

**Standard Title Page - Report on State Project**

Report No. VTRC 06-R2	Report Date August 2005	No. Pages 37	Type Report: Final Period Covered: June 2004-May 2005	Project No.: 73197 Contract No.
Title: The Use of Highway Underpasses by Large Mammals in Virginia and Factors Influencing their Effectiveness				Key Words: wildlife crossings, highway underpasses, large mammals, white-tailed deer, black bear, deer-vehicle collisions
Author: Bridget M. Donaldson				
Performing Organization Name and Address:  Virginia Transportation Research Council 530 Edgemont Road Charlottesville, VA 22903				
Sponsoring Agencies' Name and Address  Virginia Department of Transportation 1401 E. Broad Street Richmond, VA 23219				
Supplementary Notes				
<p><b>Abstract</b></p> <p>The rapid increase in animal-vehicle collisions on U.S. roadways is a growing concern in terms of human safety, property damage and injury costs, and viability of wildlife populations. Wildlife crossing structures are gaining national recognition by transportation agencies as effective measures to reduce animal-vehicle collisions and connect wildlife habitats across transportation corridors. In Virginia, white-tailed deer and black bear pose the highest risk. This 1-year study was conducted to monitor various underpass structures in Virginia to determine the structural and location attributes that make a crossing successful in terms of use by large mammals. The underpasses, most of which were not specifically designed as wildlife crossings, consist of box culverts and bridges of varying sizes.</p> <p>Remote cameras installed at seven underpass sites in Virginia have recorded more than 2,700 wildlife photographs and documented 1,107 white-tailed deer crossings in the most heavily used structures. Underpasses with a minimum height of 12 ft were successful at facilitating deer passage. Such structures were also heavily used by a variety of wildlife species, including coyote, red fox, raccoon, groundhog, and opossum. Structures with drainages that mimic natural waterways can encourage use by a diversity of terrestrial, semi-aquatic, and aquatic species.</p> <p>This report provides guidance in choosing cost-effective underpass design and location features that are necessary to consider to increase motorist safety and habitat connectivity. The findings also demonstrate that if only a minimal number of deer-vehicle collisions is prevented by an effective underpass, the savings in property damage alone can outweigh the construction costs of the structure.</p>				

**FINAL REPORT**

**THE USE OF HIGHWAY UNDERPASSES BY LARGE MAMMALS IN VIRGINIA  
AND FACTORS INFLUENCING THEIR EFFECTIVENESS**

**Bridget M. Donaldson  
Research Scientist**

Virginia Transportation Research Council  
(A Cooperative Organization Sponsored Jointly by the  
Virginia Department of Transportation and  
the University of Virginia)

Charlottesville, Virginia

August 2005  
VTRC 06-R2

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## ABSTRACT

The rapid increase in animal-vehicle collisions on U.S. roadways is a growing concern in terms of human safety, property damage and injury costs, and viability of wildlife populations. Wildlife crossing structures are gaining national recognition by transportation agencies as effective measures to reduce animal-vehicle collisions and connect wildlife habitats across transportation corridors. In Virginia, white-tailed deer and black bear pose the highest risk. This 1-year study was conducted to monitor various underpass structures in Virginia to determine the structural and location attributes that make a crossing successful in terms of use by large mammals. The underpasses, most of which were not specifically designed as wildlife crossings, consist of box culverts and bridges of varying sizes.

Remote cameras installed at seven underpass sites in Virginia have recorded more than 2,700 wildlife photographs and documented 1,107 white-tailed deer crossings in the most heavily used structures. Underpasses with a minimum height of 12 ft were successful at facilitating deer passage. Such structures were also heavily used by a variety of wildlife species, including coyote, red fox, raccoon, groundhog, and opossum. Structures with drainages that mimic natural waterways can encourage use by a diversity of terrestrial, semi-aquatic, and aquatic species.

This report provides guidance in choosing cost-effective underpass design and location features that are necessary to consider to increase motorist safety and habitat connectivity. The findings also demonstrate that if only a minimal number of deer-vehicle collisions is prevented by an effective underpass, the savings in property damage alone can outweigh the construction costs of the structure.

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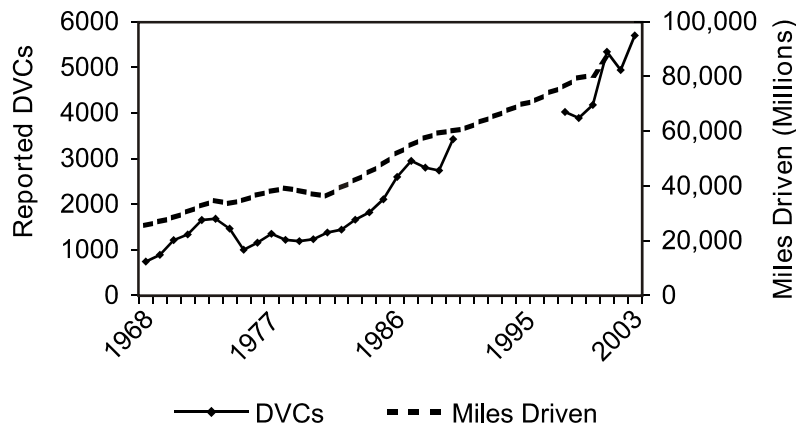
## INTRODUCTION

The increasing frequency of animal-vehicle collisions in the United States is taking an enormous toll in terms of driver safety and wildlife viability. For species that commonly attempt to cross roads, the number of animals killed can have a devastating effect on their populations. Roads and highways act as barriers for other species, isolating populations and increasing the chance of local extinction. For humans, more than \$1.1 billion in vehicle damage is caused in the United States by an estimated 1.5 million traffic accidents involving deer alone (Hedlund et al., 2003). This problem is growing as increased vehicle travel coincides with deer population growth. In Virginia, the white-tailed deer (*Odocoileus virginianus*) population has increased 400% since 1968, and Virginia's human population has increased 61%. As a result of these drastic increases, the number of reported deer-vehicle collisions (DVCs) in the state have increased nearly 8-fold in the last 35 years (Figure 1).

In Virginia, law enforcement officers are required to file a written accident report only if an accident exceeds \$1,000 in damage. Records from Fairfax County, Virginia, where deer carcass pick-up data are recorded, indicate that for every 1 DVC reported in the police records, six deer carcasses are picked up from the county's roads. Applying this expansion factor to the rest of the state, there were likely more than 34,000 DVCs in Virginia in 2003. In the same year, the average cost in property damage for a reported collision was \$2,530. This could translate into more than \$42.6 million in property damage in 1 year.

Carcass disposal is another area of significant cost. Although the Virginia Department of Transportation (VDOT) does not maintain a statewide database that systematically tracks the number of carcass pick-ups and associated disposal expenses, the disposal cost for the Reston Area Headquarters in Fairfax County alone is \$65 per trip. At an estimated 34,000 DVCs annually, carcass disposal could easily cost VDOT millions of dollars each year.

For wildlife, the number of animals killed in vehicle collisions can drastically affect their populations. In areas where animals attempt to cross roads, road mortality has significantly affected black bear (*Ursus americanus*) populations in the southern Appalachians (Brandenburg, 1996). Roads and highways also act as barriers for many animals. As roads are upgraded to accommodate greater traffic volumes, the rate of successful black bear crossings decreases significantly and black bears become reluctant to cross roads (Brody and Pelton, 1989; Virginia Department of Game and Inland Fisheries, 2002). This avoidance of roads can isolate wildlife populations and ultimately reduce biodiversity and genetic variability.



**Figure 1. Trends in Reported Deer-Vehicle Collisions in Virginia: 1968-2003. Values for some years are not shown because of changes in methodology.**

With the increase in animal-vehicle collisions and fragmentation of wildlife habitat across the United States, various mitigation measures have been researched. Most efforts employed by transportation agencies have focused on reducing collisions with ungulates (hooved mammals). The use of deer crossing signs is the most widely used effort to reduce collisions, but they have generally been found to be ineffective (Knapp et al., 2004). Wildlife reflectors, which reflect vehicle headlights to deter deer from entering the roadway, have also not been found to be effective (Cottrell, 2003; Rogers, 2004). More advanced technologies are currently being tested. These include electronic signs with varying warning messages and signal systems that detect large animals and trigger solar-powered blinking lights to alert drivers (Huijser, 2005).

Wildlife crossings, or passages beneath or above a roadway, are a form of mitigation designed to facilitate safe wildlife movement across a transportation corridor. In a literature review of 16 mitigative techniques to reduce DVCs, the only measures consistently found to achieve DVC reductions were the installations of exclusionary fencing and wildlife crossing structures (Knapp et al., 2004). Similarly, the 2003 report issued by the Insurance Institute for Highway Safety regarding methods to reduce DVCs concluded: “Fencing, combined with underpasses and overpasses as appropriate, is the only broadly accepted method that is theoretically sound and proven to be effective” (Hedlund et al., 2003, p. 14).

The longest wildlife crossings monitoring effort, which is still ongoing, is in Banff National Park in Canada. The Trans-Canada Highway that crosses the park has 23 wildlife crossings of varying sizes. From 1996 through 2001, researchers documented 10,506 deer crossings and 603 black bear crossings (among many other species). These highway mitigation measures, including fencing along wildlife crossings, have resulted in a more than 80% reduction in wildlife road-kills and a more than 95% reduction in road-kills for ungulate species (Parks Canada, 2004).

As studies continue to demonstrate the success of such mitigation, pressure to manage road-wildlife conflicts is being felt by transportation agencies across the United States. The State of Arizona was sued as a result of a driver hitting a dead elk along I-40 (*Jerry Booth v. State of Arizona*, 2CA-CV 2003-0097). In a widely publicized court case, the jury awarded the driver \$3.1 million in damages. Much of the reasoning behind the verdict was that the Arizona

Department of Transportation (DOT) did not take preventive action along the highway segment despite the presence of a foreseeable risk (growing elk and human populations) and the existence of a feasible remedy (including wildlife crossings and fencing).

Responding to the need to consider the problem of animal-vehicle collisions and the impacts of roads on wildlife, the 2005 Safe, Accountable, Flexible, and Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) provides funds opportunities to design projects and processes to reduce these impacts. Congress commissioned a comprehensive study on the causes and impacts of wildlife-vehicle collisions and fully funded the Transportation Enhancements program that provides funding for wildlife crossings. An unprecedented provision in this transportation legislation requires that transportation planners consider wildlife conservation during the planning process.

In a growing number of states, various organizations are partnering to add wildlife crossings to their transportation systems. The Florida DOT, which in 1970 constructed the first wildlife crossing in the United States, has been a leader in supporting research on the placement, design, and effectiveness of crossing structures. Florida currently has 78 wildlife crossings, and plans are underway for many more. The Arizona DOT has begun construction on 17 wildlife crossings along a 26-mi stretch of highway. The Montana DOT is adding 65 wildlife crossings (to its current 16) over the next 6 years, and California has 113 crossings planned in addition to its 69 existing crossings (Patricia Cramer, personal communication, April 11, 2005).

Most states have few structures designed specifically as wildlife crossings. Research on the use of underpass structures by wildlife is therefore often limited to monitoring wildlife use of underpasses designed for other purposes. Structures such as bridges or culverts that were constructed to span streams and rivers, protect wetlands, or provide access for farm animals or equipment may function as wildlife crossings.

Although there is evidence to conclude that wildlife crossings are used by various species in different parts of the world, relatively few rigorous studies exist. Most studies do not include predefined criteria for what constitutes the success of a crossing (Forman et al., 2003). Another research gap includes sufficient evaluations of crossing structures in the eastern United States.

Virginia has multiple structures throughout its roadway system that are likely used by wildlife. VDOT has constructed two structures designed for large mammal passage in northern Virginia, and others are currently under construction on Route 17 through the Great Dismal Swamp. However, VDOT has no information regarding the performance of any of its structures in terms of facilitating animal movement or reducing animal-vehicle collisions. Of the species that pose the highest risk in Virginia, namely white-tailed deer and black bear, research is limited on the structural and location attributes of effective crossing structures.

## **PURPOSE AND SCOPE**

The purpose of this study was 2-fold: (1) to determine the effectiveness of VDOT's existing large mammal crossings, and (2) to determine the design and location attributes that

make a wildlife crossing successful in terms of use by Virginia's large mammals and the associated influence on animal-vehicle collisions.

## **METHODS**

### **Overview**

Seven underpass structures in Virginia were chosen to obtain a representative sample of structures beneath Virginia roadways that potentially function as deer and black bear crossings. Ten independent variables including structural, landscape, and human activity attributes were measured at each site. The sites were monitored from June 2004 through May 2005 for use by large mammals. The data were then analyzed to determine the effectiveness of the underpasses and the design and location attributes that contribute to a successful underpass.

Specifically, eight tasks were conducted to achieve the study objectives:

1. Conduct a comprehensive search of the literature specifically addressing structures effective for white-tailed deer or black bear.
2. Select underpass study sites in Virginia, and collect design and location attribute data.
3. Develop deer habitat suitability indices around the sites.
4. Monitor the sites for use by large mammals.
5. Analyze DVC data relative to the location of the sites.
6. Determine the effectiveness of the underpasses with regard to their use by large mammals.
7. Determine the attributes of effective underpasses.
8. Analyze the costs of wildlife crossings relative to the potential property damage savings from a reduction in DVCs.

### **Literature Review**

A literature review was conducted to gather information on wildlife crossings in terms of the influence that structural features, landscape attributes, and placement considerations have on wildlife use. A summary table was created based on a more focused review of studies that specifically address the use of structures by white-tailed deer and black bears. Multiple online databases were searched, including TRIS, WorldCat, and Transport. Literature sources were also found through multiple websites related to wildlife crossings, such as the Federal Highway



Administration's Critter Crossings (<http://www.fhwa.dot.gov/environment/wildlifecrossings/main.htm>) and Wildlife Crossings Toolkit (<http://wildlifecrossings.info>).

## **Selection of Study Sites, Collection of Attribute Data, and Development of Deer Habitat Suitability Indices**

### **Site Selection**

The two existing and completed structures in Virginia that were designed as crossings for large mammals were selected. Wildlife biologists and VDOT personnel (district engineers, environmental managers, and culvert and bridge maintenance employees) were asked to provide locations of other underpasses potentially used by wildlife. Final sites were selected to capture the size range of potentially successful structures. Sites chosen were surrounded with suitable large mammal habitat on both sides of the structures. Time, budget, and personnel limits dictated the feasible number of sites for the study.

### **Collection of Attribute Data**

Ten independent variables including structural, landscape, and human activity attributes were measured at each site. The selection of variables was based on relevant habitat preferences for deer and black bears and factors found to influence underpass use in other studies.

The 10 variables were as follows:

1. width
2. height
3. length
4. openness
5. structure floor (whether natural or a manmade material)
6. fencing (whether present or absent)
7. distance to forest cover
8. distance to drainage
9. human use
10. traffic intensity.

Openness has been found to be a significant factor in determining the relative effectiveness of structures in terms of use by deer and other species (Reed et al., 1975). Openness is largely a measure of ambient light in the passage; the larger the factor, the less of a narrow "tunnel" appearance of the structure. The openness factor was calculated by the following:  $(\text{height} \times \text{width}) / \text{length}$  (Reed et al., 1975). Traffic intensity was based on an average annual daily traffic of high (10,000-49,999), medium (1,000-9,999), and low (0-999).

## Development of Deer Habitat Suitability Indices

To make valid comparisons of underpass use by deer, it was necessary to quantify either deer population or deer habitat suitability in the vicinity of each underpass. Because the size of the deer population immediately surrounding each site was unavailable, deer habitat suitability indices were developed. The higher the index, the higher the relative deer habitat suitability was surrounding the underpasses. These indices were later used in the statistical analyses of underpass use.

Much of the development of deer habitat suitability indices was adapted from the work of Clevenger et al. (2002a,b) and Clevenger and Waltho (2005). They found that a model generated by a geographic information system (GIS), using habitat information derived from expert literature to perform pairwise comparisons, most closely approximated an empirical model for identifying black bear habitat. For the development of deer habitat suitability indices for this study, a similar methodology was applied with the use of ArcGIS® (Environmental Research Institute, Redlands, California) and a pairwise comparison matrix (Saaty, 1977).

National Land Cover data were obtained from the U.S. Geological Survey (2005) and imported into ArcGIS®. This dataset included 13 habitat types in the areas surrounding the underpass sites. Because the home range of deer is generally no larger than 1 mi (Severinghaus and Cheatum, 1956), a 1-mi buffer was generated around each underpass site. The ArcGIS® Spatial Analyst extension was then used to determine the percentage of each habitat type within each 1-mi radius.

For the pairwise comparison, each of the 13 habitat types was rated against the other in terms of relative importance of the habitat for white-tailed deer. Ratings were based on a nine-point continuous scale: 9, extremely more important; 7, very strongly more important; 5, strongly more important; 3, moderately more important; 1, equally more important; 1/3, moderately less important; 1/5, strongly less important; 1/7, very strongly less important; and 1/9, extremely less important (Saaty, 1977). Information on which to base deer habitat ratings was obtained from four sources: Harlow (1984), Newson (1984), Shrauder (1984), and Whittington (1984); the latter three were directly relevant to deer in Virginia. Two persons, including the investigator, used the information from these sources to complete the pairwise comparison matrix (see Table 1). The comparisons resulted in weights for each habitat type. A consistency ratio was

**Table 1. Example of Pairwise Comparison Matrix for Assessing Relative Importance of Deer Habitat<sup>a</sup>**

	<b>Deciduous Forest</b>	<b>Low-Intensity Residential</b>	<b>Commercial/Transportation</b>	<b>Pasture/Hay</b>
<b>Deciduous Forest</b>	1	3	9	4
<b>Low-Intensity Residential</b>	1/3	1	8	1/3
<b>Commercial/Transportation</b>	1/9	1/8	1	1/7
<b>Pasture/Hay</b>	1/4	3	7	1

<sup>a</sup>Only four of the 13 habitat types used in the actual matrix are shown.

calculated to ensure consistency in rating development. Pairwise comparison matrices with consistency ratios greater than 1.0 were reevaluated (Saaty, 1977). The percentage of each habitat type (derived from the GIS analyses) within the 1-mi radius of each site was then multiplied by its weight (derived from the pairwise comparison). The weighted values for the site were summed to derive a deer habitat suitability index. This method was repeated for each selected site.

### **Monitoring for Use by Large Mammals**

Data from monitoring animal movements were obtained from Game-Vu (Nature Vision, Inc.) and Stealth Cam® digital scouting cameras. These remote cameras photograph images based on infrared heat and motion sensors. Game-Vu Digital Trail cameras use undetectable infrared illumination at night rather than a flash and were installed at sites where human visitation was a concern. Stealth Cam® cameras were used at the other sites because of their slightly longer range at night. Two cameras were installed at each site. For box culvert monitoring, one camera was attached to a tree, to a wooden post, or near the ground at each entrance of the structure. For bridge monitoring, two cameras were attached to trees on each end of the bridge. Because cameras could not capture the entire range beneath the one site (the Site 2 bridge), sand beds at each end of the bridge were checked weekly for large mammal tracks to supplement camera monitoring.

Structures were visited once every week during the 12-month period to download photographs from the cameras and replace batteries. Data recorded from photographs at each site included the date, time, number of photographs of each species, and direction of travel. The number of completed passages through the structure by deer and black bear, the number of turn-around events (approaches to an underpass with incomplete crossings), and the number of hesitancy behaviors by deer (indicated by muzzles lowered to the ground; Gordon and Anderson, 2003; Reed et al., 1975) were determined.

On some occasions, camera battery power depleted 1 to 2 days prior to replacement. To account for site differences in camera operative days, crossing frequency indices were calculated by dividing the number of crossings by deer and black bear at each site by the respective number of camera operative days.

### **Determination of Deer-vehicle Collisions Relative to Underpass Locations**

Using available information obtained from Virginia's Highway Traffic Records Information System and Fairfax County police records, the number and locations of DVCs reported from 1997 through 2001 and 1995 through 2004, respectively, were recorded within several miles of each monitored site used by deer. Because only reported collisions are included in these records, however, a potentially large percentage of the actual collisions that occurred was unavailable for analysis.

## Determination of Effectiveness of Underpasses

### Data Analyses

Average daily deer crossing frequency indices (total number of deer crossings divided by total number of camera operative days) at each site were evaluated according to the 10 independent variables described previously and the deer habitat suitability indices.

Multiple regression analyses were performed to determine the influence of underpass attributes on deer crossing frequency. Statistical analyses were performed with the assumption that the crossing frequency was a measure of the quality of the underpass as sensed by wildlife. For all analyses, differences were considered statistically significant when  $p < 0.05$ .

Two of the sites (Sites 3A and 3B) potentially facilitate the movement of the same populations of animal species, but they differ in structural and landscape attributes. The use of these structures by all species was therefore compared to obtain valuable information on animal preferences for crossing structures.

### Criteria for Success

To evaluate an underpass in terms of its effectiveness in reducing the barrier effect of roads and reducing animal-vehicle collisions, it was necessary to specify the criteria for success. The goals and criteria defined in Table 2 were adapted from the goals and measurements recommended by Forman et al. (2004). The goals were measured using data obtained from camera monitoring.

**Table 2. Goals and Criteria Regarding Effectiveness of Underpass for White-Tailed Deer and Black Bear**

Goals	Criterion for Success
1. Maintain habitat connectivity	Minimum passage of animals detected
2. Maintain genetic interchange	Passage by adults (primarily males in breeding season)
3. Allow for dispersal	Evidence of juvenile passage

### Determination of Attributes of Effective Underpasses

Data from the monitoring of the Virginia underpasses and the findings of the literature review were used to determine the attributes of effective underpasses.

### Cost Analysis

To transportation agencies, cost is often the largest deterrent to the construction of wildlife crossings. Because there are currently no regulatory directives or guidelines pertaining to wildlife crossings, decisions by transportation agencies to construct them are often based on the expected return in investment. This may be in the form of ecological benefits, increased driver safety, and cost savings to taxpayers. Ecological benefits include the creation of wildlife

corridors, reduced effects of fragmentation (Forman et al., 2004), and reduced road mortality. Driver safety includes a reduction in animal-vehicle collisions and the corresponding reduction in deaths, injuries, and property damage, which translates into savings for taxpayers. With regard to taxpayer savings, one human fatality from a DVC can result in a loss of millions of dollars in damage, hospital costs, and lost wages. Property damage costs alone comprise a substantial taxpayer cost.

Since assigning a monetary value to ecological benefits is difficult, the cost savings in terms of a reduction in property damage were analyzed for comparison with wildlife underpass costs. Property damage values were derived from the 2003 average cost in property damage from DVCs in Virginia (\$2,530).

Construction costs for two effective underpasses in this study, Sites 1 and 3A, were estimated to include in the analyses. Calculations were based on price per cubic yard estimates using underpass dimensions and fill heights (Site 1: 10 by 12 by 189 ft; Site 3A: 20 by 15 by 192 ft). Annualized costs, or the equivalent uniform annual costs, were calculated for these underpasses for comparison with yearly average property damage costs from DVC incidents. Annualized costs in these examples are the yearly costs of an underpass as if they were uniform throughout the service life of the structure. The final annualized construction cost was estimated for a culvert that, if not for wildlife considerations, would have been constructed as a standard 60-ft corrugated steel drainage pipe. The annualized cost of a standard corrugated steel drainage pipe ( $AC_P$ ) was therefore subtracted from the annualized cost of an enlarged structure that can also facilitate wildlife passage ( $AC_{UF}$ ). The final annualized construction cost for an underpass with fencing ( $AC$ ) was calculated by the formula

$$AC = (AC_{UF} = C_U r / 1 - (1 + r)^{-T^u}) - (AC_P = C_P r / 1 - (1 + r)^{-T^p})$$

where

$C_U$  = construction cost for the underpass and fencing

$C_P$  = construction cost for the drainage pipe

$r$  = interest rate (estimated at 0.05)

$T^u$  = service life for the underpass

$T^p$  = service life for the drainage pipe.

$C_U$  was first estimated by calculating the number of cubic yards per linear foot for box culverts with the size dimensions and fill height of Sites 1 and 3A. The price per cubic yard was obtained by averaging all VDOT contract bids ( $N = 33$ ) over an 18-month bid history (ending November 2004) for concrete Class A4 box culverts.  $C_P$  was estimated at \$125,000 (Matthew Dana, personal communication, June 21, 2005). The service life of structures, 35 years for  $T^p$  and 70 years for  $T^u$ , were based on findings from NCHRP Synthesis 254 (Blackwell and Yin, 2002). Fencing prices were estimated at \$125,000 (Jack McCambridge, personal communication, September 16, 2004).

## RESULTS AND DISCUSSION

### Literature Review

Although the literature on wildlife crossings continues to grow, it is fairly limited in terms of what is successful for large mammals found in the eastern United States. Table 3 provides information on structures shown to be used by white-tailed deer and black bears. The values illustrate the large range in size and cost of wildlife crossings used by these species.

### Selected Sites, Structure Attribute Data, and Deer Habitat Suitability Indices

#### Selected Sites

Seven underpass structures throughout Virginia were selected for monitoring (Figure 2). Because most of the structures were not designed as wildlife crossings, study sites are generally referred to as “underpasses” or “structures” rather than wildlife crossings in this report. Five of the structures (Sites 1, 2, 4, 5, and 6) were not specifically designed for wildlife movement, and two were (Sites 3A and 3B). Most structures carry water (generally a narrow, perennial stream) and offer plenty of dry substrate for animals to use when crossing.

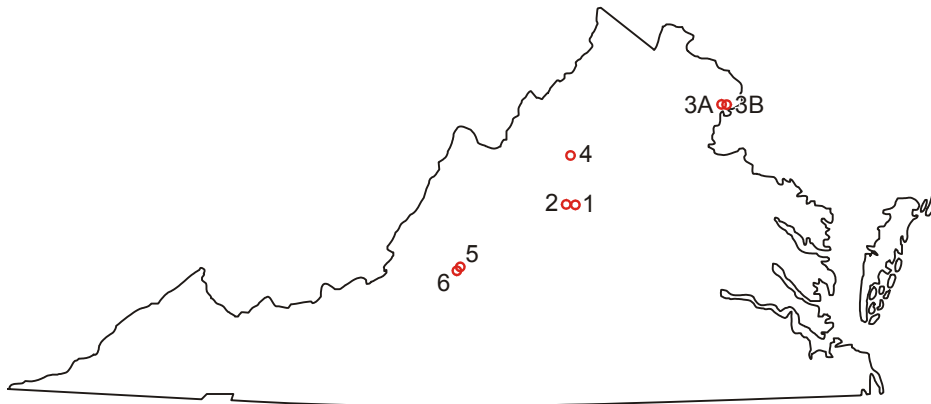


Figure 2. Locations of the Seven Underpass Study Sites

#### Site 1

Site 1 is beneath I-64 along the western perimeter of Charlottesville (Figure 3). The underpass is a single-barrel box culvert that measures 10 by 12 by 189 ft. It was installed during the construction of I-64 in 1968 so that cattle and farm equipment could access both sides of the highway. The floor of the culvert is covered with a layer of dirt, which becomes muddy with heavy rain. The surrounding habitat is heavily forested, with an abandoned dirt road (now covered with leaf litter and emergent vegetation) extending from both ends of the crossing. Fencing, which is the most extensive of all monitored sites, extends in a funnel shape approximately 0.5 mi from each end of the box culvert. The fence was likely installed when the underpass was constructed to prevent cattle from approaching the highway and has fallen along some segments because of lack of maintenance.

**Table 3. Attributes, or Recommended Minimum Attributes Based on Authors' Conclusions, of Structures Used by (or Proposed for) White-Tailed Deer and Black Bear**

Structure	Deer/ Bear	Width (ft)	Height (ft)	Length (ft)	Openness <sup>a</sup>	Fencing (ft)	Cost <sup>b</sup>	Location	Source
<b>Bridges</b>									
	Deer	NA	43	120	-	4,600 (average)	NA	Florida	Foster & Humphrey (1995)
	Both	69.6-84.6	6.9-7.9	159.1 with 72 ft open median	0.92- 1.28	210,000	NA	Florida	Roof & Wooding (1996)
Extension	Bear	NA	NA	154.2	-	NA	\$433,000 (extension only)	Florida	Macdonald & Smith (1999)
Proposed	Deer	30	13.5	86	0.76	NA	\$1.5 million	Colorado	Colorado DOT & FHWA (2001)
<b>Culverts</b>									
	Both	11.5 <sup>c</sup>	9.8 <sup>c</sup>	-	0.25 <sup>c</sup>	NA	NA	Florida	Smith (2003)
Box	Both	25	8	47	1.23	5,800	\$870,000	Florida	Land & Lotz (1996)
Corrugated steel	Deer	12.1	7.5	90.6	0.31	None	NA	Montana	Foresman (2004)
Corrugated steel	Deer	11.5	12.3	213.3	0.20	None	NA	Montana	Foresman (2004)
Elliptical metal	Both	23.0	13.1	NA	NA	NA	\$150,000- \$170,000	Alberta, Canada	Forman et al. (2003)
Corrugated metal pipe bottomless arch; proposed	Deer	24	12	178.6	0.48	NA	\$150,000	Colorado	Colorado DOT & FHWA (2001)
<b>Overpasses</b>									
	Both	170.5	NA	NA	-	NA	\$1.15 million	Alberta, Canada	Forman et al. (2003)
	Deer	52.5	NA	200	-	NA	\$3.2 million	Florida	FHWA (2000)

<sup>a</sup>Calculated using metric measurements of structure: (height x width)/length.

<sup>b</sup>Approximate cost of unit. Some costs (not specified in literature) also include materials cost.

<sup>c</sup>Recommended minimum size based on study conclusions.



**Figure 3. Site 1: Single-barrel Box Culvert West of Charlottesville**

### *Site 2*

This underpass is a bridge along the eastbound lane of I-64 5 mi west of Site 1 (Figure 4). The bridge is 307 ft long and was constructed in 1969 to span the Mechum River. The river width is approximately 45 ft, with approximately 10-ft-wide grassy strips on each side to allow the passage of farm vehicles. The remaining area beneath the bridge is sloped with sandy substrate. The surrounding habitat comprises a mixture of trees and open farmland. Bridges such as these have been constructed in some states solely as wildlife underpasses, although they are among the most expensive crossings to install.



**Figure 4. Site 2: Eastbound Bridge on I-64 West of Charlottesville**



### Site 3

Two single-barrel box culverts, approximately 0.25 mi apart, are situated beneath the Fairfax County Parkway (Figure 5). Because both culverts likely facilitate the movement of some of the same wildlife populations, they are useful for comparative purposes and are referred to as subsets of one site. These structures were designed as wildlife crossings, and installed during the construction of the parkway. Site 3A is 20 by 15 by 192 ft and has a small stream along one side of the open bottom. Site 3B is 10 by 6 by 105 ft and has a concrete bottom that allows for drainage during wet weather conditions. Approximately 40 ft of fencing was constructed along the road above both culverts. Both structures are in close proximity to wooded areas on each side. A large portion of the ceiling in the center of each structure consists of metal grating, installed to allow in light and thereby encourage deer use.



**Figure 5. Sites 3A and 3B: Single-barrel Box Culverts 0.25 Mi Apart Beneath Fairfax County Parkway**

### Site 4

Site 4 is a triple-box culvert 6 by 6 by 68 ft beneath Route 340 approximately 22 mi north of Waynesboro and just west of the Shenandoah National Park (Figure 6). Although the culvert was installed to allow stream passage, its location and size make it potentially suitable as a crossing for bear or other wildlife. The Virginia Department of Game and Inland Fisheries has studied bear populations in the area and in a 10-day period found more than 15 bears using a trail that crosses U.S. 340 to access cornfields. The box culvert is along the same section of Route 340 in which bear-vehicle collisions have occurred, including one in which the driver was killed. Installing fencing on each side of the culvert to direct bears to the culvert was considered but did not occur because the fencing would have encroached on private property.



**Figure 6. Site 4: Triple-box Culvert Beneath Route 340 North of Grottoes**

*Site 5*

Site 5 is located beneath I-81 just north of Buchanan in Botetourt County. This structure is a double-box culvert with a concrete floor (Figure 7). Each box measures 8 by 18 by 63 ft and facilitates passage of Cedar Bluff Creek. The water depth in each culvert is rarely greater than 0.5 in. This structure is in the Shenandoah Valley between the Allegheny Mountains and the Blue Ridge Mountains. Black bear inhabit these mountain ranges and cross I-81 to access the forested mountains on both sides of the highway.



**Figure 7. Site 5: Double-box Culvert Beneath I-81 North of Buchanan**

## Site 6

Site 6 is a small bridge approximately 3 mi south of Site 5, also in Botetourt County (Figure 8). The bridge, which spans Purgatory Creek, is beneath I-81 and measures 59 by 44 ft. The creek is approximately one-third the width (20 ft) of the bridge; the remaining substrate consists of rocks and sand. Like Site 5, this structure is in the Shenandoah Valley between the Allegheny Mountains and the Blue Ridge Mountains and potentially provides a passage for black bears traveling across the highway.



**Figure 8. Site 6: Bridge Along I-81 North of Buchanan**

## Attribute Data and Deer Habitat Suitability Indices

The attribute data and the calculated deer habitat suitability indices are shown in Table 4.

### Underpass Use

#### Black Bear and Deer Activity

A total of 2,702 photographs of wildlife were captured at the seven sites over a 12-month period. Six of these photographs were of black bears, and 1,040 were of white-tailed deer.

#### *Black Bears*

No black bears crossed through any of the monitored underpasses, although they approached the northern entrance of Site 1 on three occasions (June 10, September 5, and September 20; Figure 9). The bear photographed in September had an ear tag and was therefore likely the same individual. On two occasions, the bear faced the culvert entrance for 2 minutes prior to turning and leaving the area. On September 20, the bear approached the entrance a second time 38 minutes after the first approach.

**Table 4. Attributes of Underpass Structures in Virginia Monitored from May 2004 through May 2005**

Attribute	Structure						
	1 Box Culvert	2 Bridge	3A Box Culvert	3B Box Culvert	4 Triple Box Culvert	5 Double Box Culvert	6 Bridge
<i>Structural</i>							
Width (ft)	10	32	20	10	6	8	44
Height (ft)	12	45	15	6	6	8	15
Length (ft)	189	307	192	105	68	260	59
Openness (m) <sup>a</sup>	0.19	1.43	0.64 <sup>b</sup>	0.17 <sup>b</sup>	0.16	0.07	3.42
Structure floor	Natural	Natural	Natural	Concrete	Concrete	Concrete	Natural
<i>Fencing</i>							
	Present	Absent	Present	Present	Absent	Absent	Absent
<i>Landscape (distance to)</i>							
Forest cover (ft)	0	15	12	5	7	0	50
Drainage (ft)	320	0	0	0	0	0	0
<i>Human activity</i>							
Human use	3	17	10	5	1	1	2
Traffic intensity <sup>c</sup>	H	H	H	H	M	H	H
<i>Deer habitat suitability index<sup>d</sup></i>							
	72.20	74.15	65.68	67.91	72.41	62.56	64.40

<sup>a</sup> Openness was determined by calculating (height x width)/length (Reed et al., 1975).

<sup>b</sup> Because the ceilings of structures 3A and 3B have a grated center section that allows in light, the openness value was calculated using ¾ of the length.

<sup>c</sup> Based on average annual daily traffic of High (10,000-49,999), Medium (1,000-9,999), and Low (0-999).

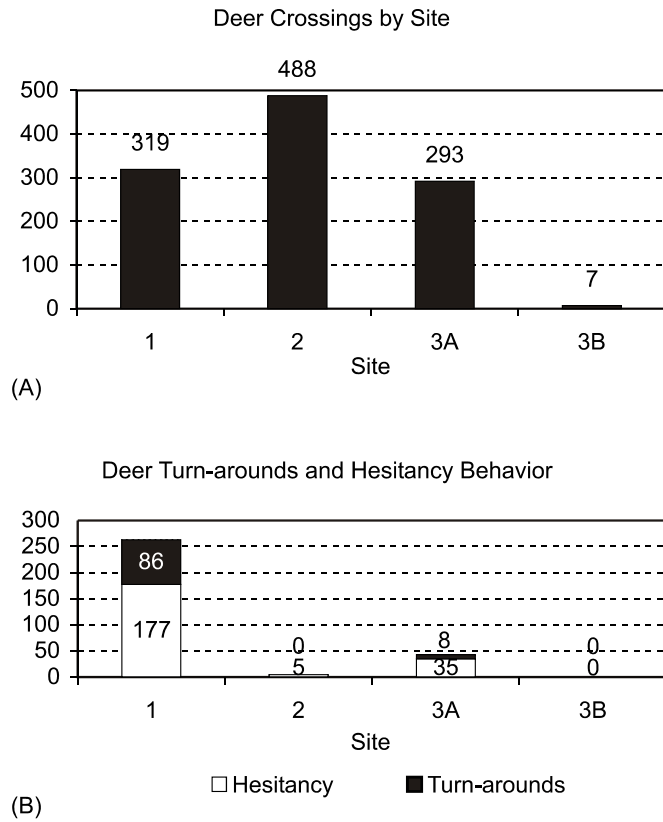
<sup>d</sup> Based on a scale of 1 to 100. Land use was similar in the immediate surroundings of study sites, reflected by the proximities of the indices.



**Figure 9. Black Bear(s) Approaching Northern Entrance of Site 1. Bears did not cross through the underpass on any occasion.**

### Deer

A total of 1,107 deer crossings occurred through four of the seven underpass sites in the 12-month study period ( $\bar{x} = 277$ ,  $N = 4$ ). Sites 1, 2, and 3A received the heaviest use, and Site 3B the least. There were no crossings or visits by deer at Sites 4, 5, and 6; the analyses in this section therefore excluded these sites. The number of crossings was highest for Site 2 (Figure 10A). Although Site 1 received relatively high use by deer, it also had the highest number of turn-around events and hesitancy behaviors (Figures 10B and 11).



**Figure 10. Number of White-Tailed Deer Crossings (A) and Number of Turn-Arounds and Hesitancy Behaviors (B) for Underpasses Visited by Deer from June 2004 through May 2005**



**Figure 11. Deer Hesitancy Behavior**

The crossing frequency index was highest and most consistent at Site 2, with 1.34 crossings per day. Site 1 averaged 1.1 crossings per day; Site 3A averaged 0.91 crossing per day; and Site 3B received relatively little use, at 0.02 crossing per day. The monthly crossing frequency indices for each site peaked in the autumn months, dropped steeply in winter, and rose in late spring. During the period of heaviest activity in the fall, Site 1 received the heaviest use, with an average of 4.7 crossings per day in September (Figure 12). This corresponds to greater periods of movement associated with mating and feeding activities. Throughout the year, deer used underpasses at all times of the day, with peak activity occurring at dusk.

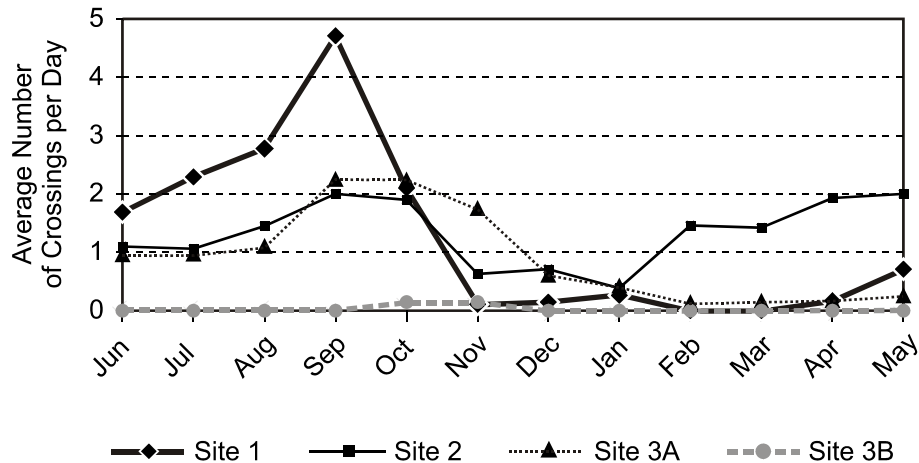


Figure 12. Average Number of White-Tailed Deer Crossings per Day Each Month from June 2004 through May 2005

### Other Wildlife Activity

Although the focus of this study was large mammal use of underpasses, the number and species of other wildlife were also recorded. Each underpass site was used by a minimum of two species. Other species detected included opossum, squirrel, house cat, bobcat, red fox (Figure 17A), coyote (Figure 17B), raccoon (Figure 17C), groundhog, mice species, amphibian species (southern leopard frog and American toad), black rat snake, at least two bird species (songbirds and a great blue heron), and fish species. Cameras at Site 3A photographed a coyote with a small mammal in its mouth (species cannot be determined). Nocturnal species used the underpasses between dusk and dawn, with daytime use generally limited to deer and groundhog (Figure 18).

Because of the proximity and similar landscape attributes of Sites 3A and 3B, the sites were useful for comparing use by different species. Activity was greater for all species in Site 3A, with 1,177 photographs, compared to Site 3B, with 708 photographs (Figure 19). Because amphibian, reptile, mouse, and fish use of the underpasses was observed but not detected by cameras, they were not included in the analyses.



Figure 13. White-tailed Deer Using Site 1 Box Culvert



Figure 14. White-tailed Deer Crossing Beneath Site 2 Bridge



Figure 15. White-tailed Deer Using Site 3A Box Culvert



Figure 16. White-tailed Deer Using Site 3B Box Culvert

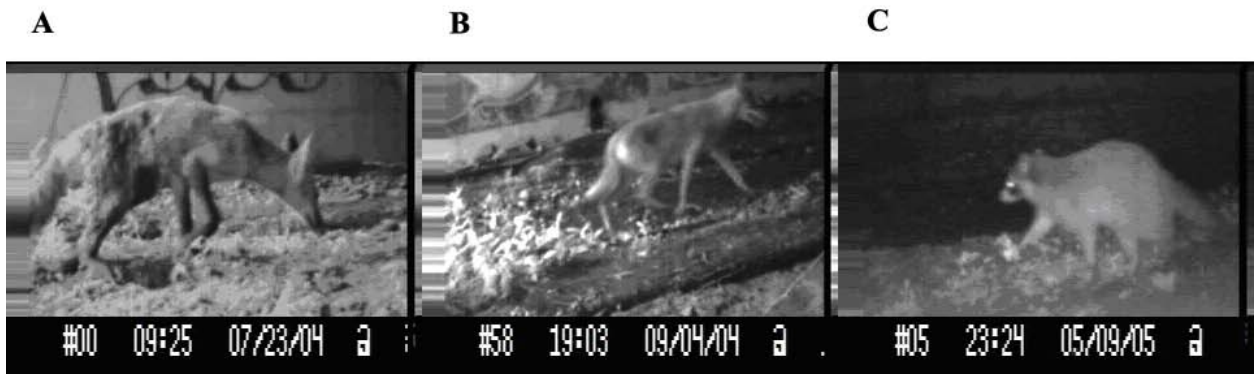


Figure 17. Red Fox (A), Coyote (B), and Raccoon (C) Using Site 3A Box Culvert

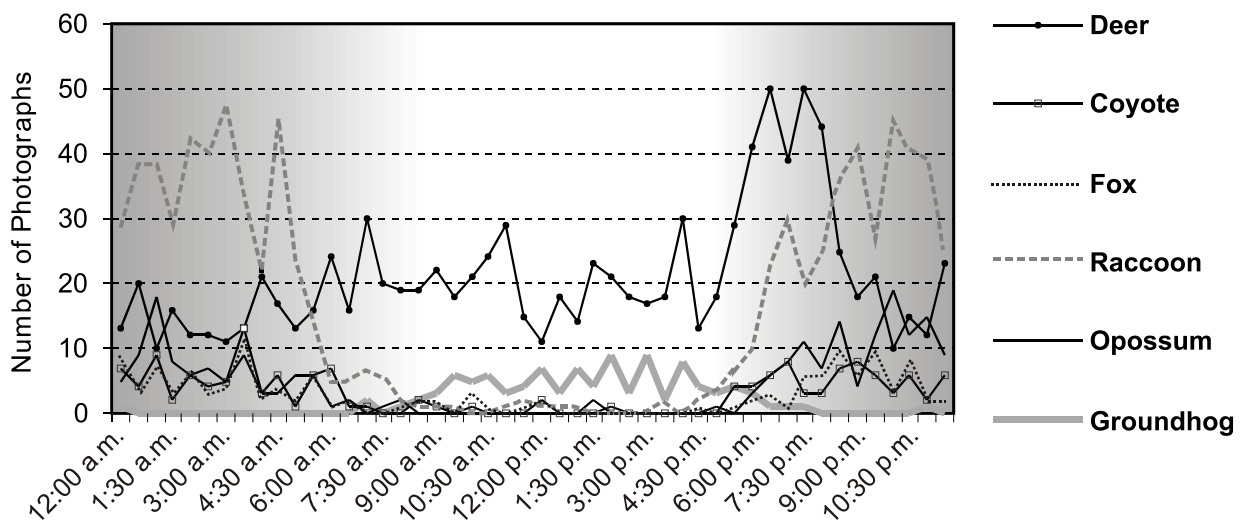
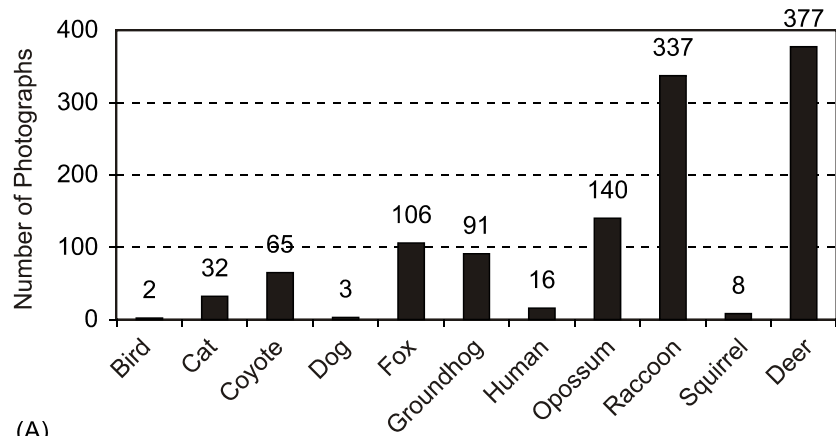
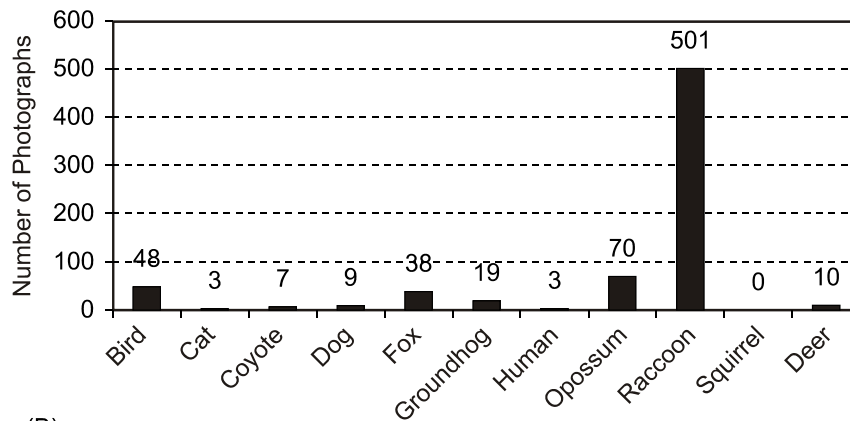


Figure 18. Number of Photographs by Time of Day of Six Species Detected at the Seven Underpasses





(A)

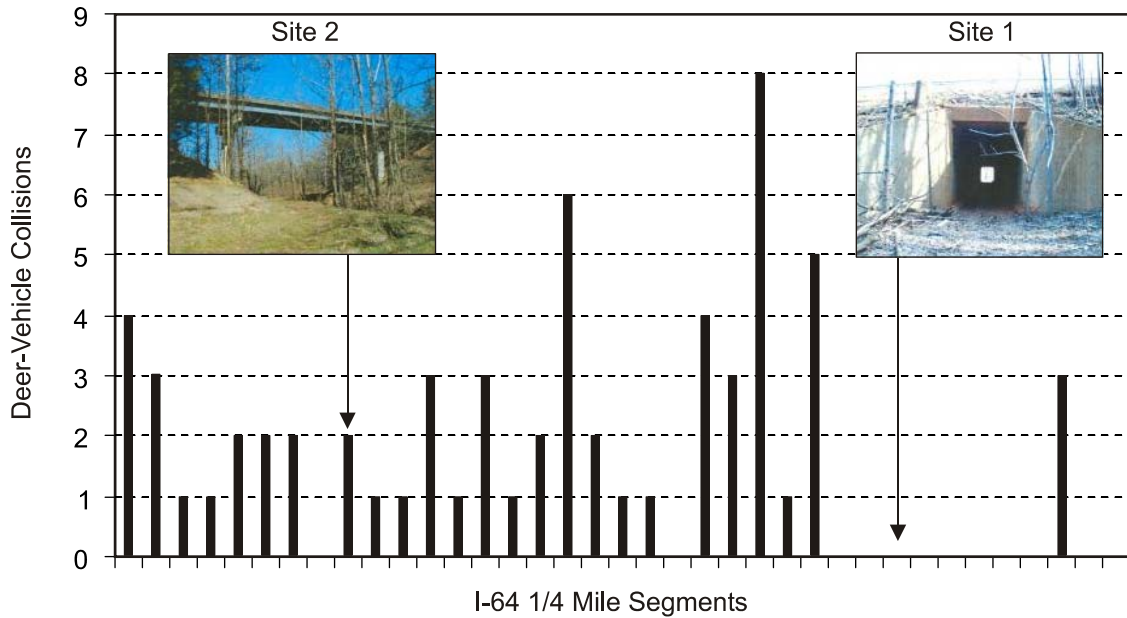


(B)

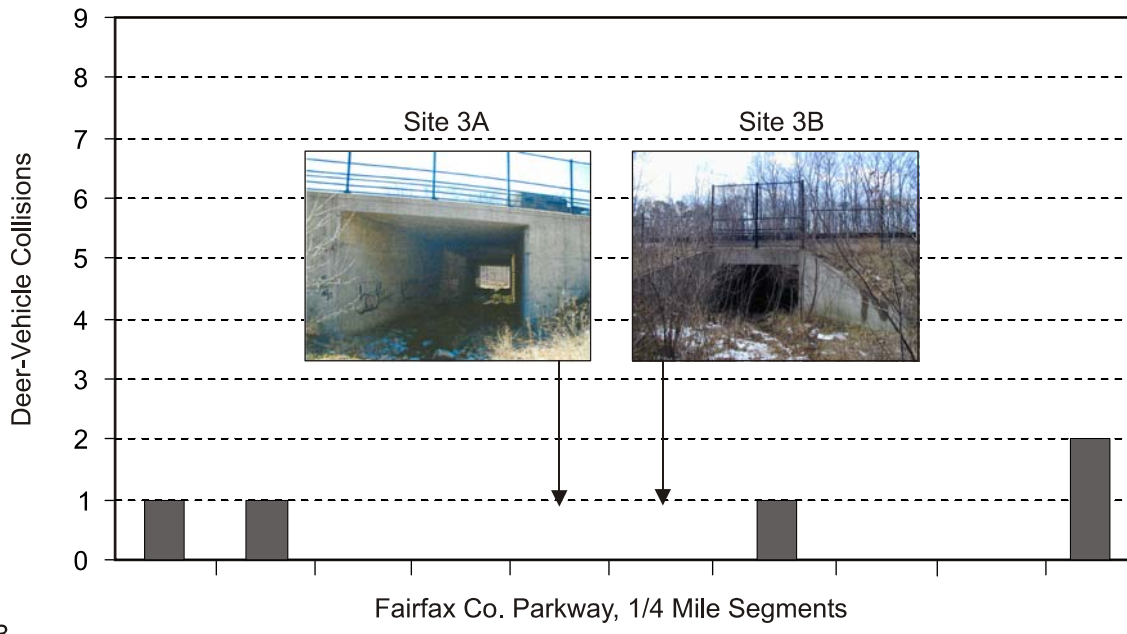
**Figure 19. Number of Photographs in Sites 3A (A) and 3B (B) Taken by Two Cameras at Each Site**

### **Deer-Vehicle Collisions Relative to Underpass Locations**

Small sample sizes restricted the statistical analyses of the number of DVCs immediately surrounding the underpasses relative to segments with no underpasses. These data were therefore depicted graphically to illustrate the number of DVCs adjacent to underpass locations (Figure 20). For Site 1, there were no reported DVCs 0.75 mi to the west and 1.25 mi to the east of the underpass within a 5-year period (1997-2001) for which data were available. At the section east of the underpass, a high ridge prevents deer from entering the highway. Within the 2.5-mi road segment (flanked by two perpendicular roads) under which Sites 3A and 3B lie, there were five DVCs within a 10-year period (1995 through 2004).



A



B

**Figure 20. Reported Deer-vehicle Collisions in Relation to Location of Underpasses Used by White-tailed Deer. DVC data for I-64 (A) include a 5-year period (1997-2001), and data for the Fairfax County Parkway include a 10-year period (1995-2004).**

### Effectiveness of Underpasses Monitored

Black bears approached but did not cross through any of the underpass sites. Because of annual fluctuations in food availability, environmental conditions, and inter- and intraspecific

interactions, however, 1 year of data collection is not sufficient to conclude that these structures are unsuitable for bears (Manen et al., 1995).

Table 5 shows the effectiveness of each underpass in terms of use by deer. Sites 1, 2, and 3A were determined to be effective road-crossing mechanisms for deer. The high crossing frequencies at these sites and the relatively low incidents of DVCs (particularly at Sites 1 and 3A) suggest that these underpasses are beneficial in terms of both habitat connectivity and driver safety.

The other sites were ineffective in terms of facilitating deer passage. For most sites, this was a result of the structure's small size and corresponding low openness factor. For the bridge of Site 6, this was not the case. At this site, the structure size was adequate, but the uneven approach and lack of visibility from one end to the other likely discouraged large mammal use. At the western opening of this bridge, a 4-ft ledge slightly impeded access to the area beneath the bridge, and the ledge and a rock cliff obstructed views of the habitat on the far side of each entrance. Effective underpasses were easily accessible with level approaches and had clear lines of site to the habitats on the far side.

**Table 5. Goals Measured and Success Determined for Use of Seven Underpasses by White-tailed Deer from June 2004 through May 2005**

Goals	Criterion for Success	Site						
		1	2	3A	3B	4	5	6
1. Maintain habitat connectivity	Minimum passage of deer detected	Yes 319	Yes 488	Yes 293	No <sup>a</sup> 7	No 0	No 0	No 0
2. Maintain genetic interchange	Passage by adults (primarily males in breeding season)	Yes	Yes	Yes	Yes	No	No	No
3. Allow for dispersal	Evidence of juvenile passage	Yes	Yes	Yes	No	No	No	No

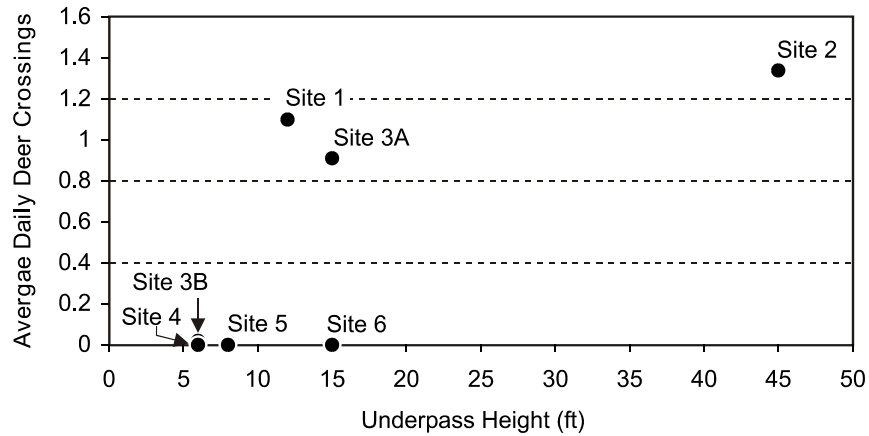
<sup>a</sup>Based on a comparison of the number of crossings at Site 3B relative to that at Sites 1, 2, and 3A, it is unlikely that 7 crossings over a 1-year period adequately met the goal of maintaining habitat connectivity. It is possible that the proximity of 3B to 3A influenced the crossing frequency at 3B.

## Attributes of Effective Underpasses

### By Species

#### *White-tailed Deer*

A large discrepancy in deer crossing frequency was apparent between structures with a height greater than or equal to 12 ft and those with a height less than 12 ft. To represent this distinction, height values were differentiated into these height groupings. Adjusting for deer habitat suitability at each site, a minimum underpass height of 12 ft was significantly correlated to crossing frequency (Beta = 0.78 ± 0.20, *P* = 0.047; Figure 21). Landscape and human activity variables were not significantly correlated to crossing frequency. Although not found to be statistically correlated to crossing frequency (possibly because of the sample size), attributes of successful structures included a minimum openness of 0.19, natural floors, forest cover within 15 ft of structure openings, and a level approach with clear visibility of the habitat on the other side.



**Figure 21. Average Daily Deer Crossing Frequency from June 2004 through May 2005 in Relation to Underpass Height**

The bridge (Site 2) had the highest deer passage rate and lowest number of incidents of hesitancy behavior and turn-arounds. This was expected because of its large size and lack of walls, unlike the box culverts at Sites 1 and 3A. Based on the success of Sites 1 and 3A in facilitating deer passage, structures the size of Site 2 are likely not the most cost-effective if constructed solely to facilitate deer passage.

Although Site 1 received the second highest number of crossings, 21% of the approaches to Site 1 were associated with turn-arounds. The high number of crossings at this site was likely influenced by the presence of extensive fencing and the structure’s position in the landscape. Despite the fence’s shortcomings (low height and multiple breaks), it may have had a role in guiding deer toward the underpass. In addition to fencing, the southeastern borders along the underpass openings slope to a high ridge. This ridge functioned as a barrier to deer movement across the highway (as evidenced by no DVCs within 1.25 mi east of the underpass), and the surrounding hillsides served as a guideway for deer toward the underpass (Figure 22). Although



**Figure 22. Aerial View of Topographic Features Surrounding the Site 1 Bridge**

the optimal placement of Site 1 undoubtedly contributed to its high use by deer, the high number of hesitation and turn-arounds is likely explained by its relatively low openness index (0.19).

Conversely, the larger structure (Site 3A) had an openness index of 0.64 and a low number of hesitancy behaviors and turn-arounds (3%). Despite the lower deer habitat suitability rating of Site 3A (65.68) compared to Site 1 (72.20), Site 3A had only 26 fewer crossings than did Site 1 throughout the year. In addition, the crossing frequency at Site 3A was more consistent throughout the year than at Site 1. The size dimensions, presence of a creek, and ceiling grating of Site 3A are therefore thought to be more appropriate features for encouraging deer passage than those (or the lack thereof) at Site 1.

Previous studies on deer and other ungulates found that the animals preferred underpasses at least 23 ft wide and 8 ft high (Carsignol, 1993, as cited in Forman et al., 2003; Foster and Humphrey, 1995; McGuire and Morrall, 2000), which is substantially wider (and likely costlier) than what was necessary to achieve a high crossing frequency in this study. Successful underpass dimensions for white-tailed deer in this study were in line with Smith's (2003) minimum height recommendation of 12 ft and minimum width recommendation of 10 ft. The length should be short enough to result in an openness index of at least 0.25 to discourage the high percentage of turn-arounds at Site 1. Lower structures may also be successful if the structure is wide and short (in length) enough to have a high openness index.

### *Black Bear*

Research on black bear size preferences for underpasses is conflicting. Clevenger and Waltho (2005) found that black bears prefer more constricted crossing structures with low heights and narrow widths. Other research has shown bears to use underpasses with larger, more open dimensions, such as bridges and a culvert 25 by 8 by 47 ft (Table 3). The presence of herbaceous vegetation at structure entrances has been found to be important in bear underpass use (Smith, 2003), and distance to nearest drainage was found to be positively correlated with black bear use (Clevenger and Waltho, 2005). The fact that black bears approached Site 1 on three occasions, remaining at the entrance up to 38 minutes but not crossing through, may indicate that its structural dimensions are unsuitable for black bears. Further studies on black bear wildlife crossing preferences are needed.

### *Other Wildlife*

Structures that were effective for deer were also used heavily by other species. With the exceptions of Sites 3A and 3B, cameras were positioned to maximize the likelihood of deer and bear photographs and were therefore not optimally placed for capturing photographs of smaller animals. Because of the low camera positioning and the sites' proximity to each other, Sites 3A and 3B were useful for comparing use by small and medium species. Compared to Site 3B, Site 3A received more use in terms of number of photographs and number of species using the structure. Besides structure size differences, the only perceptible difference between these sites was the structure floor. Site 3A had an open bottom with a creek passing between two areas of dry land, whereas Site 3B had a concrete bottom that remained dry the majority of the year. In

addition to the larger size and natural bottom of Site 3A, the presence of various-sized rocks in the underpass (for cover for small species) also likely influenced its use.

For some animals, the habitat within the underpasses appeared to be a center of activity within their home range. Many of the smaller mammals would enter the underpass in one entrance, remain for several minutes to hours, and leave from the same entrance. Animals, including deer, raccoon, red fox, and a great blue heron, were photographed drinking and/or foraging from the creek in Site 3A on multiple occasions. Raccoons often appeared to be searching for prey. For medium and large animals, the underpasses generally appeared to be a means to access habitat on either side of the road. The photograph of a coyote with a small mammal in its mouth may suggest that carnivores use underpasses for catching prey. Although the coyote may have been carrying the prey from one side of the road to the other, there is some evidence that crossing structures have been used for hunting (Foster and Humphrey, 1995; Hunt et al., 1987).

## **Fencing**

The only structure in this study with extensive fencing was Site 1, although this fence was likely erected with the highway and underpass in 1968 to funnel cattle through the underpass. The 5-ft-tall fence has not been maintained and has several breaks through which animals can easily pass. Despite these shortcomings, it may have had a role in guiding deer toward the underpass and reducing DVCs adjacent to the underpass. Although the Site 2 bridge (which did not have fencing) received the heaviest use by deer, there were higher incidents of DVCs adjacent to the structure than at Site 1.

Fencing extending from underpass openings has been shown to greatly increase the effectiveness of structures. Following fence construction between wildlife crossings along the Trans-Canada highway, ungulate-vehicle collisions decreased by more than 95% (Parks Canada, 2004). The addition of fencing to crossing structures along a Wyoming interstate also significantly reduced DVCs (Ward, 1982). Although studies do not provide clear guidance on fencing lengths, chain link fences that are 10 ft high and 1.1 mi long have effectively funneled deer and black bear through an underpass in Florida (Roof and Wooding, 1996). Deer fencing should have a height of 8 to 10 ft to prevent deer from entering the roadway. Gallagher et al. (2003), however, found that deer stopped using an established feeding area when faced with a 5.5-ft fence constructed of burlap, presumably because they were reluctant to cross a barrier that obstructed their view of the opposite side.

Regular maintenance of fencing is necessary to repair sections damaged by downed trees and limbs. Escape ramps and one-way gates are important components along a fence to prevent wildlife from becoming trapped in the roadway. The Arizona DOT constructed a series of escape ramps 5 to 7 ft high and one-way gates along a fence 8 ft high between underpass structures on S.R. 260 (Brown et al., 1999).

## **Location and Placement**

Views differ regarding the most effective placement of wildlife crossings and whether structural features or location and landscape features are more important in determining a structure's success. Some studies have attributed success to placement, based on optimal location features or along actual travel routes, rather than the dimensions of a structure (Beier and Loe, 1992; Foster and Humphrey, 1995). Topography and watercourses can affect animal movement across a road. Linear guideways such as ridgelines and drainages have been found to correlate with road-crossing hotspots (Barnum, 2003). Designing structures for the dual purpose of drainage and wildlife passage can therefore be cost-effective compared to constructing separate structures.

Other studies have found structural attributes to be more important determinants of a structure's success (Mata et al., 2005). In this study, height was the most important determinant of deer crossing frequency, although placement was also important. The hilly topography around Site 1, for example, seemed to serve as a natural guide for deer toward the underpass (Figure 22), and all sites used by deer were surrounded by suitable deer habitat on both sides of the structures. Deer have likely altered their movement patterns over the years to cross through structures that meet the minimum size requirements, as it is unlikely that the heavily used underpasses (1,107 deer crossings) were coincidentally placed immediately along deer travel routes. Wildlife passage has been found to increase as animals learn a structure's location and become accustomed to it over time (Land and Lotz, 1996; Walker and Baber, 2003).

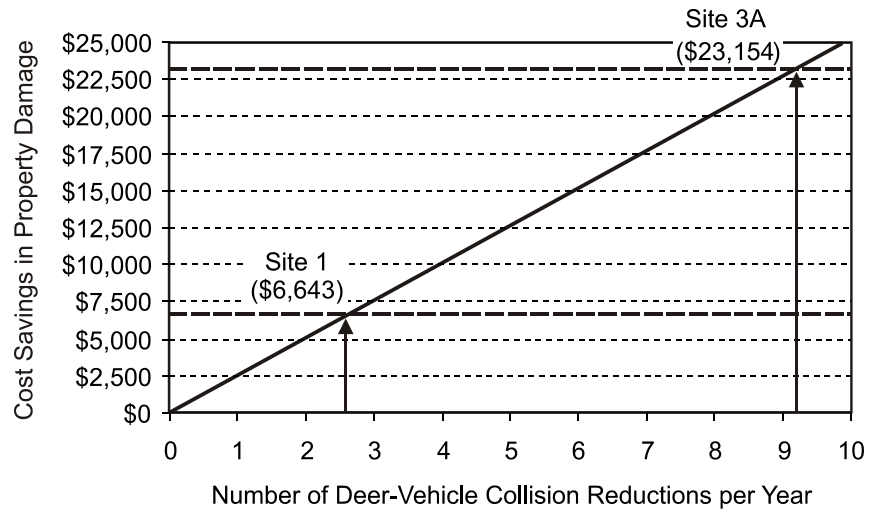
The optimal number and spacing of adjacent wildlife crossings are not well documented. To obtain high passage rates for a variety of species, frequently spaced crossing structures (490 to 980 ft) of varying sizes have been recommended (Clevenger and Waltho, 1999, 2005). Smith (2003) found that a maximum distance of 660 to 820 ft between structures was necessary to sustain 90% passage for most species, including deer.

## **Costs Compared with Savings in Property Damage**

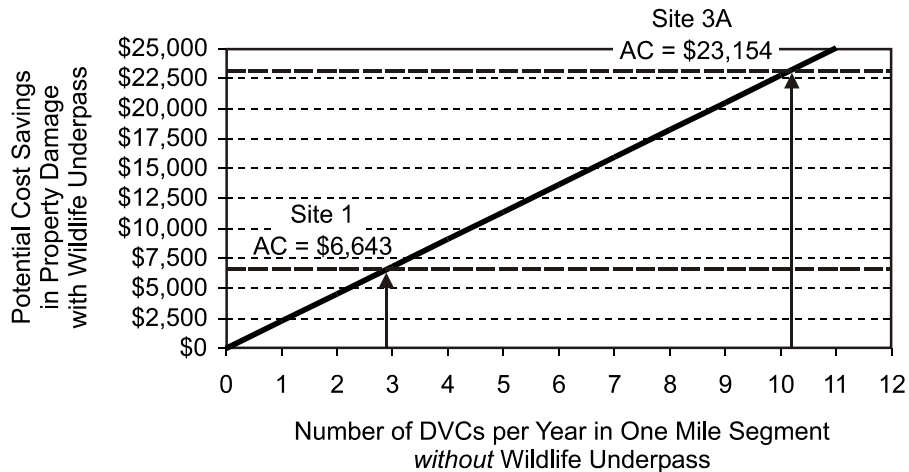
Using the method previously described, the annualized costs were calculated as \$6,643 for Site 1 and \$23,154 for Site 3A (based on total costs of \$257,864 and \$588,077, respectively). These underpasses are cost-effective in terms of property damage savings when they prevent a minimum of 2.6 DVCs per year and 9.2 DVCs per year, respectively (Figure 23).

Because the Site 1 and Site 3A underpasses were constructed at the same time as the road, there are no pre-construction DVC data. However, considering that the number of deer crossings in Site 1 and Site 3A was 319 and 293, respectively, it is probable that more than 2.6 and 9.2 DVCs, respectively, were prevented that year. If this is the case, the savings in property damage alone outweighs the annualized cost of the underpasses.

Wildlife crossings with fencing have resulted in more than a 95% reduction in road-kills for ungulate species on the Trans-Canada Highway (Parks Canada, 2004). Using a conservative estimate of 90% DVC reduction, Figure 24 illustrates the potential accident cost savings with the



**Figure 23. Cost Savings in Property Damage from Reduction in Deer-Vehicle Collisions**



**Figure 24. Potential Cost Savings in Property Damage Assuming 90% Reduction in DVCs per Year with Wildlife Underpass Construction**

presence of a wildlife underpass with fencing. For example, there would be a savings of more than \$20,000 per year in property damage in an area with an underpass that would have averaged nine DVCs per year with no underpass. For underpasses with construction costs similar to those of Sites 1 and 3A, property damage cost savings would exceed underpass construction costs at areas that had 2.9 and 10.2 DVCs per year (pre-construction), respectively.

## CONCLUSIONS

- *Properly sized and located structures receive heavy use by wildlife, thereby reducing animal-vehicle collisions.* For large mammals in Virginia, appropriate structure design is essential for maximizing the benefit from wildlife crossing construction.



- *Only underpasses 12 ft or greater in height were successful at facilitating deer passage. This attribute alone, however, was not sufficient to guarantee the success of a crossing.*
- *The smallest underpass that was successful in terms of deer use measured 10 by 12 by 189 ft with an openness (metric) of 0.19. The high percentages of hesitancy behavior and turn-arounds at this site compared to those of more open sites, however, suggest that more open structures (with a minimum openness of 0.25) would be preferred.*
- *Based on the minimum cost of an effective structure (with fencing) in this study, a wildlife crossing is cost-effective in terms of savings in property damage alone when it prevents at least 2.6 DVCs per year. Given the high deer crossing frequencies in this study, this number was likely easily achieved.*
- *Structures that were suitable for deer passage were also suitable crossing mechanisms for a variety of other wildlife species. An underpass that served the dual functions of wildlife passage and creek conveyance received the largest diversity of terrestrial, semi-aquatic, and aquatic species.*
- *More research on structure size preferences for black bears is needed to provide transportation agencies cost-effective options for wildlife crossing construction.*

## **RECOMMENDATIONS**

1. *VDOT should consider wildlife crossing construction with new road construction and maintenance projects where appropriate. Designing structures for the dual purpose of drainage and wildlife passage can encourage animal use and is cost-effective compared to constructing separate structures.*
2. *When constructing wildlife crossings, VDOT should consider the following structural and placement factors for deer: a minimum height of 12 ft or a combination of width, height, and length dimensions such that the openness factor ( $W \times H/L$ ) is a minimum of 0.25.*
3. *VDOT's Structure and Bridge Division should consider the maintenance or replacement of bridges or culverts as an opportunity to enhance structures for wildlife use. This study and previous research support the consideration of the following structural improvements to encourage use by deer: enlarging culverts; constructing fencing along structures; adding grating or similar openings to culvert ceilings to allow additional light; planting vegetation up to structure entrances; adding dirt, grass, or other ground cover to culvert floors; and constructing bridge extensions to allow room for wildlife movement on both sides of a river.*
4. *VDOT should collaborate with other state agencies in identifying road corridors appropriate for potential wildlife crossing placement in Virginia. A follow-up implementation project to act on this recommendation is planned.*

5. *VDOT should consider methods to improve and increase the current dataset on animal-vehicle collisions in Virginia.* Animal-vehicle collisions are significantly underreported in Virginia, limiting the fundamental information needed for effective mitigation such as wildlife crossings. Tools that allow road maintenance crews to record carcass pick-ups quickly and systematically would allow VDOT researchers and management to prioritize efforts to increase safety and reduce carcass disposal costs. A project to implement this recommendation is planned, involving the testing of GPS-enabled personal data assistants to record carcass pick-ups.

## **COSTS AND BENEFITS ASSESSMENT**

As discussed previously, the annualized costs of two effective underpass structures were estimated at \$6,643 and \$23,154 (based on total costs of \$257,864 and \$588,077, respectively). These costs are cost-effective in terms of property damage savings when they prevent a minimum of 2.6 DVCs per year and 9.2 DVCs per year, respectively (Figure 23), at the underpasses. Because the Site 1 and Site 3A underpasses were constructed at the time of road construction, there were no pre-construction DVC data. However, considering that the number of deer crossings in Site 1 and Site 3A were 319 and 293, respectively, it is probable that more than 2.6 and 9.2 DVCs, respectively, were prevented that year. If this is the case, the savings in property damage alone outweigh the annualized cost of the underpasses.

Using an estimate of 90% DVC reduction for underpasses with construction costs similar to those of Sites 1 and 3A, property damage cost savings would exceed underpass construction costs at areas that have 2.9 and 10.2 DVCs per year (pre-construction), respectively (Figure 24).

## **ACKNOWLEDGMENTS**

The author is grateful to Kristen Knight for her invaluable and dependable field assistance and data entry. Appreciation is also extended to John Muse, Robert Jones, and Michael Pelton for identification of study sites; Kurt Kunze and John Goss from the Valley Conservation Council for field assistance, Bruce Carlson for statistical support; James Gillespie for his valuable crash course in cost/benefit analyses; Michael Vaughan for assistance with photo identification; and Douglass Horton and Matthew Dana for information on structure cost estimates. Thanks also to G. Michael Fitch, Amy O'Leary, and Michael Perfater for supporting this research and providing advice when needed. The project also benefited from the efforts of Sande Snead and Ann Overton in generating interest in this research. The author greatly appreciates the opportunity provided by VDOT and VTRC to conduct this study.

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