

Modifying Structures on Existing Roads to Enhance Wildlife Passage

10.1. Introduction to Retrofitting: Why and When to Modify Existing Structures

Our understanding of the impacts of roads on all wildlife (both large and small species) and on wildlife habitat has increased significantly over the last 25 years (Andrews 1990; Spellerberg 1998; Forman et al. 2003; Andrews et al. 2008). During this period, many wildlife crossing structures have been built on newly constructed roads and on existing roads when improvement projects have been warranted (Bissonette and Cramer 2008). Unfortunately, most of the existing road networks were constructed before this knowledge base had accumulated, and consequently, few measures were previously taken to mitigate for negative effects to wildlife. Forman (2000) estimated that at least 20% of the land area in the United States is directly affected ecologically by roads.

Over the last decade, opportunities to remedy impacts on small animals across existing road networks have emerged with increasing frequency. One means of mitigation is to “retrofit,” or modify existing structures originally designed for other purposes, such as cross drainage (i.e., allowing for movement of water from one side of the road to the other). Retrofit or retrofitting is defined as follows (Merriam-Webster 2013): “To furnish with or install new or modified materials or features not available or considered necessary at the time of construction; to adapt to a new purpose or need.” Some transportation departments consider installing new structures in an existing road a form of retrofit-

ting; however, in this chapter the term is limited to modifying existing structures.

10.1.1. Why Retrofit?

New wildlife crossing structures that are specifically designed for the species of interest and combined with fencing or barrier walls offer the greatest opportunity for mitigating the negative impacts of roads. Whether placed before or after the original construction of the road, their design and placement may involve a lengthy process and significant financial resources that may not be immediately available. However, where roads are already in place, retrofitting existing transportation infrastructure offers opportunities to reduce wildlife mortality and habitat fragmentation. In many cases, improvements to existing structures (those not initially intended for wildlife use) not only accommodate the movement needs of wildlife, but are publicly less controversial. This is because they typically cost much less than constructing new structures and can be completed in shorter time frames with less disruption to normal traffic flow.

Retrofitting an existing structure (e.g., culvert, bridge, or traffic interchange) to accommodate small animal passage is usually much cheaper than building a dedicated structure, but the amount of money that can be saved depends on (1) the type of retrofit needed; and (2) whether the modified existing structure is to be replaced in the near future, or simply extended as part of the road project. For example, a simple bolt-on shelf, such as those produced by Critter-Crossing Technology, LLC (Missoula, Montana, United States; Figure 10.1),



Figure 10.1. Installation of a bolt-on metal shelf, produced by Critter-Crossing Technology, LLC, for small animal passage within a drainage culvert, as shown by drawing (based on an actual image) of a short-tailed weasel (*Mustela erminea*) crossing the shelf (inset). Credits: Reproduced by permission of Kerry R. Foresman; © Victor Young Illustration (inset, adapted from original photo by Kerry R. Foresman).

can be installed in almost any existing structure with little modification, provided the structure's hydrologic function is not compromised. Larger shelves can only be cast into new structures before they are installed, so the existing structures must already be planned for replacement in order to realize any cost savings; this makes retrofitting a less cost-effective option. Retrofitting is not feasible in cases where a wildlife-appropriate design requires a bridge to be longer or higher or a culvert to be wider or higher; the only cost-effective approach to enhancing wildlife passage would be replacement of the existing structure.

10.1.2. When to Retrofit

A process to determine when retrofitting existing structures is a viable measure for improving habitat connectivity should include the following evaluations, made in this order: biological, structural, and cost-benefit. First,

a Rapid Assessment (Section 10.6.1) can be performed to determine whether a biological need is present at any existing structure location. Second, an evaluation of the ability of the existing structure to accommodate passage by the target species should be conducted. Finally, a cost-benefit analysis is necessary to determine if it is more cost effective to retrofit the existing structure or replace it with a new structure.

Retrofitting opportunities fall into three categories:

1. When barrier or mortality effects on small animals are chronic and so severe that it is inadvisable to wait for a full highway project to construct a wildlife-specific structure, retrofitting may be possible to minimize, at least temporarily, the negative effects in a much shorter time period.
2. When highway projects are in the planning stage, there are often opportunities to include lower-cost

retrofits of existing structures as part of the entire package.

3. When funding is not allocated for any existing road projects, but a structure is suitable for retrofitting to accommodate small animals, this can sometimes be accomplished as a stand-alone project; such a retrofit can be done at a lower cost than would be possible if the structure were replaced with a large animal wildlife passage.

10.2. Policies Supporting Retrofits

Few, if any, policies exist in the United States or Canada that are directly related to retrofitting existing structures. Two examples of programs that encourage retrofitting existing structures are in the states of Massachusetts and Washington. The Massachusetts Department of Transportation (MassDOT) has produced two documents that provide guidelines for mitigation: “Design of Bridges and Culverts for Wildlife Passage at Freshwater Streams” and “GreenDOT Implementation Plan.” Although neither refers to retrofits by name, they address the promotion of fish (and other aquatic organism) passage via maintenance and replacement of existing structures.

In Washington, an executive order signed by the state Secretary of Transportation in 2011 is the only policy measure that suggests support for work that has primarily ecological benefits. This order makes reference to priorities for maintaining and enhancing habitat connectivity. One important emphasis is restoration of fish passage in multiple jurisdictions, including retrofit projects throughout the state. In certain cases, measures that promote ecological infrastructure have been included. Although not specific to retrofits for terrestrial species, the policies are supportive and allow creative coupling of project elements to benefit both aquatic and terrestrial species.

10.3. Species Considerations

Small animals do not have the body size constraints of large animals. However, a number of factors are important in creating functional passages for small animals. Such factors include the biology of the species (Kintsch and Cramer 2011; Chapter 2) as well as the characteristics of the external environment (Section 10.4).

Differences in mobility are important for many small animals (Case Study 10.3.4). Other biological factors include the following, in order of general importance:

- Migration between seasonal habitats and breeding areas
- Access to suitable habitat and resources
- Establishment of new territories
- Avoidance of human pressures
- Predator avoidance and defense

10.3.1. Focal Species and Ecological Groups

Given that wildlife-crossing design considerations are highly dependent upon species-specific needs, the first step in designing or retrofitting crossing structures is to identify important focal species, or ecological groups (e.g., functional groups, Cavallaro et al. 2005; movement guilds, Case Study 10.3.4). Species whose movement paths are intersected by roads are highly susceptible to habitat fragmentation. These effects are further magnified when they involve species with federal or state threatened, endangered, sensitive, or other special status. There are existing models for species prioritization; for example, Lambeck (1997) developed a useful approach for species prioritization that involves categorizing focal species as area-, dispersal-, resource-, or process-limited.

10.3.2. Indicator, Umbrella, and Flagship Species

Indicator, umbrella, and flagship species are sometimes referred to collectively as “surrogate species” (Caro and O’Doherty 1999). Indicator species are important for evaluating levels of environmental degradation, population trends, and threats to biodiversity. Umbrella species have been used to determine minimum areal extent and habitat composition for conservation areas as well as for site selection of reserve networks (Roberge and Angelstam 2004). Flagship species have similar purposes to umbrella species, but are also important in raising public awareness for conservation (Caro and O’Doherty 1999).

As an example, umbrella species are those whose resource requirements are spatially broad; thus, they provide an umbrella of protection for many other species (Wilcox 1984; Noss and Cooperider 1994). One

major benefit of using umbrella species includes reducing the number of species that need to be monitored to gauge success, which translates into reductions in time and cost for evaluation and monitoring (Roberge and Angelstam 2004). A systematic process is recommended for setting goals and objectives and determining selection criteria for evaluating suitability of a candidate species or group as an effective umbrella species (Noss et al. 1996; Caro and O'Doherty 1999; Roberge and Angelstam 2004).

10.3.3. Addressing Specializations

There are many examples of mitigating effects for species with special requirements. It is important to identify key species of conservation interest that have specializations requiring uncommon mitigation planning measures. Two such examples in Florida include the federally threatened, endemic sand skink (*Plestiodon reynoldsi*), and the rare and endemic Florida scrub lizard (*Sceloporus woodi*). These species are both xeric-oriented species that prefer open (not vegetated), sandy areas exposed to full sunlight (Ashton and Ashton 1991; Branch et al. 2003). They are both limited in range and mobility so habitat fragmentation by roads is a serious concern. These requirements pose challenges to mitigation. A dark, cool, and moist culvert would likely not be suitable (P. Moler, Florida Fish and Wildlife Conservation Commission [retired], personal communication), and only existing tall bridges (generally not present in these habitat areas) would likely allow enough sunlight penetration to provide the warm soil conditions preferred by sand skinks. Management would have to include providing open, continuous pathways under the structure and on the approach areas. On low traffic volume roads, lighting grates could be imbedded in the pavement to allow light penetration inside existing culverts (Brehm 1989). The ideal mitigation measure for these species would be an overpass, ultimately an expensive solution.

Examples of other specialized needs would be certain small mammals requiring dense cover specific to their habitats. Thus far, designing underpasses or small culverts for small animal use has not included plant growth, which means these rodents will be less likely to use them. Culverts that allow light penetration and have soil as substrate and vegetation for cover, high open bridges, or overpasses vegetated with native

plants all facilitate natural ecosystem dynamics, enhancing small animal passage, invertebrate movement, and seed dispersal. Consideration of these specializations can be applied in road mitigation planning, including the determination of retrofit priorities.

10.3.4. Case Study: Small Animal Movement Guilds

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Lack of knowledge about species' ecology frequently stymies adequate consideration of species' movement needs. In this case, a lack of sufficient data often results in inaction or inadequate designs. Recognizing this problem, Kintsch and Cramer (2011) developed a "Species Movement Guild" classification. These guilds categorize wildlife based on their body size, mode of locomotion, and preferred crossing structure characteristics. These preferences are largely based on predator avoidance behaviors and the need for continuous habitat conditions through a crossing structure. The classification system facilitates an understanding of the influential features that render a structure functional or nonfunctional for different types of wildlife. Further, a classification approach allows transportation biologists to evaluate the physical and environmental conditions and potential constraints on movement from the perspective of groups of species.

The species movement guilds comprehensively address how wildlife use different types of structures to cross under and over roads, and allow any wildlife species to be categorized into one of eight classes—the three guilds that include small animals are presented below.

Low Mobility Fauna. This guild is based on smaller size, slower modes of movement, smaller home ranges, and the need for ambient conditions. Some frogs and salamanders are included in this guild because they need ambient conditions of light, moisture, and natural substrates (Jackson 1996). Crossings proven effective for amphibians are as short as possible and lined with soil (Jackson 1996; Aresco 2005a). Grates on top of these passages allow for ample light, rain, and air, thus mimicking local conditions (Brehm 1989), but the passages should also be situated to prevent flooding (Puky and Vogel 2004; Chapter 9). While distances between crossing structures should vary with site-specific habitat features and mitigation and planning objectives,

recent studies suggest approximately 60 m or less is best for amphibian and reptile use (e.g., Ryser and Grossenbacher 1989; Jackson 2003). Specific types of fencing are necessary to guide these animals to these passages (e.g., Dodd et al. 2004; Aresco 2005a; Pepper et al. 2006).

Moderate Mobility Fauna. This guild includes small- to medium-sized mammals, snakes, and some salamanders and turtles that are fairly adaptable to a variety of structure types. Foresman (2004) found these animals could move under roads on metal shelves placed inside smaller culverts. McDonald and St. Clair (2004) found that small mammals had much higher success moving through shorter rather than longer structures. Also, a lack of natural vegetative cover at the approaches to crossing structures limited use among small mammals. Overall, these animals crossed more readily in culverts that were shorter in length (approximately 90 m or less), had vegetation close to the openings, were free of water year-round, or included a shelf structure above the water level to facilitate movement.

High Mobility Fauna. This guild is comprised of medium-sized mammals and large reptiles that are naturally accustomed to enclosed spaces and are somewhat tolerant of more enclosed underpasses. Examples of this group include bobcat (*Lynx rufus*), gray fox (*Urocyon cinereoargenteus*), Canada lynx (*Lynx canadensis*), North American river otter (*Lontra canadensis*), and American alligators (*Alligator mississippiensis*). Bobcats will use existing crossing structures (Ng et al. 2004), although in some cases they are less prone to using them and prefer to cross roads at grade, even when fences are present (Cain et al. 2003). While Cain et al. (2003) found bobcats using more open structures in southern Texas, Smith (2003b) recorded passage use by fox, coyote (*Canis latrans*), and bobcat through several medium-sized box culverts (2.4 to 3.1 m wide, 1.5 to 1.8 m high) under two-lane roads in Florida. River otters, American alligators, and cottonmouths (*Agkistrodon piscivorus*) used box culverts (1.8 m wide $\times$ 1.8 m high) to cross under a four-lane highway in Florida (Barichovich and Dodd 2002).

10.4. Habitat Considerations

In addition to considering species biology and vagility, it is most important to determine the habitats on

which they rely, and therefore the highest priority locations for retrofitting. Additional considerations should include environmental factors such as the range in temperature and moisture associated with particular habitats important for target species groups. In lieu of performing field-based assessments of species presence, habitat or ecosystem characteristics can be used to predict presence (Chapter 8). Species or habitat information can then be used to determine both priority locations for retrofitting and the design of the structures and approach areas; these determinations should mimic the conditions of the adjacent habitat and improve functionality for the target species. Further discussion of how to prioritize locations for retrofitting can be found in Chapter 8.

10.5. Structural Retrofit Considerations

Ideally, retrofitting should only occur as a function of adaptive management following the proactive design and construction of appropriate features intended to address ecological infrastructure. In other words, retrofitting is done to further enhance existing features that minimize road impacts. The process of identifying retrofitting opportunities to enhance wildlife passage should include (1) selecting the target species or group and confirming their presence, (2) having a basic understanding of the structure and site characteristics that may enhance usage by the particular target species or group at any given location (see also Chapter 9), (3) developing an inventory and conducting evaluations of existing structures, and (4) determining feasibility of applicable solutions and devising a retrofitting strategy. Generally, there are two ways to retrofit existing structures: external or internal enhancements to structures (Sections 10.5.1 and 10.5.2).

10.5.1. External Enhancements to Structures

Several enhancements can be made external to the structure to improve suitability and function of that structure (Table 10.1; see also Friedman 1997; Smith 2003b; Pepper et al. 2006; Smith 2011; Smith and Noss 2011). In general, these enhancements should act as elements of the natural habitat that would have been present before the road was in place. When incorporating any of the features described in Table 10.1 into a project, maintenance needs should also be included in

Table 10.1. Guidance for, and benefits of, external enhancements to structures to improve suitability and function

Enhancement	Guidance	Benefits
Soil	Replace roadbed aggregate with topsoil typical of the adjacent habitat. Use topsoil from the existing location if possible; otherwise use similar soil additives to improve soil quality.	Fosters growth of vegetation similar to adjacent habitat areas. Increases suitability for species that prefer vegetative cover or move below the soil surface. Using local soil sources minimizes introduction of invasive species.
Contouring	Lessen the gradient of severe slopes. Reshape and smooth overly rugged terrain adjacent to the passage entrance.	Creates a natural funnel toward the structure. Enhances animals' ability to move toward and find the entrance.
Drainage	Contour approach areas to direct stormwater away from the road and the structure (special structural features to reduce flow rates and direction may be necessary along with native plantings). Replace adjacent roadway drainage swales with soil-covered culverts and native plantings to provide continuous dry access (see Figure 10.2).	Eliminates accumulation of stormwater and prevents creation of depression pools or flooding within the structure, and reduces erosion (which may reduce maintenance costs). Enhances use by species hesitant to cross areas inundated by water.
Natural cover materials	Add natural materials in approach areas typical of the adjacent habitat—for example, stumps, logs or brush-piles, bark, leaf litter, or rocks. Plant native vegetation, including appropriate groundcover, shrub, and tree species (see Figure 10.3).	Encourages use by species that prefer cover and those that are susceptible to desiccation from light or temperature extremes. Reduces exposure to predators.
Screening	Use hedgerows or densely planted shrubs, or artificial materials such as walls or opaque fencing to separate or buffer the structure and approach areas from the road.	Reduces visual impact of the road and improves suitability for species sensitive to noise and lights from highway traffic.
Fencing	Add directional fencing to guide small animals to structure entrances (Section 9.7.2; see also Table 10.2). Important factors include the following: 1. height of the fence (based on jumping and climbing abilities of the target species or group); 2. characteristics of the material used to block access (e.g., level of transparency, mesh size); 3. presence of a “lip” or angled-in top edge (to prevent animals from climbing over); 4. depth that the fence is buried (to prevent the target species from tunneling under); and 5. material longevity (affects maintenance and replacement costs).	Increases use of the structure and prevents access to the road by small animals. May reduce visual impact of the road.

the budget to adaptively manage the needs of the target species (or those species benefitting the most from the structure). Specifically, many of these features may require replacement, supplementation, or continued maintenance on an annual, or seasonal, basis. More detail about maintenance considerations is provided in Chapter 11, and adaptive management options with respect to post-construction monitoring are provided in Chapter 12.

Fence materials are discussed in Table 10.2 (see also Sections 9.2.5 and 9.7.2); of these, all can trap snow or debris and eventually impede flow of stormwater if placed in inappropriate locations or not maintained.

Further, all require periodic maintenance to remove vegetation, thus preventing animals from climbing over the fence. These materials are easily climbable for treefrogs and most lizards (with the exception of aluminum flashing for lizards). To maximize effectiveness, fencing should be at least 90 cm above ground and 30 cm below ground.

The most cost-effective of these materials is 0.25 in (0.65 cm) metal mesh (Smith and Noss 2011). Specifically, hot-dipped, galvanized metal mesh of at least 23-gauge and with at least 29% weight in zinc is among the best for longevity, durability, and low maintenance; it allows stormwater penetration and prevents most

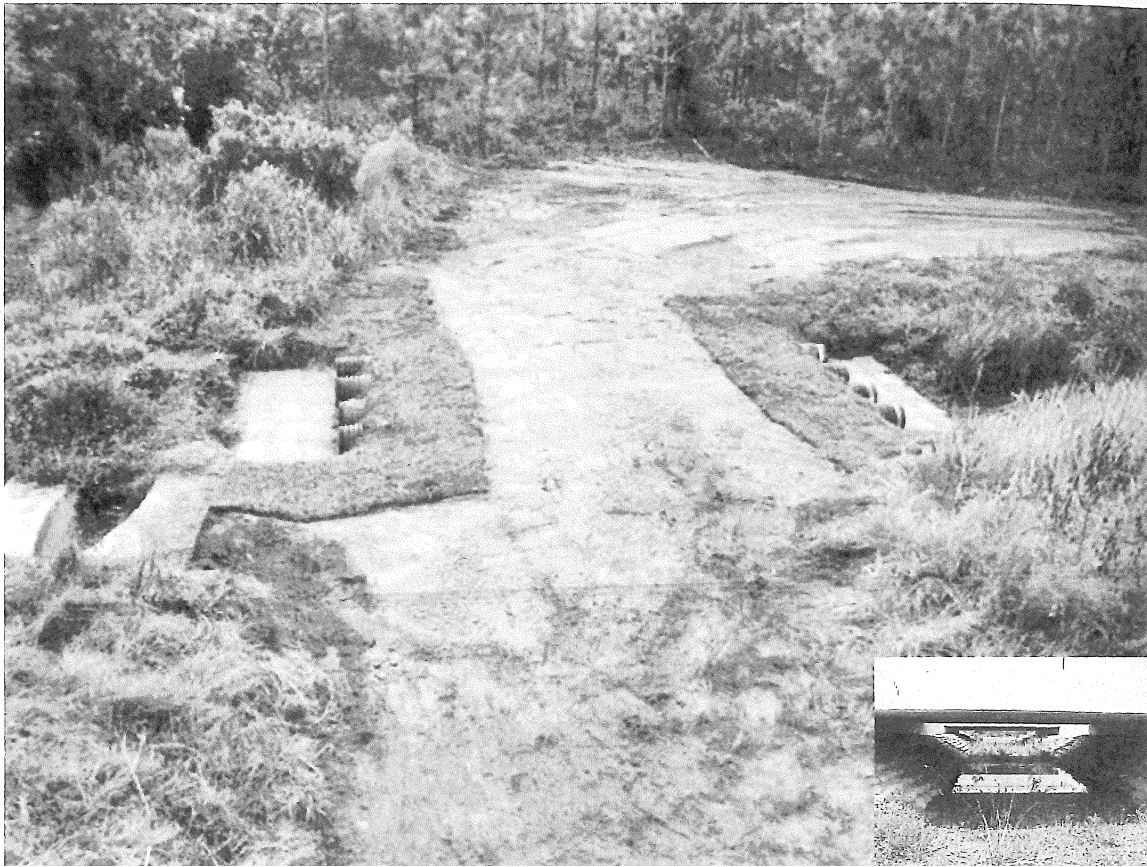


Figure 10.2. An example of creation of a land bridge over a swale and re-contouring of approach area to improve access, facilitate drainage, and reduce pooling within the passage (inset). *Credits: Daniel J. Smith.*

animals from trespassing and climbing. Its primary limitation is that it does allow for the visual impact of the road. Some species (e.g., frogs, salamanders, turtles, snakes) may be negatively affected by this characteristic. Aluminum flashing is the most effective biologically, but is cost prohibitive and potentially may cause significant stormwater drainage issues or flooding on the road.

10.5.2. Internal Enhancements to Structures

There are several enhancements associated with modifying a structure that can improve suitability and function (Table 10.3; see also Krikowski 1989; Langton 1989; Jackson 1996; Friedman 1997; Iuell et al. 2003; Smith 2003b; Foresman 2004; Aresco 2005a; Righetti et al. 2008; Smith 2011; Smith and Noss 2011; Trocmé and Righetti 2012; Yorks et al. 2012). All characteris-

tics should be designed according to a target species' or group's physiological and ecological needs and preferences. Further, because each potential structure available for modification will vary with respect to surrounding ecological infrastructure, customized structure designs and maintenance regimes should be incorporated into the construction contract (Chapter 11).

10.6. Site-Based Assessments

Field assessments of potential modifications to existing infrastructure can be conducted well in advance of transportation planning schedules. This proactive evaluation allows planners to address ecological infrastructure considerations in retrofit project designs and budgets. In addition, such assessments may reveal small



Figure 10.3. Planting of native trees, shrubs, and ground cover can enhance suitability of approach areas to crossing structures. *Credit: Daniel J. Smith.*

modifications (Tables 10.1 and 10.3) that can be made outside of major construction project planning as part of ongoing operations and maintenance (Chapter 11).

Typically, these assessments are conducted as needed on a project-by-project basis, are rarely standardized, comprehensive, or transparent, and often only focus on large species. Recent years have seen a shift toward evaluating existing infrastructure in a more systematic manner. In Colorado, a three-year study of Interstate 70 developed a basic framework for evaluating wildlife passage at existing bridges and culverts (Kintsch and Cramer 2011). MassDOT (2010) published a report that presents considerations for evaluating existing structures at freshwater streams and offers best practices for accommodating wildlife passage at these road-stream crossings. However, while these contributions are valuable, a comprehensive

methodology is still needed for evaluating how various structure and landscape characteristics promote or inhibit passage with specific consideration of the varying needs of different species.

10.6.1. Rapid Assessments

If cost and time are significant limiting factors, a Rapid Assessment process can be a practical and effective approach (Chapters 6 and 8; see <http://www.rapidassessment.net> for additional information). This is a collaborative process that may involve a diverse group of public and private stakeholders or experts from a single consulting firm; they typically review existing data and information on the project site. They then use this information as well as local knowledge to form professional opinions on species and habitats affected, identify ecological hotspots, and develop

Table 10.2. Pros and cons of different directional and barrier fencing materials for small animals (see also Sections 9.2.5 and 9.7.2), including engineering and maintenance considerations for various temporary or permanent retrofit options

Material	Pros	Cons
Aluminum flashing	Does not allow trespass Small animals cannot climb Opaque, negligible visual impact of road to animals Longevity—20+ yrs High durability, little long-term maintenance	Prevents normal stormwater flow, trapping runoff and potentially causing flooding on the roadway Increased visual impact to residents and drivers Most expensive material
Shade cloth	Prevents most trespass Few small animals can climb Minimal visual impact of road to animals Longevity—10 to 15 years Least expensive material	Severely impedes normal stormwater flow, trapping runoff and potentially causing flooding on the road Increased visual impact to residents and drivers Durability is poor, subject to damage from maintenance equipment, may require frequent repairs for tears or holes Requires rigid backing for support, such as wire fencing which increases initial costs
Superscreen™	Prevents most trespass Few small animals can climb Minimal visual impact of road to small animals Longevity—10 to 20 years Moderate material cost	Severely impedes normal stormwater flow, trapping runoff and potentially causing flooding on the roadway Increased visual impact to residents and drivers Durability is poor, subject to damage from maintenance equipment, may require frequent repairs for tears or holes Requires rigid backing for support, such as wire fencing, which increases initial costs
0.65 cm (0.25 in) plastic mesh	Very little trespass Few small animals can climb Allows stormwater flow through Some visual impact to residents and drivers Less expensive than most other fencing materials presented in this table (exception is shade cloth) Moderate material cost	Increased visual impact of road to small animals Longevity—only 5 to 7 years due to weakening from sunlight exposure Moderate durability, may be damaged by maintenance equipment and may require repairs to perforations Requires rigid backing for support such as wire fencing, which increases initial costs
0.65 cm (0.25 in) metal mesh*	Very little trespass Few small animals can climb Pliable, allows manipulation to create an extended lip or angled edge to deter climbing and jumping Allows stormwater flow-through Some visual impact to residents or drivers Longevity— +20 years High durability, little long-term maintenance required Moderate material cost	Increased visual impact of road to small animals
1.25 cm (0.5 in) metal mesh*	Pliable, allows manipulation to create an extended lip or angled edge to deter climbing and jumping Allows stormwater flow through Reduced visual impact to residents or drivers Longevity— +20 years High durability, little long-term maintenance required Moderate material cost	Allows frequent trespass for many species Easy for many small animals to climb, including some species of turtles Some entanglement issues for small snakes that may partially fit through the openings (see also Box 11.1) Increased visual impact of road to small animals

* Metal mesh materials specifically refer to hot-dipped, galvanized metal mesh (sometimes called “hardware cloth”) that is at least 23 gauge and at least 29% weight in zinc.

Table 10.3. Guidance for, and benefits of, internal enhancements to structures

Enhancement	Guidance	Benefits
Shelves (Culverts)	For culverts associated with streams, wetlands, lakes, or other water features that may be seasonally or permanently inundated, add shelving (e.g., hanging metal, Figure 10.1) above the high water line. Ensure vertical clearance above the shelf is sufficient for use by the target species. For arboreal species, an elevated bolt-on shelf within the culvert may be useful as a walkway.	Encourages passage by terrestrial species in structures designed for conveyance of water.
Ledges (Bridges)	Arrange (or rearrange) bank and structure stabilization or scour prevention materials (e.g., large rocks or rubble riprap, gabions [wire baskets filled with rocks]) to create a clear, level pathway or ledge. Earthen ledges may require retaining walls made of concrete, soil-cement, or geotextile material to protect against erosion or destabilization. Ledge substrate should consist of aggregate bedding materials of variable size mixed with soil or pavement blocks filled with soil or bedding materials (i.e., materials resistant to erosion).	Creates a dry pathway above the high water line under structures that span water features (e.g., rivers or creeks) and encourages passage by terrestrial species. Proper arrangement (or rearrangement) of materials will prevent the inadvertent barrier to species that prefer smooth surfaces (Figure 10.4).
Soil substrate	Use native soils as the substrate within the structure. Consider the soil type in the surrounding habitat along with moisture needs of target species when determining soil type to place inside the structure. Maintain soil depth based on needs of target species, particularly fossorial (burrowing) species.	Increases small animal passage by providing a more natural and continuous surface throughout the passage. Use of appropriate soil types and soil depths can ensure proper moisture retention, which in turn will encourage species passage based on moisture or dryness needs. Use of native soils can also facilitate growth of native plants, which provides cover and forage for many small animals.
Rocks, debris, and tubes	Include rocks or woody debris along the walls of the structure. Use metal or PVC tubes (along the base of the wall) covered by rocks or woody debris to provide a concealed movement pathway for small mammals.	Rocks and woody debris encourage passage by those species that require cover or protection from predators. Tubes provide additional cover as well as a means of escape from predators for many herpetofauna and small mammals.
Lighting	Provide natural lighting (via grates or fiber-optic solar technology, see also Section 9.5.2) within the structure, particularly in longer passages (e.g., multi-lane divided highways). Place culvert lighting grates, when situated in medians of divided highways, on the upslope of median swales or raised slightly above grade if placed at the lowest elevation (to reduce stormwater flow into the structure).	Species that are deterred by darkness, or diurnal species, may be more likely to pass through structures with some lighting. Use of natural light via grates requires less maintenance than use of man-made lighting technology. Grates placed above grade can help minimize stormwater flow into the structure, thereby reducing erosion or washout of substrate within the structure and reducing animal exposure to runoff pollutants.
Removal of obstructions	Selectively remove or thin vegetation near structure entrances, or within structures, where it may have become too dense and may be obscuring the opening or preventing animal passage. Remove other obstructions, such as fence material or storm-washed debris, at the entrance of, or within, the structure.	Increases likelihood of passage for small animals, particularly those that are deterred by low visibility conditions created by dense vegetation. Increases visibility of and access to the structure entrance.

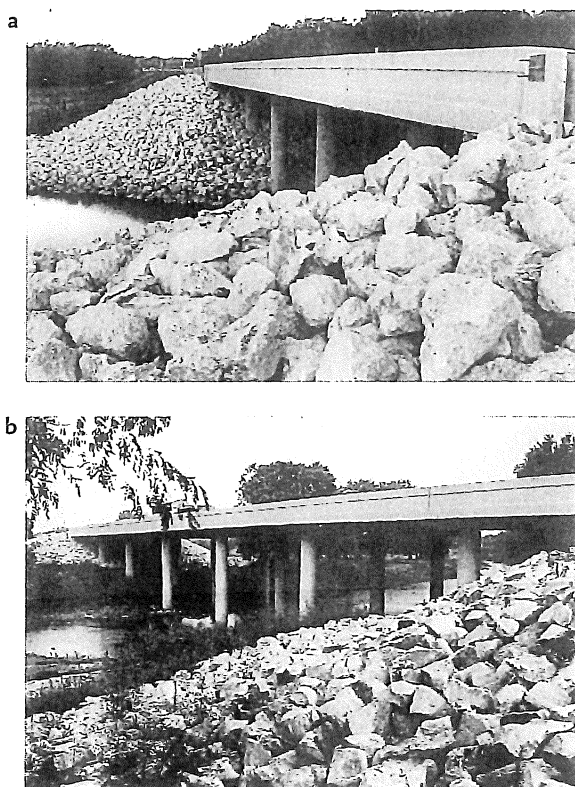


Figure 10.4. Examples of improper (a) and proper (b) placement of riprap to allow terrestrial wildlife movement adjacent to waterways. Credit: Daniel J. Smith.

recommendations for retrofit needs (see Table 3.1 in Cavallaro et al. 2005 for an example). Additional details are provided in Box 10.1. Participants should strive to keep the process simple and include only what is necessary to solve the problem in a timely and cost-efficient manner (Chapter 6).

10.6.2. System-Wide Facility Evaluations

Transportation agencies can use system-wide facility evaluations to conduct more effective mitigation planning. By proactively evaluating existing structures over an entire or partial road network, the agency has the information necessary to easily incorporate retrofits or new mitigation measures into proposed road improvement projects. These assessments are another example of the type of information that is especially important to introduce early in the transportation planning process (Chapter 6). System-wide facility evaluations may be particularly relevant in regions

Box 10.1. RAPID ASSESSMENT TO RETROFIT FOR FISH PASSAGE

In the northern Rockies, aquatic biologists developed a protocol for assessing fish passage through existing culverts (Ruediger and Lloyd 2003; Box 6.1). The process was designed to (1) determine if the existing culvert was a barrier to fish passage, and (2) prioritize the need for retrofitting (i.e., replacement with a more appropriately designed culvert) among the hundreds to thousands of other culverts needing replacement. In this case, a low-cost Rapid Assessment was possible because ample information had been collected on fish-culvert priorities for this area over the past 40 years. The cost was significantly less because few new field assessments were necessary due to this existing knowledge base. Each new field assessment cost about \$3,000 per culvert.

with high stream densities (e.g., Pacific Northwest; Box 10.2), or where wetland systems are extensive (e.g., southeastern United States) and high densities of herpetofauna and numerous water conveyance structures exist.

10.6.3. Case Study: Florida DOT Statewide Inventory and Prioritization Project

Daniel J. Smith

A systematic approach used in Florida combined modeling and field site assessments (Smith 1999, 2003a, 2006) to identify and prioritize areas where the existing road network compromised ecological infrastructure (see Chapter 8 and references therein). Specifically, chronic roadkill sites, focal species hotspots, greenway linkages, presence of listed species, and strategic habitat conservation areas (a designation identified by the Florida Fish and Wildlife Conservation Commission to indicate the likely occurrence of suitable habitat for certain species that may be required to maintain viable populations) strongly influenced modeling results. Over 15,000 road segments were prioritized; 81% were located in conservation areas or designated greenways. Ninety-five scheduled road construction projects coincided with modeled high-priority road segments and

Box 10.2. WASHINGTON STATE PASSAGE ASSESSMENT SYSTEM

In the State of Washington, an assessment methodology, called the Passage Assessment System (PAS), was developed to assist in the evaluation of existing bridges and culverts and identification of potential retrofit measures that would enhance the structures' ability to function as wildlife passages (Kintsch and Cramer 2011). The PAS guides users through a series of standardized evaluation questions; these include questions about a number of variables that influence the likelihood of successful passage. Methods for assessing how different crossing characteristics may affect various species are also provided. The PAS may be adapted to any location and is intended for use by ecologists and biologists familiar with local wildlife needs and transportation infrastructure and planning. It provides an objective tool to determine if structures are suitable for retrofits to improve their functionality as wildlife passages or, if no such retrofits are appropriate, to identify structure replacement options for improved ecological infrastructure.

thus presented opportunities for addressing ecological infrastructure.

Field site assessments were conducted to (1) verify accuracy of modeling results, (2) characterize ecological conditions of road segments identified in the prioritization model, and (3) evaluate wildlife-passage functions of existing structures and provide recommendations for mitigation and restoration. The model correctly predicted areas where ecological infrastructure was compromised 87% of the time. Based on the field assessments, recommended mitigation measures ranged from installation of passage structures to minor measures. These minor measures included signage, speed restriction, fencing, landscaping, and re-contouring of approach areas to encourage use of existing drainage structures.

Finally, monitoring was conducted to determine the capacity of existing highway drainage structures to function as wildlife passages (Smith 2003b). Fifty-five

Table 10.4. Thresholds for size of existing drainage culverts based on 90% vs. 60% of detections of herpetofauna and small mammals (Smith 2003b). Culverts in the study ranged in width from 61–610 cm, in length from 8–61 m, and in height from 30–365 cm

Thresholds: 90% (upper), 60% (lower)	Herpetofauna (n = 580)	Small mammals (n = 270)
openness index value ($w \times h / l$), m	0.28 0.23	0.42 0.08
width, m	3.4 2.7	3.1 1.5
length, m	11.6 14.5	11.6 18.3
height, m	1.5 1.4	1.5 1.2

Note: Herpetofauna and small mammal groups included certain species that frequented culverts as part of their home range rather than solely as movement corridors.

different species and taxonomic groups (from 36,870 individual records) were identified using 67 bridges and 223 culverts on 37 different roads of varying traffic levels and road widths; these were represented in 7 general landscape types. Analyses suggested that culvert width and height were important, and use by herpetofauna and small mammals generally increased as the dimensions increased. However, culvert length, distance between adjacent structures, and road verge width (i.e., distance to the habitat) had the opposite effect, so that use by these animals decreased as these dimensions increased (Smith 2003b). The results also suggested that use of structures decreased as frequency of human presence or domestic predator presence surrounding the mitigation site increased. Thresholds for faunal use (Tables 10.4 and 10.5) were suggested by the results, and these were then used to identify opportunities and make recommendations for retrofitting existing structures, such as adding fencing, restoring local plant communities and landscape features, screening of traffic noise and lights, and restricting access by humans and domestic predators.

10.7. Applying Retrofitting Solutions

Once a structure is determined to be a candidate for retrofitting to enhance wildlife passage, the next step is

Table 10.5. Thresholds for other parameters associated with existing drainage culverts based on 90% versus 60% of detections of herpetofauna and small mammals (Smith 2003b)

Thresholds: 90% (upper), 60% (lower)	Herpetofauna (n = 1,428)	Small mammals (n = 888)
distance to habitat (road verge width), m	3.7 7.8	3.7 7.9
distance between adjacent structures, m	260 875	250 585
human presence, no./yr	3 46	1 46
domestic predators, no./yr	1 1	1 20

to determine how to do this. Given variable objectives, and the unique characteristics of every structure and site, there is no simple answer. An array of possible retrofits can be implemented at existing culvert locations to promote passage by different species. Kintsch and Cramer (2011) initiated a database of retrofit options, largely focusing on options for larger species that also included a number of ideas for enhancing structures for small mammals and herpetofauna. This living database is a useful resource for practitioners seeking to learn from similar efforts in other locations. Other syntheses and compilations of solutions that address small mammals and herpetofauna include Iuell et al. (2003), SETRA (2005), van der Ree et al. (2007, 2015), and Proceedings of the International Conference of Ecology and Transportation (<http://www.icoet.net/>), and this book.

These resources provide a number of enhancement options for commonly encountered situations. For example, at a location with a culvert that conveys water but could also be used by smaller animals, shelves can be installed inside the culvert to facilitate wildlife movement above the flow of water (Figure 10.1; Table 10.3). Simply adding guide walls may suffice in guiding fauna toward an existing culvert (Table 10.1). Other enhancements focus on maintenance efforts, such as clearing debris and installing a sediment trap, modifying the drainage system, or restoring a perched culvert (Chapter 11). Still others may involve enhancing native vegetation in the approaches or installing

woody debris throughout the culvert to provide cover for small species (Tables 10.1 and 10.3). For example, Connolly-Newman and authors (2013) found that including dead tree branches in underpasses increased use by small mammals by almost 43%. As no two situations are identical, practitioners are encouraged to consider the range of possible enhancements and how they may be implemented and adapted for a given site.

Following any retrofit application, targeted monitoring of such enhancements is important. Monitoring can help determine whether adjustments are needed as part of an adaptive management process (Chapter 12). This, in turn, will create a positive feedback loop for designing improved enhancements at future locations (Section 12.7).

10.7.1. Temporary versus Permanent Measures

In some cases it may be appropriate to initiate temporary measures. As implementation of permanent measures can take considerable time, temporary measures can be taken to partially alleviate the impact and generate the necessary support from the public and transportation agencies (Box 10.3). This may include erecting a temporary barrier to prevent roadkill, imposing temporary road closures during migration periods, and using volunteers to move animals from one side of the road to the other (e.g., bucket brigades, Chapter 9).

Where some of these measures may be suitable on a longer-term basis on unpaved roads or those with very low traffic, they still require continued maintenance and constant participation by volunteers. On paved roads with moderate to high traffic, these are not ideal solutions to the problem and even moderate traffic levels can limit their effectiveness. More permanent, low-maintenance solutions are more appropriate for the long term, even where traffic levels are moderate.

10.8. Applying Retrofits to Single Sites, Single Roads, and Road Networks

10.8.1. Case Study: Single Site—Turtle Use of Retrofitted Culverts in an Urban Setting in Ontario, Canada

Brennan Caverhill

Seven of eight native turtle species in Ontario are at risk of extinction, primarily due to habitat loss and

Box 10.3. LAKE JACKSON

Aresco (2005a) studied the impact of traffic on turtles attempting to cross US 27, a four-lane highway that bisects Lake Jackson, Florida, United States. This mortality was so extensive (e.g., 343 turtles along 700 m of road in 40 days) that turtles could not successfully cross all four lanes of the highway. This decreased probability of crossing success was validated through a model developed by Hels and Buchwald (2001) that indicated less than 2% success based on crossing speed of the animal and traffic volume (Aresco 2005a).

A temporary drift fence system was installed to lead turtles to an existing cross-drainage culvert while Aresco and a supportive public lobbied the state for a permanent structure. The drift fence was 0.61 m (2 ft) high and made from woven vinyl erosion-control material typically used in construction projects. The fence was buried to prevent animals from burrowing under.

In 3 years, over 8,800 turtles were recorded either attempting to cross the road or along the temporary drift fences. Prior to installation of the fence, turtle mortality was approximately 12/km/day. Following installation of the fence, turtle mortality was approximately 0.1/km/day.

The use of frequently (daily or more) monitored, temporary drift fences greatly reduced roadkills and enhanced habitat connectivity through the use of a cross-drainage culvert. This study presented the highest attempted road-crossing rate (1,263/km/year) published to date for turtles and was one of the first to document male-biased sex ratios adjacent to the road as a consequence of hundreds of reproductive adult females being lost from the population due to road mortality (Aresco 2005b).

Despite the incredible level of mortality observed, it took over 10 years for advocates to gain the political and financial support for the project. Because of lesser concern for human safety and economic damage, in many cases, road mitigation projects with small vertebrates do not take place without political pressure and public support. Lake Jackson represents one of the greatest successes in applying retrofits to reptiles. Additionally, it demonstrates the tremendous effort required to educate public officials and taxpayers on the value of incorporating ecological infrastructure for small animals in transportation projects.

road mortality (Ireland and Karch 2010). Situated in the Greater Golden Horseshoe area with more than 5 million people, provincial Highway 24 carries more than 400 vehicles/hour, as determined in 2011 Traffic Inventory Counts by the Ontario Ministry of Transportation (MTO); the highway also bisects several wetlands that comprise important turtle habitat. In April 2008, a concerned citizen reported to the Toronto Zoo's Ontario Turtle Tally program eight dead-on-road Blanding's turtles (*Emydoidea blandingii*) and two snapping turtles (*Chelydra serpentina*), both at-risk species, at a single location on this highway. After field visits by the Toronto Zoo and MTO, a 25 m long, 1.8 m diameter corrugated steel drainage culvert was found at the swamp-creek crossing where turtles were found dead on the road. In August 2008, MTO installed temporary silt fencing extending approximately 75 m in both directions from the culvert along both sides of the

road. Following this installation, no turtle mortalities occurred at the site in 2009, so a permanent chain link fence was installed in March 2010 with the goal of continuing to prevent turtle-vehicle collisions by guiding animals to the culvert.

From April 2010 to October 2011, researchers from the Toronto Zoo's Adopt-A-Pond Wetland Conservation Programme used visual surveys, radio tracking, and live trapping to study resident turtle populations and their response to the retrofitted culvert. Data from the 19 radio-tagged Blanding's turtles showed 70 road crossings where each individual crossed 1–17 times. Researchers observed these turtles traveling through the retrofitted culvert at least 15 times. Based on the Gibbs and Shriver (2002) model, the probability of turtles being killed by crossing on the road was 93%. Because no roadkills were documented, it was assumed that all other crossings occurred through the aquatic culvert.

Further observations of the turtles indicated that the fence successfully prevented their access to the road.

Although researchers also observed (directly as well as via images from a remote camera installed near the mouth of the culvert) other wildlife including fish, amphibians, birds, and mammals using the retrofitted culvert, the chain link guide fence was not successful in preventing all animals from accessing the road. For example, daily road surveys in 2010 along the approximately 200 m stretch of road spanning the culvert resulted in observations of 76 individuals from 11 vertebrate species (mostly frogs, birds, and mammals) found dead in the study area. Monitoring is ongoing for this project. Funding was generously provided by the Toronto Zoo, Environment Canada's Habitat Stewardship Fund, the Ontario Ministry of Natural Resources' Species at Risk Stewardship Fund, MTO, and the Ontario Road Ecology Group.

10.8.2. Case Study: Single Road—The Effect of Retrofits on Habitat Connectivity at Paynes Prairie, Florida, United States

Daniel J. Smith

High numbers of roadkill herpetofauna were recorded over several decades on US 441 (a 4-lane divided highway) that bisects Paynes Prairie State Preserve (a 5,000 ha freshwater marsh) in north-central Florida, United States. After much pressure from citizens, park staff, and local elected officials to institute mitigation measures, the Florida Department of Transportation (FDOT) developed plans in 1996 to construct a system of culverts and guide walls to improve habitat connectivity and reduce wildlife mortality (Dodd et al. 2004). This project was the first mitigation project in the United States driven by large numbers of herpetofauna being killed, many of which were snakes. Prior to construction of the passages and fencing, the site had the highest documented level of persistent snake mortality. It is an example of using existing structures and complementing them with new features to improve overall performance.

The system of culverts and guide walls (Figure 10.5) is a designed retrofit that includes (1) the use of four existing concrete box culverts (two are 1.8×1.8 m, located at higher elevations toward the perimeter of the basin and two are 2.4×2.4 m, located at lower elevations toward the center of the basin); (2) the addition



Figure 10.5. The Paynes Prairie wall and culvert passage system, Florida, United States. Credit: Daniel J. Smith.

of four concrete round pipe culverts (0.9 m wide each, placed between each of the existing 2.4×2.4 m box culverts); and (3) a concrete guide wall extending through the length of the basin (approximately 2.5 km) that is 1.1 m high with a 15.2 cm lip at the top that extends out away from the road to help prevent small animal from climbing over (Dodd et al. 2004). The culverts are 44 m in length and spaced 200–300 m apart (with 2 separated by 400–500 m) across the basin.

Prior to construction, 2,411 roadkills were recorded over the course of 1 year (12 months); following construction, only 158 animals were counted, again over 12 months (excluding hylid treefrogs, whose roadkill counts increased post-construction given their ability to climb over the guide wall; Smith and Dodd 2003; Dodd et al. 2004). Within the prairie basin, mortality was reduced by 93.5% (65% when hylids were included). Almost 66.6% of the post-construction roadkills occurred at gaps where the barrier wall was absent to allow access to private properties. Of the 1,891 vertebrate roadkills recorded in the post-construction survey (excluding hylids), 73% occurred in the habitat-transitional (ecotones) areas and adjacent uplands beyond the terminus of the guide wall.

Pre- and post-construction monitoring were conducted to evaluate change in use of the culverts by wildlife (Dodd et al. 2004). Only 28 vertebrate species were found in the 4 culverts prior to construction, while 42 vertebrates (excluding fish) were recorded in the 8 culverts following construction. Use of culverts increased from 5 amphibian species to 13 following construction.

Overall, the retrofits demonstrated significant improvement over pre-construction conditions, dramatically reducing road mortality and increasing wildlife use of culverts.

However, several problems emerged, some of which were able to be addressed, while others were not. The fencing created a tourist attraction for people to observe wildlife, which resulted in a safety hazard due to the feeding of alligators. Fencing was added to separate the public from alligators in the adjacent wetlands. Road mortality continued and even increased at gaps at access roads and along adjacent private land. Siltation and pooling of water occurred in the culverts and could be an issue for terrestrial animals. Additionally, growth of vegetation on the wall facilitated movement over the wall by treefrogs and other climbing species. The issue with trespass by arboreal species is a pervasive one with current road mitigation designs. Solutions to this problem may include use of other materials that prevent climbing or use of other crossing structures designed for arboreal species such as treefrogs (Chapter 9). Most of the climbing issues at Paynes Prairie were addressed with scheduled maintenance operations (e.g., more frequent mowing or vegetation removal along or near the guide wall) and certain design modifications (e.g., a 30.5 cm wide strip of aluminum flashing along the top edge of the wall at an upward 45 degree angle toward the habitat side). While improved design features are needed to increase the breadth of effectiveness, no single or suite of mitigation features works for all wildlife species in a given location. Paynes Prairie is particularly notable for (1) being the first retrofitting project in the United States that targeted a small animal wildlife community and involved such extensive construction, (2) its success in reducing mortality and increasing connectivity in that location, and (3) serving as a model for other retrofit projects.

10.8.3. Case Study: Road Network-Adaptive Management Associated with Retrofits on Two Major Road Corridors in Central Florida, United States

Stephen Tonjes and Daniel J. Smith

In 2004, data collection began for a study of 13 wildlife crossings in central Florida, United States; this was commissioned by the FDOT. Two major roads in rural areas, consisting mostly of natural and range lands,

were upgraded from two to four lanes. Rather than constructing large dedicated crossings, the wildlife agencies concurred with retrofitting several of the existing water conveyance structures with wildlife ledges during scheduled highway widening.

Following construction, researchers quickly discovered significant functional problems with the design and construction of many of these structures. Numerous species (particularly herpetofauna) continued to be killed on the road, and passage use by terrestrial species was significantly less than expected. As a result, FDOT established a Wildlife Crossing Design Team (WCDT) to evaluate and devise corrections that addressed the deficiencies. These improvements required additional funding through a separate design project. Rather than waiting for formal plan review, the WCDT and the project manager met several times, including on the site, during both design and permitting. An unfavorable permitting review initiated another round of adaptive management meetings. Because of the flexibility of the WCDT, the permitting setback was quickly resolved with a much less expensive and more functional design.

Five structures were programmed for modifications to improve their function, which included two culverts (one with shelves, one without) and three bridges with ledges. Modifications to the culverts included replacement of temporary wooden ramps with permanent concrete ramps (Figure 10.6), rehabilitation of the median lighting grate, and addition of an earthen bridge over a drainage swale. Two bridges required removal and rearrangement of riprap (Figure 10.7) and construction of ledges made of soil and bedding stone aggregate. Efforts at the other bridge included addressing erosion problems, filling gaps within submerged wire-basket gabions to prevent ensnaring aquatic turtles, and the addition of PVC tubes to provide covered pathways through lengthy open areas for small mammals. All five structures included additions to existing directional and barrier fencing for herpetofauna, including the installation of 1.2 m high, 0.635 cm mesh, galvanized hardware cloth buried to 0.3 m depth.

10.8.4. System-Wide Implementation: Examples from Arizona and Washington

Two examples of using retrofits to improve connectivity statewide are initiatives by Arizona and Washington transportation agencies. Arizona DOT implemented a

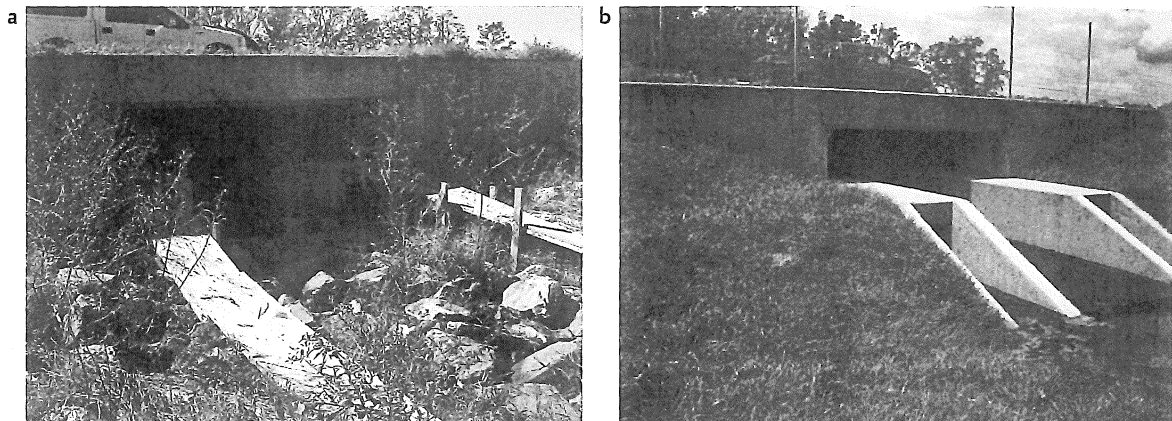


Figure 10.6. Following a road-widening project, this culvert was retrofitted to include ledges to facilitate small animal passage, initially with temporary wooden ramps (a). Due to structural and functional problems, modifications were made to replace the wooden ramps with permanent concrete ramps (b). *Credit: Daniel J. Smith.*

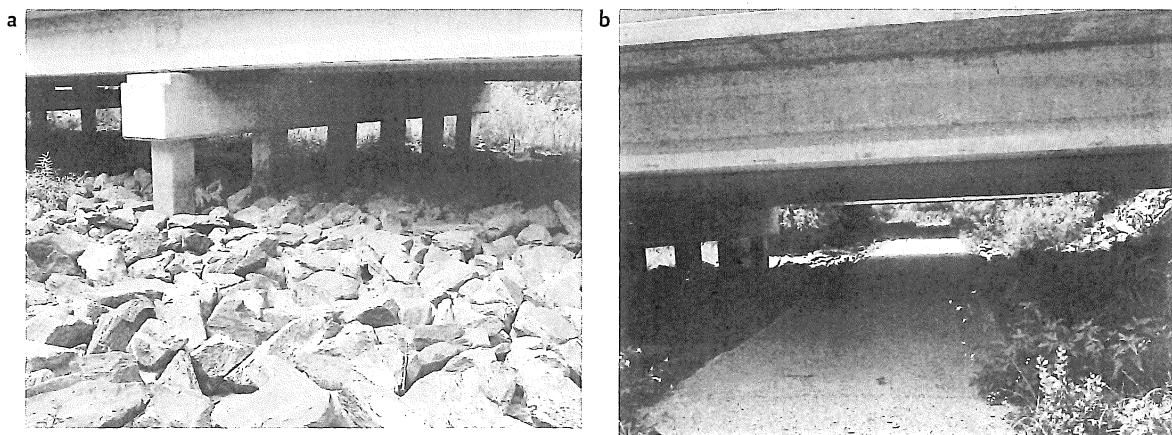


Figure 10.7. Boulders of this extent and size (a) are typically used across the United States, yet they are difficult for many wildlife species to cross. Retrofits to this bridge included removal of large rocks to create continuous paths of different sized bedding stone aggregates mixed with soil (b). *Credits: Daniel J. Smith (a) and Stephen Tonjes (b).*

program that would prioritize existing structures for retrofits rather than pursuing new construction of more expensive wildlife crossing structures (Nordhaugen et al. 2006; Eilerts and Nordhaugen 2010). Priorities were set by cross-referencing the Arizona Wildlife Linkages Assessment (Nordhaugen et al. 2006) with a statewide inventory and evaluation of existing structures that had the potential to be modified for wildlife passage. For structures in areas not scheduled for major upgrades, low-cost retrofits were planned, including addition of, or changes to, directional fencing, removal of riprap, and construction of ramps or pathways. For

example, some of these measures have been used to increase Mohave desert tortoise (*Gopherus agassizii*) use of seasonal drainage culverts.

In Washington, Washington State DOT (WSDOT), as part of a multi-organizational team, began the development of a statewide habitat connectivity retrofit program (McAllister 2010). This project occurred as a result of the WSDOT Secretary's Executive Order, "Protections and Connections for High Quality Natural Habitats." This large-scale, multi-year project identified valuable wildlife movement corridors between large blocks of high-quality habitat using least-cost distance

and circuit-theory models (Section 8.4) for 16 focal species. The results of these models will be used to develop priorities for future retrofit projects to improve habitat connectivity. At a finer scale, the program will assess existing structures to determine retrofit needs and opportunities where habitat connectivity can be enhanced. As part of this effort, WSDOT commissioned the development of a retrofit inventory and analysis tool, called the Passage Assessment System (Box 10.2).

10.9. Key Points

- After roads are built, retrofitting the existing transportation infrastructure is the only option for restoring ecological infrastructure (i.e., reducing wildlife mortality, maintaining habitat connectivity). Given the vast existing road network, the majority of wildlife mitigation measures are included retroactively. This may have the illusion of being a reduced-cost option over installing new structures; however, when compared to proactively incorporating the necessary enhancement features in the initial planning phase, retrofits often end up being more costly.
- Ideally, proactive design and construction of appropriate features that address ecological infrastructure occur when the road is originally built; retrofitting then occurs only as a function of adaptive management.
- Transportation agencies and the public should support policies and legislation that facilitate the inclusion of retrofits directly in construction project budgets (vs. maintenance budgets).
- Whether through the identification of focal species, umbrella species, or species' specializations, it is important to consider species' biological needs and patterns when considering types and locations of retrofits.
Grouping animals based on movement guilds can benefit a greater number of species within a wildlife community and can be more effective in targeting appropriate retrofit designs.
- Following considerations of species' biology, retrofit locations should be selected in conjunction with the habitats on which these species rely.
- After assessing which species are moving through surrounding habitats, design of structures, both internally and externally, should reflect the biological conditions that are being targeted for restoration and maintenance.
- Several retrofit options are available and range from lower-cost minor enhancements (e.g., signage, contouring approach areas) to higher-cost major improvements (e.g., directional and barrier fencing, structure modifications).
- As transportation and ecological infrastructure vary among locations, retrofit designs should be site based. Field assessments are necessary to identify retrofit options at specific sites.
- Rapid Assessments are an option when cost and time are limited.
- Any planned retrofit project should include measures for monitoring and maintenance, which in turn will allow for adaptive management to design and test retrofits for improved ecological function. Temporary measures can be taken to alleviate impacts while generating financial resources and public support for more permanent measures.

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