WILDLIFE CROSSINGS

Roadway crossings (i.e., overpasses and underpasses) specifically constructed or retrofitted for wildlife use are located throughout the United States and the world. Several examples are shown in Figure 1 (*1*, *2*). A wide range of wildlife crossings has been implemented for different types and sizes of animals (e.g., frogs, badgers, deer, elk, and bear). The focus of this summary will be on the study, use, and designs of larger structures specifically implemented for large mammals like the white-tailed deer.

Wildlife crossings are typically constructed to increase the permeability of a roadway and decrease the fragmentation of habitat. These structures, however, are typically only installed with exclusionary fencing or some other type of barrier system that funnels the animals to the crossing(s). A properly located crossing/fencing facility used by white-tailed deer can reduce deer-vehicle crashes (DVCs). The significant reductions in roadway animal mortality that resulted from the implementation of several crossing/fencing installations are discussed in the "Exclusionary Fencing" section of this toolbox (*3*, *4*, *5*, *6*). It is generally accepted that a properly located, designed, and maintained exclusionary fence/wildlife crossing(s) project is currently the most effective means of reducing animal-vehicle collisions while still providing a linkage for animal movement. The benefits and costs of this type of installation, however, need to be evaluated on a case-by-case basis.

The animal mortality reductions produced by exclusionary fencing/wildlife crossing(s) combinations are presented in the "Exclusionary Fencing" section and are not repeated here. This summary will discuss the type and application prevalence of wildlife crossings, summarize a recently published review of wildlife crossing research, and describe a list of factors believed to impact the use of wildlife crossings by ungulates (e.g., white-tailed deer) (*7*). Finally, the results of a study that evaluated the potential of a low-cost at-grade wildlife crossing installation design are summarized, and a list of wildlife crossing resources presented. The resources listed contain much more detailed information about wildlife crossing case studies, choosing crossing location(s), and structural design. A discussion of the science or technologies used to properly determine the location and design specifications of wildlife crossings is beyond the scope of this summary.

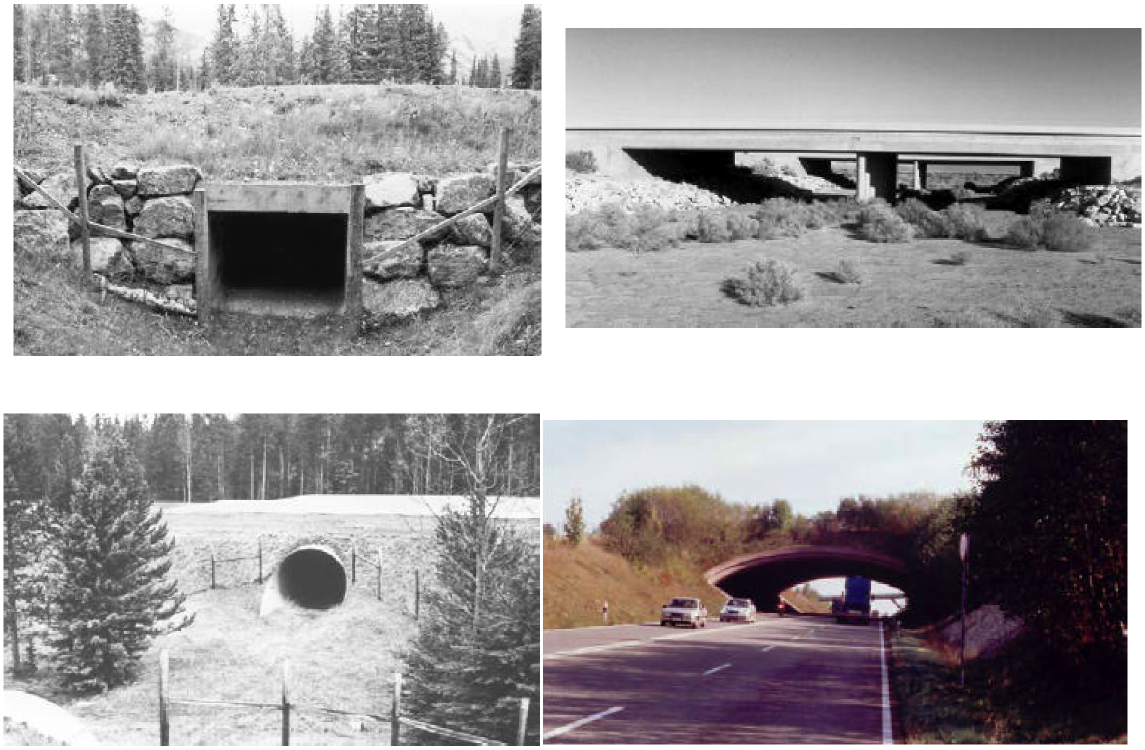

FIGURE 1 Example underpasses and overpasses (*2*).

Type of Wildlife Crossings

Wildlife crossings are typically categorized by their characteristics. The general categories of wildlife crossings include underpasses (e.g., culverts and tunnels) and overpasses (i.e., bridges) (See Figure 1). Crossings have also been segmented by their height. Small and large underpasses are differentiated by a height or diameters of 5 feet (*7*). Other characteristics that can also be used to differentiate wildlife crossings include structure materials (e.g., concrete or metal) and shape (e.g., box, circular, elliptical, or open-span underpasses; and hourglass or box overpasses). The design choices for a particular wildlife crossing are significant, and the answers are often unique from location to location. Additional information about crossing design choices and white-tailed deer/large ungulate preferences is shared in this summary.

Other types of underpasses can also be implemented for wildlife. These underpass designs include bridge extensions and viaducts. Bridge extensions, for example, are completed to include space for animals to travel along a waterway and under a roadway. This type of improvement can be implemented as part of a bridge rehabilitation project. A viaduct is typically constructed to span a natural valley and is considered the least costly approach to completing the chosen roadway alignment. Animals can pass under a viaduct and this might be another variable to consider when their installation is being evaluated as part of an alignment.

Wildlife Crossing Applications

At least two documents in the last 15 years have attempted to summarize the use of wildlife crossings in the United States (*2*, *8*). In 1992, Romin and Bissonette sent a survey to all 50 state wildlife agencies (*8*). Forty-three agencies responded and eight of them indicated that underpasses or overpasses had been built or modified to reduce deer mortality on their state roadways (*8*). These states included California, Colorado, Idaho, Minnesota, New Jersey, New York, Utah, and Wyoming (*8*). A recently published book also indicates that the first documented wildlife passage was constructed in Florida sometime in the 1950s (*7*). It is likely that this passage was not designed specifically for deer, but the state of Florida is now considered one of the leaders in the area of wildlife crossings within the United States.

A more recent survey of state departments of transportation was also recently completed (*2*). The results of this survey are summarized in *National Cooperative Highway Research Program (NCHRP) Synthesis 305 – Interaction Between Roadways and Wildlife Ecology* (*2*). Thirty-five agencies responded to the question “Has your department used structural measures as mitigation or part of a project to conserve wildlife?” (*2*). About two-thirds of the states indicated that they had used bridge extensions and/or wildlife underpasses (*2*). Overpasses, however, were only being used or planned by seven states (*2*). California, Connecticut, and Montana were planning wildlife overpass structures at the time of the survey, and Florida, Hawaii, New Jersey, and Utah already had them (*2*). The implementation of wildlife crossings in many locations appeared to be in response to problems with deer (*2*). *NCHRP Synthesis 305* includes a short summary of a number of wildlife crossings (*2*).

The consideration of wildlife crossings during roadway construction and reconstruction is prevalent in Europe (*1*, *2*). In fact, the use of overpasses (i.e., "landscape" or "green" bridges) for wildlife is much more widespread in Europe than in North America (*1*, *2*). In 2001, a team of ten experts visited five European countries to discuss their wildlife habitat connectivity activities (*1*). The countries visited were Slovenia, Switzerland, France, Germany, and the Netherlands (*1*). France indicated that it was the first country in Europe to use overpasses and had as many as 125 structures in the early 1990s (*1*). Germany had over 30 overpasses and is constructing or planning almost 30 more (*1*). Switzerland also had more than 20 overpasses and continues their construction (*1*). In North America there are also at least two overpasses within the Banff National Park of Alberta, Canada (*2*).

General Wildlife Crossing Research Review

The type and number of animal species using individual wildlife crossings has been the subject of a large number of studies. A representative sample of these studies was recently summarized by Forman, et al. in *Road Ecology: Science and Solutions* (*4*, *7*, *9*, *10*, *11*, *12*, *13*, *14*, *15*, *16*, *17*, *18*, *19*, *20*, *21*, *22*, *23*, *24*). These studies were reviewed by Forman, et al. for the existence of a stated hypothesis, objective, and criteria for crossing success (*7*). Data collection and analysis methodologies were also evaluated (*7*). In general, the value of any study is primarily related to the validity of their experimental design and general transferability of its results. A summary table created by Forman, et al. of the information they collected is repeated in Appendix B at the end of this summary (*7*).

A summary of the conclusions reached from the information in Appendix B is presented below (*7*). The relevance of these conclusions to our knowledge of wildlife crossing use and/or DVC-reduction capabilities is specifically noted where appropriate.

- Very few of the documents that describe wildlife crossing studies have included a stated hypothesis and/or predefined study criteria for measuring crossing success (*7*). This approach to experimental design limits the value of the conclusions from these studies. Stated objectives and measures of effectiveness are necessary to determine whether a crossing has been successful. Typical measures of success are related to wildlife movements (i.e., crossing use) and animal mortality or DVC reduction. Only three of the 17 studies considered had a stated hypothesis or criteria, but the majority did have stated objectives (See Appendix B or *7*).

- All but three studies focused on one species (*7*). The interaction of species and multiple species requirements of wildlife crossings may limit the applicability of these studies. It has been suggested that the target species for crossing design be the one most likely to use the crossing, but is also believed to have the most species-specific requirements for using a crossing. The structure design based on this target species should then be able to serve other species with less sensitivity to crossing variables. Most of the current crossings designed to serve medium to large mammals are used by white-tailed deer.

- Most studies base their measure of wildlife crossing success on the total frequency of its use by one or more species (*7*). This measure of success tends to ignore the fact that the frequency of crossings is not only related to the number and distribution of a species in the area, but also the time of the year. A more appropriate measure of success would be to compare the observed crossing usage by a species to its expected crossing frequency. A similar approach might also be taken to properly evaluate the DVC or animal mortality reduction impact of wildlife crossings. In this case, however, the expected probability of an individual animal being hit by a vehicle would need to be calculated, taking into account measures of species and vehicle exposure variability, and compared to what is observed.

The use of total crossing frequency as a measure of wildlife crossing success may also not be specific enough to determine whether it has adequately reduced the barrier effect of a roadway. The frequency of crossing use should be compared to the stated objectives of the crossing for each specific species. For example, although related, the "successful" frequency of crossings for the maintenance of genetic variation in a species is different than that needed to maintain a species population.

- Few studies focus on large carnivores, reptiles, and amphibians, and very few studies have included human activity on and near a wildlife crossing as a variable to its use (*7*). Studies have shown that the movements of particular types of animals are significantly impacted by the presence of humans (*22*, *24*). If a crossing has nearby development or is regularly used by humans it can impact its permeability impacts and crash reduction effectiveness.

- Most studies have not indicated that predator species use wildlife crossing as traps to catch prey (*7*). Forman, et al. believe that the basis of this idea is primarily anecdotal, possibly based on the observation of opportunistic predator encounters with prey species, but not a generally observed pattern (*7*, *25*).

- Almost none of the studies have properly compared the animal usage impacts of different wildlife crossing types (e.g., underpasses and overpasses) and other crossing design variables (*7*). In addition, information about how to locate and space wildlife crossings is minimal. For example, an important question that still needs to be answered is whether the installation of several closely spaced inexpensive crossing is more effective than one costly structure in a suboptimal location (*7*). The answers to these types of questions would allow more effective and efficient use of limited funds to construct wildlife crossings.

Factors that Impact Wildlife Crossing Use

Despite some of the general shortcomings of past research on wildlife crossings, a combination of their results (focusing on those more properly designed and documented) with current practice general ecological principles can and have been used to identify some of the factors believed to impact the use of wildlife crossings. There have also been a few studies that specifically focused on wildlife crossing design decisions and their impact on use (*13*, *14*, *16*, *21*, *22*, *24*). Several wildlife crossing are discussed in the following paragraphs. If possible, specific suggestions about the factors have been provided, and their impact on ungulate (e.g., white-tailed deer) crossing use is noted. All of the factors discussed also generally interact, and tradeoffs in design decisions are often necessary.

Animal Species

Certain species tend to prefer particular crossing designs. For example, a grizzly bear may prefer a very large and open crossing, but a cougar may be more comfortable using a more restricted crossing (*7*). Ungulates have been shown to prefer crossings that appear more open (*24*). It is in the nature of deer to avoid confining spaces where a means of escape does not appear to be clear (*5*, *7*, *9*). Clevenger and Waltho have statistically confirmed that ungulate and carnivore species groups do respond to underpass structure designs differently (*22*, *24*).

A good objective for a wildlife crossing is to serve as many species as possible with the design implemented. Ungulates currently use many crossing designs that were implemented for other target species (e.g., the Florida panther) or not even initially constructed for wildlife use. Specific suggestions about the type (e.g., overpass or underpass) and dimensions of a crossing are discussed in the next section.

Crossing Type and Dimensions

Two variables that are closely related to the animal species use of a crossing are its type (e.g., overpass or underpass) and dimensions (e.g., height, width, and length). However, because of the variability in species requirements and the physical constraints of each potential crossing location the application of one design at every site is unlikely. Wildlife crossing designs need to be considered on a case-by-case basis.

Crossing Type A combination of the research and a knowledge of animal behavior indicate and support the idea that different species are more likely to prefer an underpass or an overpass (assuming there is a choice and the options are properly designed). . The variability in wildlife crossing locations and design, however, makes the direct and proper comparison of underpass and overpass preferences difficult. But, a comparison in Banff National Park (located in Alberta, Canada) of two overpasses within about 650 feet of an underpass was completed, and it was found that ungulates (including deer) tended to prefer overpasses (*7*, *26*, *27*). Other animals such as black bear, for example did not appear to have crossing type preference, and cougars seemed to prefer the underpass (*7*, *26*, *27*). However, these results do not mean that ungulates do not use underpasses. They are often the species group that uses many of the existing underpasses with the most frequency (where the choice of an overpass or underpass is not available).

Underpass Dimensions The dimensions that are used or have been suggested for underpasses that may be used by white-tailed deer or other large animals have varied (*7*, *9*, *22*, *24*, *28*). The typical height of existing underpasses used by large wildlife is about 6.5 feet, but range up to 13 to 16 feet (*7*). However, a height of at least 8 feet and widths of at least 23 feet have been recommended for underpasses used by ungulates (*7*, *13*, *28*, *29*). Foster and Humphrey, however, found white-tailed deer in Florida using underpasses that were only 6.9 feet in height (*13*). In addition, deer have used underpasses as narrow as 20 feet (*13*, *30*). Finally, in the 1970s Reed, et al. suggested that a height and width of about 14 feet was needed to provide the necessary feeling of openness for deer (*9*). Overall, it would appear that heights of as low as 7 to 8 feet and widths as narrow as 20 to 25 feet may be considered minimum design criteria for deer use of underpasses. However, similar to all other roadway geometric design components, designing for the "minimum" is often not appropriate.

There does seem to be general agreement that underpasses should be as short as possible, and an unobstructed view through or across wildlife crossings also seems to be important design feature for certain species or species groups (*13*, *31*). For example, as previously indicated, deer appear to prefer larger and more open underpasses (*5*, *9*). In the past, an "openness" index that combined underpass width, height, and length was proposed as a valid measure for properly designed underpasses (*9*, *32*, *33*, *34*). The openness index = ((underpass width)(underpass height))/(underpass length) (*9*, *32*).

In Colorado underpasses designed for deer had an openness index of 0.31 (metric), and mule deer were reluctant to use it (*9*, *35*). Additional studies have found that mule deer were not as reluctant to use structures with openness indices between about 4.6 and 5.6 (metric) (*3*, *36*). Reed and Ward suggest a minimum openness index of 0.6 (metric) for mule deer that are highly motivated to cross a roadway (*32*). Putman, summarizing a large German study by Olbrich, however, indicated that red deer (a relative of the North American elk) and fallow deer did not use underpasses with an openness index less than 1.5, (metric) and roe deer had the same reaction to openness indices less than 0.75 (metric) (*33*, *34*). It has been suggested that the equal treatment of height and width in the openness index may not be appropriate, and the strength of the potential relationship between this measure and underpass use may be species specific and time dependent (*13*).

The wide range of underpass dimensions (whether measured directly or by an openness index) that are used and have been suggested supports the previous conclusion that there is a need for more species-specific crossing design variable analysis (*7*). Fortunately, several studies have been completed in Banff National Park that started to focus on the species and/or species group crossing use impacts of structural, landscape, and human activity variables (*7*, *22*, *24*, *33*, *34*). The structural variables considered were height, width, length, the openness index, and noise level (*22*, *24*).

In 1998, Clevenger found that monthly ungulate use at underpasses was negatively correlated with crossing length and positively correlated with the openness index (*22*).

More specifically, in 2000 Clevenger and Waltho found that three of the structural variables they considered (i.e., openness index, noise level, and width) were the most significant underpass characteristics related to ungulate (e.g., white-tailed and mule deer) use (*24*). However, the intercorrelations between the openness index and underpass length, noise level, and the variable for the distance to the nearest town limited the usefulness of these results if they were not evaluated along with known ungulate behavior (*24*). It was also generally concluded that structural design variables (e.g., openness) were more important to ungulates than carnivores, and that the impacts of specific design decisions was greater when the structure was new and animals had not yet adjusted to its existence (*7*, *24*). Overall, the openness index, of the 14 variables considered, had the strongest relationship to ungulate use and when all the species were considered together, but it had a weaker relationship with carnivore use than a series of landscape and human activity variables (*24*).

Overpass Dimensions As previously indicated, the use of overpasses in the United States is relatively limited, but they are also either currently planned or being designed in several states (*2*). The widths of six existing overpasses in North America range from about 16 feet to 171 feet (*7*). Most overpasses around the world, however, are about 100 to 165 feet wide (*7*). A European study summarized by Forman, et al. indicated that overpass width was one of the most important factors to large mammal use, and that an overpass width of less than 66 feet (20 meters) had significantly less mammal crossing activity (*7*, *20*). It was suggested that the width of an overpass be based on its purpose and the target species, but that widths of 164 to 197 feet (50 to 60 meters) seemed to be adequate (*7*, *20*). The Dutch use an hourglass design that is about 98 feet (30 meters) wide in the center and about 262 feet (80 meters) wide at its ends (*7*). They consider this design the best for large mammals in The Netherlands (*7*).

A "bridge effect" index has also been suggested for overpasses, but its use as a measure that might impact crossing use by deer has not been evaluated (*3*, *32*). The theory is that an overpass can be high, long, and narrow enough that a deer would be reluctant to use it (*32*). The "bridge effect" index is equal to ((overpass width)(overpass height)$^{1/2}$))/(overpass length) (*32*). Little guidance is available about what "bridge effect" index amount might be preferable for deer, but it was found that deer were only slightly to moderately reluctant to cross overpasses in Colorado with "bridge effect" indices of 0.34 and 0.65 (metric) (*3*, *32*). Overpasses in Utah with a "bridge effect" of 0.26 (metric) were also considered successful (*32*). The potential impacts on the species use of an overpass due to the geometrics represented by this index are unknown.

Crossing Location

Location is generally considered the most critical factor that impacts the use of a wildlife crossing (*7*, *13*, *17*, *20*, *22*, *24*, *31*). Upfront and proper planning to determine the most optimally feasible crossing location is key. Unfortunately, as indicated in the general review of wildlife crossing research, the information available on properly choosing a crossing location is scarce (*7*). Locations are often chosen through combinations of expert judgment, the identification of "high" DVC or animal mortality locations, and an evaluation of information about significant animal movements, migratory or movement patterns, and habitat. It has been suggested, however, that a location that removes a barrier or reestablishes a habitat connection or migratory route may be most successful (*7*). The location of a crossing must be considered at both the local and systematic landscape level (*7*).

Ward, et al. did make a recommendation that the spacing of crossings in an area of Colorado should be in one mile increments, but the variability of potential locations makes the general transferability of this specific dimension questionable (*3*). In fact, in 2003 the Colorado Department of Transportation published a report that focused on identifying the best locations for wildlife crossings (*37*). It recommends that crossing locations be evaluated on a case-by-case basis, and that habitat suitability (plus its interaction with the landscape and highway design) be used as the primary indicator of crossing activity (*37*).

Clearly, the proper determination of a crossing site requires a systematic location-specific analysis of crash and/or carcass data, and the magnitude and variability of species, land cover, vegetation, and habitat information. Other data of interest also includes species densities and movement patterns, the number of vehicles traveling on a roadway, and other human activity indicators. Several agencies or researchers have combined expert opinion with this type of information to assist with locating wildlife crossings (*38*, *39*, *40*). The Colorado Department of Transportation report previously mentioned, for example, suggested the systematic mapping of landscape and roadway features/conditions to assist in the identification of the most likely animal crossing locations (*37*). In addition, Florida has developed a system that incorporates many of these pieces of data through a geographic information system (GIS), and they use this coordinated information in the planning of roadways and the identification of potential crossing locations (*40*). Several other states also have created or are creating statewide habitat connectivity maps (e.g., New Mexico).

Human Activity

Measures of nearby human activity (e.g., number of hikers, bikers, or horseback riders using the structure, and distance to the nearest town) have been found to significantly reduce the use of wildlife crossings (*24*). Not surprisingly, these types of measures were found to have a greater impact on the use of crossings for carnivores than ungulates (*24*). Overall, structural openness and the distance to the nearest town were the first and second variables most significantly related to the overall use (i.e., carnivores and ungulates combined) of the crossings studied in Banff National Park in Alberta, Canada (*24*). It was recommended that crossings be designed and located to minimize the influence of nearby human activity (e.g., direct use of the crossing and nearby development) (*22*, *24*). Structure entrance barriers that allow animal movement, but restrict non-pedestrian flow (e.g., big rocks) and the purchase of adjacent land are two potential methods of reducing human activity at a crossing.

Crossing Floor Covering and Adjacent Landscaping

Several studies have shown that most large animals prefer wildlife crossings with a floor, whether an underpass or overpass, be covered with soil and natural vegetation (*33*, *34*, *36*). An example of a "green" bridge in Europe is shown in Figure 1 (*1*). The ability to implement this type of floor covering (and keep it intact) is based on the type and dimensions of the crossing used. A natural crossing floor with vegetative cover and a clear escape route (as well as browsing material) appears to be the preference of white-tailed deer. "Green" overpasses also need to be designed to support the dead and live weights expected.

The use of proper landscaping or vegetative cover at both entrances of an underpass or overpass is also important to its use by particular species (e.g., ungulates) (*24*, *33*, *34*). This vegetation may attract and calm an approaching animal, and it can also be used to help direct animals to a crossing along with fencing. Clevenger and Waltho did find that the use of a crossing by carnivores was more strongly related to its distance to the nearest major drainage than most of the structural variables they considered, but still had a weaker relationship than that between carnivore use and several measures of nearby human activity (*24*). For ungulate use, the strength of the relationship between the distance from the crossing to the nearest major drainage is about the same, but opposite, of that for carnivore use (*24*). However, it was suggested that this might be an indicator of the predator-prey relationship rather than the impact of the direct impact of these landscape variables (*24*). Greater distances from the crossing to the nearest forest cover were also related to smaller crossing use by ungulates, but the strength of the relationship was still lower than several of the structural variables considered (*24*). The need to locate crossing in habitat that support the target species for the structure is generally discussed in the crossing location section of this summary.

Others: Fencing and Structure Age

The installation of a crossing without exclusionary fencing or something that directs animals to and across the crossing is not recommended. However, it should be remembered that many crossing structures are used by animals that were not initially designed for wildlife, and these installations are only normally bordered by typical right-of-way fencing. As indicated previously, crossing location is very important, but then adaptation by wildlife to just about all crossings appears to occur in some manner.

In fact, it has been shown that the use of a crossing often increases with the age of the structure (*9*, *15*, *24*). For example, Reed, et al. concluded that the data describing the use of an underpass in Colorado showed mule deer adapted to it sometime between the second and third year of migration (*9*). There is a time of adjustment for animals to new passages and during that time the species prefer those structures that match their natural behavior and crossing needs (*7*). It has been suggested that once individual animals adapt to a particular crossing the role of its structural dimensions is reduced in comparison to adjacent landscape features or human activities (*24*, *41*). It has also been suggested that with fencing and a near optimal location a crossing will most likely experience some use despite its shortcomings (*7*).

At-Grade Crossings

A unique at-grade crosswalk design has also been tested as a lower cost DVC-reduction alternative to grade separation (*42*). In Utah, four at-grade crosswalks were installed along United States 40 (a four-lane divided roadway) and five were installed along State Route 248 (a two-lane undivided roadway) (*42*). The number of deer carcasses was collected before and after the installation of the crosswalks along study site and control segments (*42*). The control segment for the United States 40 installations was adjacent to its study segment, and the control segment for the State Route 248 installations was along a comparable nearby roadway. Data were collected for 36 months before and 15 months after the installation of the crosswalks (*42*).

The general design of the crosswalk installation consisted of 7.5-foot (2.3 meter) exclusionary fencing that led animals to an opening (*42*). This opening was approximately 30 feet (9.1 meter) from the roadway, and a short three-foot fence was retained in the exclusionary fence gap. The animals needed to jump this short fence to use the crosswalk. The 30 feet (9.1 meter) between the opening and the roadway pavement was a dirt path bordered by round cobblestones (*42*). The objective was to funnel the mule deer on to the roadway crosswalk. The crosswalk was edged by cattleguard lines on the pavement to help motorists identify its location. The location of the crosswalks was chosen based on the number of observed deer crossings (*42*).

The mule deer carcass data collected were then analyzed (*42*). First, the location of the carcasses was investigated. Most of the carcasses that were found in the study area were just beyond the exclusionary fencing (*42*). About 59 percent of the carcasses were found outside the fenced area along United States Route 40, and 75 percent along State Route 248 (*42*). Then, the change in the number of mule deer carcasses along the segments with and without the crossing/fencing installations was compared (*42*). The number of mule deer killed in the test segments was about 37 to 42 percent below what was expected, but it could not be statistically concluded that this change was anything more than normal variability in the data (*42*). The researchers did believe that the introduction of the exclusionary fencing reduced the number of mule deer -vehicle collisions, but no conclusions could be reached that the at-grade crossing installation had a statistically significant impact (*42*). One problem was that some mule deer entered the right-of-way through the gap in exclusionary fencing, and then grazed on the vegetation along the roadside rather than crossing the roadway (*42*).

Overall, the researchers believed that an updated design of an at-grade crossing might be more effective (*42*). They recommended that the exclusionary fencing be placed closer to the roadway, and that the roadside vegetation in the area be made less attractive to mule deer (*42*). The application of this design would most likely only be effective along lightly traveled roadways with drivers that understood or had been educated about the mule deer migratory time period (*42*). The crossing location of the mule deer could then be defined for drivers with the crosswalk infrastructure.

Additional Wildlife Crossing Resources

The following paragraphs briefly describe some of the general reference documents used in this summary, websites that may be of interest to the reader, and two ongoing/planned wildlife crossing research projects.

A large number of documents have been referenced in this summary. However, there were three that contained a wide range of information and were used extensively (*1*, *2*, *7*). These documents included:

- *Wildlife Habitat Connectivity Across European Highways* (*1*). This summary was published as part of the American Association of State Highway and Transportation Officials (AASHTO) and Federal Highway Administration (FHWA) international scan tour program. It is a discussion of habitat connectivity activities in five European countries with recommendations about how some of these activities might be transferred to the United States. This document can be found at: international.fhwa.dot.gov/.

- *NCHRP Synthesis 305 – Interaction Between Roadways and Wildlife Ecology* (*2*). This synthesis was completed as part of the National Cooperative Highway Research Program (NCHRP) and published in 2002. In general, *NCHRP Synthesis 305* summarizes information available about roadway planning, design, construction, operation, and maintenance decisions, and how they interact with ecological systems and wildlife. It also contains the results of a survey of state departments of transportation that focused on activities related to wildlife mitigation along roadways. *NCHRP Synthesis 305* can be found at: www4.trb.org/trb/onlinepubs.nsf.

- *Road Ecology Science and Solutions* (*7*). Richard Forman and 13 other authors recently published this book. It consists of 14 chapters that focus on a wide range of interactions between roadways and ecology. Some of the individual chapters focus on roadsides and vegetation, wildlife populations, wildlife impact mitigation, water and sediment, wind and air, and roadway chemical impacts. It is generally believed that this book may be the first focused consideration of the "road ecology" issue.

A series of documents that described the results of the long-term and ongoing study of overpasses and underpasses in Banff National Park (in Alberta, Canada) have also been used to a great extent in this summary (*4*, *6*, *22*, *24*, *25*, *26*, *27*).

There are also two web-based resources that the reader is encouraged to visit. They contain more detail and information about wildlife crossings (and links to additional webpages) than could be included in this summary. These sites include:

- *Critter Crossings: Linking Habitats and Reducing Roadkill.* This site was developed by the United States Department of Transportation Federal Highway Administration Office of Natural Environment. It describes the impact of transportation on wildlife and shares some potential physical and procedural solutions to the problem. The critter crossings link can be found at: www.fhwa.dot.gov/environment/. Additional examples of measures that can be used to help reduce the impact of roadways on wildlife can also be found at another related Federal Highway Administration website: *Keeping it Simple: Easy Ways to Help Wildlife along Roads*. A link to this website is located at the same address as critter crossings.

- *Wildlife Crossing Toolkit.* This website was initiated by United States Department of Agriculture (USDA) Forest Service and created at the Jack H. Berryman Institute of Utah State University. Its audience is professional biologists and engineers. The website contains a searchable database of mitigation measure case studies, and articles about reducing animal mortality and increasing habitat connectivity along roadways. It also includes graphical examples of crossing types, a glossary of biological and engineering terms, and the information initially contained in the ARTEMIS Clearinghouse from the Western Transportation Institute of Montana State University. The *Wildlife Crossing Toolkit* can be found at www.widlifecrossings.info. The ATREMIS Clearinghouse can be found at: www.coe.montana.edu/wti/default.htm.

There are also at least two ongoing or planned research projects in the area of wildlife crossings that should produce useful information. The Western Transportation Institute at Montana State University is working for the Federal Highway Administration to develop *Guidelines for Designing and Evaluating North American Wildlife Crossing Systems.* They plan to review and synthesize the information available about the design, monitoring, and performance of wildlife crossings. In addition, protocols for monitoring wildlife crossings will be developed and research gaps identified. A second wildlife crossing project has also started as part of the National Cooperative Highway Research Program (NCHRP). The objective of this project is to develop guidelines for the selection, configuration, location, monitoring, evaluation, and maintenance of wildlife crossings. The results from both of these efforts are expected to address some of the gaps in the state-of-the-knowledge with respect to wildlife crossings, and also assist in their proper application.

Conclusions

There appears to be a significant amount of information available on the use and general effectiveness (typically measured by animal use) of *specific* wildlife crossing/fencing installations. The animal mortality reductions that have resulted from several of these installations are described in the "Exclusionary Fencing" summary of this toolbox. It is generally accepted that a properly located, designed, and maintained crossing/fencing combination can significantly reduce animal mortality along a roadway segment.

The documentation reviewed for this summary contained some very useful information. An evaluation of the results from two national surveys revealed that wildlife crossings are used in more than 20 of the United States, and that the great majority of these crossings were underpasses. Other options for wildlife crossings include overpasses, bridge extensions, and viaducts. A general review of wildlife crossing research concluded that most were completed for particular wildlife crossing(s) and focused on the species use of the structure (versus its potential animal mortality reduction impacts). Very few studies were designed and/or documented for the possible general application of their results. In addition, only some of the more recent studies have begun to formerly evaluate the impact of design decisions (e.g., crossing type, location, and dimensions) on wildlife crossing use (and their subsequent impact on DVCs). Significant gaps in the current state-of-the-knowledge (or its documentation) exist in the crossing design decision-making area. The two ongoing/proposed research projects described previously should contribute additional wildlife crossing decision-making material, and reduce the gaps in the current state-of-the-knowledge.

A number of factors were also identified that are believed to impact the use of a wildlife crossing. The factors described in this summary included animal species, crossing type (e.g., underpasses and overpasses) and dimensions, crossing location, human activities, crossing floor covering and landscaping, fencing, and structure age. In general, it has been found that the location of a wildlife crossing is key to its success, and it is preferable that it matches the natural movement patterns of the target species. Ungulates (including white-tailed deer) generally prefer overpasses or large open underpasses. A method of escape (i.e., the ability to see through or across the structure) is important to their movement. However, their initial use of a wildlife crossing appears to be most strongly correlated with structural design variables rather than adjacent landscape and human activity. These other features (i.e., adjacent landscape characteristics and human activity) become more important as individual animals adapt to the existence of a crossing. In the long term, natural groundcover on and/or within a structure, natural vegetation leading to its entrances, and minimal human activity and nearby development are also preferred crossing characteristics.

A wide range of underpass and overpass designs has been implemented and is used by ungulates. Underpasses can be square, circular, or elliptical and made from either concrete or steel. It would appear that heights as low as 7 to 8 feet and widths as narrow as 20 to 25 feet may be considered minimum design criteria for the use of an underpass by deer. Suggested minimum openness indices have ranged from 0.6 (metric) for mule deer and 0.75 (metric) for roe deer to 1.5 (metric) for red and fallow deer. However, designing for the "minimum" is not a typical approach to many roadway component or bridge designs, and it would typically not be the preferred or recommended approach in the case of wildlife crossings. Overpasses are either square or hourglass shaped and it has been suggested that they be constructed with widths (at their narrowest point) of 100 feet or more. These types of designs have been used successfully in Europe for many years.

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APPENDIX B

Table B-1. Sample Wildlife Crossing Study Characteristics (*Adapted from 7*).

		Design		Data Collection				Analysis			
Source	**Location**	**Hypothesis Stated?**	**Objectives Stated?**	**Number of Structures**	**Method[a]**	**Duration (Months)**	**Monitoring Frequency**	**Level[b]**	**Species[c]**	**Criteria for Success?**	**Observed/ Expected[d]**
Reed, et al. (*9*)	WY, USA	No	Yes	1	Counters Transects	48	Weekly	S (S)	Mammal (u)	No	Observed
Ballon (*10*)	Upper Rhine, France	No	No	4	Transects	9	Weekly	S (M)	Mammal (u)	No	Observed
Hunt, et al. (*11*)	NSW, Australia	No	Yes	5	Traps Transects	2	1 per 8 Days	S (M)	Mammal (s, m)	No	Observed
Jackson and Tyning (*12*)	MA, USA	No	Yes	2	Observation	< 1	Daily	S (S)	Amphibian	Yes	Observed
Woods (*4*)	Alberta, Canada	No	Yes	8	Transects Telemetry	36	1 per 3 Days	S (M)	Mammal (u)	Yes	Observed
Foster and Humphrey (*13*)	FL, USA	No	Yes	4	35mm Camera	2-16	Continuous	S (M)	Mammal (m, lc, u) Bird Reptile Human	No	Observed
Yanes, et al. (*14*)	Central Spain	No	Yes	17	Transects	12	16 Days per Year	G (M)	Mammal (s, m) Reptile	No	Observed
Land and Lotz (*15*)	FL, USA	No	Yes	4	35mm Camera	24	na	S (M)	Mammal (m, lc, u) Reptile	No	Observed
Rodriguez et al. (*16*)	South-central Spain	Yes	Yes	17	Transects	11	1 per 3 Days	G (M)	Mammal (s, m, u) Reptile Amphibian Human	No	Observed
Roof and Wooding (*17*)	FL, USA	No	No	1	Transects 35mm Camera Telemetry	12	1 per 3 Days	S (M)	Mammal (s, m, lc)	No	Observed
AMBS Consulting (*18*)	NSW, Australia	No	Yes	3	35mm Camera	9	Continuous	S (M)	Mammal (s, m)	No	Observed

Table B-1. Continued.

Pfister, et al. (*19*)	Switzerland, Germany, France, Netherlands	No	Yes	16	Video Camera	24	na	S (M)	Mammal (s, m, u) Bird Reptile Amphibian Invertebrate	Yes	Observed
Rodriguez, et al. (*20*)	South-central Spain	Yes	Yes	17	Transects	10	1 per 3 Days	S (M)	Mammal (m) Human	No	Observed
Rosell, et al. (*21*)	Catalonia, Spain	No	Yes	56	Transects	11	16 Days per Year	G (M)	Mammal (s, m, u) Reptile Amphibian	No	Observed
Clevenger (*22*)	Alberta, Canada	No	Yes	11	Transects	12	1 per 3 Days	S (M)	Mammal (lc, u) Human	No	Observed
Veenbaas and Brandjes (*23*)	Netherlands	No	Yes	31	Transects	5	na	S (M)	Mammal (s, m, u)	No	Observed
Clevenger and Waltho (*24*)	Alberta, Canada	Yes	Yes	11	Transects	35	1 per 3 Days	S (M), G, C	Mammal (lc, u) Human	No	Expected

[a]Method: Transect = sand traps. Traps – live-trapping. Observation = direct observation. 35mm Camera = remote camera monitoring. Telemetry = radio-telemetry. Counters = motion-sensitive game/trail counters. Video camera = remote-operated video camera monitoring.
[b]Level = level of analysis: Individual species (S) [single-species S (S), or multiple species S (M)]. Species groups or guilds (G). Community level (C).
[c]Species types: s = small mammals. m = medium-sized mammals. lc = large carnivore. u = ungulate. Human = human impact on passage analyzed.
[d]Observed/Expected: Obs = observed passage frequency counts. Exp = expected passage frequency based on probability of occurrence in vicinity of passage.
[e]na = not available in publication or report.