	8 no. wildlife tunnels were installed along an approximate 1 mile portion of the realignment. The box culvert passages range from approximately 246-328 ft/75-150 m in length.

The information gained from the installations is highly limited. Although most accommodate two-lane roads, they are all unique in terms of topography soil, vegetation and surrounding human disturbance and land uses. The designs in some cases were compromised and experimental and established without a clear baseline, success criteria or detailed monitoring guidelines. This is changing as newer systems are built with greater attention to essential detail for critical appraisal that will aid in setting new standards.

Other than for tortoises, there do not appear to be any passage systems built specifically for reptiles in California. However, standard and purpose built passages for other species are known from camera monitoring to be used by a wide variety of vertebrates, for example at Vasco Road (Table 2.a), passages were used on multiple occasions by California kingsnake, Northern Pacific rattlesnake and Pacific gophersnake.

Elsewhere in North America, passages for freshwater turtles and snakes have been built. Generally, past monitoring of passage use has been absent or by way of short duration sampling. Monitoring of passage use is critical for assessing the efficacy passages. In recent years a number of new projects have been completed or are at the planning stage for endangered and road-sensitive herp species in California. No study has yet demonstrated what can be considered fully successful outcomes for a barrier and passage system and lack of monitoring remains a substantial issue.

Many of the existing California type 5 micro-passage systems built for salamanders (Table 2a) are surface passages, formed from polymer concrete (resin bonded minerals) or otherwise are rounded metal or standard concrete. Because of their small size, standard plastic, metal or cast concrete structures (other than polymer concrete) must be buried relatively deep (to a depth of 3 ft or more) below the road surface to avoid damage and collapse caused by the heaviest vehicle loadings.

Passages made from polymer concrete, are typically authorized to accommodate higher loads than standard concrete (Figure 39). Metal grates (e.g. cattle guards) similar to those used for larger livestock may also be strong enough, but use has been limited to lower-speed roads. Metal gratings in a highway setting for fast-moving traffic are being investigated. This is due to safety concerns and risk of failure, such as the grating becoming detached and loose on the highway.

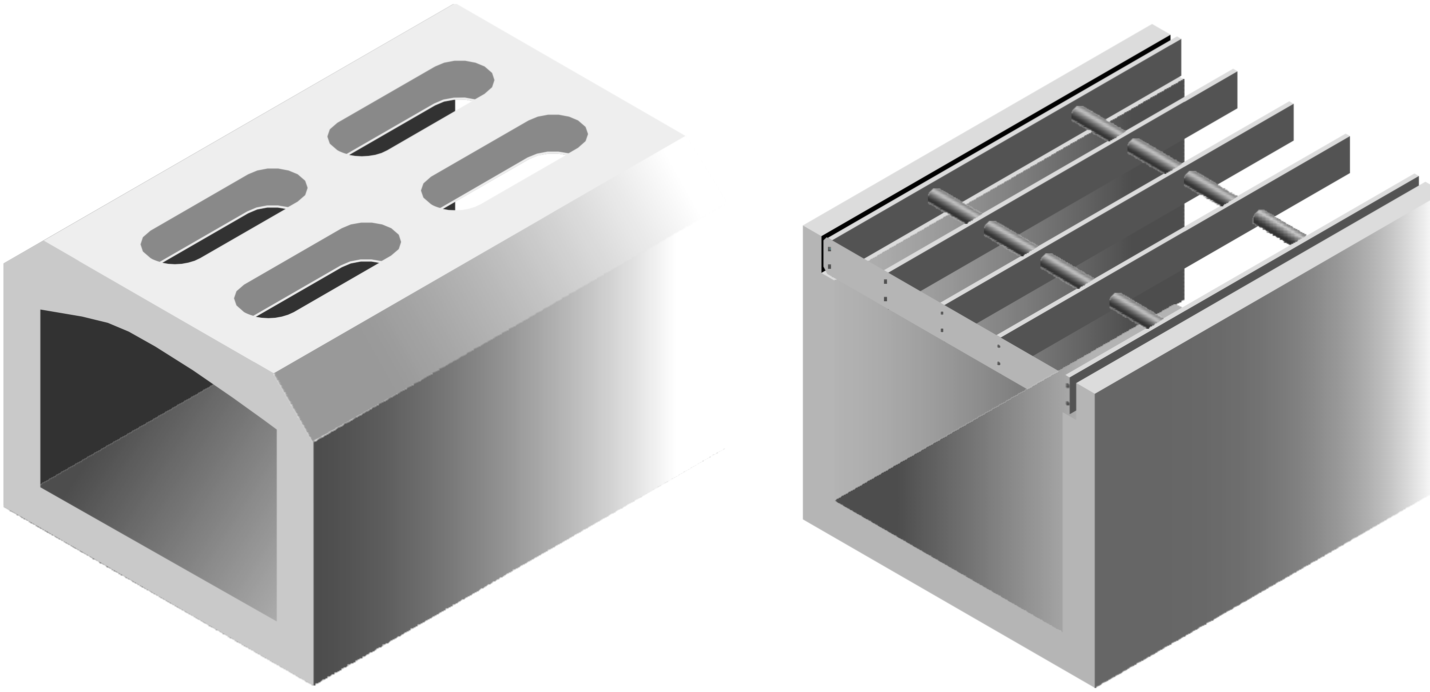


Figure 39: *Micro-surface passages flush with the road surface maximize exposure to ambient environmental conditions and weather, including prevailing light and rainfall conditions.*

Figure 40: *One of several purpose-built slotted polymer concrete surface passages (bottom left) built in 1999 for the Santa Cruz long-toed salamander at Seascape Uplands, Santa Cruz. These were constructed along with short sections (center, running up slope) of one-way plastic panel fencing to try to minimize construction impacts on houses and the gardens that remain a part of the salamander's terrestrial habitat. Image: Tom Langton*

Figure 41: *General alignment of three purpose-built polymer concrete slotted surface-passages with one-way plastic panel fencing, (shown) and mesh (not shown). Passages show as narrow grey lines across the road. These were built 2001 and 2003 next to Lake Lagunitas in Stanford, California, for California tiger salamander. Image: Tom Langton*

Passage sizing (Type 4)

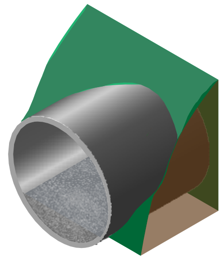
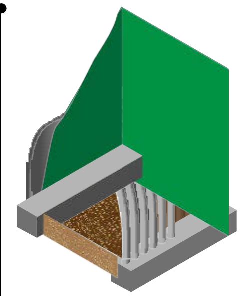
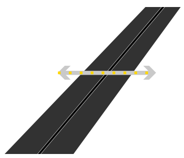
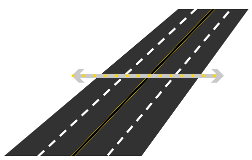
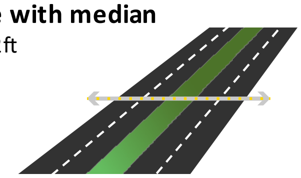
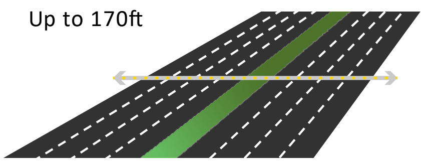
Deciding on the dimensions for a new passage structure and what is needed to carry a significant number or specific proportion of a population across a road is not an exact prescription. When the larger passages over or under a road are not practicable it may be a case of designing in accordance with the existing landscape restrictions to see if likely outcomes could offer acceptable rates of crossing. Many installations are not used by a high proportion of potential users when animals 'baulk' at the entrance or turn around after a certain distance and this will vary with species and behaviors.

Use of a passage may also vary between years and according to animals adapting to them, for example developing experience and following the olfactory trails of other passage users. Table 3 provides a general guide to minimum dimensions that should be considered for passages where amphibians and/or reptiles are the target species. The dimensions in the table are presented according to the size of the length of the road and embankment and different passage shapes.

These dimensions are likely to result in some degree of acceptance by the target species but each species will vary in its requirements and so great caution is required. There is a tendency to build passages too small and for animals to turn back, especially in passages over 65 ft and even at 50 ft.

These figures should be considered **a minimum** for at least some level of use to be expected. However each project will require a unique evaluation according to the total objectives of the system (built structure and habitat manipulations) to determine what will be sufficient in terms of passage size, the arrangement of barriers and the aim of the system in terms of population movements.

Table 3. Recommended minimum width and height (W/H) dimensions for different types of Type 4 (herp passages less than 10 ft / 3.0 m wide), according to passage length and the size (width) of a road. Note, at smaller sizes, passages may only enable lower percentage of migrants to make a full crossing, especially under four or more lanes.

	 Rectangular	 Circular	 Rectangular Bottomless	 Arch Bottomless
Two lane Up to 66ft 	3 ft 3”/2 ft 6” 1000/750 mm	3 ft 4” 1000 mm	3 ft 7”/2 ft 1100/600 mm	3 ft 3”/2 ft 4” 1000/700 mm
Four lane Up to 100ft 	5 ft/3 ft 4” 1500/1000 mm	4 ft 5” 1400mm	4 ft 11”/2 ft 8” 1450/800 mm	4 ft 5”/2 ft 4” 1400/700 mm
Four lane with median Up to 132ft 	5 ft 9 “/4 ft 1” 1750/1250 mm	5 ft 4” 1600mm	5 ft 11”/3 ft 3” 1800/1000 mm	5 ft 4”/3 ft 7” 1600/1100 mm
Eight lane with median Up to 170ft 	6 ft 6”/4ft 11” 2000/1500 mm	6 ft 8” 2000mm	6 ft 8”/3 ft 7” 2000/1100 mm	

Type 6: Microbridges/raised roadways

Innovative designs may be required to address unique situations according to the species involved and local land use challenges. One example of such an approach is the use of an elevated road segment (“low bridge”) design for use as a wildlife underpass. A low viaduct bridge forms part of the connectivity system at State Road 246 between Buellton and Lompoc (see Table 2a). However even smaller scale constructions are possible.

A small scale pilot study was made along unpaved road 9S09 in the Sierra National Forest of the movement of Yosemite toad towards and under a bridge structure during the breeding seasons of 2018 and 2019. The road bisects a Yosemite toad breeding meadow and upland habitat. HALT (Hobbs Active Light Trigger) and Reconyx cameras with time-lapse were placed under the elevated road segment during trials to monitor passage use. Cameras recorded toads approaching the structure successfully and using it for a full crossing.

The forest and paved road setting is extensively used by recreational vehicle users; the peak use of the roadway coincides with the migratory period of the toad (i.e. most sensitive time of the year). The low bridge was about 100 ft/30 m long, 16 ft/5.0 m wide and 8 in/0.2 m high (Figure 42).

Made largely from a local sustainable material (timber) it was built together with directional fencing in order to allow toads and other small animals a safe passage without the need for excavating the ground or bridging the road.

This is not a state road environment but it demonstrates that positive measures are available that can be taken for a vehicle-impacted species. In some cases compensatory measures may include creating offsite structures to benefit a species.

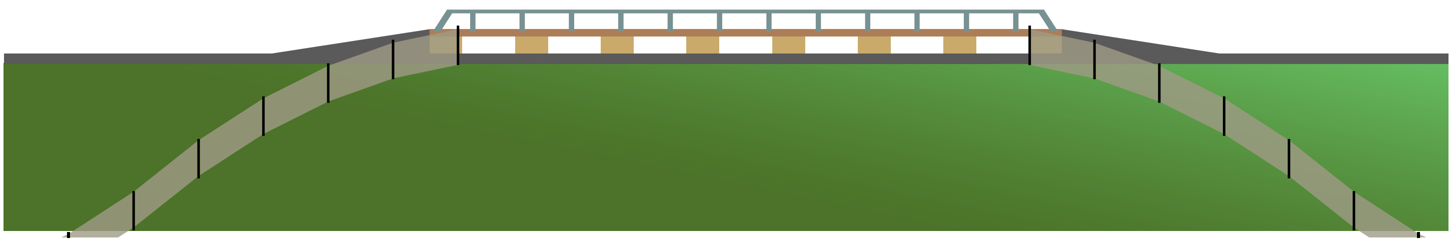


Figure 42: *General schematic design for a micro-bridge or low elevation bridge structure. There may be some future potential for designs for use on paved roads.*

Figure 43: *Experimental raised micro-bridge for the Yosemite toad (Anaxyrus canorus) in the Sierra National Forest. Images show 'safe space' and directional fencing to help guide animals to the underpass. Images: Cheryl Brehme*

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Barriers are divided into two categories; **guide wall** and **fence** types, as described below. They prevent and help direct the movement of amphibians, reptiles and other small animals near hazardous areas. This may be just to keep them off roads or in addition to help direct them to a passage to cross a road safely. They may be built as the lower part of a general wildlife or livestock road safety barrier.

For channeling the movement of smaller herp species these structures generally range in height from 12 to 28 in/30 to 70 cm above ground and are, in addition buried underground, up to 12 in/30 cm. Buried fences may also be offset at 90 degrees underground, to help prevent animals from tunneling under them. Taller barriers are needed for the more agile species, including some of the longer snakes. These may need to extend to heights of 60 in/150 cm tall. Many barriers have built-in overhangs or can be shaped and angled in the ground to reduce or prevent over-climbing.

There is a wide range of wildlife barrier materials. Choice of barrier or fence material will vary according to the purpose of the barrier, local site and climatic conditions and expert judgment. One of the keys to greater passage use is helping migrating animals to locate the entrances and to enter. In many instances, this relates to the angle of approach, which is dictated by the alignment of the barrier with respect to an often fixed direction of approach.

Migrating adults may turn back and not breed if barriers are not aligned at the correct angles to guide them to the crossing points. This may vary by species. Some may make return attempts to move in a particular direction, while others may give up after a single or few attempts and not breed that year. Some herps live for 20 years or longer and have good directional senses. Weather patterns may also dictate the number of days that individuals are active and able to follow barriers to find and use passages.

Spacing and maximizing barrier use

Designing crossing systems often requires an early decision as to the best locations for passages. The number and type of passage/s required will relate to the need to retain existing, or to restore species' dispersal patterns and migratory behavior and the level of connectivity required to sustain populations long-term.

The length of road requiring guide wall and/or fence measures may range from a few hundred feet to several miles long. Barriers are normally needed on both sides. There is a relationship between barrier angle and inter-passage distance (Figure 44).

Passages in some circumstances can be close together, at around 60 ft/18.3 m apart and multiple passages may be needed to cover, for example a 600 ft/183 m migration route hotspot. When the aim is to allow the maximum numbers of animals and their young to make seasonal movements forwards and backwards across a road, passages must be close together so they are easily found and used by a high proportion of animals.

If passages are positioned further apart due to physical constraint barriers should be angled to enable animals to perceive a degree of forwards trajectory as opposed to a flat wall that they may more readily turn back from. However, when barriers are angled they may make some near-road habitat inaccessible and also impose constraints on adjoining land-use that may be prohibitive. Such land may be effectively be 'lost' as habitat to target species and so placement of passages to prevent the need for heavily angled barriers is an important consideration.

Passage entrance deflector boards are an important fine detail, in some cases curved and referred to as 'swallowtails' are often needed to help animals to not move past them and to enter the passage system. These can be made from wood and other light materials and should not be positioned in a manner that blocks movement of animals exiting the passage from the other direction (Figures 45 and 46). They should extend into the passage a short distance.

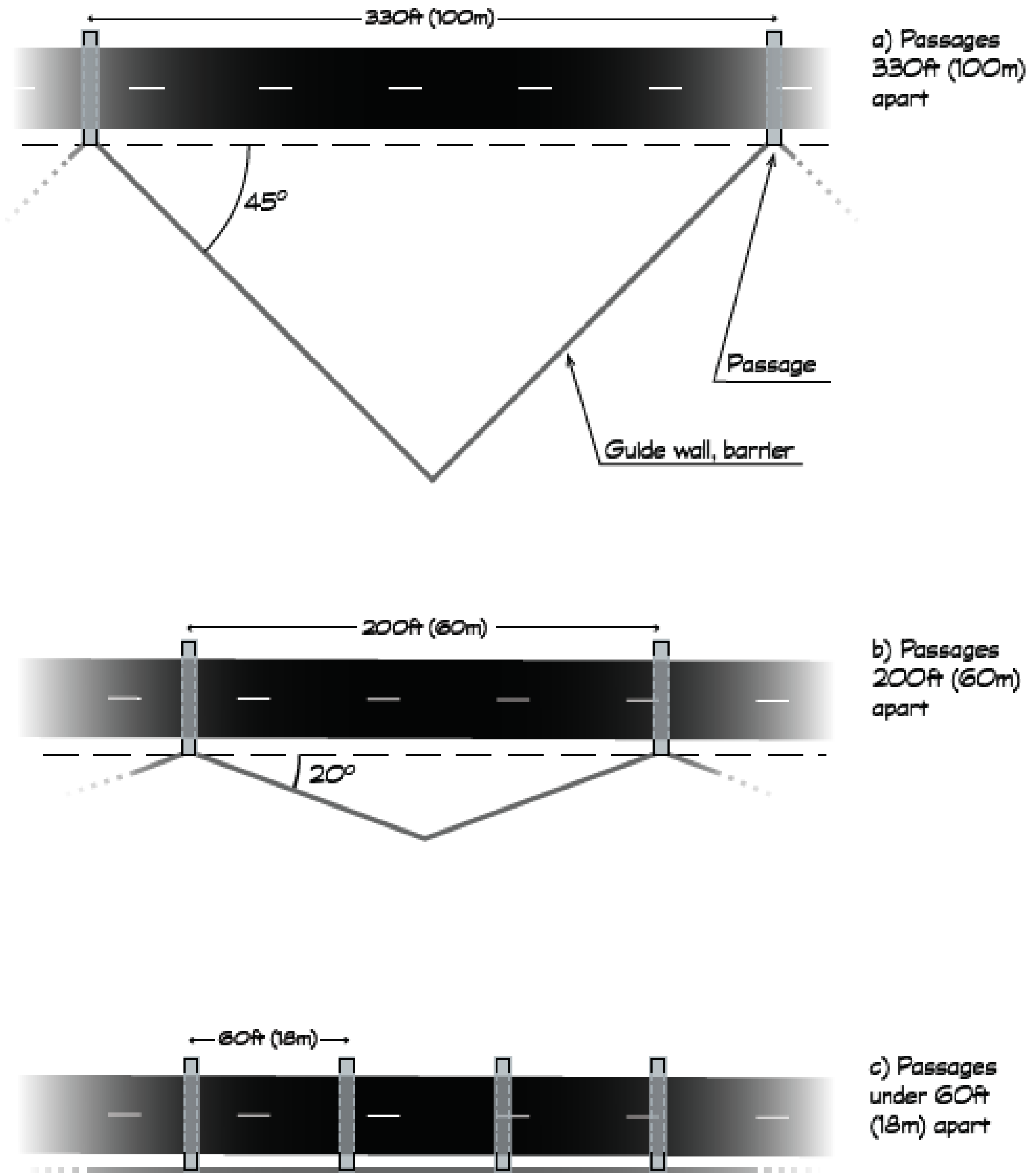

Figure 44: *Recommended angle of barriers leading to passages that are designed to maximize successful migration crossings. At 60 ft/18.3 m or under, barriers can be installed parallel to the roadway, but if the distance between passages increases, they must be installed at a suitable angle.*

Figure 45: *A small 'bottomless' or 'stilt' passage (cast concrete roof and sides on foundations, with a natural soil base) under a 2-lane road. There is an extensive late-season leaf litter component that amphibians shelter under. The barrier and deflection panel are made from galvanized sheet metal fence material with an overhang. Image: Tom Langton*

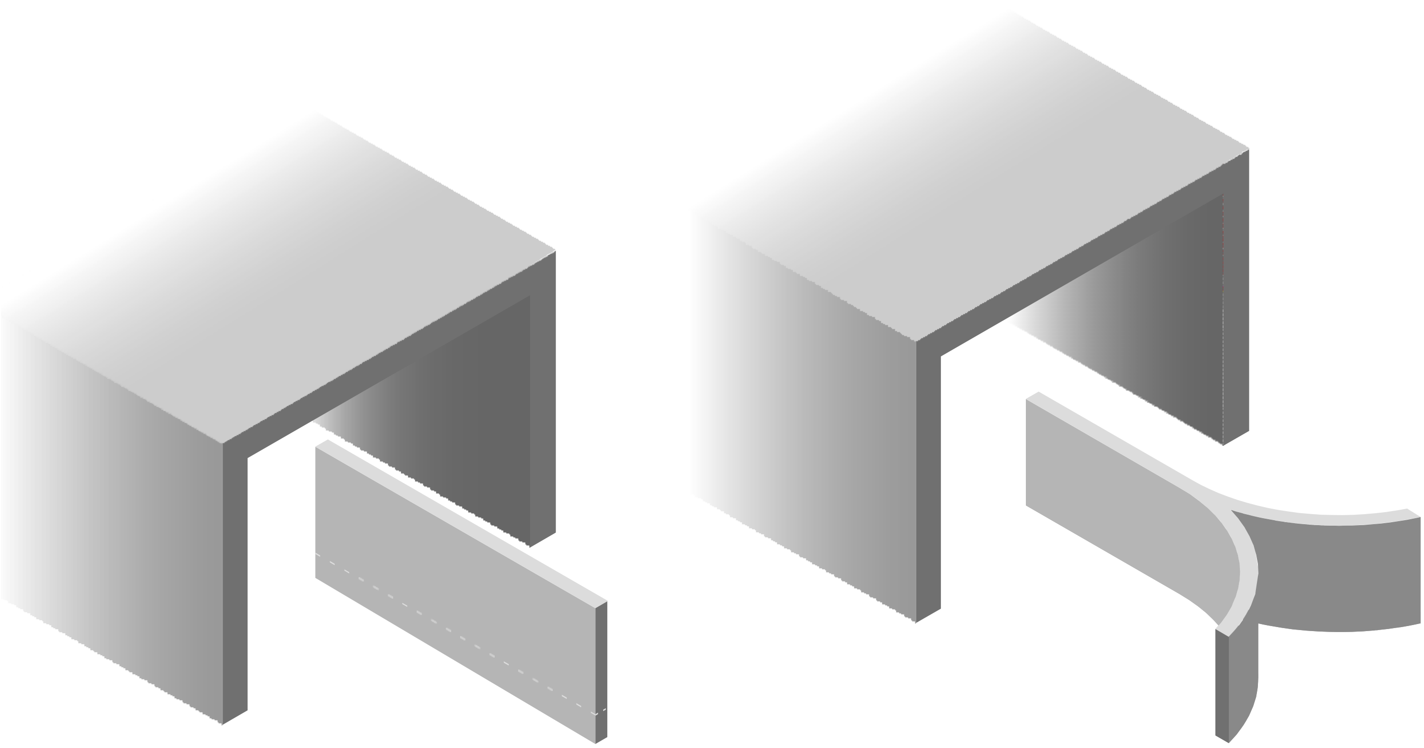

Figure 46: *Passage entrance deflector boards, in some cases referred to as a 'swallowtail'. These can be made from wood and other light materials and vary in their design.*

Barrier height

It is difficult to generalize about how high a barrier should be, as recommended dimensions will vary, based on the target species of a road project and road safety provision for large mammals. For amphibians and reptiles alone, the following guide gives general recommended minimum heights from the ground to the top of the barrier. Some species have particular behaviors and climbing and jumping abilities, so it may be helpful to check with specialists familiar with the species concerned, to decide the best material to prevent over-climbing. Barrier material choice is crucial in making successful barriers and needs detailed consideration as it also may influence barrier height.

It is important to recall that vegetation growth rates differ across various climates, and that guide walls and fences can easily become overgrown with vegetation. Some may not need maintenance for several years while others may need vegetation cutting twice or more times a year. The environment around a barrier should be carefully considered; for example, fences in some woodlands may have low overgrowth but frequent falling branches that can break a fence or form a bridge that animals can climb across. Ease of fence repair is another consideration.

Table 4 gives recommended minimum barrier heights for different groups of herpetofauna including the use of overhangs that may be necessary to prevent over-climbing by the more adept species. Horizontal overhangs may have a downward pointing edge, to make them more difficult to climb over.

Table 4. Recommended minimum barrier height (in inches) for connectivity systems for different groups of herpetofauna. Division of species into small and large categories is slightly arbitrary and varies between groups so expert advice may assist with final choice.

Species group	Smaller sizes	Larger sizes	Comments on barrier overhang requirement
Lizards	13”	30”	Needed for most species.
Snakes	25”	43”	Large rattlesnakes and whipsnakes may require substantial overhangs. Some studies show Snakes are more likely to negotiate vertical barriers if the barriers are shorter than the body length of the snake.
Tortoises	18”	18”	Should not be needed for barrier material that cannot be climbed.
Turtles (freshwater)	15”	35”	Should not be needed for barrier material that cannot be climbed.
Salamanders and newts	15”	15”	Needed
Toads	18”	25”	Needed
Frogs	30”	38”	Needed for most species

Barriers – species interactions

The extent to which animals may use visual and olfactory cues from their environment, when navigating, makes barrier type (solid versus open mesh construction) a significant influence in terms of response when encountering them.

Observations indicate that several species of Chelonians (turtles and tortoises) will tend to walk along barriers that they can see through but are more likely to move away from a barrier that is solid. Tortoises that follow open mesh fencing may dehydrate and even die from heat exhaustion in some circumstances if they do not find shade or cover.

Studies done by USGS to inform this BMP found that for California tiger salamander (CTS) the 'transparency' of barriers (mesh vs. solid) influenced the speed and time of travel along it. CTS moving along solid fencing moved at an average of almost twice the speed and were three times less likely to turn around and repeatedly move back and forth than with an open mesh fence. Open mesh fences without a visual barrier, for example types used for exclusion fencing during construction, are not suitable as directional fencing for crossing systems.

Trials have demonstrated that frog, turtle and snake species are not only able to climb fences but spend significantly greater amounts of time interacting with hardware cloth mesh fencing than plastic solid barrier fencing. Such responses are considered likely also to occur in some species of salamander, newt, toad and lizard. Many amphibians, particularly juveniles, can climb vertical smooth surfaces readily in wet weather conditions. Risk of excessive barrier interaction can help practitioners in deciding the most effective barrier.

Studies to inform this BMP showed that addition of a simple 6" visual screen to the bottom of an open mesh fencing can help decrease the interactions between a species and fence material. A solid barrier can also influence the speed at which animals travel along a fence. Adding a visual screen to existing mesh or other see-through type of fence gives it many of the qualities of a solid barrier. Such provisions may be retro-fitted to existing fences for a certain number of species but to be fully operational the barrier needs to satisfy the prevention of under-digging and meet other needs for a successful barrier, for example, where needed an overhang. It must also be fixed very tightly and securely to prevent animals becoming wedged between the added material and the older fence.

There are many reasons why hardware cloth, mesh, or solid barriers may be desirable in particular landscapes, habitats, and climates with considerations that include rain and wind permeability, durability, and aesthetics. Solid barriers are generally more expensive than those with gaps but may be more durable, depending on materials used. For each location, temperature, light and moisture variation patterns will dictate barrier longevity.

Guide walls

Guide walls are a more durable and permanent type of barrier. They often also have a soil/slope retention purpose on sloping ground. Made from concrete, zinc-coated (galvanized) steel or other metal alloy sheeting, or with polymer concrete, they are often built into the road embankment as an integral part of the road structure. On a steep bank or edge, walls may stop erosion from occurring in places where the aim is to maintain a platform for animals to move toward passage entrances. Guide walls often have the added benefit of being a 'one-way' barrier allowing small animals caught on the road corridor to easily leave into the 'safe' side of the barrier.

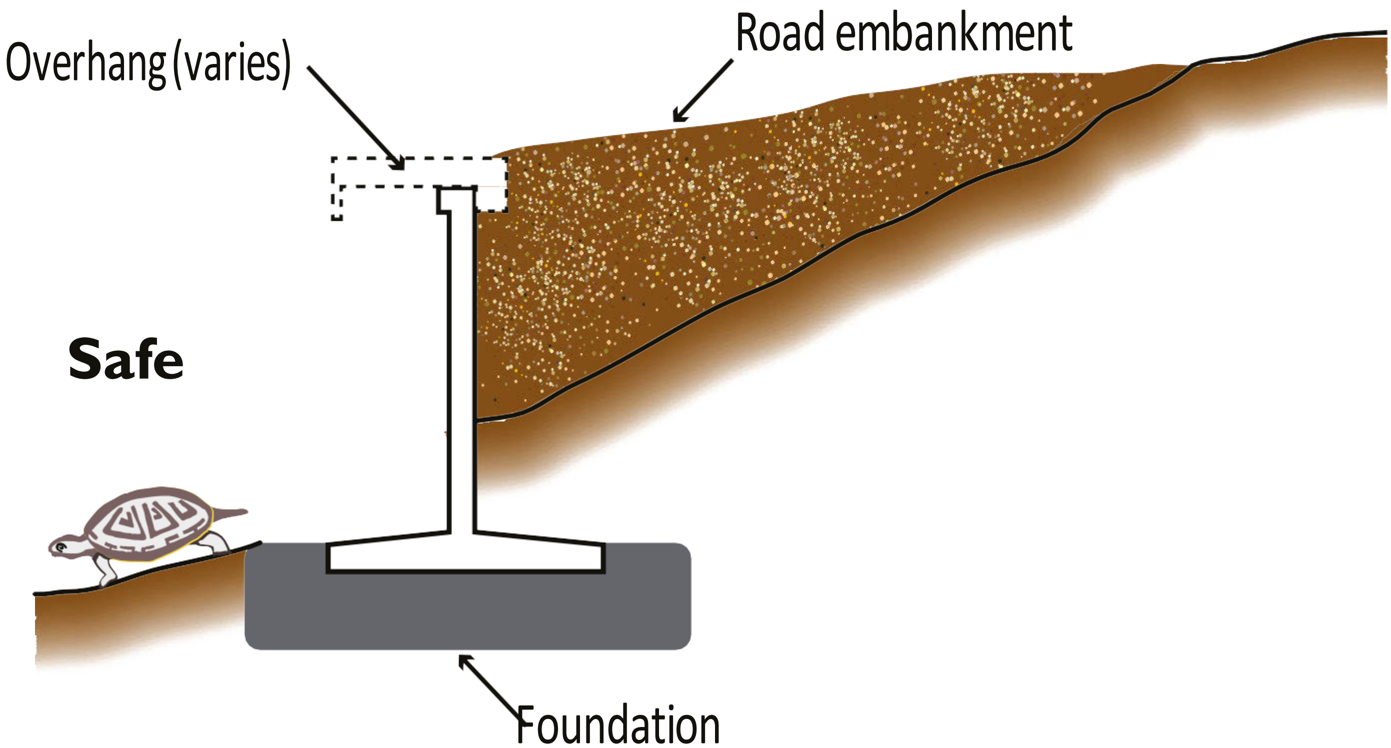

Figure 47: *Backfilling behind the guide wall barrier allows unimpeded one-way animal movement from the direction of the road to prevent entrapment, as well as enabling lateral movement towards the passage entrances. An overhang may be required according to the type and size of animals.*

Guide walls are also more resistant than fences to factors such as damage by heavy snow and snowplow use. Solid guide walls may be more resilient than thinner plastic or mesh fence material and stand up better to being knocked over or damaged by debris falling from vehicles, or of highway (vegetation) maintenance equipment. The hard surface at the base of the barrier may reduce vegetation overgrowth, reducing barrier maintenance needs.

Figure 48: *Guide walls for small snakes and lizard species on a single lane road with cycle path. Attached to a Type 5 (20 in/0.5 m wide) micro-passage, is a molded plastic barrier on the left hand side and a polymer concrete barrier on the right hand side. Both barrier types are circa 20 in/0.5 m above ground. Image: Tom Langton*

Fencing

Fencing categories include those that are temporary or semi-permanent in lifespan. These may be made of less durable material than guide walls, comprising a thin sheet material attached to support posts. Fences are often defined both by the material used and their life expectancy. Some are suitable for short term (temporary fencing) pre-construction species containment or exclusion work and for experimental work determining the spatial use of habitat, while others, are more durable and used if the fence is intended to last for the same design life of the road (permanent fencing).

Fences may act as a wind break and provide shade. Vertical fences may also cause heating by sunlight of the near-fence soil. In some desert conditions solid materials can more easily catch and trap soil and windblown dust than wire fences and become buried. Normally solid materials allow no visibility through them. Fine mesh fences can also allow low visibility through them.

A general design for a temporary fence is shown in Figure 49. The thinner polythene/geotextile/plastic material including woven polypropylene (silt cloth or shade cloth) may be used for temporary applications, but tends to lack strength and durability. These fence types are easily damaged or destroyed by seasonal weather event extremes or the actions of more powerful large mammals. Because of this, they require regular checks and repairs to retain their integrity.

Where a fence traps moisture, amphibians may use the sides of buried barriers as places to shelter and great care may be needed when they are removed.

Lifespan expectancy for semi-permanent barriers is up to 25 years and permanent fencing for 25-50 years or more. In some cases wood boards and posts can be used to make barriers. Ground moisture levels, soil characteristics and presence of insects will dictate how long these more sustainable materials will last both with or without preservative treatment. Exclusion fences to isolate a development area and remove animals (Figure 50) will not normally be suitable as a barrier for crossing systems.

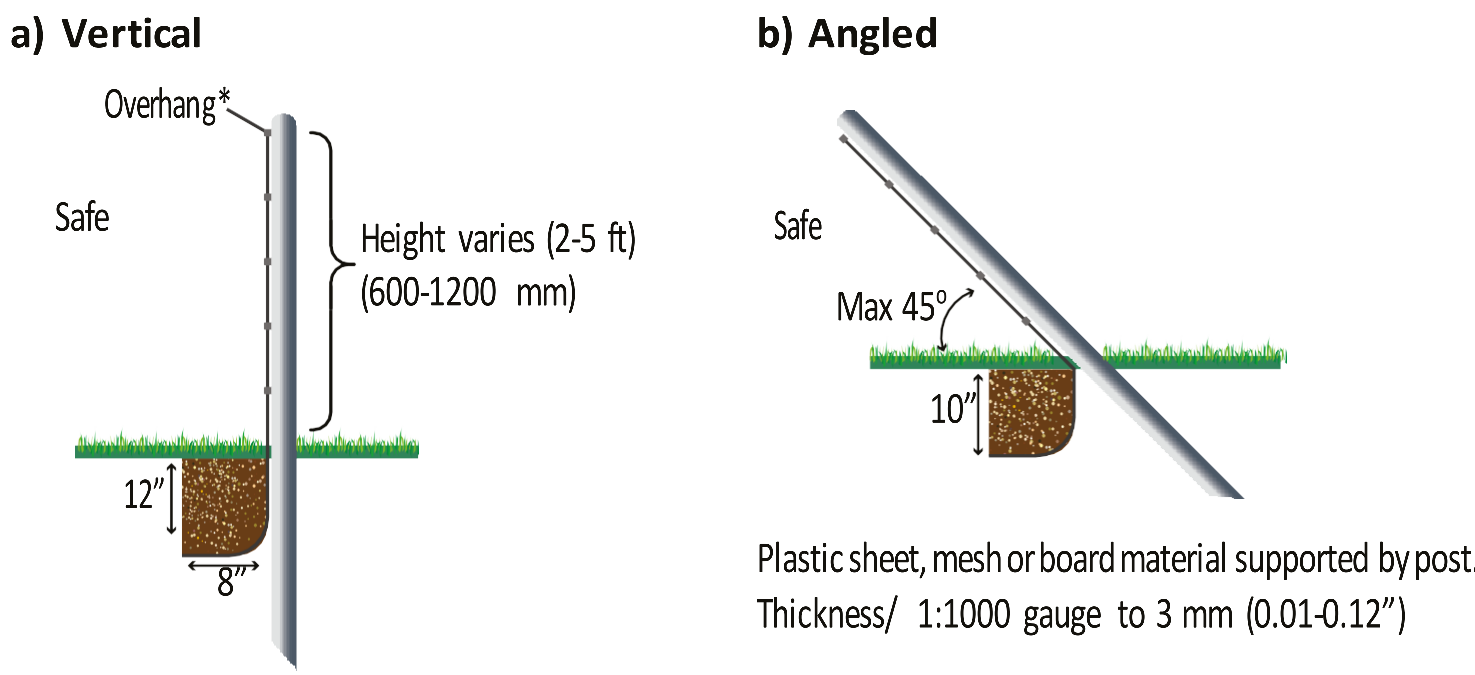

Figure 49: *General construction of a temporary herp exclusion or enclosure fence, from thinner plastic materials, supported on posts with staples, nails or cable ties.*

Figure 50: *A rigid monolithic plastic (HDPE) mesh fence with overhang. Fine holes of under 0.2 in/5 mm) give a degree of visibility through them. These are often seen on construction sites but should not be confused with fences designed for permanent road and rail crossing systems. Image: Vince Morris*

Fences are sometimes made from thick plastic that is extruded in sheets. Plastic sheeting (polypropylene/polyethylene) of up to one-tenth of an inch (1-3 mm) thick is commonly used, fixed vertically or at an angle on wood, plastic or metal posts. Sometimes plastic culverts have been cut in half to form a concave shape. Thicker injection-molded or sheet plastic purpose-made panels both straight and curved are also available. These can be held in place with plastic, wood or steel support posts, with partial earth covering on one side (Figure 51). Lifespan expectation is a few years for thinner material and 10-25 years or more for thicker material according to site conditions.

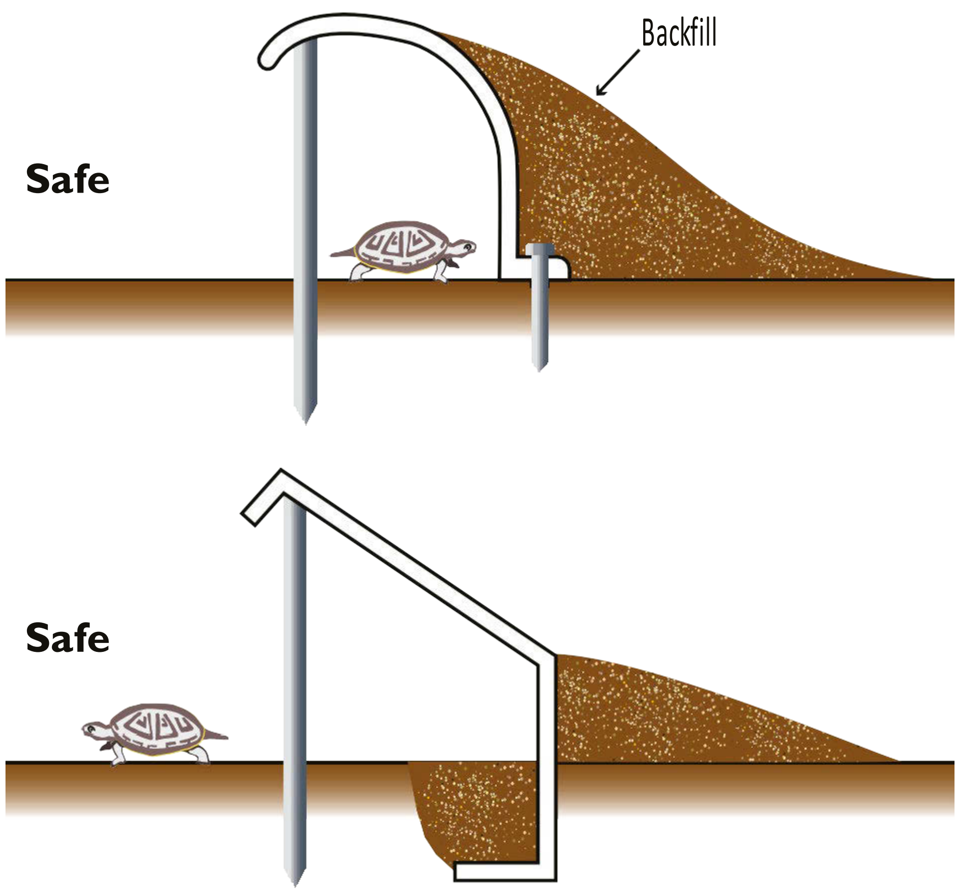

Figure 51: *Examples of solid precast and bent plastic panel fences that may have temporary, semi-permanent and if robust enough, permanent usage.*

Thicker plastics may hold up better to physical stressors; for example, from the weight of light snow, from large mammal trampling or digging, such as can be done by badger (*Taxidea taxus*) or from human vandalism. Sheet and less stable solid plastics may become distorted through expansion, causing warping. Fixed joints that do not allow for daily expansion movement may crack open (Figure 52). Most plastics will degrade (harden, become brittle and rip/split apart) due to heat and ultraviolet light exposure, especially in full sunlight. Coatings and UV retardants may slow this process, but pollution caused by material degradation (e.g. eroding, rusting and flaking) should be considered as a potential wider environmental hazard.

Figure 52: *Some types of cast plastic barrier may expand and contract in heat and sunlight, causing problems for joints. Fixings should be constructed to allow space for such movements.*

Light-colored fencing has been used in areas that are exposed to overly sunny and windy conditions, such as desert environments and exposed hillsides. Lighter colors compared to dark or black material may reduce heating and drying the near-fence environment. In highly exposed areas, heating and drying along barriers may prove harmful or even lethal to amphibians and reptiles (see also Shelters).

Transparent or "see through" fences

Galvanized steel and plastic mesh and plastic-coated steel mesh allow much of the natural movement of air and water and some windblown soil through them. Steel mesh fence is sometimes treated to make it a brown color, to prevent reflection and help it blend into the landscape. These fences may be most suitable in environments that are harsh and exposed, have high winds and/or poor soil drainage.

However, as mentioned earlier, when herps can sense the environment beyond through a fence, they may lose energy due to pausing, poking, or pacing back and forth, and from trying to climb or dig under them. Some may be snared or caught up trying to push through. This type of fencing is not recommended if trying to guide animals to a passage. For retrofitting, in some circumstances a solid visual barrier may be attached to it at ground level (see section above, Barriers - species interactions).

Figure 53: *Fine wire mesh tortoise fencing (barely visible in photograph) on metal posts along Interstate 15 in San Bernardino County, located within desert habitat at a culvert underpass. Image: Cheryl Brehme*

Figure 54: *Typical wire mesh and stock fencing on metal posts in desert tortoise habitat. Image: Dean Swensson*

Figure 55: *Tortoises and turtles are adept climbers of wire mesh fence and so mesh fence alone may not contain them. Image: Ken Holmes*

Figure 56: *A Yosemite toad at a monolithic 5 mm diameter HDPE fence. Herpetofauna generally spend more time attracted to permeable barrier material, probably gaining visual and olfactory information from the other side that is otherwise screened by a solid barrier. This may influence travel times along fencing, leaving species exposed to factors such as predation and dehydration. Image: Cheryl Brehme*

Figure 57: *Dual purpose permanent barrier for deer and small animals. The tall deer mesh fence with metal support poles is built together with a small galvanized steel animal guide wall with an overhang. Image: ACO*

Figure 58: *Here, a free-standing metal fence and a large mammal fence separate in order to go around a road over-bridge that runs perpendicular to the main highway. Note a 'stop grid' beneath the car. The deer fence also has a gate positioned in front of the point at which the car (and agricultural vehicles) can enter the surrounding landscape. Image: Tom Langton*

Barrier installation and drainage

As previously mentioned, in many instances the placement of a wildlife barrier in natural or semi-natural habitat may impede surface water flow and drainage. This can lead to waterlogging and other undesirable effects such as subsidence. Some temporary (e.g. silt fence) and semi-permanent barriers may have perforations representing up to 50% of their surface area, enabling unimpeded water passage.

Solid fence material may cause increased moisture or waterlogging on one or both sides of the fence. They may need to be perforated at and below the ground surface.

For more permanent barriers, drainage needs are resolved by designing adequate 1 ft/30 cm or more (deep and wide) stone-filled drainage channels that pass under the fence and that have sufficient capacity to collect and discharge to prevent flooding. These may be spaced roughly every 30-100 ft or so in places or according to the local intensity of ground and surface flow. With guide walls, the running of interception trenches on the roadside of the barrier can bring surplus rainwater to designed drainage discharge points that run under the barrier.

Turn-arounds and Stop grids

Turn-arounds

The outer ends of barrier installations and the places where barriers/fences meet at side or access roads need careful consideration. Migrating or moving animals may arrive at a barrier and turn away from a passage entrance especially if it is not angled correctly. Without deflection boards, they may walk past it and towards the outer end of a barrier. Turn-arounds are a barrier than has been installed so that it reverses the direction of travel of animals back in the direction that they came from and towards a passage entrance.

These are effective in changing the direction of movement of many amphibians and reptile species. Inadequate length of guide wall or fence, or fence ends made without complete turn-arounds can result in individuals 'es-caping' from or walking past the barrier system and onto the road surface (Figure 59).

Studies to inform this BMP documented over 90% of a sample of herps (lizards, snakes, toads), as well as 69% of small mammals, change course back towards the direction of origin after leaving a turn-around of around 4 ft/1.5 m length. Turn-arounds should be smooth curves, not angular and the turn-back should be at least 3 ft/0.9 m from the roadside barrier. Ideally it should be between 6ft/1.8 m and 15 ft/4.5 m in length, 6 ft/1.8 m wide and tapering slightly at its end back towards the main barrier to encourage 'leavers' to move towards the nearest passage entrance. Preferably the ends of barriers are at a transition point in habitat. In addition the barrier can be extended beyond the final turn-around to continue at a 90 degrees angle in a straight or curve alignment for a distance of around 30 ft, with a second turn-around at its end to further minimize risks of fence 'overshoot'.

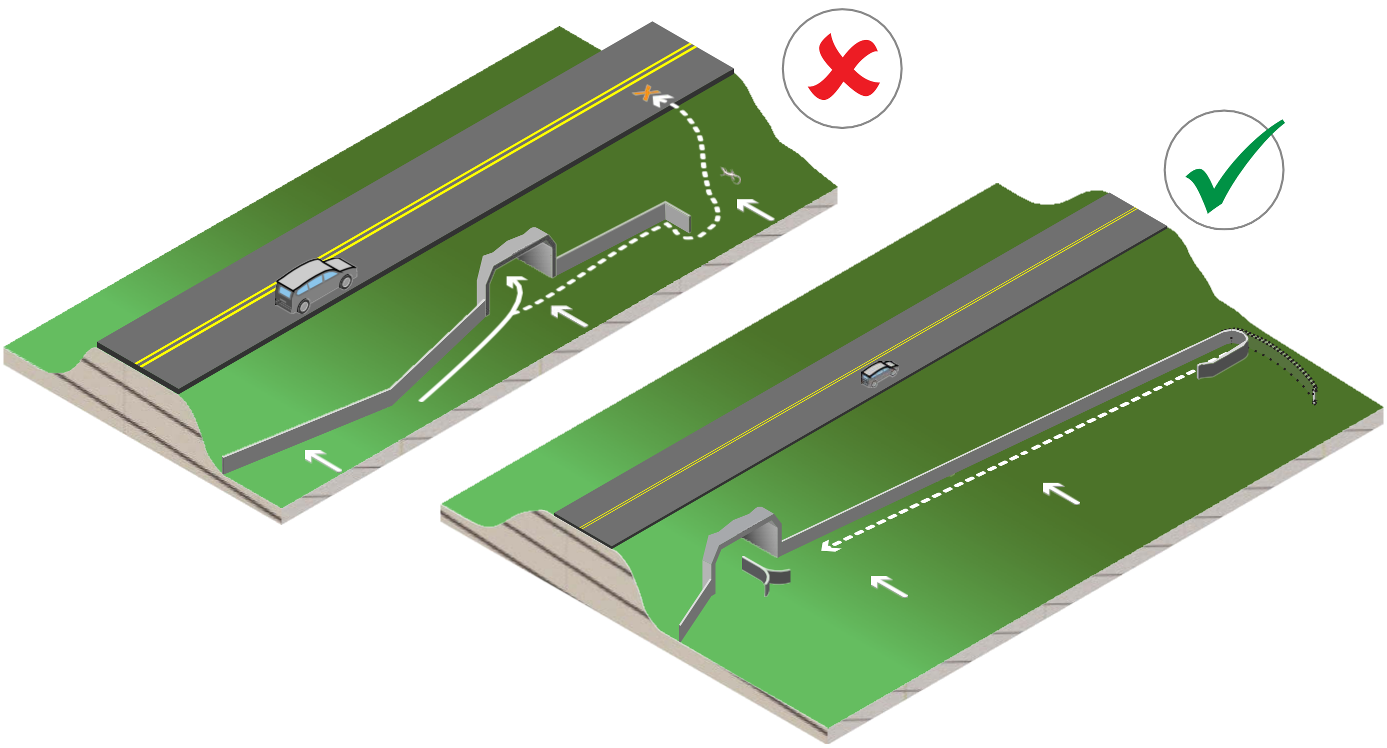

Figure 59: *When barriers are not long enough and the associated turn-arounds are inadequate, a proportion of a population may find its way on to the road. A curved turn-around and a secondary curved turn-around to catch wanderers, will also help minimize these risks.*

Installed barriers are sometimes not long enough to prevent 'overshoot' and need to be made with a safety margin if there is any uncertainty. Prior studies are often needed to detect the road area across which animals are likely to move. For amphibians, for a small to medium sized population, barriers with turn-arounds towards a single or small cluster of waterbodies should be placed a minimum of 160 ft/ 50 m from the ends of the outer passage in any system. Input from species experts should be considered in determining the appropriate length and the distance may need to be greater. Other strategies to prevent 'escape' onto the road at barrier ends include ending the barriers at natural landscape features, e.g. the base of a cliff or steep slope. Fencing may be run along the edge of side-roads, perpendicular to the main road but curving in shape to a distance of 80-130 ft/25-50 m, with a turn-around at the end to help to minimize overshoot.

Private and public access roads that open onto main roads are a particular fencing challenge. Small 'cattle guard' type designs, include purpose made 'stop grids' (Figure 60) that are effective to some extent for halting the movement of smaller species and juveniles of larger species according to the width of the grating, which needs to be as wide as possible.

Smaller animals drop down between the grating gaps and then move back along the main fence to a passage entrance or into adjacent habitat rather than cross the road surface. Stop grids may not have wide enough gaps for larger species and those that can jump. Larger steel and concrete constructions such as those designed to retain horses and large stock from moving along a road into unsafe areas may be appropriate with larger gaps and similar design to prevent entrapment.

Figure 60: *A purpose-made 'stop grid', built where a side road approaches a main road in a herp migration location. Gratings may be made with wider gaps but must conform to road regulations. Image: ACO*

One other option that has been used to enable access through a small animal barrier is for access gates to be outfitted with a rubber flap at the base. The rubber flap is attached to the gate and made flush by including a 12 inch wide hard material strip below the closed gate to ensure tight seal. Sometimes buried passages and turn-arounds can be installed along the side-roads to maximize safe movement along a fence line and enable movement under a side road.

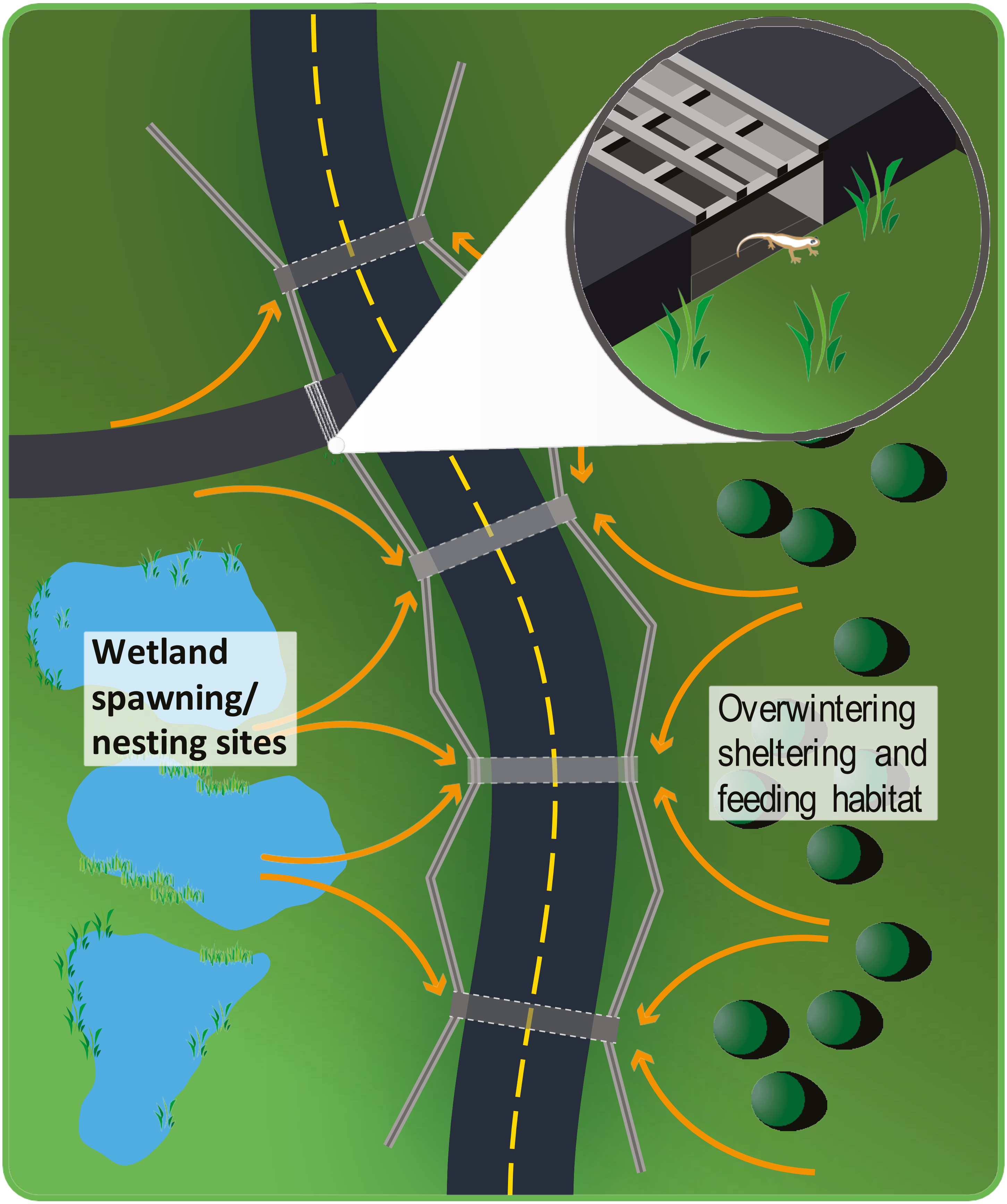

Figure 61: *Typical situation where stop grids may be used on a low-vehicle use side road within a crossing system, to prevent animals from using the side road to enter the main highway.*

Jump-outs

As with larger animals, amphibians and reptiles may, in difficult to design-for circumstances, get caught on the wrong side of a barrier, get trapped next to the road and remain in peril. In some cases with complex or compromised locations, it may be necessary or precautionary to install jump-outs for herpetofauna along barriers. The problem is addressed by one-way barriers that are angled inwards (away from the road) at a climbable angle. Ramp jump-outs can also be built to the top of a vertical fencing section to allow animals to reach adjacent habitat (Figure 62). As with one-way fences, jump-outs may also be used to assist the 'self-escape' of animals on areas facing development as well as for roadways.

Figure 62: *A jump-out constructed within a section of solid HDPE sheet fence, constructed along a road edge. The jump-out is outfitted with decaying logs to form a ramp for small turtle species and it directs them to the safe side of the barrier. Image: Animex fencing*

One BMP study found two jump-out types – earthen ramp and modified rectangular plastic mesh cone – allowed small animals to move back into surrounding habitat. Cone jump-outs are sometimes used to aid the removal of animals from areas to be built on. See Figure 63. As a note of caution, however, larger herpetofauna species and small mammals may become trapped if they get stuck in narrow cones. They can be modified to prevent this and jump-outs must be designed so as not to snare the head or body of wildlife, including non-target species.

Figure 63: *A gopher snake (Pituophis sp.) exiting a rigid monolithic HDPE mesh fence rectangular cone jump-out from an exclusion area. Image: Vince Morris.*

Shelters

Studies indicate that under unusual or extreme climatic conditions (heat and cold) or when disorientated, wildlife can become stranded along long lines of fencing. This can also be attributed to a species' behavioral response to a barrier, and this can cause excess use of energy, exhaustion, dehydration and ultimately death.

Barriers may prevent particularly long-lived species from getting to places they 'remember' once their habitat has been fragmented. Shade shelters have been used along desert tortoise fencing to provide a resting place during periods of intense heat (Figure 64). Shade should be provided at regular intervals along the fence. These should be considered for areas with longer lengths of barrier in particular.

Figure 64: *This shade structure is made from a: 12-14 in PVC pipe tied to the fence. Tortoises may die from heat-stress when pacing a mesh fence line where no shade is available. Image: Cheryl Brehme.*

Scuppers

Highway median vehicle barriers may be comprised of cast concrete blocks ('Jersey barriers' or K-rail); solid metal or steel cable. These barriers are placed down the middle of roadways, between lanes of opposite-flowing traffic. The decision on median barrier type varies according to a range of factors in particular the width of the median. Jersey barriers stand 3.2 ft/1.0 m or more high. Solid barriers in the median may be fixed in place or be free standing.

Jersey barriers may be used on a temporary basis to divert traffic during construction or installed permanently to prevent cross-centerline accidents. They may also be placed on road edges as a safety measure, such as to prevent vehicles from leaving the roadway or for protecting fixed objects off the roadway but within the state right of way.

These solid dividing barriers also further sever the connection of herpetofauna and most other animals from their required habitats. Solid barriers can be outfitted with "scuppers" or small openings and this may be done to prevent water build-up on one side. These also enable small animal passage. However, there are no studies to document whether they are used or effective. There is a need for greater consideration of the need for purpose-made gaps without compromising public safety. Modifying these types of solid barriers to better assist herp movement should be considered; however alone they will not improve connectivity for species and are not a substitute for under and over-road passages.

Table 5. Examples of commercial manufactures and suppliers of wildlife barriers and passages and other specialist materials and located in the southwestern United States. These suppliers may also provide more detailed information on developments with guide wall and fencing materials and products. These listings do not represent any endorsement of product or services.

Name	US Headquarters	Web Link to further Information
ACO USA	Phoenix, Arizona	http://www.aco-wildlife.com/home/
Animex Wildlife Fencing	San Francisco, California	https://animexfencing.com/
Ertec Environmental Systems	Sacramento, California	http://ertecsystems.com/Products/Wildlife-Exclusion-Fence---Special-Status-Species-Protection

Key Points

- Passage structures and their associated components, including barriers should be designed to last for the life of the roadway or railway. Anticipate that different materials have different purposes and will vary in their durability and life cycle.
- Barriers comprise both solid guide walls that are often built into the road structure and free-standing fencing that may require periodic renewal.
- Some projects may involve the installation of barriers only and no new structure if the sole objective is to prevent road-related mortality.
- Material type is an important design consideration with barriers as species vary in their responses to the fabric used. The barrier type chosen will influence species behavior and speed of travel along a barrier and solid barriers are preferred.
- The relationship between inter-passage spacing and the angle of fence alignment will play a key role in determining the level of use of a passage system.
- Anticipated maintenance requirements, including the need for periodic repairs must be built into the project as a whole or the system may fail at a later date.
- Debris from the roadway is known to frequently damage crossing infrastructure.
- Depending on climate and local rates of vegetation growth, trimming may be needed two or more times per year to prevent overgrowth that can enable animals to climb over barriers of low height.

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Assessing whether built connectivity systems are functional and meet their intended objectives is an important step in implementing best management practices (BMP). Most passage and barrier measures are costly to build and maintain, particularly large structures such as wildlife overpasses. Once transportation agencies have gone through the effort of planning, designing and funding measures, they need to know how well they perform. In the last 20 years, much research has been conducted on the performance of various measures to reduce collisions with large wildlife. However, herpetofauna have received relatively little attention.

Evaluating the performance of measures taken can help improve future designs using an adaptive management approach. Over time, as more measures are evaluated for a variety of herpetofauna and in different landscape contexts, more reliable information and insight will be obtained to support development of better BMPs. At present, inference may be taken from what works best for a few study species only, and more research on the efficacy of crossings built for herpetofauna is needed.

Design goals

Passage systems are designed to prevent or reduce mortality and to link populations by allowing safe movement of animals across roads and railways. The criteria used to measure whether goals are achieved however, will depend on the intended purpose of the measures. These purposes might include decreases in road mortality, support movements of migratory species and appropriate levels of gene flow, increase in the number of documented safe crossings, each way, and more. Preliminary guidelines have been developed to monitor how well measures perform and contribute to conservation value. Goals can range from simple measures focused on a single target species to ones that focus on restoring and maintaining complex ecological processes and functions and helping to preserve landscape connectivity.

The fact that passage structures are used by animals does not necessarily guarantee that they are effective. Equally, low levels of use can sometimes be sufficient for particular objectives, such as ensuring a minimum level of genetic interchange. Assessing effectiveness can be complicated, as there are many interpretations of functional mitigation and impact reduction. Stating the goals precisely, both in a descriptive and quantitative way from the start will set the baseline against which future assessment and management decisions can be made.

Performance objectives

After determining the objectives of the measures, a second critical step is to design a monitoring approach that applies appropriate methods of data collection and analyses. Performance assessment of passages and barriers requires robust sampling designs and adequate resource allocation to conduct a proper evaluation.

Study design

Designing a research framework including study design requires information on the recommended duration of data collection to sufficiently answer management questions. Sampling is an important part of the design that takes into account seasonal variations and inter-annual variability. Understanding and determining appropriate sample sizes will help ensure that monitoring data collection and analyses are robust. Understanding the appropriate duration of the study and the amount of available funding is a critical first step.

Study designs should be able to test for impact-mediated changes by comparing levels of target species occurrences before and after passages and barriers are installed. Understanding population size/s from the start is often essential to interpret findings. Impacts of concern generally consist of: 1) mortality rates and 2) movement rates. Effective measures should result in positive changes (reduced or prevented mortality rates and/or sustained or increased movement/connectivity) after the measures have been put in place.

Examples of many study designs testing for these changes can be found in published literature (Roedenbeck et al. 2007; Rytwinski et al. 2015; van der Grift et al. 2013).

Some common designs assessing impacts (I) include collecting data:

a) before (B) and after (A) measures with control studies (C) areas: (Before-After Control-Impact BACI), often considered the best design where feasible

b) before and after measures with no control areas (BA); and

c) post-measures, with control study areas (AC)

However, in many cases of real-time installations, the simple monitoring of numbers of target species approaching barriers and passages and their levels of use is often the most critical information to obtain. These numbers can then be tied back to an index of population persistence such as the relative abundance of adults or breeding numbers using standardized counting. They can also be used to compare with future trends.

Factors affecting built system performance

In evaluating passage and barrier measures it is also important to determine what variables might be affecting results and ultimately system performance. Factors may include human disturbance, fencing defects or unrepaired damage or vegetation overgrowth that allow herps to enter the right-of-way, or passages blocked by debris. Such factors should be monitored (and managed) in order to ensure evaluations take into consideration how these influence herp mortality and movement within and around a passage and/or barrier structure.

Figure 65: *Post-construction monitoring may involve a wide range of methods used to estimate population size and passage use, created habitat use and impacts of gene flow. Image: Marcel Huijser*

Figure 66: *Cameras have become an integral part of small wildlife passage studies. In this passage, a short-focusing camera with night vision has a wide-angle infrared time-lapse. It takes four pictures per minute as a sampling technique that misses few amphibians. Image: HCI Ltd.*

Figure 67: *Telemetry (radio or satellite tracking technology) is becoming easier with lighter transmitters and can be used to help answer key questions about species movements and habitat use. Image Kathy Baumberger.*

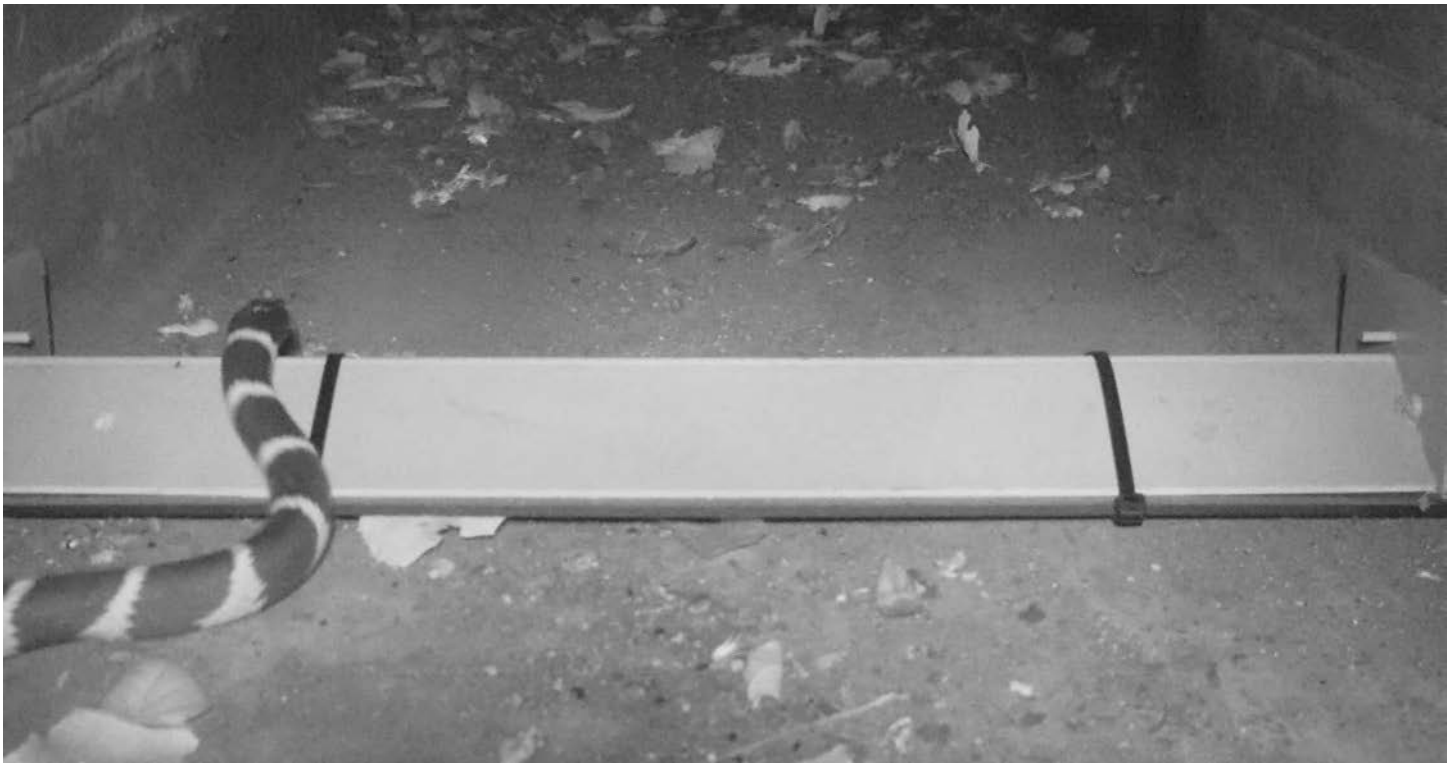

Figure 68: *California kingsnake (Lampropeltis californiae) crossing a HALT wildlife monitoring apparatus in a small passage system at night, breaking a fine light beam to enable a photograph to be taken.*
Image: Michael Hobbs

Figure 69: *Lizard crossing a HALT wildlife monitoring apparatus during the day time, alongside a barrier system.*
Image: Michael Hobbs

Table 5. Some methods of measuring the effectiveness of wildlife movement structures for amphibians and reptiles.

Metric	Methods	Example references
Changes in road-kill rates	• Surveys • Encounter surveys • Citizen science • Review of existing databases	Consentino et al. 2014 Helldin and Petrovan 2019
Use of passage structures and barriers	• Sign surveys • Tracking beds • Camera traps • Video cameras • Sooted track plates	Boarman and Sazaki 1996; Hobbs and Brehme 2017; Jarvis et al. 2019; Ottburg and Van der Grift 2019; Woltz et al. 2008
Movements and dispersal	• Radio-telemetry • PIT system • Camera-trapping without individual identification • Movement/behavioral observations	Boarman et al. 1999; Carr and Fahrig 2001; Honeycutt et al. 2016; Jackson and Tyning 1989; Pagnucco et al. 2012
Genetic and demographic connectivity	• Cell sampling	Cushman 2006; Herrmann et al. 2017; Marsh et al. 2008
Changes in wildlife populations and demographics	• Capture-mark-recapture	Cushman 2006; Gibbs and Shriver 2005

Figure 70: *Inspection and assessment of built structures post-construction is an integral part of adaptive management and the process of maintaining wildlife crossing systems in the long run.*
Image: Marcel Huijser.

Duration

The length of study time will vary depending on the objectives. Changes in mortality rates before and after construction can be determined. Monitoring plans need to provide sufficient time and data to make strong inferences with regard to passage and barrier performance.

It may take several years for habitats to settle and for wildlife to adapt and learn to use crossing structures. Ideally, monitoring should be conducted for a minimum of 3 to 4 years from first use. Longer term checking at ten year intervals is also desirable for determining outcomes.

A variety of methods can be used to measure the performance of measures and the selection of the appropriate method should consider resources available and the measurable outcomes needed to properly evaluate system performance. For example, surveys may check for change in rates of herp mortality; radio-telemetry tracks individual behaviors and movements; non-invasive genetic sampling and camera traps can identify levels of individual and genetic connectivity; and mark-recapture can be used to measure change in population size and distribution.

Adaptive management

An important reason to monitor amphibian and reptile passages and barriers is to understand their effectiveness and to ensure the project objectives are met. Lessons can be learned regarding problems and successes that may be used to inform structural modifications and also to assist in future design and decision-making.

On projects that are phased over longer periods of time in particular, coordination between research and project management divisions will allow for timely changes to project design plans that reflect the most current insights from monitoring activities.

Key Points

- Clear criteria and performance monitoring measures that tie back to the objectives of the project should be developed at the design stage This will enable biologists to reliably assess achievement of success thresholds for the project.
- Performance assessments of passages and barriers require robust sampling designs and adequate resource allocation. Sampling must take into account factors including seasonal variations and inter-annual variability. Monitoring plans need to provide sufficient time and data to make strong inferences with regard to passage and barrier performance.
- Lack of resource have been a major limitation in the past, especially for essential longer term evaluations. It is important to understand the sample sizes that will ensure robust analyses that can be used to inform any adjustments to the structure that might be needed.
- Study designs should compare distribution and numbers of target species before and after passages and barriers are installed with reference to control comparison sites if appropriate.
- It is important to determine by periodic review and checks whether factors unrelated to the wildlife structure might be affecting results and performance.
- Evaluating the performance of measures can help improve connectivity systems through an adaptive management approach by informing the need for potential improvements and also contributes to better future wildlife passage designs.

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Maintenance

As in many other detailed aspects of transportation projects, there are a number of features where, if one aspect fails the whole system may not operate correctly, with consequences. Crossing systems require a 'perfect' approach during design and construction if they are to function well and justify the significant investment in their installation. This also applies to the post-construction or maintenance phase. This is the case with wildlife passages and barriers and with habitat measures such as breeding water provision and habitat restoration. Detailed attention must be paid with aftercare in order to achieve a long-lasting success.

Passages

Smaller passages such as culverts may become partly or completely blocked with washed sediment, wind-blown soil, natural debris and discarded trash. Sometimes mammals may dig into soil in a bottomless passage, causing a blockage. Passages require regular checking during the year. Specialist equipment may be needed to reach into them to remove obstructions (Figure 71) and this includes items such as plastic bags that get lodged on camera and that may interfere with monitoring.

Vegetation usually cannot grow other than at the entrances of smaller passages. Where possible and if the target species will tolerate it in the smaller passages, low depths of soil or no soil can make maintenance easier and less costly. This approach may also discourage predators to establish burrows or dens in passages. Passages may silt up completely in storm events and need substantial effort to clear. A high pressure hose may be needed to do this and is useful to refresh passages every few years or after a suspected road spillage, notably for slotted surface tunnels where oil, salts and other potentially harmful residues may accumulate on the passage floor.

Figure 71: *Blown leaves may in some locations fill and become compacted in a small passage thus reducing wildlife use. An extending pole device can clear them as shown in this slotted surface passage.*
Image: Michael Hobbs.

Barriers

Possibly the most common and easiest way in which a crossing system can fail is if an animal breaches the barrier. This may be due to its poor construction, a lack of maintenance, or general material failure from exposure to weather. The failure of materials contributes to the creation of gaps in barriers or renders the barrier climbable by wildlife. Structures are often neglected at which point vegetation overgrowth, debris and dust accumulation may occur. Infrastructure should be inspected after severe storm events as damage due to fallen trees and large branches and other debris. Damage from vehicle collision and materials falling or thrown from vehicles is also a threat to free-standing barriers.

Areas with fences that are prone to vegetation over-growth require maintenance during the vegetation growing season to retain their structural integrity. In some wetter and warmer conditions, vegetation growth can overwhelm a barrier in a matter of weeks, making it easily climbed over. Keeping a clear path along at least one and ideally both sides of a barrier fence is always advantageous for efficient access and repairs.

Long-term checks and repair schedules should be written for inclusion within the overall road maintenance plan, This is passed on and conveyed to road maintenance managers and crews following construction. Although repair and renewal costs are hard to predict, adequate amounts of funding should also be set aside, possibly into an endowment, to ensure crews have enough resources to maintain connectivity structures in the long-term. Such funds and maintenance plans may be incorporated into vegetation control plans; roadside fire and hazard management plans; or the management of environmentally sensitive areas as appropriate.

Common problems for modular barriers may stem from the lack of materials being able to expand and contract due to changes in temperature; this can result in cracking and detachment. Damage and digging underneath by burrowing animals may be rare, but can be extensive when they happen. Mounding of soil dust by wind action and from invertebrates such as ants building mounds, extreme weather and human vandalism may need preventative or reactive remedies according to their type and likely frequency. A quick visual check of a system every few months is advisable particularly before and during anticipated seasonal movements of target species. In some cases movements can take place over just a few weeks of the year and be triggered by specific weather conditions. It is helpful to keep a modest amount of any specialized fence material in storage for repairs at the end of the installation, so that it is available to make rapid repairs.

Repairs and retrofitting

As well as for new construction, measures can be taken during repair and renewal work to improve or maintain a wildlife passage system. Improving conditions in large tubular and box shaped culverts to assist uninterrupted movement of fish or for larger mammals are well-established actions to restore and improve wildlife passages. These improvements may equally apply to herp species at many locations. These are described in the next two sections.

Small passage structures

It is often surprising how relatively straight forward it is to repair and even improve on an existing passage system where the barrier requires attention. However, maintenance crews are often overstretched and training and guidance may be needed to identify and remedy failing systems.

Away from purpose-built structures, repair work to culverts that benefit wildlife generally can be where a drainage culvert discharges on a slope and over time, erosion has worn away the ground under the culvert end, preventing small wildlife movement in one or both directions (Figure 72).

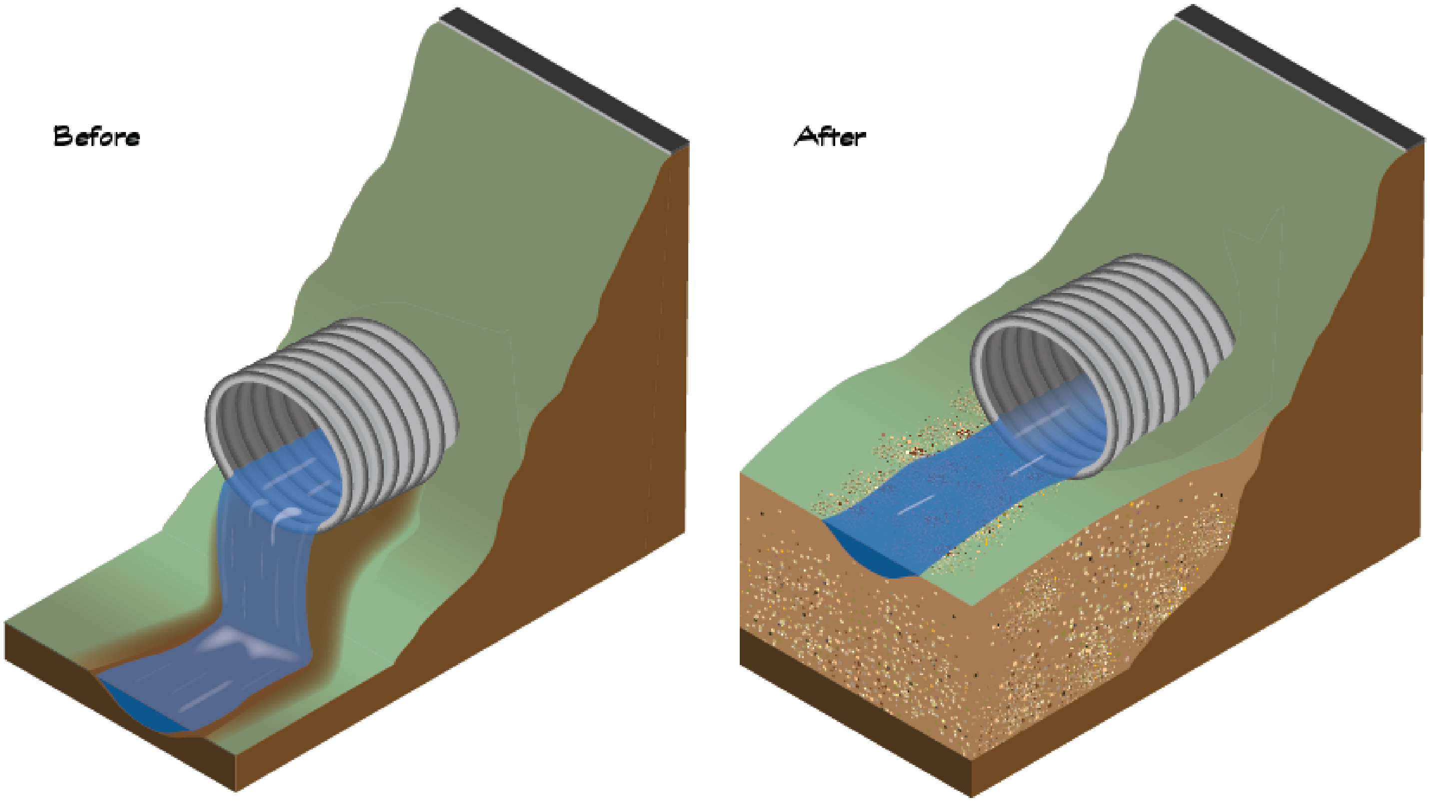

Figure 72: *Many existing culvert ends are eroded so much that the end hangs in mid-air. The incidental use of them by amphibians and reptiles, and other animals for safe passage is precluded or limited in one or both directions. Passage shown before and after improvement.*

Larger passage structures

The maintenance of larger passage structures may involve the repairing of erosion around the base of hard structures, providing a smooth surface transition from the stream bed and along the base of an aquatic passage, both upstream and downstream. This is considered a significant priority.

Where a water course flows strongly for long periods and prevents movement of target species that require dry land or slow water flow to move through, culvert side shelves (Figure 73) may be retrofitted along the inside of larger stream culverts for use as walkways for semi-aquatic and terrestrial species, less adapted to aquatic conditions. If this is not feasible, a new side passage beside the main culvert can be provided (Figure 74).

Retrofitting projects may include consideration for the addition of suitably positioned barriers at stream crossings to keep wildlife away from the road surface and to funnel individuals toward the culvert or newly installed wildlife passages. Smaller stream culvert and bridge headwalls often constitute a partial barrier to wildlife movement and connecting these to fences of around 150 ft/45 m in length, positioned at a slight angle towards the passage, may capture a large proportion of animals that might otherwise cross the road surface close to the structure.

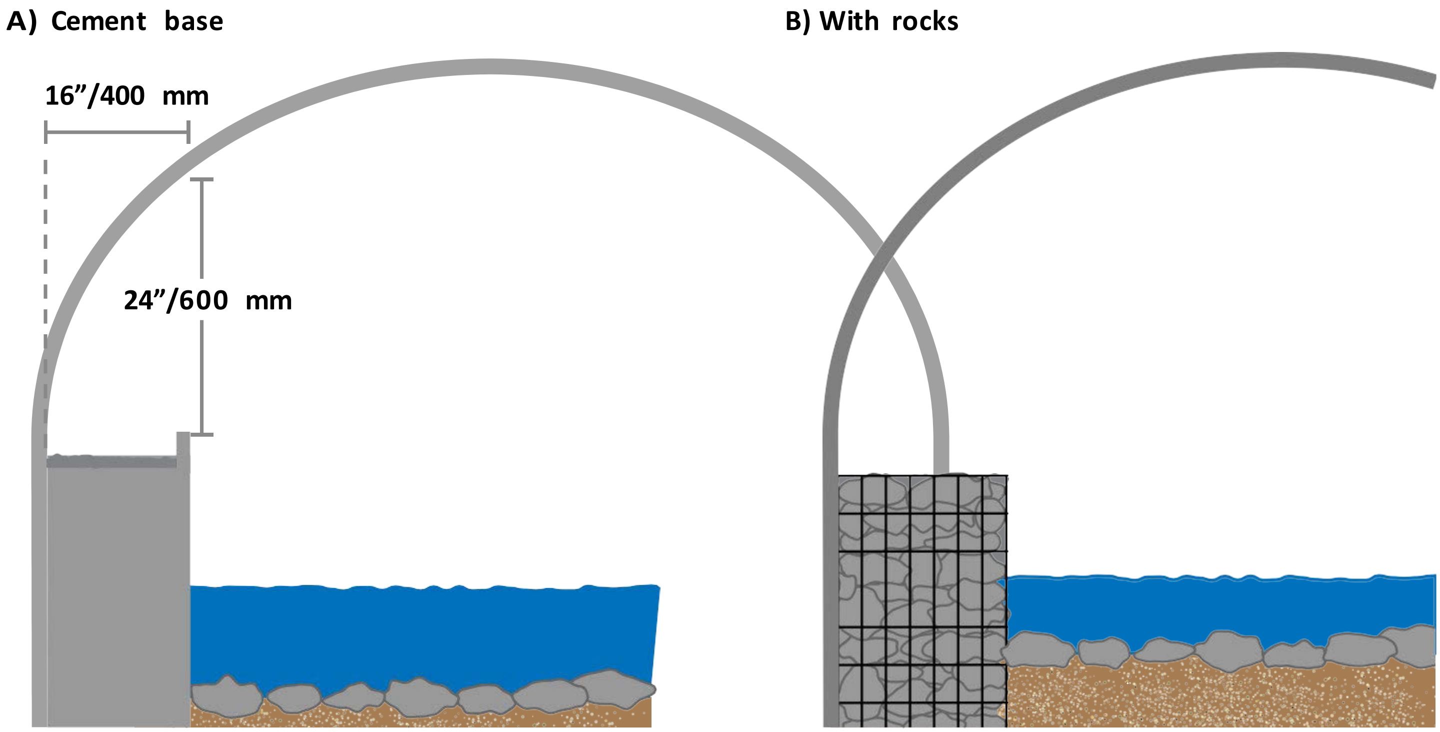

Figure 73: *Some culverts and bridges over fast-flowing waterways are suitable for the installation of dry or high ledges that can provide safe passage for wildlife during periods of peak flow. For amphibians and reptiles a ledge formed by cast concrete or gabion baskets 16 in/0.4 m wide and with an outer height clearance of 24 in/0.6 m should be sufficient. A lip at the shelf edge will help hold substrate (native strata) placed on the ledge.*

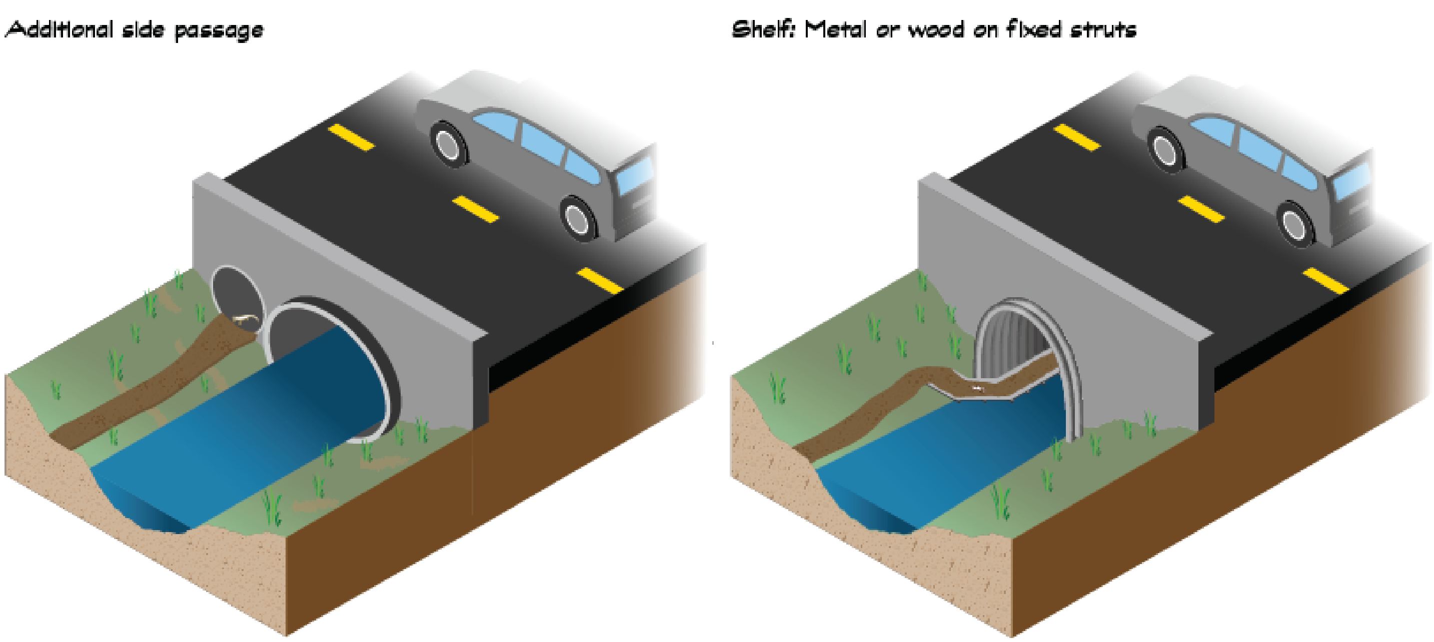

Figure 74: *Circular culverts (left) spanning riparian corridors, where fixing a shelf is not feasible, a dry side passage may be provided. With arched culverts (right), the size of the structure may be large enough for fixing a self-supporting ledge or shelf along the inside wall of the culvert.*

Wildlife passage may happen by chance in similar circumstances. For example, within a fish passage structure installed by Caltrans under Highway 101 north of Willits on Ryan Creek (District 3), winter flow deposits a 'bench' of fine sediments, including a bench suitable for wildlife passage by small medium and large vertebrates.

Small improvements to existing bridge abutments can greatly enhance herp connectivity, such as in the example (Figure 75) where two ledges are constructed within the existing bridge rip-rap lined embankment. Many smaller bridges with rip-rap protection on their upper slopes may be slightly modified to enable wildlife passageways to be formed. Flat, vegetated paths are more suitable for facilitating wildlife movement, helping to prevent animals from climbing up to cross via the road surface. Additional improvements, such as the use of barriers with turn-arounds, should also be considered. These turn-arounds serve to discourage access to the roadway and promote return to the river corridor.

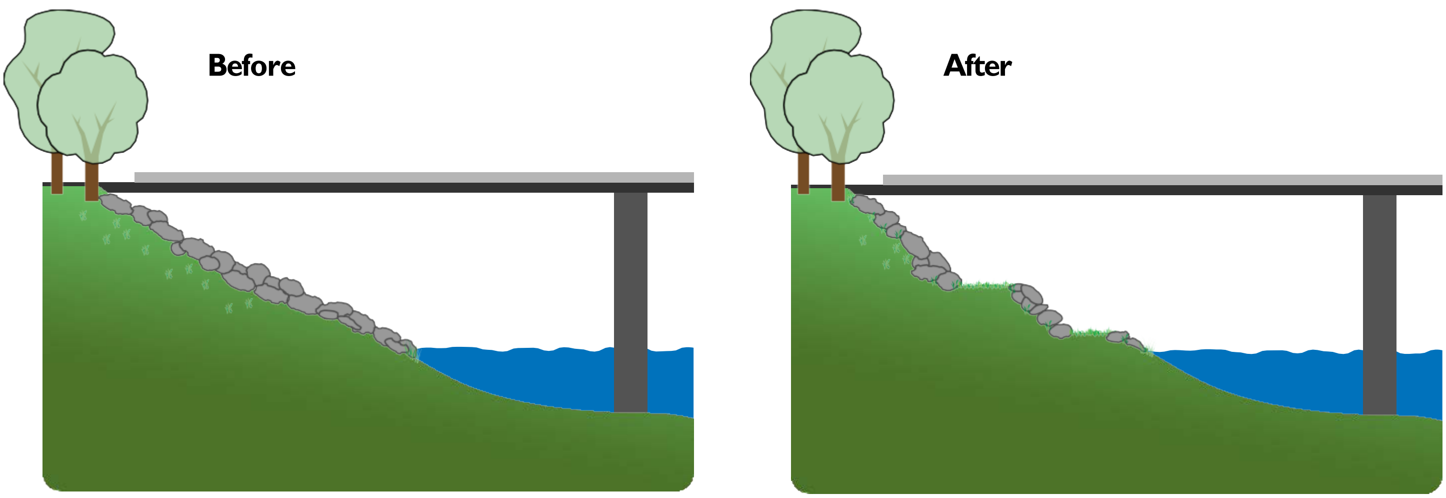

Figure 75: *Small improvements to existing bridge abutments can greatly enhance herp connectivity.*

Enhancements

There is a variety of enhancements that can be made to existing culverts or other structures to improve ease of use by amphibians and reptiles. These improvements include repairing the eroded ends of culverts and installing dry or high ledges (see earlier). Further, the lining of culvert bases with a non-hazardous flat surface may ease passage. Improvements also include habitat restoration/enhancement at the ends of passage structures so that suitable habitat is provided right up to the passage end on both sides.

Opportunities to improve existing systems may require scoping studies. These might look at the capacity for existing structures to be improved and a cost-benefit analysis. Sometimes land habitats are left bare next to the road and these can be restored with native soil and planted (Figure 77) or left to colonize naturally. Placing or constructing ponds that amphibians can use for breeding close to passage structures can help sustain the population and augment usage of the new structure and ensure genetic interchange as long as suitable permanent barriers are in place. Care should be taken if these are created adjacent to roadways and within Caltrans right of ways where amphibians and reptiles are not impacted by routine maintenance such as mowing.

Figure 76: *Corrugated culverts without a flat base may be difficult to navigate for some species. Here a foothill yellow-legged frog (Rana boylii) can be seen at the side of a corrugated metal passage under Highway 70 at the Shady Rest Area, Butte County, California. Image: Garcia and Associates. See: Garcia and Associates. 2008.*

Figure 77: *Planting next to a span bridge underpass. Image: Sally Brown.*

Figure 78: *Often small existing or created pools placed near a passage and barrier system result in the attraction of a range of animals to the location, making passage use more likely. For some herp species, and especially amphibians, breeding in such ponds raises the probability of both adults and juveniles moving to the other side of the road. Image: Tom Langton*

Figure 79: *A cast-in-place concrete stream passage with a mammal shelf, that could be enhanced for use by herpetofauna with addition of directional fencing. Image: Tony Clevenger*

Key Points

- Barrier construction is as important as that of the passage. Materials may expand and contract, become warped and form gaps that animals can move through. Sunlight may break down barriers in exposed locations. Plan for barriers to last as long as the life of the road or to need periodic renewal as well as intermittent repair.
- Crossing systems require careful maintenance if they are to function properly and justify the significant investment in road mitigation and compensation actions.
- Passages and barriers require regular and frequent inspections. Damage due to storm events or extreme weather is common as well as the accumulation of leaf litter and other debris in smaller culverts and passages.
- Barriers may be compromised at any time by vehicles and loose cargo leaving the road. They may be overgrown by vegetation and damaged by falling branches. The need for regular inspections and repairs should be anticipated.
- The most common way in which a crossing system can fail is if an animal breaches the barrier or climbs over one due to the lack of maintenance.
- Long-term checks and repairs should be written into a maintenance plan that is then passed on to road maintenance crews. An endowment or long-term maintenance fund should also be established to ensure routine maintenance of passage structures.
- During roadway construction or retrofit jobs, repairs or enhancements can be completed to better accommodate herp and wildlife passage and improve system effectiveness. Examples are culvert side shelves fitted along the inside of larger culverts for use as walkways or dry ledges during periods of high flow for semi-aquatic and terrestrial species.

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Maintenance

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Barrier quality assessment

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Adaptive approach to crossing structures development

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List of Appendices

APPENDIX 1 Density of 'very high' and 'high' risk road assessment herpetofauna in California

Maps showing the densities of 'very high' and 'high' road risk species were created by USGS. Maps were produced by overlaying species ranges identified as being at "high" or "very high" risk of negative road impacts in the California amphibian and reptile road risk assessment. Color-coded densities reflect the number of at risk species across California presented within general taxonomic groups (frogs, toads, salamanders, aquatic snakes, lizards, and terrestrial snakes). Greater densities indicate areas of concern where roads are predicted to impact higher numbers of species. A density map over all herpetofauna species was shown in Chapter 1.

Reference: Watson, E. and C.S. Brehme, 2020. Spatial Mapping-California Essential Habitat Connectivity Lands, Highways, and High-Risk Species in Brehme CS and RN Fisher. Chapter 3: Research to Inform Caltrans Best Management Practices for Reptile and Amphibian Road Crossings. USGS Cooperator Report to California Department of Transportation, Division of Research and System Innovation, 65A0553

Figure 80: *Density of High and Very High Risk Species - Frogs*

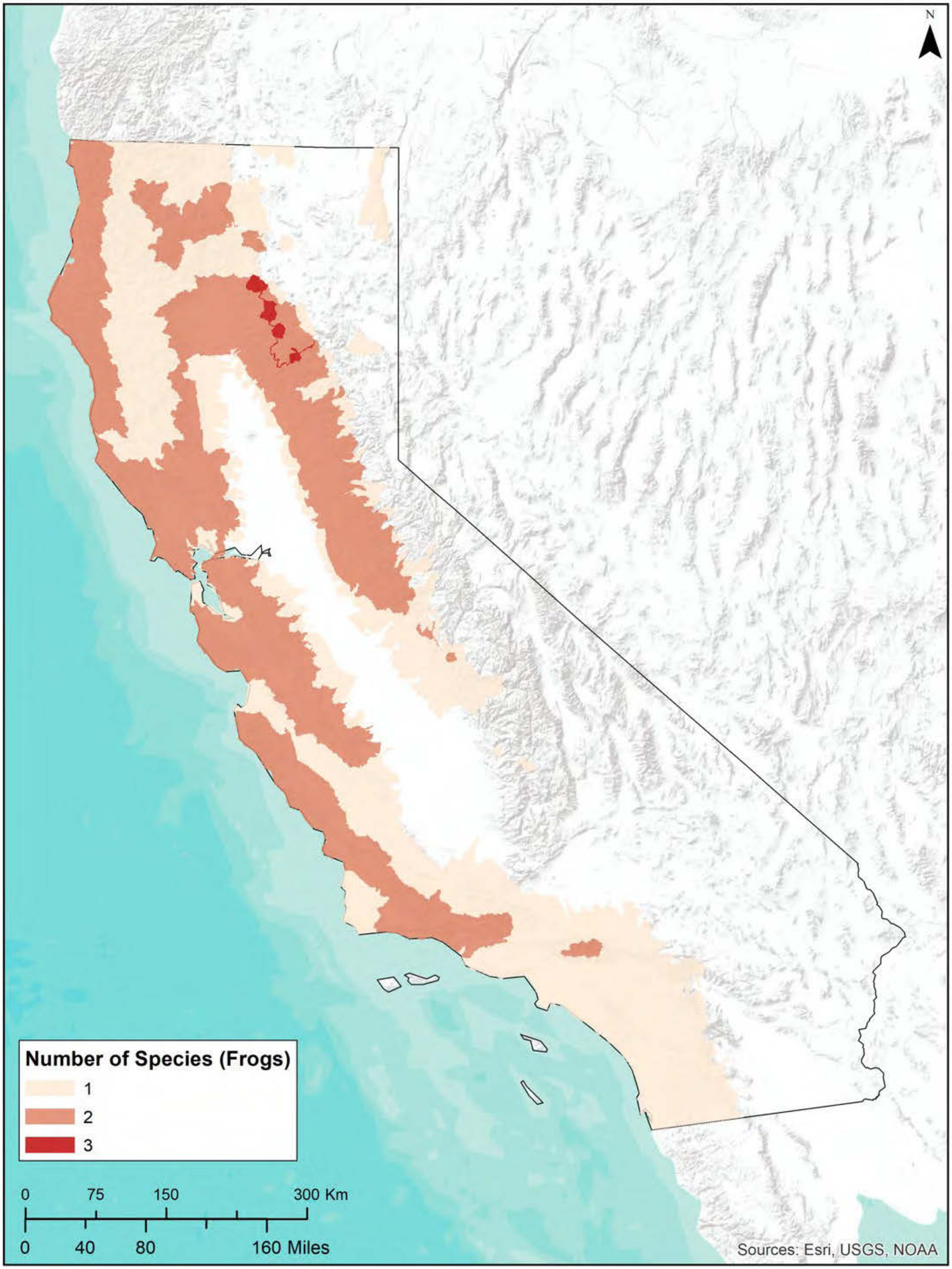


Figure 81: *Density of High and Very High Risk Species - Salamanders*

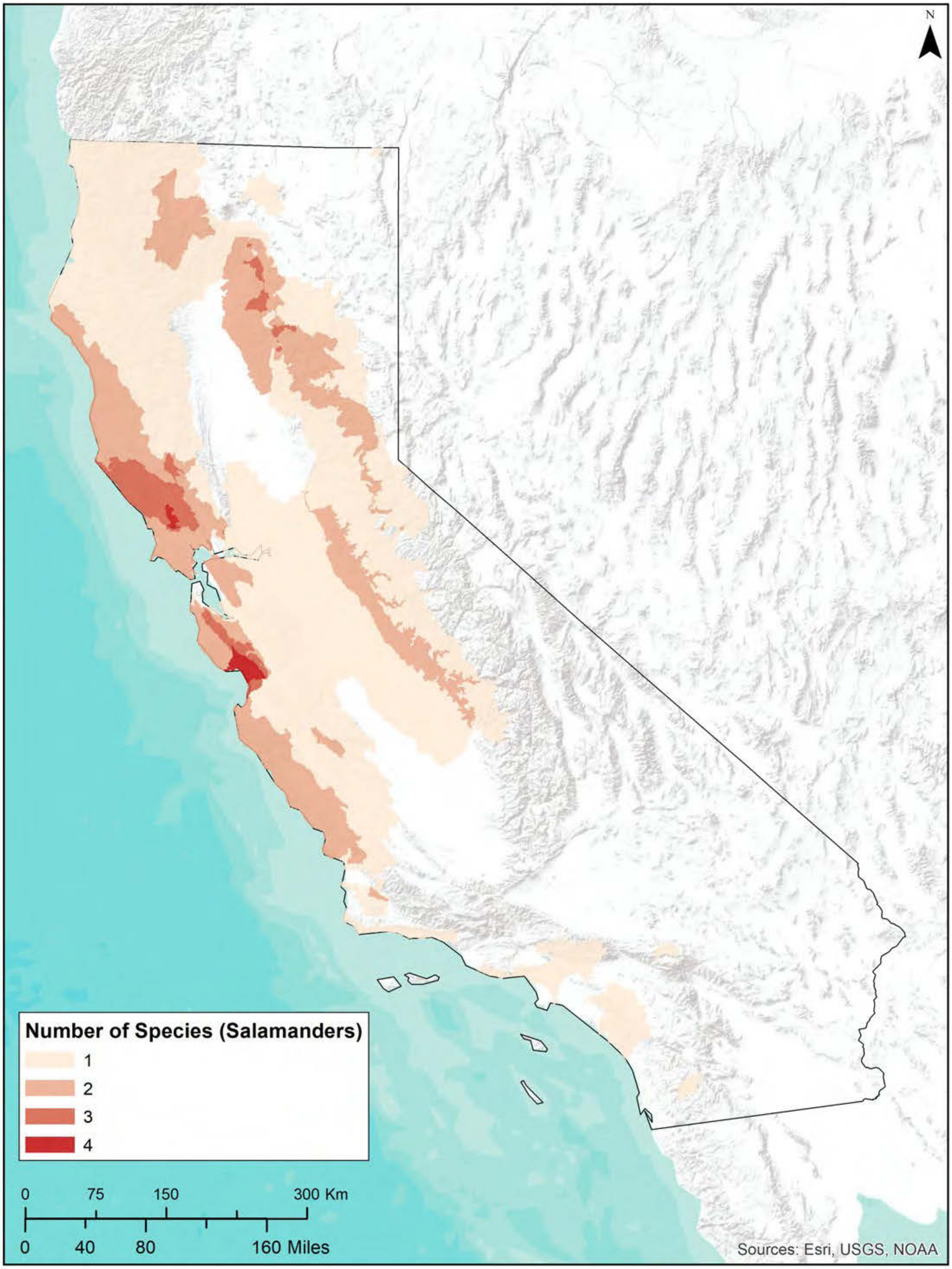


Figure 82: *Density of High and Very High Risk Species - Aquatic Snakes*

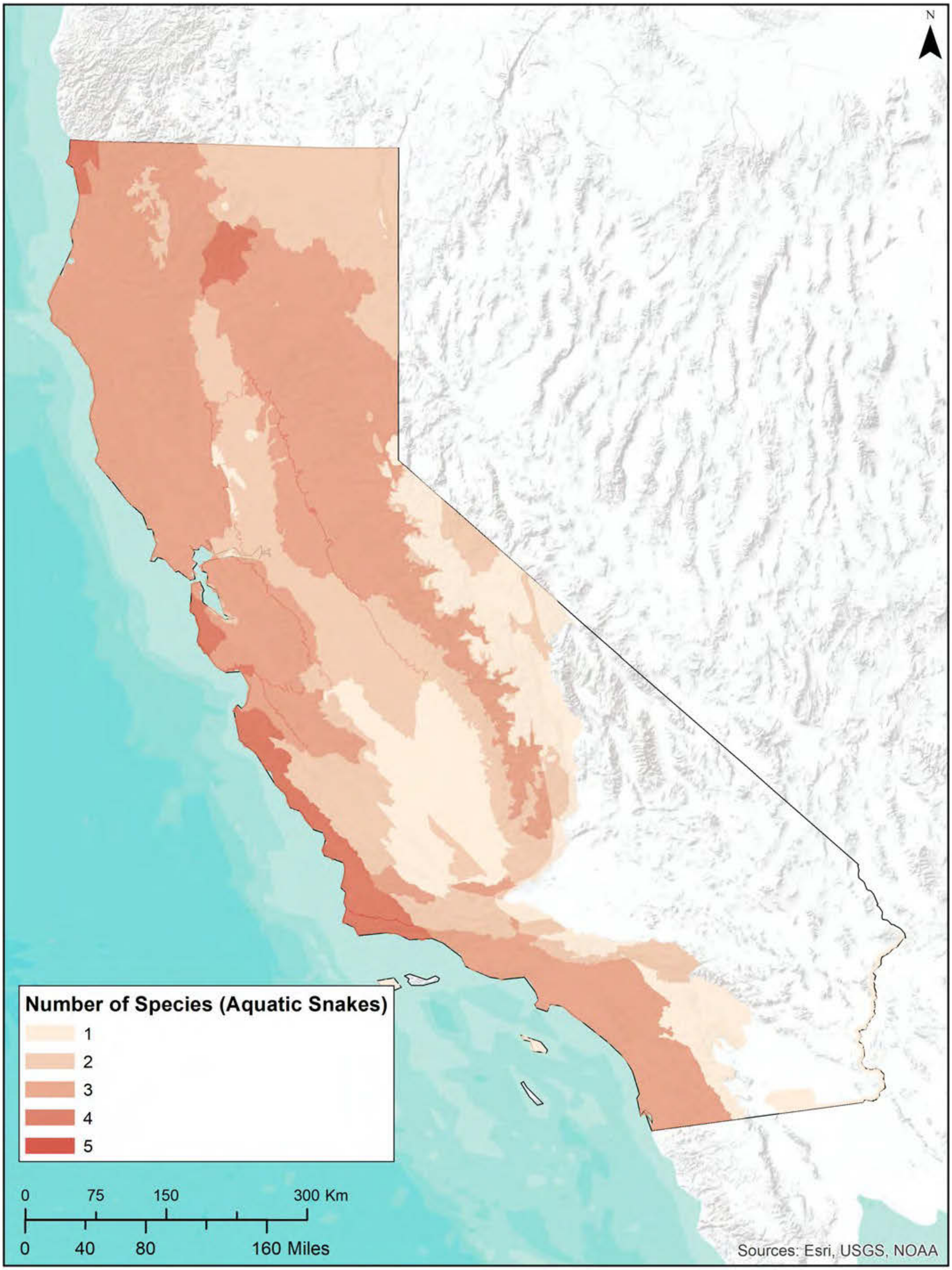


Figure 83: *Density of High and Very High Risk Species - Lizards*

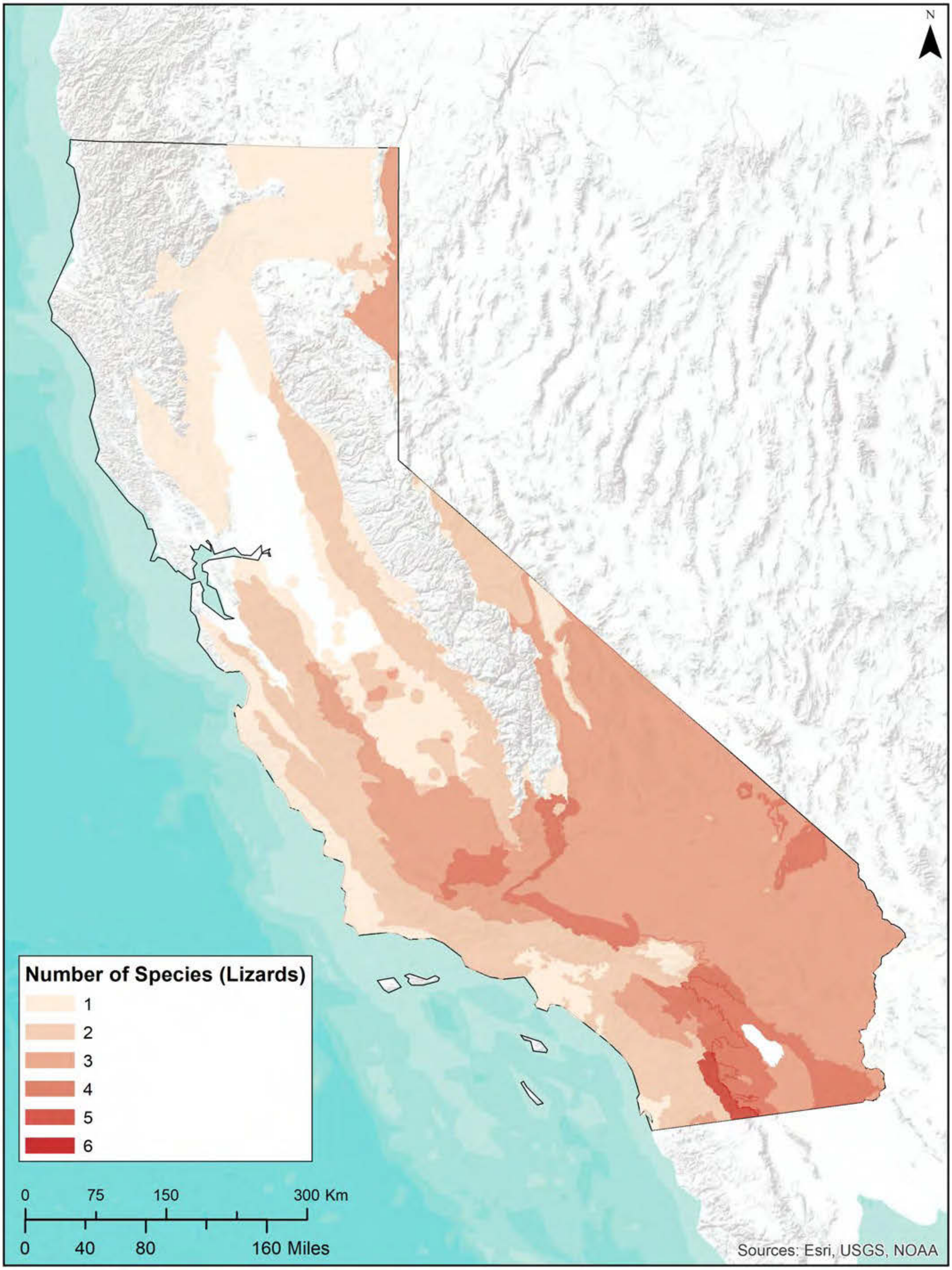


Figure 84: *Density of High and Very High Risk Species - Terrestrial Snakes*

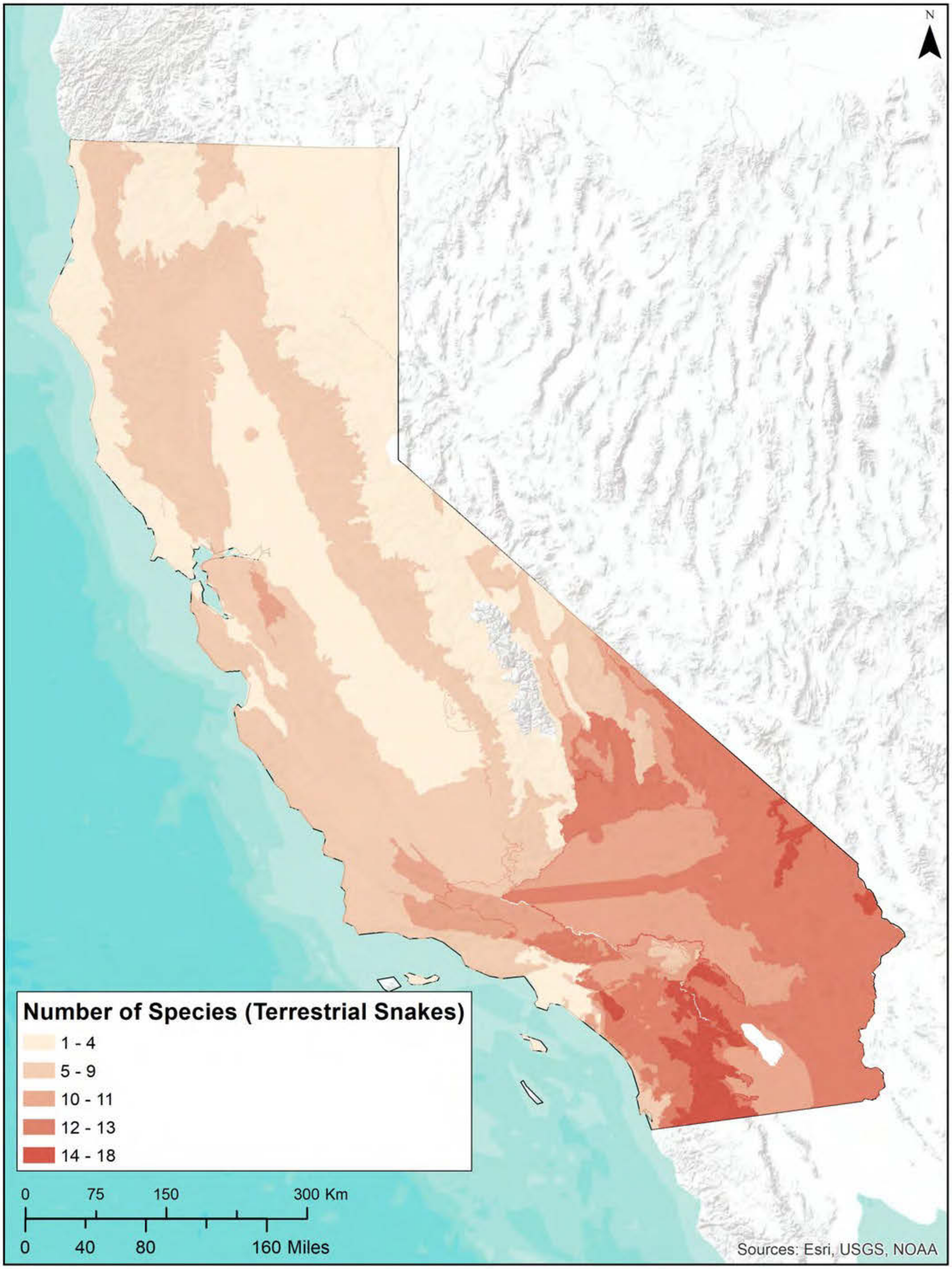


Figure 85: *Density of High and Very High Risk Species - Toads*

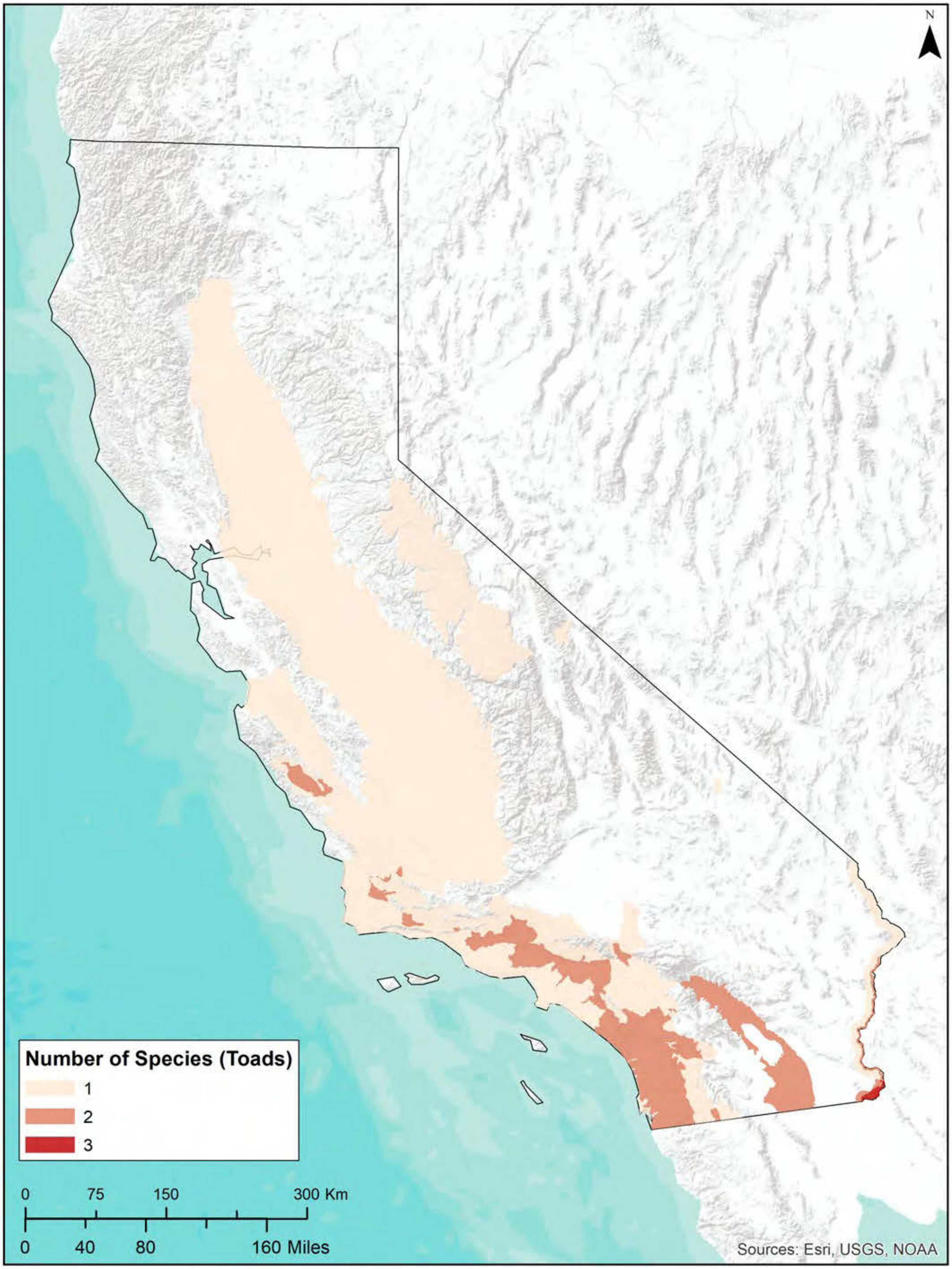


Figure 86: *Density of High and Very High Risk Species - Tortoise*

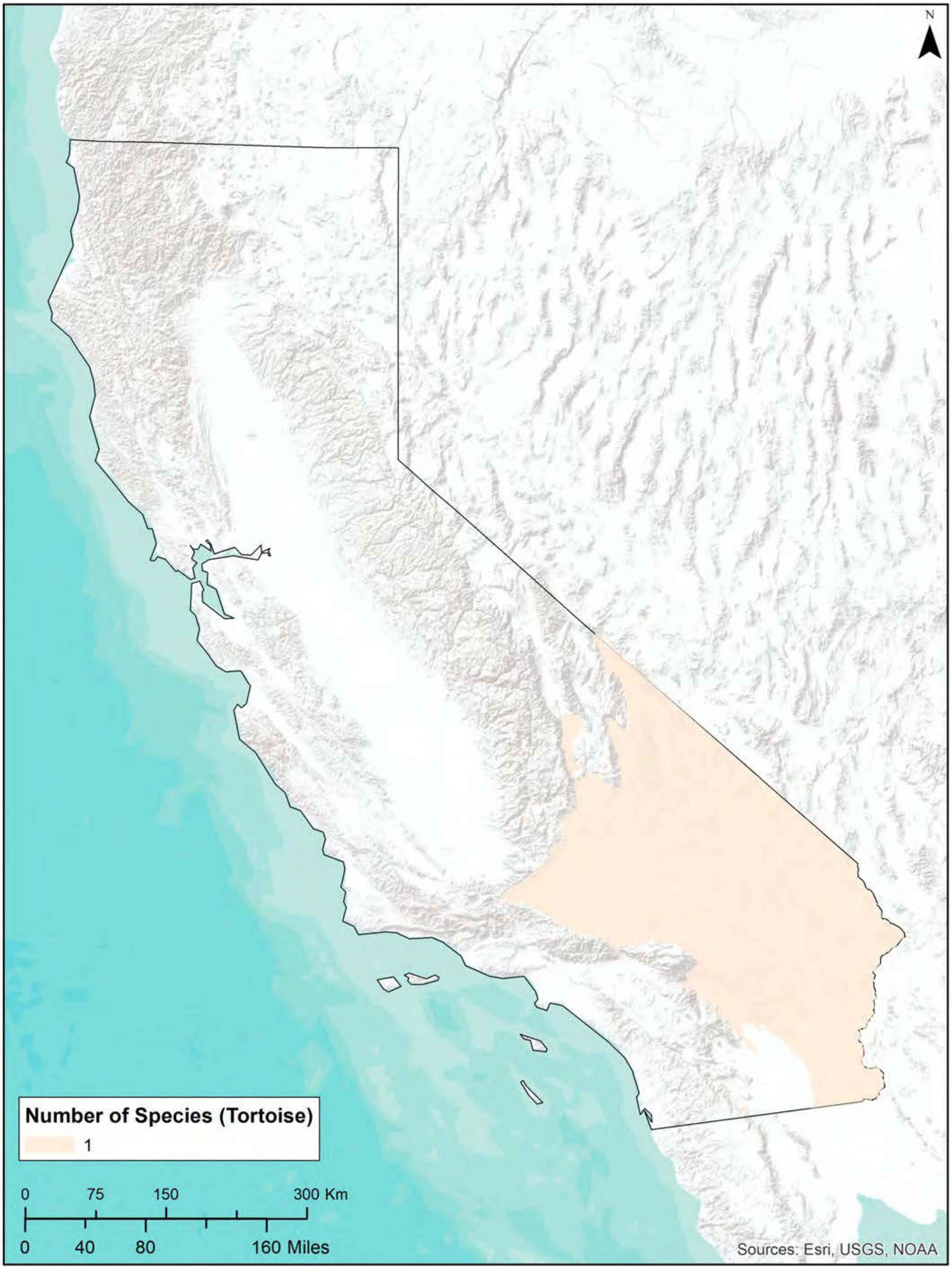


Figure 87: *Density of High and Very High Risk Species - Turtle*

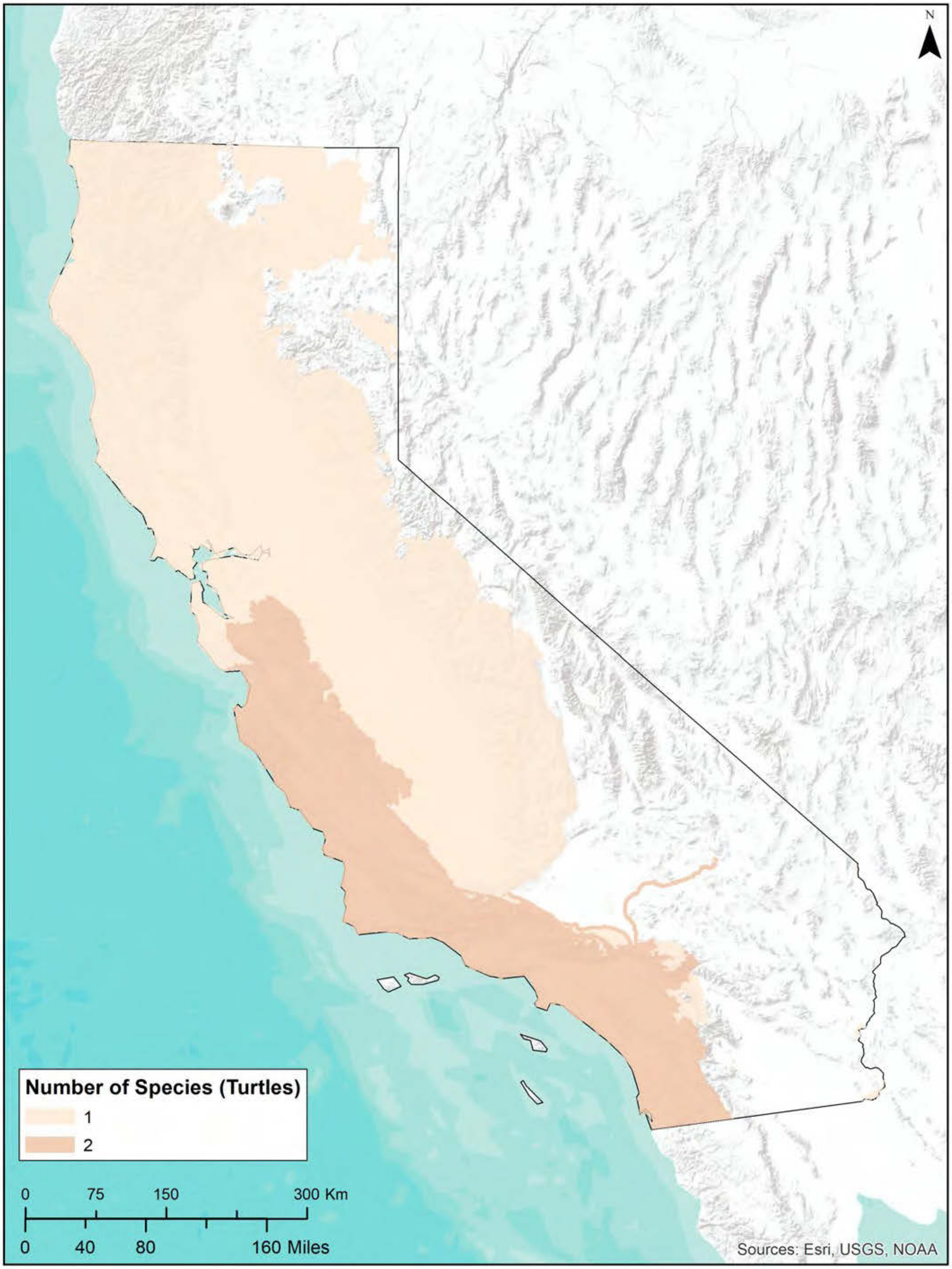
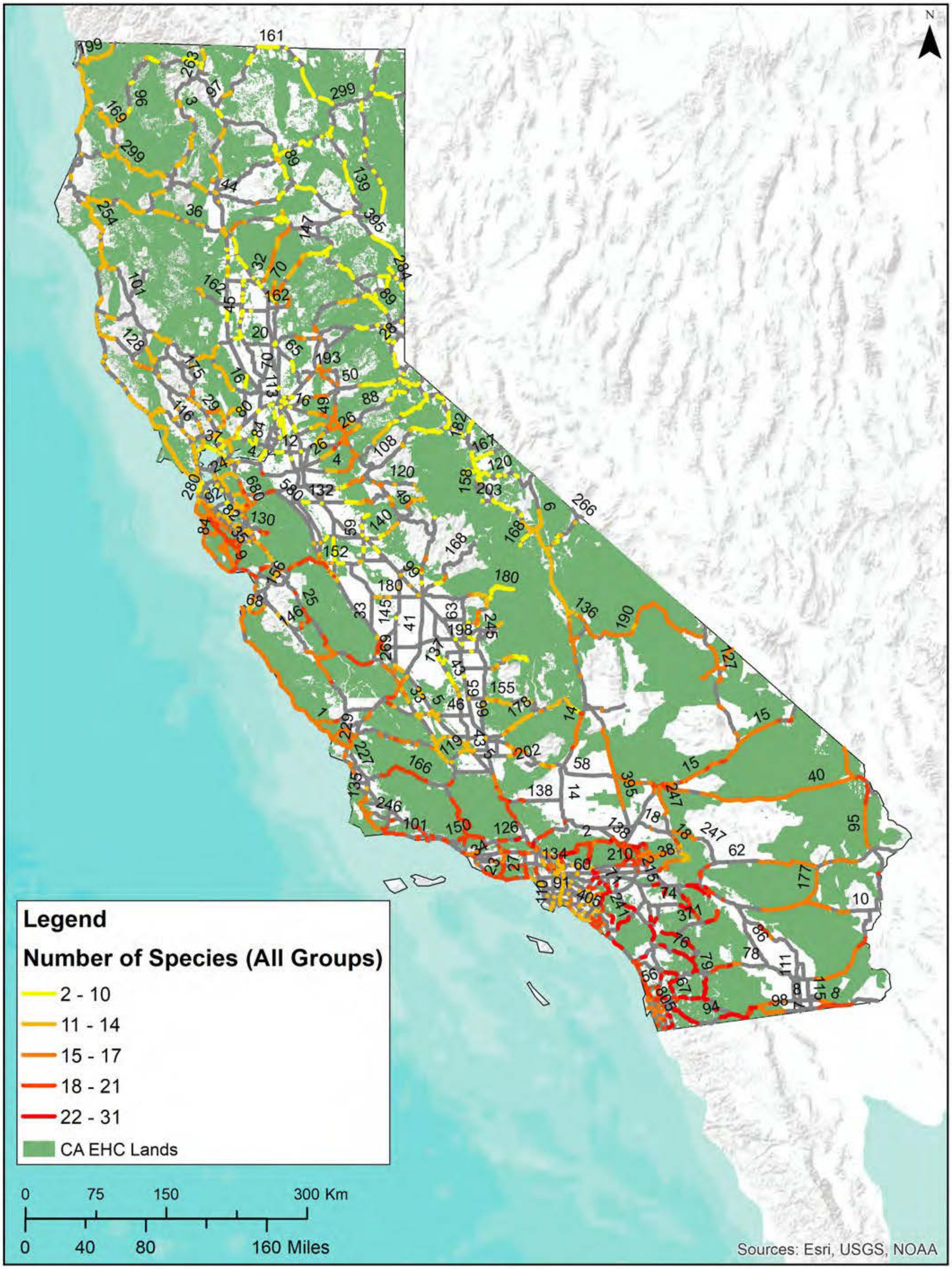
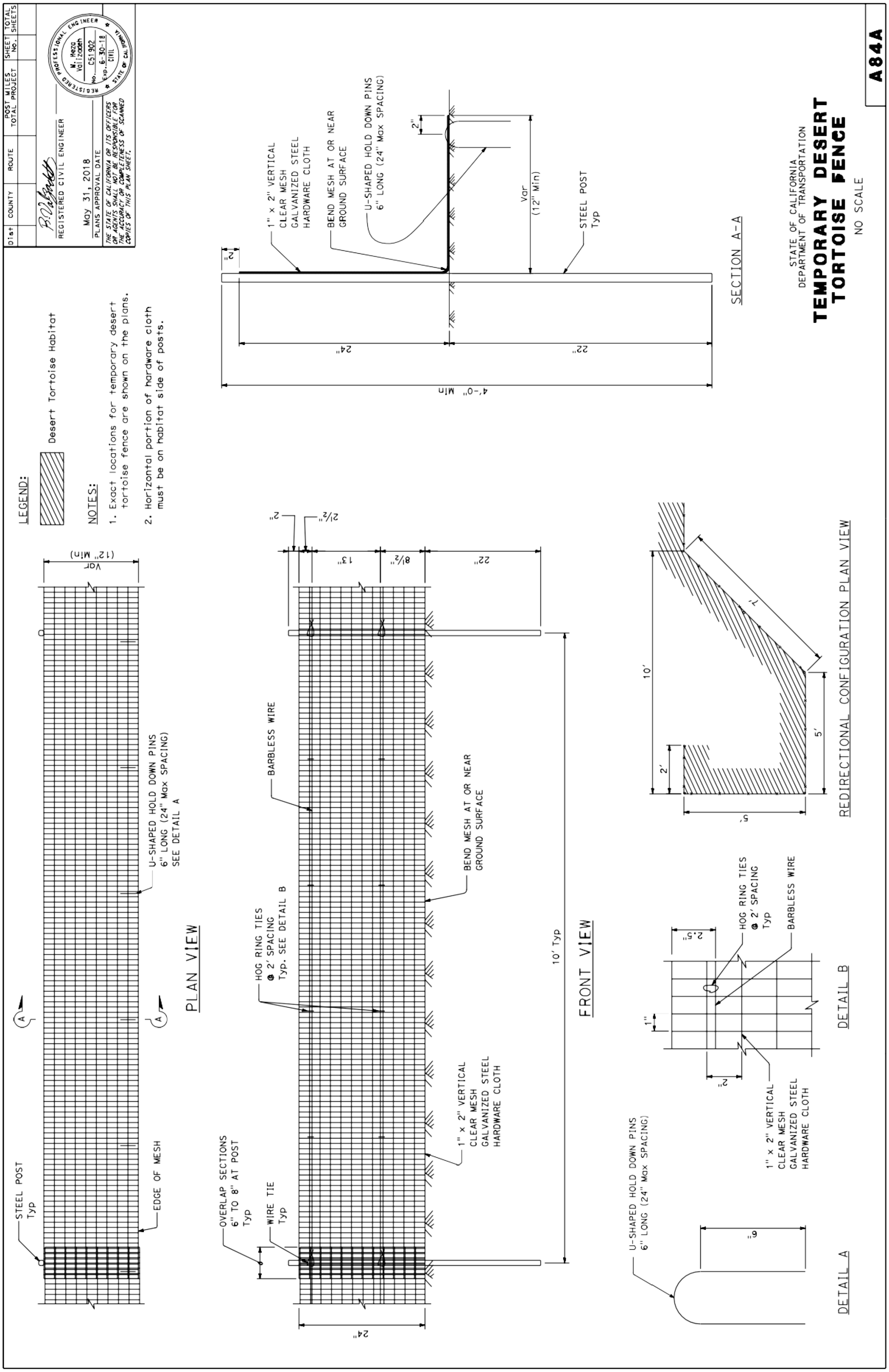
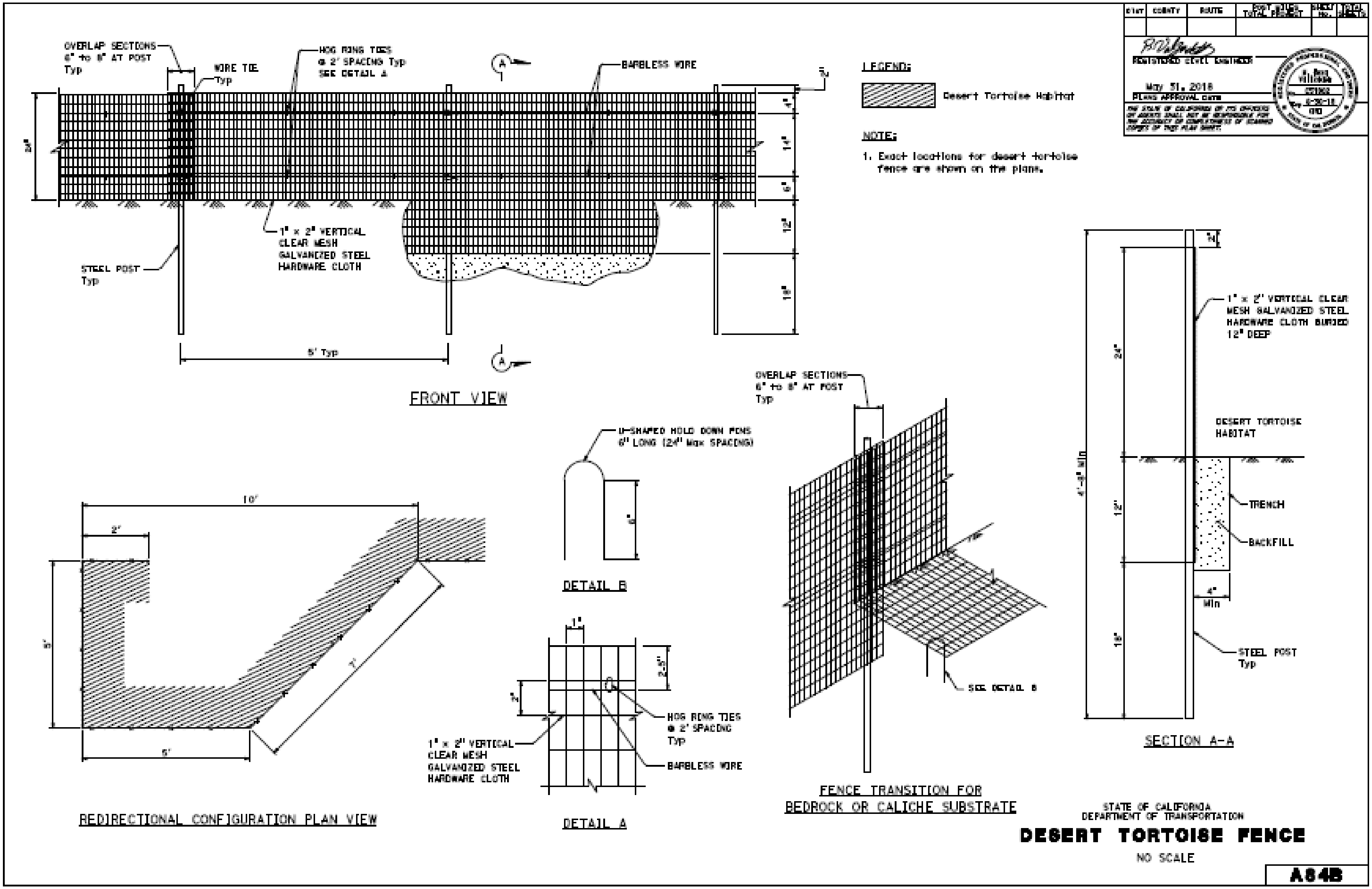


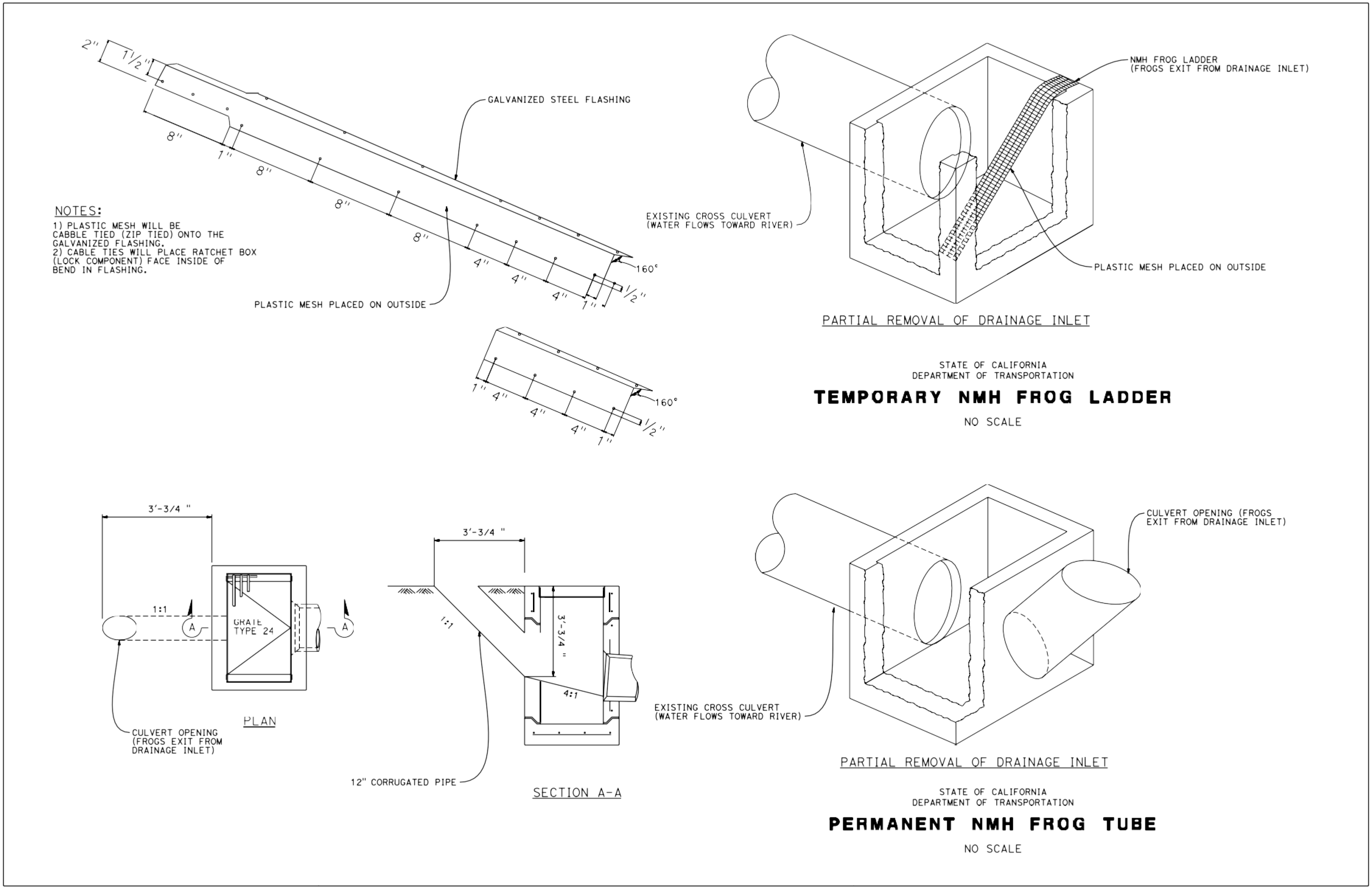
Figure 88: *Density of High and Very High Risk Species - All Groups*



APPENDIX 2 Desert tortoise fencing construction specification (Caltrans 2018)




OVERLAP SECTIONS 6" to 8" AT POST Typ
WIRE TIE Typ
HOG RING TIES @ 2' SPACING Typ SEE DETAIL A
BARBLESS WIRE
LEGEND:
Desert Tortoise Habitat
NOTE:
1. Exact locations for desert tortoise fence are shown on the plans.
REGISTERED CIVIL ENGINEER
May 31, 2018
PLANS APPROVAL DATE
24"
4"
14"
6"
12"
18"
1" x 2" VERTICAL CLEAR MESH GALVANIZED STEEL HARDWARE CLOTH
STEEL POST Typ
5' Typ
FRONT VIEW
1" x 2" VERTICAL CLEAR MESH GALVANIZED STEEL HARDWARE CLOTH BURIED 12" DEEP
DESERT TORTOISE HABITAT
TRENCH
BACKFILL
4" Min
4'-6" Min
STEEL POST Typ
SECTION A-A
U-SHAPED HOLD DOWN PINS 6" LONG (24" Max SPACING)
DETAIL B
10'
2'
5'
7'
REDIRECTIONAL CONFIGURATION PLAN VIEW
1"
2.5"
2"
HOG RING TIES @ 2' SPACING Typ
1" x 2" VERTICAL CLEAR MESH GALVANIZED STEEL HARDWARE CLOTH
BARBLESS WIRE
DETAIL A
OVERLAP SECTIONS 6" to 8" AT POST Typ
SEE DETAIL B
FENCE TRANSITION FOR BEDROCK OR CALICHE SUBSTRATE
STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DESERT TORTOISE FENCE
NO SCALE
A84B



Caltrans engineering drawing for drop-inlet culverts on intermittent or perennial drainages for small animal escape purposes: the ‘frog tube’. The frog ladder variant also enables amphibians to escape if they become entrapped in the drainage structure.

APPENDIX 4 Glossary of terms

Barrier a general term used to describe a structure that blocks or guides herp movement and includes all types of permanent guide walls and fencing types

Breeding pond Normally in respect of amphibians this is the freshwater bodies where amphibians spawn or lay eggs, tadpoles develop and metamorphose. Egg laying reptiles may also lay eggs in soil on moist wetland margins & small islands of wetlands/ponds.

Bottomless culvert (Stilt passage, open bottom culvert) A passage formed as a small bridge where the construction is an inverted U shape with each side supported on foundations. The central ground area is left as natural or deposited substrate to retain a more natural environment for wildlife use.

Cast in place (cast in situ) A construction made from poured materials often with steel reinforcement, the shape being formed by temporary shuttering.

Connectivity The degree to which the landscapes facilitates or impedes movement of individuals among resource patches.

Compensation Wildlife provision to rebalance the losses from developments if minimization mitigation is not possible or is insufficient to sustain equivalent wildlife value.

Cover board (survey tile, tin or sheet) A flat or corrugated square or rectangle made from a variety of materials such as wood and metal that attract additional heat or moisture under different weather conditions and times of day. Placed along a barrier they may assist in survey, trapping or for shelter of amphibians and reptiles.

Crossing system The combined design of passage and barriers together with habitat restoration, construction or enhancement measures created to mitigate or compensate for transport corridor wildlife impacts.

Culvert A mostly pre-cast water channel normally round, elliptical or rectangular (box culvert) that may be adapted as a wildlife passage. Normally concrete, galvanized steel or plastic. Some culverts are cast in-place. Type 4 wildlife passage category: over 3.3. ft/1.0 m diameter/height but under 10 ft/3.0 m.

Culvert shelf A board made from durable material, placed on supporting structures or attached on rods the sides of culverts to facilitate movement of small non-aquatic animals, when a watercourse is in full flow.

Culvert side-passage A passage built alongside and parallel with a water drainage culvert where the size or intensity of drainage water prevents placement of side shelves for wildlife to use it when high flow periods coincides with a species peak movement seasons.s

Curb (kerb) Vertical edge that is concrete or stone where tarmac joins a sidewalk, May be of angled shape to form a drop curb preventing a barrier to small animal movement.

Deflection board (swallowtail) Vertical board either straight or curved, placed at the entrance/exits of passages to increase the probability of an animal entering the passage.

Denning area Habitat, often rocky land where reptiles, notably snakes may spend several months in winter or in drought at high density as a place of retreat.

Directional fencing A fence angled to encourage animals to move in a particular direction towards a crossing point.

Dormant period This includes aestivation (during hot and dry weather) and hibernation during cold/freezing) weather for periods weeks or months.

Drop-inlet culvert A usually rectangular or square chamber with a steel grating, formed with concrete, collecting surface water on one side of a road for discharge often on the other side via a culvert under the road. It’s silt trap function may entrap herpetofauna and other small animals.

Dual purpose barrier A guide wall or fence with a higher component designed to prevent movement of the largest wild mammals and livestock and with a lower component designed to prevent movement of smaller animals.

Entrance unit A built structure made from wood, plastic or other material occasionally used at the ends of surface passages, that serves to join the passage and barrier and to help reduce animals walking past a passage entrance. May also provide shade from sunlight.

Escape ramp A hard structure, often narrow, placed in a drainage trap to enable animals to climb out. May also be made from soft woven plastic fiber (climb cloth) or perforated stainless steel.

Fencing a general term for barriers that are free standing and not built into the side of a hard road structure or embankment. (See Guide wall).

Fencing (temporary) A lower cost barrier, normally involving support posts made from usually thin plastic material such as polythene, with a life expectancy of 5-10 years but often less. Recyclable semi-permanent fencing may also be used as temporary fencing.

Fencing (semi-permanent) A barrier involving support posts or free standing often made from polypropylene, injection molded, extruded sheets and meshes, or metal mesh, with a life expectancy of 15 -25 years, occasionally more in sheltered conditions (woodland).

Fencing (permanent) A barrier created with a life expectancy of 30 years or longer.

Fiber reinforced Plastic (FRP) (also fiber-reinforced polymer) Strong lightweight material made from fine strands or particulates of a wide range of materials including glass (GRP) carbon and synthetic materials that have use in innovative crossing system design.

Gate barrier A flap (rubber) mesh or hard material attached to the bottom of a service gate in order to maintain the continuity of a barrier where vehicle or pedestrian access is required. Often a concrete pad is below the gate when closed to ensure a close fit.

Generation time The average length of time that a species takes to complete its life cycle. Often used in assessment of the viability of meta-populations or artificially fragmented populations..

Guide wall A solid barrier, built into the side of the road structure/embankment or free standing, made from hard materials with a normal life expectancy of 50 years or more. Typically made from concrete, polymer concrete or metal.

Hardware cloth (wire mesh) Fencing made from normally steel wire made into square or rectangular grids. Different mesh sizes can be obtained from fine 'rodent' mesh up to 1 x 2 inch.

Habitat re-connection (Habitat defragmentation) The physical process of re-joining fragmented habitat, through habitat restoration, reconstruction (Recreation)/rewilding usually involving soil, water and vegetative management with crossing structures.

Herpetofauna Scientific name for reptiles and amphibians. Herpetology is the study of reptiles and amphibians. This may be shortened to Herp or Herps for frequent use.

Hibernacula A refuge for small animals from cool or frozen seasons but may be used at other times. Can be natural such as rock piles and rock, tree and shrub root fissures & adopted mammal burrow areas. Often constructed in schemes to enhance habitat for particular species. Made from rock and log material, often with soil and turf components. Normally designed so as not to become waterlogged.

Infra-red camera A remote battery powered camera used for wildlife monitoring that illuminates at night using Infra Red LED source to give a viewable still or video images of nocturnal as well as daylight and crepuscular amphibian and reptile movement.

Jump-out (Escape structure) A device or adjustment (ramp/funnel/gate) fitted to a wildlife fence that enables animals to pass through or over it, but not to return in the other direction. For example, to enable animals to self-remove from unsafe areas (such as roads) into a safer environment.

Landscape bridge A road built across a river or dry gulch or canyon to enable shortest access and to prevent excessive and environmentally damaging construction of a longer road to navigate steep hillsides. Allows unimpeded wildlife passage. Type 1B passage

Mass migration Synchronized often seasonal and sudden movement of a large proportion of breeding adults or new young between habitats of different type within their home range.

Median (central or center median) Strip of land dividing traffic moving in opposite directions.

Median barrier (Jersey barrier) A concrete low center of gravity safety wall built in sections positioned in the median (also sometimes placed in the road and side for temporary diversions) to separate traffic lanes and particularly in permanent installations to help prevent vehicle crossing onto oncoming traffic from the other direction.

Median refuge An area open to the air in the median acting as a refuge with the aim of encouraging increased use of a long underpass.

Median skylight An area in the median with a grating that enables light to enter longer underpasses with the aim of increasing passage illumination.

Meta-population A population made up of sub-populations fragmented in habitat patches, that is dependent upon dispersal of individuals between subpopulations to be viable over the long term.

Mesh fence (metal) (hardware cloth) A fence grid made from metal wire with square or rectangular gaps, often ¼ or ½ inch square or 1 x 2 inch that can limit movement of animals over a certain size. Animals may see light and habitat on the other side. May be climbable by species with digits and claws.

Mesh fence (plastic) An extruded fine fence made from plastic with holes that can vary from very small to up to 2 mm. Animals may see some light and habitat on the other side. May be climbable by species with digits and claws.

Micro-passage (Micro underpasses, micro tunnel) Smaller culverts and purpose made passages under three-foot span (<3.0ft/0.9 m) diameter/height. A Type 5 crossing structure.

Micro-bridge A low raised surface bridge supported by heavy timber, placed on an existing track or road with spaces below for small animals to move through. A Type 6 crossing structure.

Mitigation Specific action taken to try to reduce and remove the likely impacts of change caused by transport route construction and operation.

Mountain/hill tunnel A major excavation through solid ground for road, rail and waterways that leaves the surface vegetation largely undisturbed and so allows unimpeded wildlife passage. Type 1A passage

Multi-span overpass An overpass with more than one span, sometimes crossing two roads, a road and a rail line or canal and other linear features including private land access routes.

One-way barrier A guide wall or fence that enables unrestricted movement of target animal/s in one direction but prevents movement in the other direction.

Overwintering area A location in the habitat where herpetofauna may spend several months in winter as a place of retreat from cold, often giving birth to young close to the burrows or cavities.

Passage (wildlife passage, wildlife crossing structure) General term for a structure or method of transport route construction that enables total or partial dispersal and movement of wildlife across a linear transport infrastructure.

Pitfall trap A buried bucket or container designed to catch animals for survey or translocation purposes very carefully monitored and regulated to ensure high welfare standards.

Pitfall trap ladder A stick or manufactured device enabling mammals to escape from a pitfall trap for herpetofauna, where they may starve or cause mortality in trapped amphibians and small reptiles.

Portal structure A passage built over or underneath (portal bridge) a road entering a mountain/hill tunnel, designed to enable safer lateral movement of animals around a steep slope or cliff.

Plastic fence (temporary) A low (under 3.3 ft) fence made from very thin plastic usually polythene, used for very short-term guidance including pitfall trap drift fencing and short-term enclosure or exclosure of small animals. polyethylene or polypropylene by extrusion as sheet or panel material or from injection mold fabrication.

Plastic fence (semi-permanent) A fence, normally temporary or semi-permanent made from polyethylene (often High-density polyethylene HDPE) or polypropylene, by extrusion as sheet or panel material or injection molding to intricate shapes.

Population Viability Analysis Mathematical approach to assessing the conditions when genetic variety (heterozygosity) is maintained by minimum levels of (meta-) population connectivity. Often expressed in respect of movement of one breeding animal in each direction per generation time.

Rip rap Boulders or broken rock placed near road and drainage structures to reduce or prevent scouring and erosion during peak flow and storm events. Gaps between boulders may entrap turtles in freshwater, terrestrial and marine environments.

Road Effect Zone Area each side of the road where fauna and flora distribution, abundance, or behavior is modified directly or indirectly over the short or long term as a result of transport corridor construction or operation.

Road Risk Ranking of species for the risk of extirpation from road-related impacts, according to life history and behavioral traits.

Road segment A uniform section of road that is identified separately in an asset register.

Scupper (basal cut-out) A gap under 30 cm high at the base of Median barriers; the strong often reinforced concrete blocks that separate lanes of traffic moving mostly in opposite directions on multilane highways. Scuppers normally formed to allow surface water flow, may be used by smaller animals so they are not trapped against highway fast lanes.

Shade shelter an arch shaped single piece device, designed to provide shade cover for reptiles moving along fences in hot arid habitats (notably tortoises) in order to reduce stress and potential mortality.

Shoulder Paved or unpaved lane at the side of the road, generally for emergency use.

Silt cloth (mono-filament plastic mesh) A temporary barrier material made from geotextiles such as woven polypropylene often used for retaining sediment and controlling erosion on construction sites and that can be used to control wildlife movements on a temporary basis.

Slots Small spaces in the top of a micro-passage that make the passage inside similar to the road environment above.

Stop-grid (stop channel) A channel with a metal grating, placed where a side road joins with a main road, used to prevent wildlife access across a break in fencing. They allow smaller amphibians and reptiles to avoid crossing a road by dropping down into the channel and moving towards ‘safe’ habitat or crossing structures. Stop-grids are a small type of ‘In-roadway’ barrier (deer/cattle guard) .

Substitute habitat Critical component of a species range that is constructed by natural or artificial means on one or both sides of a road. E.g. substitute pond, substitute den.

Surface passage (surface tunnel) Smaller wildlife passage with a slotted or grated top allowing external water, air, heat and light rapid ingress. Designed to minimize passage length.

Turn-around The placement of a wildlife barrier usually in a U-shape, so that animals are encouraged to turn back towards their direction of approach and to prevent access to a hazardous transport route environment.

Turtle Terrapin living in fresh or brackish waters

Viaduct Long multi-span bridge. May sometimes be used to describe smaller structures that bridge habitat.

Wildlife overpass (also: overcrossing, green bridge, biobridge, landbridge) General term for a structure that passes over a road or railway. Type 1C passage

Wildlife underpass (also: culvert, tunnel) General term for a wildlife passage structure that crosses under a road, railway embankment or other obstruction. Type 3 passage

APPENDIX 5 Acronyms

ACE	Areas of Conservation Emphasis (CDFW)
AASHTO	American Association of State Highway and Transportation Officials
BACI	Before-After Control-Impact
BMPTG	Best Management Practices and Technical Guidance
BLM	Bureau of Land Management
CALTRANS	California Department of Transportation
CDFFP	Calif Dept of Forestry & Fire Protection
CDFW	Calif Dept of Fish & Wildlife
CEHCP	California Essential Habitat Connectivity Project
CAISMP	California Aquatic Invasive Species Management Plan
CEQA	California Environmental Quality Act
CESA	California Endangered Species Act
CNDDB	California Natural Diversity Database
CSSC	California Species of Special Concern
DAPTF	Declining Amphibian Populations Task Force
DOT	Department of Transportation
DRISI	Division of Research, Innovation and System Information. (CALTRANS)
EIA	Environmental Impact Assessment
ESA	Endangered Species Act (US)
FHWA	Federal Highway Administration
FRP	Fiber-Reinforced Plastic
HALT	Hobbs Active Light Trigger
HDPE	High Density Polyethylene
ICOET	International Conference on Ecology and Transportation
IENE	Infra Eco Network Europe
MSU	Montana State University
NEPA	National Environmental Protection Act
REZ	Road Effects Zone
USFS	U.S. Forest Service
USFWS	U.S. Fish & Wildlife Service
USGS	U.S. Geological Survey
WERC	Western Ecological Research Center (USGS)
WTI	The Western Transportation Institute (Montana State university)

APPENDIX 6 List of Figures

APPENDIX 7 List of Tables