EXCLUSIONARY FENCING

Exclusionary woven wire fencing has been used to alter the behavior of white-tailed and mule deer for many years. This approach to deer-vehicle crash (DVC) reduction attempts to physically separate animals and vehicles, but will also have impacts on the natural and necessary movement of the animal population. A number of studies have attempted to evaluate the impacts of regular fencing or exclusionary fencing with and without additional complementary infrastructure (e.g., one-way gates, earthen escape ramps, and/or wildlife crossing) on deer activities and/or DVCs (*1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19*). A description of the results from both types of studies is included in this summary.

A range of fencing-related subjects is discussed in the following paragraphs. First, the results of studies that considered the apparent relationships between roadway/roadside characteristics (including fencing) and the occurrence of DVCs are briefly summarized (*10*, *16*, *17*). However, these studies are discussed in more detail within the hunting and herd reduction summary of this toolbox. Second, studies that investigated the impacts of fencing on white-tailed deer activities and/or DVCs are described (*4*, *5*, *6*, *7*, *11*). The number and location of white-tailed deer, DVCs, or deer carcasses observed with respect to the roadway right-of-way (ROW) and/or exclusionary fencing, fencing height, and fencing location are often the focus of these studies. Third, several studies that document the activities of deer and/or the DVC-reduction impacts of exclusionary fencing when combined with other complementary infrastructure (e.g., one-way gates, earthen escape ramps, and/or wildlife crossings) are summarized (*8*, *12*, *13*, *14*, *15*, *18*, *19*). Finally, several studies that consider electric fencing area briefly summarized, and a study that considers the DVC-reduction effectiveness of exclusionary fencing and proposes a benefit-cost installation guideline is presented (*9*, *20*, *21*, *22*, *23*).

DVC Modeling and Fencing

Several studies have investigated the apparent relationships between factors that define the roadway/roadside environment and the occurrence of a white-tailed deer carcass or DVC along a section of roadway (*10, 16, 17*). At least two of these studies included the existence of some type of roadside fencing in their evaluation (*10*, *17*). The results of these two studies are described in detail within the hunting or herd reduction summary of this toolbox, and the conclusions they make about fencing and DVCs are somewhat contradictory. The data from the Kansas study indicates that the number of DVCs reported along a segment increases with the existence of traditional ROW fencing, but the Pennsylvania study showed a reduction in the probability of a segment being a "high" DVC site as the amount of fencing (and at least 3.0 feet (0.91 meters) in height) increased within 328.1 feet (100 meters) of the roadway (*10*, *17*). This contradiction is most likely the result of, among other things, the differences in the experimental design and statistical approaches taken, and the fact that correlations in data do not necessarily define a cause-and-effect relationship. The Kansas study also did not include the fencing variable in their model (*17*). The Pennsylvania researchers concluded and recommended that increasing the maintenance and repair of deer fencing would reduce the probability of a section being classified as a "high" crash site (*10*, *17*).

Fencing, Deer, and/or Deer Carcass Location

A series of studies was completed in the 1960s and 1970s that focused on the impacts of the initial roadway construction and fencing of Interstate 80 in Pennsylvania (*1*, *2*, *3*, *4*, *5*, *6*, *11*). The general focus of these studies was the changes in white-tailed deer activity on and near the new roadway. The study area location of these evaluations was centered on an 8-mile (12.9-kilometer) segment of Interstate 80 near Snow Shoe, Pennsylvania. Some of the studies also considered other segments of Interstate 80.

The location and activities of the white-tailed deer observed near Interstate 80 was measured in a similar manner for each study (*1*, *2*, *3*, *4*, *5*, *6*, *11*). A vehicle with a spotlight traveled along the shoulder of the roadway segment (typically at 10 to 20 miles per hour (16.1 to 32.2 kilometers per hour)), and the number of the data collection run, date, time, location, approximate white-tailed deer distance from the paved highway, number of white-tailed deer, sex, and apparent age were recorded. The activity and/or behavior (e.g., feeding, etc.) of the white-tailed deer were also sometimes identified within segment increments about 200 feet long (*1*, *2*, *3*, *4*, *5*, *6*, *11*). Each of the

Pennsylvania studies focused on a different characteristic of the new roadway. The impact of the interstate highway, topography, vegetation, and fencing along the roadway were evaluated (*1*, *2*, *3*, *4*, *5*, *6*, *11*).

The first two studies of white-tailed deer activity along Interstate 80 were completed immediately before the roadway was opened, and before/after it was opened to about 45 miles of local traffic (*1*, *2*). The objectives of these studies were to evaluate the white-tailed deer activity in the area and determine how this activity related to the local vegetation and topography. During both studies, however, there were only short segments of 4- and 5.5-foot fencing within the interchange area and along one side of a one-mile section of the study area (*1*, *2*, *3*). It was assumed that the results from these studies generally represented a "no fencing" or "before roadway opening" situation (*1*, *2*, *3*). Their results were used for comparison purposes in the some of the studies that followed.

From 1969 to 1970, a 7.4-foot (2.26-meter) exclusionary fence was installed along the Interstate 80 study area, and the roadway was opened across Pennsylvania in September 1970 (*4*, *6*). White-tailed deer activities and locations were observed from July 1970 to July 1971 (i.e., before and after the roadway was fully opened) (*6*). The objective of the study was to evaluate the impact of the fencing and increased traffic volume on the behavior of white-tailed deer. The fencing was installed on both sides of Interstate 80, and consisted of 47 inches (119.4 centimeters) of woven mesh (which started five inches (12.7 centimeters) from the ground), three strands of nine-gauge galvanized steel wires 7 to 8 inches (17.8 to 20.3 centimeters) apart, and an extension bar placed at a 45 degree angle (away from the roadway) with another three wires six inches (15.2 centimeters) apart (*6*).

Spotlight observations of the white-tailed deer activities began in October 1970 and lasted until July 1971 (*6*). A total of 97 data collection runs (51 westbound and 46 eastbound) were completed during a seven-hour period from just before dusk until just after midnight (*6*). A total of 744 white-tailed deer were observed (*6*). Seventy-five percent of the white-tailed deer were within the right-of-way and grazing (*6*). Very few (n = 2) of the white-tailed deer were observed on or between the interstate pavement surfaces (*6*).

The researchers concluded that the reason for these results was the large number of gaps remaining below the fencing after its installation. During the study about 11 white-tailed deer were observed going under the fence, and it was shown that a gap of only 9 inches (22.9 centimeters) was needed for this to be accomplished (*6*). However, track evidence (and deer hair in the fence wire) throughout the study segment also indicated that fence jumping had occurred. No attempt was made to account for or repair the gaps below the fencing during this study (*6*).

Only 22 deer were reported killed by vehicles along the study segment between September 20, 1970 and July 31, 1971 (*6*). Tubbs, however, statistically evaluated the fencing by comparing the observed proportion of white-tailed deer on each side of the fencing to the same information observed in a previous study by Carbaugh, et al. (when only local traffic was using the roadway) (*1*, *6*). This comparison showed that, although most of the white-tailed deer were within the roadway ROW, there was a statistically smaller number observed on in the area on both sides of the fencing after it was installed and the roadway was in full operation (*6*).

The researchers also concluded that during the nine months in which the white-tailed deer were observed there appeared to be a relationship (from linear regression analysis) between the number white-tailed deer observed and the number of roadside carcasses removed (*6*). It was concluded by Tubbs that DVCs had significantly decreased from the time of the previous studies, but he did not make any conclusions about whether this apparent reduction was connected to the fencing (*1*, *6*). He did conclude, however, that since most of the white-tailed deer were still within the right-of-way, this “reduction” was probably due to the white-tailed deer becoming “ . . .conditioned to the increased volume of traffic and the roadway, and not crossing it if food were readily available on one side of the roadway (*6*)”. He recommends that the reason for the reduction in roadside white-tailed deer carcasses be further investigated. There was no discussion in the study report about the general and expected natural variability of DVCs along new roadways.

In 1975, Falk also compared the number of white-tailed deer carcasses collected along the same 8-mile (12.9-kilometer) fenced segment with those along a similar, but unfenced, 8-mile (12.9-kilometer) segment about 135 miles west in Monroe County (*5*). Carcass data collected from 1970 to 1974 was used in the comparison. It was found that during this five-year time period the average number of white-tailed deer carcasses per mile (1.6 kilometer) per year on these two segments did not appear to be significantly different (*5*). The conclusion was that the overall existence of the fencing (given its condition of disrepair) in the initial segment did not appear to have an impact on DVCs (*5*). There was no discussion about whether this conclusion was statistically significant.

Fencing Height, Deer Carcasses, and/or DVCs

Approximately two years after the Tubbs study, Bellis and Graves did a similar evaluation along approximately the same Pennsylvania segment (*4*, *6*). The majority of the data collection completed for this study was along six miles (9.7 kilometers) of Interstate 80 near Snow Shoe, Pennsylvania, but a survey of the fence quality and observations of white-tailed deer were completed for 8.42 miles (13.6 kilometers), and the overall segment length in which there were study activities was about 10.19 miles (16.4 kilometers). This study area included the Interstate 80 segment considered previously (*1*, *2*, *6*). Two types of fencing are the in study area: 1) short segments (1.1 to 1.4 miles (1.8 to 2.3 kilometers) of 5.25-foot (1.6-meter) chain link fence (near the interchange and rest area), and 7.0 to 7.3 miles (11.3 to 11.7 kilometers) of 7.4-foot (2.26-meter) white-tailed deer exclusion fence (*4*).

Data related to white-tailed deer location and activities were collected from December 1974 to March 1976 (*4*). The specific segment of Interstate 80 observed was the same study area as the previous research, but also included an additional 2,000 feet (609.6 meters) (*4*). The primary objective of the study was to more clearly evaluate the DVC- or carcass-reduction effectiveness of the fencing along the segment (*4*). However, only six white-tailed deer were killed along the segment during the study time period, and the researchers were generally forced to evaluate the fencing based on their white-tailed deer observations (*4*). Speculation is also offered about the reasons why the number of white-tailed deer killed along this section of roadway had decreased from the time the roadway was opened (1968) and the time of this study (1974 and 1975).

As previously mentioned, the fencing along this segment of Interstate 80 was in general disrepair (*4*). Overall, 486 gaps (i.e., spaces greater then 9 inches (22.9 centimeters) in height at the bottom of the fence) and 7 flaps (holes made by humans) were found along the ROW exclusionary fencing, and tracks and hair evidence showed that 118 were used by white-tailed deer (*4*). Eighty-three downbends of 3 to 5 inches (7.6 to 12.7 centimeters) at the top of the fence were found, and broken wires (from falling branches or trees) at the top of the fencing observed at 96 locations (*4*). The damage at 12 locations was considered to be excessive (e.g., entire sections of the fencing being removed by humans or the fence height being reduced to 40 inches or lower) by the researchers (*4*). Overall, track evidence appeared to indicate that the 5.25-foot (1.6-meter) chain link fence was easily jumped by white-tailed deer, but they apparently preferred to go under the 7.4-foot (2.26-meter) fence.

From December 1974 to August 1975, before modifications to the fencing, seventy observation runs were made along a six-mile (9.7 kilometer) segment of Interstate 80 near Snow Shoe, Pennsylvania (*4*). The results were the same as Tubb's study and approximately 75 percent of the white-tailed deer observed were inside the roadway right-of-way fencing (*4*, *6*). In September 1975, however, to test the fencing as a white-tailed deer deterrent, it was modified on the south side of the six-mile (9.7 kilometer**)** study segment (*4*). These modifications included:

- Two miles of gaps at the bottom of the fencing were plugged with logs, but the total height of the fence was also reduced to 4.3 feet (1.3 meters).

- Two miles of fencing was reduced to 4.3 feet (1.3 meters) in height but none of the bottom gaps were filled with logs.

- Two miles of fencing remained at 7.4 feet (2.26 meters), had its bottom gaps filled with logs, and the damage to the top wires was repaired.

The 7.4-foot (2.26-meter) fencing on the north side of the roadway was not modified in any manner, and was used as a control (*4*). The white-tailed deer along the segment were then observed for the next seven months (September 1975 to March 1976), and this "after fence modification" data was compared to the data from the nine-month (December 1974 to August 1975) "before fence modification" study period (*4*).

Overall, the researchers concluded that the monthly fluctuations in the number of white-tailed deer observed during the study period were due to normal seasonal variations in population and/or movement (*4*). The number of white-tailed deer observed along the control side of the roadway, for example, increased by 333 percent (*4*). However, the results from the modified fence segments contained conflicting results. There was a 156 percent decrease in number of white-tailed deer in the ROW along the segment that had a 4.3-foot (1.3-meter) fence with its gaps fixed, but a 157 percent increase along the segment with a fence height of 7.4 feet (2.26 meter) and its gaps fixed (*4*). Both changes were significantly smaller than the increase observed in the control area. The researchers concluded that filling the gaps at the bottom of the fence appeared to be more important than fencing height (*4*). The two-mile segment with the 4.3-foot (1.3-meter) fence height and no gaps fixed experienced an increase in white-tailed deer within the ROW that was not significantly different than the control side of the roadway (*4*).

Based on these results, and the constraints of this study design, the researchers could not make any conclusions about the efficiency or effectiveness (or DVC-reduction impact) of the different fencing designs/heights considered (*4*). The confusing results are a good example of the temporal and spatial complexities and variability connected with the study white-tailed deer behavior (which are impacted by many factors) and/or the DVC-reduction impacts of a countermeasure. Controlling for or quantifying this variability from the impact of a particular DVC countermeasure is required to determine how it will affect the probability a DVC will occur along a specific segment of roadway.

Bellis and Graves did believe and conclude, however, that the traffic volumes in 1974 and 1975 appeared to produce a situation that prevented white-tailed deer from crossing or entering the roadway proper (versus the ROW) and producing a DVC (*4*). This conclusion appears to be based on the researchers observation that no white-tailed deer were observed on the roadway surface, that this number had decreased through this series of Interstate 80 studies, and that only six were killed along the segment of interest throughout this 16-month study (*1*, *2*, *4*, *6*). However, this is opposite of the general relationship between traffic volume, white-tailed deer densities, and DVC patterns that is currently observed today, and described in the hunting or herd reduction summary of this toolbox. They recommended that fencing not be installed as a white-tailed deer deterrent along high-volume roadways, but that if it was installed the focus should be on the strength of the bottom of the fencing and proper installation/maintenance (*4*). It was also suggested that the installation of fencing closer to the roadway (possibly just on one side of the roadway) might allow white-tailed deer to feed and not attempt to cross the roadway.

In 1975, Falk also attempted to measure the effectiveness of exclusionary fencing as DVC reduction device Pennsylvania, but he used a slightly different approach (*5*). Three segments of Interstate 80 were studied. The first segment was the previously described 8-mile (12.9-kilometer) site near Snow Shoe, Pennsylvania in Centre County. The second segment was an adjacent 2-mile (3.2-kilometer) section of Interstate 80, and the third segment was an 8-mile (12.9-kilometer) section of Interstate 80 about 135 miles to the west in Monroe County (*5*). The focus of this discussion will be the fencing analysis completed in the 2-mile (3.2-kilometer) Centre County segment (*5*). The results of a comparison of the fenced and unfenced 8-mile (12.9-kilometer) segments were previously described.

The two Centre County study segments had 7.4-foot (2.26-meter) exclusionary fencing along both sides of Interstate 80. The 2-mile (3.2-kilometer) segment was the focus of this study, and its fencing was initially inspected for damage and gaps (*5*). Then, for analysis purposes, the 2-mile (3.2-kilometer) segment was divided into three sections. The first 1/2-mile (0.8-kilometer) of fencing was unmodified, but the next mile (1.6 kilometers) of fencing was completely repaired). The fencing along the next 1/2-mile (0.8-kilometer) also remained unmodified (*5*).

The location and number of white-tailed deer observed in each of the three segments described above were compared to each other in an effort to evaluate the effectiveness of the 7.4-foot (2.26-meter) fencing (*5*). This information was gathered during Spring and Winter study time periods six to seven weeks long. Five observations were made before the one mile (1.6 kilometer) fence in the test section was repaired, five after it had been repaired (e.g., top wires repairs, trees removed, and bottom gaps 9 inches (22.9 centimeters) or more plugged), and five more after the researchers returned the fencing in the test section to its original state of disrepair (although the trees on the fencing were not replaced) (*5*). Falk concluded that the total number of white-tailed deer crossing into the ROW with the repaired fence was significantly less than the two adjacent control sections (*5*). During the Winter observations ROW penetrations by white-tailed deer were smaller overall, but higher in the control sections than the test section. During the Spring, the control sections experienced an increase in white-tailed deer activity but the test section (with the repaired fencing) showed a reduction (*5*). More white-tailed deer were observed going under the fence rather than over. Falk concluded that the 7.4-foot (2.26-meter) height of the fencing may not be as important as plugging the fence gaps (i.e., proper installation and maintenance) (*5*).

Fencing Height/Location and Deer Carcasses/DVCs

Interstate 80 Study

From August 1970 to January 1972 white-tailed deer carcasses were counted along the entire 313-mile (503.7-kilometer) length of Interstate 80 in Pennsylvania (*11*). The objective of this study was to investigate the apparent relationships between roadway/roadside characteristics and the locations of these carcasses (*11*). The data collected at each white-tailed deer carcass location and at all 16,777 roadway markers (typically every 200 feet) included (on both sides of the roadway): vegetation (i.e., wooded, non-crop fields, crops, pasture, or other), topography (i.e., the cut and fill combinations of each side of the roadway), the height of the ROW fencing, and the distance from the fence to the highway and the nearest wooded area (*11*).

Four types of fencing existed along Interstate 80 at the time of this study: 1) 5-foot (1.5-meter) woven mesh fencing, 4-foot (1.2-meter) rectangular mesh fencing, a 5.5-foot (1.7-meter) woven wire mesh fencing topped with three smooth wires, and a 7.4-foot (2.26-meter) fencing with three smooth at the top and another two strands on an 45-degree (away from the roadway) extension (*4*, *5*, *6*, *11*). The 5-foot (1.5-meter) fence was only used in interchanges areas, and the 4- and 5.5-foot (1.2- and 1.7-meter) fencing was mostly located in agricultural and semi-agricultural areas (*11*). The 7.4-foot (2.26-meter) fencing was primarily located in the forested mountains (*11*). On average, the fencing in the mountains was twice as far way (i.e., 90 feet (27.4 meters) from the roadway as the fencing in the agricultural land (i.e., 45 feet (13.7 meters)) (*11*).

A total of 874 deer were killed within the study area during the 15-month time period considered (*11*). Overall, the researchers found more white-tailed deer carcasses adjacent to the 7.4-foot (2.26-meter) fence than the 4.0- to 5.5-foot (1.2- to 1.7-foot) fencing (*11*). They concluded that this was probably due to the fact that the 7.5-foot fencing was only installed in "high" DVC areas (*11*). The correlations between the adjacent land characteristics and the fencing locations may also be part of the explanation. Appropriately, they did not believe the data available allowed a proper analysis of the fencing height impacts on the location of DVCs or deer carcasses. Of course, the data collected in this study may also show that the 7.4-foot (2.26-meter) fencing was not effective at reducing DVCs or deer carcasses, and this would agree with at (which agrees with the results from the previously described Pennsylvania studies of Interstate 80 (*4*, *5*, *6*, *11*). No data summary of the observed white-tailed carcasses by adjacent ROW fence height was provided (*11*).

An examination of the vegetation and topography information collected, however, did lead the researchers to some more general conclusions (*11*). They concluded that fencing location (with respect to the woods), of the roadway/roadside characteristics considered, appeared to have the strongest relationship with the location of white-tailed deer carcasses. The highest carcass numbers were found along segments where the fence was located at the edge of the woods or within 75 feet (22.9 meters) of the woods (*11*). These sites generally had good cover for the white-tailed deer near the fence, but grazing opportunities inside the fence (*11*). The lowest number of carcasses was found when the fence was more than 75 feet (22.9 meters) away from the woods (*11*). These areas were characterized by a small amount of cover for the white-tailed deer near the fence and grazing opportunities outside the ROW (*11*). The number of carcasses was also low when the fence was within the woods. The researchers concluded that the carcass location patterns seemed to be more related to the amount of land with grazing opportunities available than the proximity of the woods to the roadway (*11*). No clear relationship was found between the topography of the adjacent roadside and the carcass locations (*11*).

Interstate 84 Study

In the 1980s the relationships between the height and ROW location of exclusionary fencing (See Table 1) and the observed location of white-tailed deer along Interstate 84 in Pennsylvania was also studied (*7*). Fencing 9 feet (2.7 meters) and 7.2 feet (2.2 meters) in height were considered (See Table 1). A data collection methodology similar to those in the Interstate 80 studies was used, but information from the tracking of some radio-collared white-tailed deer data was also used to determine their behavior and activities (*7*). Data was also collected about white-tailed deer locations for each mile (1.6 kilometer) of the study segments (See Table 1), and information about the adjacent vegetation (i.e., open or wooded), topography (i.e., cut, fill, or level), and location of the ROW fence (i.e., within the woods, at the woods edge, 82 feet (25 meters) or less from the woods, 82 to 328 feet (25 to 100 meters) from the woods, and greater than 328 feet (100 meters) from the woods) was summarized (*7*).

TABLE 1 Fencing Descriptions and Location (*Adapted from 7*)

Fence Height	Description
9.0 feet (2.7 meters)	• Woven-wire mesh with an opening width that progressively increased from 3 to 7.5 inches (7.6 to 19.1 centimeters) from ground level to 4.0 feet (1.2 meters) in height, and then decreased again to 3 inches (7.6 centimeters) within the remaining 5.0 feet (1.5 meters). • 14.3 miles (23.0 kilometers) of this fencing was installed on each side of Interstate 84 from State Route 507 to just beyond the State Route 739
7.2 feet (2.2 meters)	• Woven-wire mesh with a gap width that increased from 3 to 8 inches as it increased in height from 0 to 4.6 feet (0 to 1.4 meters) above ground. Three strands of wire above the square mesh extended the height an additional 1.5 feet (0.46 meters) and a 45-degree angle away from the highway with two additional wires. • 11.4 miles (18.3 kilometers) of this fencing was installed along Interstate 84 for just east of State Route 739 interchange.

The white-tailed deer location data revealed a number of patterns. Overall, the spotlight data showed that the number of white-tailed deer groups in the ROW adjacent to the 9-foot (2.7-meter) fencing was smaller than those adjacent to the existing 7.2-foot (2.2-meter) fencing (*7*). This difference, however, only seemed to hold for wooded (versus non-wooded) segments, segments with adjacent cuts/fills (versus level ground), and segments with a fencing location in the woods (versus at the edge of the woods or greater than 82 feet (25 meters) from the woods) (*7*). The amount of data available for these comparisons was not documented.

An evaluation of the white-tailed deer carcasses along the Interstate 84 study area produced different patterns. No statistically significant differences were found between the number of white-tailed deer carcasses observed along the roadway segments with the two fence heights, or for differences in adjacent vegetation cover, topography, and fence location (*7*). Overall, 100 incidents occurred during the two-year time period considered for this study (*7*). However, recall that Puglisi, et al. (described earlier) did find a relationship between the number of white-tailed deer carcasses they observed on the roadway and the fencing location (*11*).

Fencing with Complementary Infrastructure

A number of studies have also been completed that focus on the impacts of installing exclusionary fencing with complementary infrastructure (*8*, *12*, *13*, *14*, *15*, *19*). These additional facilities are typically related to the movement rather than the exclusion of the animal. For example, in at least two studies the evaluation considered the impacts of one-way gates and exclusionary fencing (*13*, *14*). These gates provide a method of escape to white-tailed deer and other animals that may enter a fenced ROW. Another study compared the use of one-way gates and alternative earthen escape ramps (*19*). Similarly, exclusionary fencing is almost always, and appropriately, installed when roadway wildlife crossings (e.g., overpasses, underpasses, and at-grade) are constructed (*8*, *12*, *15*). In this case, the objective of the fencing is to funnel the animals to the crossings that allow movement across the roadway (versus the complete barrier of fencing and its subsequent migratory impacts). In many cases, all three measures are installed along a roadway segment (*8*, *12*, *15*, *18*, *19*).

The focus of studies summarized in the following paragraphs is typically, but not always, the use of the escape gates, earthen escape ramps, or crossings by the animals. The potential DVC or roadway carcass reductions attributed to the entire installation is also sometimes provided. In the case of combined DVC-reduction measures (e.g., fencing and overpass), however, the reduction impacts due to each component are not typically presented or possible to determine. But, it is generally assumed, for example, that wildlife crossings are typically ineffective without the addition of exclusionary fencing. This assumption sometimes leads to the suggestion that the DVC or carcass reductions observed after the installation of a combination of measures is entirely due to the fencing. The following paragraphs, however, are based on the assumption that the existence of the wildlife crossings and/or one-way gates or earthen escape ramps (or other DVC-reduction actions taken by the implementing agency) may increase the potential DVC or carcass reduction of an exclusionary fencing installation.

Fencing with One-Way Gates

Exclusionary fencing is sometimes combined with one-way gates. These gates are designed to provide a ROW exit to animals that may become trapped between the exclusionary fencing (See Figure 1). Two studies are described in the following paragraphs that focus on the use of one-way gates with exclusionary fencing (*13*, *14*). One the studies considered the use of one-way gates by mule deer in both a controlled and field environment (*14*). A number of one-way gate designs were evaluated by observing whether they were properly used (i.e., they did not allow passage in the unintended direction) and the individual preference of captive mule deer (*14*).

Based on the results of the evaluation mentioned above a one-way gate design with only a 6 percent failure rate (i.e., deer using the gate to go into the ROW) was installed within 1.5 miles (2.4 kilometers) of 8-foot (2.44 meters) fencing (*14*). This fencing was adjacent to a wildlife underpass along Interstate 70 near Vail, Colorado (*14*). In this field experiment, the individual use of the eight gates installed did vary, but their overall failure rate was only 3.8 percent (*14*). The variation in the use of the gates was attributed to their location (e.g., near good ground cover or not), and the negative movements were primarily the result of fawn use (with their small size) and human interference ((i.e., people leaving the gates open). The researchers recommended that the use of one-way gates should be considered when 8-foot (2.44-meter) fencing was installed along roadways (*14*). However, since the time of this study it appears that the use of these gates has declined (apparently because the animals have adapted to the use of the underpass) (*8*).

No DVC or deer carcass observations were documented for the Interstate 70 one-way gate evaluation, but this data was considered in a Minnesota study (*13*, *14*). The same one-way gate design was installed along two new sections of Interstate 90 and Interstate 94 (*13*). The two roadway sections of interest consisted of a 13.2-mile (4-kilometer)

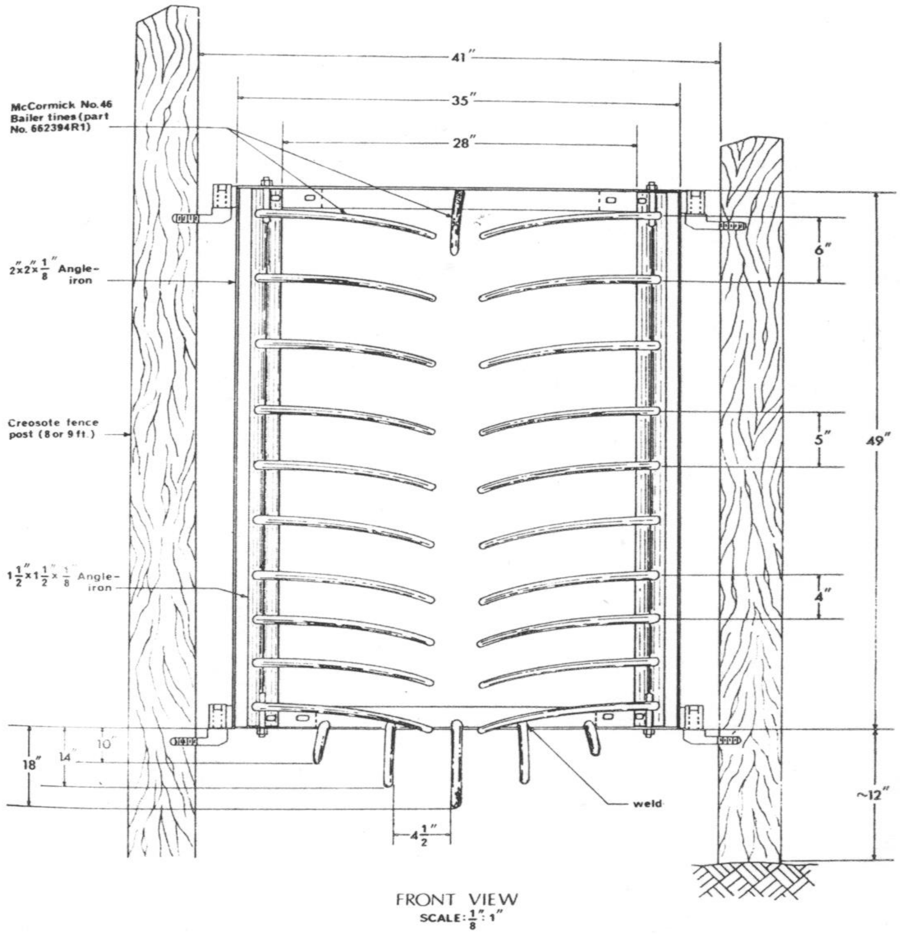

FIGURE 1 One-way gate design (*14*).

segment along Interstate 94 and a 16.8-mile (5.1 kilometer) section along Interstate 90 (*13*). Each segment had 7.9-foot (2.4 meter) ROW fencing and 18 to 20 one-way gates (*13*). A typical 3.9-foot (1.2-meter) ROW fencing installation, however, was attached to each end. The gates were placed near the end of each 7.9-foot (2.4-meter) fencing section, and also at locations where it was believed white-tailed deer might want to enter or exit the ROW.

Data on the white-tailed deer use of the one-way gates was collected with counters and track beds (i.e., section of sand that allow tracks to be counted and then smoothed). Track beds were also installed at each end of the 7.9-foot (2.4-meter) fencing (*13*). The one-way gate movement counters were checked biweekly, and it was impossible for the researchers to know when during the two-week period a malfunction in the counter may have occurred. The equipment along Interstate 90 was also vandalized several times. In addition, six of the nine gates along the Interstate 90 segment never had counters or track beds installed because they were in three feet (0.91 meters) of water for most of the study time period (*13*). These factors may have all at least partially contributed to the study results that show only 69 percent of the wildlife gate passages were in the correct direction (*13*).

The researchers did provide several suggestions for future one-way gate installations. They suggested that the gates and fencing must be maintained properly and in good working order to be effective, and that the fences/gates should be located at the top of the ROW backslope (to avoid possible standing water) and long enough to avoid white-tailed deer movement around the ends (*13*).

The researchers also concluded, however, that the combination of 7.9-foot (2.4-meter) fencing and one-way gates theoretically reduced the number of white-tailed deer carcasses along the roadway segments by 60 and 93 percent (for Interstate 90 and 94, respectively) (*13*). They apparently compared the number of white-tailed deer killed along the segments in the year following the installation of the one-way gates and the 7.9-foot (2.4 meter) fencing to an assumed number of expected kills. Unfortunately, this reduction calculation appears to be based on some extrapolation of the number of observed along older adjacent roadways during the year before the interstates were opened (*13*). In addition, the rationale for how the expected number of carcasses was calculated is only implied and not properly documented (*13*).

Based on their results, however, the researchers did conclude that the 7.9-foot (2.4-meter) fencing along Interstate 94 did keep white-tailed deer off the roadway ROW, but that the same fencing along Interstate 90 was not long enough (i.e., white-tailed deer entered around the ends) and the water in the ditch on this segment caused white-tailed deer to walk on the roadway (*13*). An analysis of both installations in 1978 dollars, assuming the carcass reduction estimates are correct, and using a series of assumptions related to vehicle repair costs, the value of a white-tailed deer, and interest/inflation rates resulted in an average benefit-cost ratio of 2.28 (*13*). The researchers believed that this analysis was a "…fair, but conservative evaluation…" but did not include fencing or gate maintenance costs in the calculation (*13*).

One-Way Gates and Earthen Escape Ramp Use

In the late 1990s the use of one-way gates by deer was compared to that of an earthen escape ramp design (See figure 2) (*19*). There was some concern that the one-way gates (See Figure 1) were not really designed well for deer, and that they were reluctant to use them (*19*). Earthen escape ramps are simply piles of dirt covered with natural vegetation against a wall that is installed along the exclusionary fence. It is suggested the ramp height be 4.9 feet (1.5 meters), and that the exclusionary fence be lowered to that level when adjacent to the ramp (*19*). The deer use these ramps to escape the roadway right-of-way, and do not appear to have a problem jumping down from this 4.9-foot height (*19*).

FIGURE 2 Example earthen escape ramp (*19*).

A study in Utah compared the use of 16 earthen ramps to 18 one-way gates (*19*). In 1997, nine ramps were installed along United States 91, and in 1998 seven ramps were properly constructed along United States 40 (*19*). There were also 10 and 8 one-way gates, respectively, within each of these 1.5-mile roadway segments (*19*). Only about 33 and 49 percent of the deer approaching the gates on each roadway segment, respectively, actually used them (*19*). In addition, a standardized index of ramp and gate use was developed and it was found that overall the earthen escape ramps were used 8 to 11 times more than the one-way gates (*19*). The observed amount of deer mortality also decreased along United States 91 after the ramps were installed (*19*).

The researchers had several recommendations based on their findings (*19*). First, it was recommended that exclusionary fence maintenance and repair programs be institutionalized in Utah (*19*). The regular maintenance of these installations maximizes their effectiveness. They also recommended the use of earthen ramps, and suggested that their location be chosen by qualified personnel or that they be installed no less than 0.25 miles apart (*19*). A 0.5-mile spacing was recommended, however, where the level of the deer collision problem was not known or was less persistent (*19*). The closer 0.25-mile spacing was still recommended within one mile of the ends of the fencing (*19*). Other recommendations included locating the ramps near natural points of movement (e.g., drainage areas), placing them at 0.25-mile spacing near desirable forage, surfacing them with natural vegetation for appearance and to reduce erosion, and shielding them from roadway noise and view if possible (*19*).

Fencing with One-Way Gates and/or Grade-Separated Wildlife Crossings

A sample of five studies that considered the combined installation of exclusionary fencing and grade-separated wildlife crossings are summarized in the next few paragraphs (*8*, *12*, *15*, *18*). In some cases these installations also included one-way gates, but these were not the focus of the studies described.

Colorado Interstate 70 and Highway 82 In 1979 a study in Colorado attempted to determine the DVC-reduction impact of several countermeasures (*8*). The countermeasures evaluated in this research included 8-foot (2.44-meter) fencing, overpasses and underpasses, prototype deerguards (i.e., cattleguards that work on deer) designs, highway lighting, and animated deer signs (*8*). The researchers found that none of the deerguard designs they considered were effective, and the results that focused on lighting and signs are discussed in other sections of this toolbox.

The impacts of 8-foot (2.44-meter) exclusionary fencing were studied at six locations. These locations include the

- Vail Study Area: 1.5 miles (2.4 kilometers) of fencing (with one-way gates) along each side of a wildlife crossing and on both sides of the interstate.

- Avon Study Area: 2.3 miles (3.6 kilometers) of fencing (with one-way gates) between the Avon interchange and the Eagle River bridge on the north side of the interstate.

- Edwards Study Area: 2.3 miles (3.6 kilometers) of fencing (with one-way gates) west of the Edwards interchange on the north side of the interstate.

- Eagle Study Area: 4.8 miles (7.7 kilometers) of fencing (with one-way gates) east of the Eagle interchange on the north side of the interstate.

- Diamond S Study Area: 1.1 miles (1.8 kilometers) of fencing along the divided four-lane Highway 82 approximately one mile (1.6 kilometers) northwest of its junction with Highway 133 (on one side the roadway).

- Carbondale Study Area: 1.1 miles (1.8 kilometers) of fencing along Highway 82 on the north side of the roadway.

The Vail fencing installation in this study was closely associated with an underpass specifically designed for wildlife usage (the use of the underpass was also studied) (*8*).

The other locations may encompass and/or be adjacent to crossing structures (some of which may have been studied), but these combinations were not documented (*8*).

Deer densities along each fenced segment, except Vail, were estimated (*8*). The locations of mule deer carcasses, however, were recorded for all six study areas (*8*). The researchers considered the change in the number of carcasses within each segment from year to year. The percent reduction in the mean annual number of carcasses counted at the six locations ranged from 67.8 to 86.5 percent (*8*). The average annual reduction was about 78.5 percent (*8*). The number of years of data used to calculate the mean annual number of carcasses before and after the fencing installations ranged from 1 to 5 years and 5 to 10 years, respectively (*8*).

It was concluded that the variation in the reductions observed from year to year were probably related to weather conditions (e.g., the severity of the winter), fence length, and the number/behavior of the mule deer near the fenced area (e.g., where they could graze) (*8*). It was also recommended that the cause-and-effect of the fencing (with the associated crossings) on the number mule deer carcasses should be applied with caution because the reductions (and their variability) calculated were based on data from different areas and time periods (*8*). It was also emphasized that the 8-foot (2.44-meter) fencing must be properly constructed and maintained to achieve the effectiveness seen in this study (*8*). Finally, they recommended that exclusionary fencing be installed at least 0.5 miles (0.8 kilometers) past concentrated areas of mule deer activity, and that wildlife crossings be provided every mile (1.6 kilometer) (*8*). These recommendations were based on their observations of lateral deer movement adjacent to the six fencing locations (*8*).

Wyoming Interstate 80 A Wyoming study also considered the behavior of mule deer and DVC impacts related to a fencing and underpass installation (*15*). Initially, an 8-foot (2.44 meter) "game-proof" fence was built along a 6.7-mile (10.8 kilometers) segment of Interstate 80, and then a year later another 1.1 miles (1.8 kilometer) of fencing was installed because the mule deer were going around at least one end of the fence (*15*). The

7.8-mile (12.6-kilometer) segment of roadway also included four wildlife underpasses and three machinery underpasses (*15*). These structures varied in length from 110 to 393 feet (33.5 to 119.8 meters), were 10 to 50 feet (3.0 to 15.2 meters) wide, and 10 to 17 feet (3.0 to 5.2 meters) high (*15*). A typical 46-inch (116.8 centimeter) ROW fence remained across most of the openings to these crossings, but mule deer easily jumped this height (*15*). A total of 30 one–way gates were also installed (*15*).

Each year this segment of Interstate 80 was crossed twice by about 1,000 mule deer, and 37 to 60 DVCs occurred (*15*). The researchers collected information about the behavior of the mule deer (from visual observation, track counts, radio collars, and cameras) and also counted the number of mule deer carcasses along and adjacent to the fenced study segment (*15*). This data was used to evaluate the impacts of the fencing and crossings (*15*).

Before the initial fencing, 53 mule deer were killed within the segment being considered (*15*). Another eight mule deer were killed just to the west of the planned fencing location (*15*). Another 59 mule deer were killed in the first year (i.e., two migration periods) after the initial fencing construction (*15*). About 55 percent of these carcass locations, however, occurred just outside the ends of the fencing. Repairs were done to the fencing, and it was also extended 1.1 miles (1.8 kilometers). During the next six migration periods only one was found in the fenced area and three near the extended end of the fencing (*15*). The number of carcasses found near the fence end that was not extended, however, continued to be found at about the same rate (*15*). It was concluded that the fencing/crossing combination resulted in a mule deer carcass reduction, within the fenced area, of more than 90 percent (*15*). Similar to the other research projects, it was again suggested that having the correct length of fencing was very important, and that proper fence construction and vigilant repair/maintenance are needed (*15*).

Trans-Canada Highway One of the most studied exclusionary fencing and wildlife crossing installations exists along a 16.2-mile (26.1-kilometer) segment of the Trans-Canada Highway (TCH) (*12*). This section of roadway was reconstructed from a twolane undivided to a four-lane divided cross section between 1983 and 1985, and in December 1984 an 7.9-foot (2.4-meter) ROW fence was installed along 6.8 miles (11 kilometers) of the widened portion of the TCH (*12*). The bottom of this fencing was kept within 5.9 inches (15 centimeters) of the ground. A similar fence was installed on the adjacent 9.4 miles (15.1 kilometers) in September 1987 (*12*). No widening or fencing installation had occurred on the adjacent 33.6-mile (54.1-kilometer) section of the TCH at the time of this study, and data from this segment was used for comparison purposes (*12*).

In addition to the fencing, eight underpasses specifically designed for use by animals crossed this study segment of the TCH (*12*). In addition, four wildlife crossing opportunities also existed at three water underpasses and one railway overpass (*12*). Several one-way gates were also installed in the fencing, but the exact number was not documented (See Figure 1).

An evaluation of the ungulate (i.e., elk, bighorn sheep, mule deer, moose, and white-tailed) carcass numbers along the two fenced sections of the TCH was completed (*12*). Two approaches were taken to measure the potential difference in carcasses before and after the fencing installation. The "after fence" expected number of ungulate carcasses along the 6.8-mile (11-kilometer) segment was calculated by considering how its carcass numbers had historically compared with the control segment (assuming that this relationship would continue with the widening) (*12*). The number of years used to define the historical relationship was not documented, but could have been as many as 14 years (*12*). Overall, a 94 percent reduction in ungulate carcasses was estimated for this 6.8-mile (11-kilometer) segment. The reduction in ungulate carcasses along the 9.4-mile (15.1-kilometer) segment was calculated by comparing the before and after fencing (installed in September 1987) data from 1985 to 1989 (*12*). An overall ungulate carcass reduction of about 97 percent was estimated (*12*).

The post-fencing reduction of just white-tailed and mule deer carcasses along the 16.2-mile (26.1-kilometer) study segment was estimated at about 95 percent (*12*). However, of the 645 ungulates killed by man (e.g., train hits, vehicle hits, and other sources) in the study area from 1985 to 1989, only 61 were white-tailed deer (12 on the roadway segments of interest) and 103 mule deer (22 on the roadway segments of interest) (*12*). In fact, only one mule deer and one white-tailed deer were killed along the 6.8-mile (11-kilometer) segment during the entire study period (all fenced). Along the 9.4-mile (15.1-kilometer) segment it appears that 17 and 10 mule deer and white-tailed deer were killed before the fencing, and four and one, respectively, after the fencing (*12*). Overall, this is a measured deer mortality reduction of about 82 percent (*12*).

The TCH researchers concluded that there was a significant reduction in the number of white-tailed and mule deer on both segments of roadway, but it was also concluded that there was no significant increase in the number of white-tailed and mule deer killed along the second segment of roadway after it was widened to a four-lane undivided cross section but before it was fenced (*12*). These results may be due to the small sample size or the fact that animals moving in small groups (rather than large herds) may be impacted less by roadway widening (*12*). The number of elk and bighorn sheep killed did increase within the widened segment (*12*). It was concluded that the large reduction in ungulates killed along the roadway segments was primarily due to the fencing and the active removal of animals (within the fenced segments) by park wardens (*12*). The additional reduction that might be due to the one-way gates, cattleguards at fence openings, and the wildlife crossings were not discussed or summarized (*12*).

Another study of the reduction in ungulates killed along the TCH was completed after an additional 11.2 miles (18 kilometers) was widened (for a total of 27.4 miles (44.1 kilometers)), and a 7.9-foot (2.4-meter) exclusionary fencing was installed on both sides of the roadway (*18*). Data related to collisions between wildlife and vehicles were collected between May 1981 and December 1999, and overlapped with the data used in the previous study (*12*, *18*). It does not appear, however, that any additional wildlife crossings were constructed along the construction of the additional 11.2 miles (18 kilometers).

Only two years of data before and after the various fencing installation dates along the TCH were evaluated (*18*). This short period of time was chosen to minimize the impacts of ungulate population changes on the results, but also limits its strength as a safety analysis (*18*). A chi-square analysis indicated that the first two segments of roadway (see the previous discussion) had three of four "high" wildlife carcass locations near the ends of their fencing (*18*). As expected, however, the number of wildlife carcasses or wildlife-vehicle collisions along the roadway segments decreased after the fencing was implemented (even with annual increases in traffic flow) (*18*). Overall, a statistically significant reduction in ungulate mortality of 80 percent was calculated after the fencing (along with the crossing previously mentioned) was installed (*18*). The individual reductions in elk and deer carcasses were also significant (*18*).

Electrified Fencing

Several studies have considered the exclusionary effectiveness of "electric fencing" on white-tailed deer movements (*20*, *21*, *22*, *23*). These studies were not done along roadway ROW, and their results have been somewhat mixed. It should also be recognized that the fencing materials and technologies used in even the most recent studies summarized have most likely been updated and improved. No studies were found that attempted to evaluate the impacts or feasibility of installing electric fencing along portions of a roadway ROW.

The focus of one study was the use of electric fencing to exclude white-tailed deer from 255 acres of hardwood forest in the Adirondack Mountains (*20*). The researchers that completed this 1969 study concluded that the fence repelled white-tailed deer, and partially controlled their use of the study area (based on a significant reduction in browsing) (*20*). However, it was also determined that the amount of control offered by the fencing (a six-foot (1.8-meter), five-strand (three with charge), copper-clad steel wire design) was too marginal and the cost too high for them to recommend its use (*20*).

Another study investigated the use of a baited electric fence around one and five hectare areas of apple seedlings (*22*). This study used a single strand electric livestock fence, and the strand was 3.3 feet (one meter) above the ground and had aluminum foil flags attached to it at 32.8 feet (10 meter) intervals (*22*). The underside of this foil tent was covered in peanut butter (*22*). Both the visual effect of the foil and the smell of the peanut butter attract white-tailed deer. The fencing was intended to be somewhat of a physical barrier, but more of a physiological aversion barrier to the white-tailed deer. The fencing surrounded apple seedlings, and the results indicated that the fence was highly effective at repelling white-tailed deer (*22*). Browsing was almost eliminated and new growth greater than that occurring in the nearby comparison, but unfenced, plots (*22*). These results continued for three growing seasons. However, the fencing did stop working for several short periods of time because overgrown vegetation touched it (*22*). In addition, maintenance costs because about one day per month was spent trimming vegetation, replacing foil, and recoating the foil (*22*). The researchers believe, however, that it is an economical alternative to the non-electric 8-foot (2.44-meter) woven wire fence (*22*).

In 1985 evaluated the effectiveness of five different designs for electric fence (*21*). Testing with captive deer within the Penn State Deer Research Facility revealed that all but the 57.9-inch (147-centimeter) vertical five-strand high-tensile smooth-steel wire (spaced at about 12 inches (30.5 centimeters) with the bottom strand 10 inches (25.4 centimeters) from the ground) fence design was penetrated by the white-tailed deer *(21*). Testing of this design was then completed around 10 fields (with varying crops) that had areas between 1.6 and 53 hectares (*21*). The benefit-cost ratio analysis, which included increases in crop yield but not installation or maintenance labor costs, were believed to be acceptable for all 10 sites (i.e., alfalfa, black cherry, corn, fruit trees, small grains, and vegetables) (*21*). It was concluded that this high-tensile wire design offers a low-cost alternative to the non-electric 8-foot (2.44-meter) woven wire fence (*21*).

Finally, researchers considered the use of three different 2-foot (0.6-meter) single-strand electric fencing designs to reduce deer damage to cornfields (*23*). Two types of chemical repellents were also tested (*23*). The study was conducted from 1984 to 1985 on 51 pairs of cornfields that ranged in size from 0.34 to 5.15 hectare (*23*). Each pair consisted of similar test and control plots, and the fencing treatment was randomly assigned to a sample of these pairs. Eleven fences of 17-gauge steel wire were coated with peanut butter and vegetable oil (*23*). Fifteen fences were constructed with a highly visible 0.4-inch (1.0-centimeter) wide yellow polyethylene ribbon with five interwoven strands of stainless steel (*23*). Ten fences were made with a highly visible plastic-backed 0.2-inch (0.5-centimeter) wide aluminum foil ribbon (*23*). The results indicated that white-tailed deer damage was less in the fields surrounded by these single-strand electric fences, and there was no difference in the impact of the three designs (*23*). Each design also had favorable benefit-cost ratios up to five years after their installation (*23*). The researchers recommended only the peanut-butter-coated and the polyethylene ribbon designs because they were easier to install, more durable, and the least expensive (*23*).

The feasibility of installing electric fence at any location (especially along a ROW) would appear to be related to, among other things, fencing installation needs, costs and benefits, animal and human safety, the provision of power, and fencing maintenance. The installation of these fences needs to be correct and also becomes easier as the ground becomes more level. Electric fencing maintenance needs to be vigilant to keep it operating, and requires nearby vegetation to be removed or cut regularly. Enough power is also needed to shock a white-tailed deer, and this will shock other animals and humans. Questions about whether white-tailed deer will somehow adapt to, or at times ignore, the fencing have not been evaluated. Finally, the fence and the wire also need to be strong enough to handle the impact of a white-tailed deer. No studies have considered the impact and/or feasibility of electric fencing in the roadway ROW, but all these factors would need to be evaluated before installation is considered. There may also be newer fencing technologies that may make the feasibility of this type of fencing installation more realistic.

Fencing, DVCs, and Benefit – Cost Analysis

One study was found that focused on the benefit-cost feasibility of installing exclusionary fencing along a roadway environment (*9*). As part of the study, however, an estimation of the DVC-reduction connected to the installation of 8.0-foot (2.44-meter) fencing had to be derived (*8*, *9*). The benefits related to this reduction that were used in this study include the vehicle repair cost savings and the benefit of a saving a deer (*9*). The value of a deer used in this study was $350 (1976 dollars), and the range of vehicle repair costs was $324 to $564 (1970 to 1975 dollars) (*9*). The costs considered were the difference between installing an 8.0-foot (2.44-meter) fence versus a regular 3.6-foot (1.1-meter) ROW fence, and fencing maintenance (arbitrarily assumed to be one percent of the installation cost annually) (*8*, *9*).

Overall, six fencing installations were used in this benefit-cost evaluation (*9*). In fact, these six installations are the same Colorado Interstate 70 and Highway 82 locations described in the "Fencing with One-Way Gates and/or Grade-Separated Wildlife Crossings" section of this summary. Five of the location calculations included costs for 8.0-foot (2.44-meter) fencing on one side of roadway, and three of these also included the installation/maintenance costs of one-way gates (*8*, *9*). One location also included 8.0-foot (2.44-meter) fencing on both sides of the roadway, one-way gates, and a 10-foot by 10-foot (3.05-meter by 3.05-meter) underpass (*8*, *9*). The length of the fencing locations ranged from 1.1 to 4.8 miles (1.8 to 7.7 kilometers).

The documented effectiveness of these six locations varied. The mean annual percent reduction in DVCs (as measured by carcasses) for the two installations with just fencing was 70.0 and 82.0 percent, the reduction for those with fencing and one-way gates ranged from 78.9 to 86.5 percent, and the reduction calculated for the fencing installation with the one-way gates and the underpass was only 67.8 percent (*9*). The number of years used to calculate these reductions was not documented (*9*).

Benefit-cost ratios were calculated for all six locations (*9*). The benefit-cost ratios for the five locations without the underpass ranged from 2.83:1.0 to 12.37:1.0 (*9*). The location with the underpass had a benefit-cost ratio of 2.59:1.0 (*9*). This low benefit-cost value was attributed to the high cost of fencing on both sides of the roadway and the underpass, and the relatively low estimated effectiveness of this facility (*9*). All of these factors are related to the topography within which this installation was erected, rockslides, and purposeful human damage to the fence (*9*).

The researchers involved in this study also completed a sensitivity analysis of the benefit-cost calculation inputs (*9*). Not surprisingly, they found that the results were sensitive to errors in vehicle repair cost and the value of the deer saved (*9*). Of course, it was also shown that when costs were held constant, there was more benefit to installing exclusionary fence along roadway segments with high mortalities (*9*). They also calculated the minimum number of deer that would need to be killed each year along a one mile (1.6 kilometer) segment to produce a benefit-cost greater than one (*9*). They assumed a fencing DVC reduction of 75 percent, a $500 cost for vehicle repairs, a $350 deer value, a 6.0 percent discount rate, a fencing cost of about $85,000 per mile, and an underpass cost of approximately $250,000 (all 1978 values) (*9*). It was found that the benefits from 8-foot (2.44-meter) fencing on one side of roadway was close to its cost when six deer were killed per mile (1.6 kilometer) (*8*, *9*). Similarly, a benefit-cost ratio near one was achieved for fencing on both sides of the roadway when eight deer were killed per mile (1.6 kilometers), and for 12 deer per mile (1.6 kilometer) with fencing on both sides of the roadway was combined with an underpass (*9*). The one-way gates were apparently not included in this evaluation. The researchers recommended, however that a benefit-cost ratio closer to 1.35 be used to determine installation levels, and for this ratio the number of deer killed per mile (1.6 kilometer) for the three designs 8, 16, and 24 respectively. The researchers recognized a number of inputs in their study were arbitrarily set, but they think the range of values they presented were reasonable (*9*).

Conclusions

This summary described the results from a series of studies that examined the various impacts of exclusionary ROW fencing. Examples of studies that considered the similar impacts of fencing installations with one-way gates, earthen escape ramps, and/or wildlife crossings were also discussed. Research conclusions related to DVC location modeling, electric fencing, and benefit-cost analyses were also presented.

Overall, the fencing installation evaluated in the studies summarized had documented white-tailed/mule deer carcass (i.e., mortality) reductions of 60 to 97 percent. Some of installations evaluated included exclusionary fencing only, others combined fencing and one-way gates, and a sample of the sites included fencing, one-way gates, and wildlife crossings. Almost all of the studies with a documented reduction, however, had fencing that was approximately 8-feet (2.44-meter) in height. Several studies attempted to evaluate or compare the impacts of different fencing heights, but they either did not have enough data to make a valid conclusion, found conflicting results, and/or failed to control for variables that would confound the observed effectiveness of the fencing (e.g., existing holes and gaps).

Unlike most of the DVC countermeasure research summarized in this toolbox, however, the results from the exclusionary fencing studies all consistently showed a reduction in the number of white-tailed or mule deer carcasses observed adjacent to the fencing installation implemented. Unfortunately, the design and validity of some of these studies are still questionable, and their results should be used with caution. For example, the highest and some of the lowest reductions (a range of about 30 percent) in roadside carcasses were observed in studies that evaluated installations with fencing, one-way gates, and one or more wildlife crossings. Some of the factors that may have produced this wide range of results for similar installations are discussed in the following paragraphs.

Three of the primary factors that appeared to impact the effectiveness of the fencing installations summarized were proper fencing installation, active maintenance/repair, and the vigilant removal of animals that do enter the fenced ROW. For example, it was found that white-tailed deer prefer to breach a fence rather than jump it, and they only need a gap as small as 9 inches (22.9 centimeters) at the bottom of a fence to enter the ROW. In addition, the combination of exclusionary fencing with other complementary infrastructure (e.g., one-way gates, earthen escape ramps, and/or wildlife crossings) may increase the amount of the observed DVC reduction along a segment (trapped animals are provided an escape and other animals can cross the roadway without the possibility of a vehicle conflict). The installations that combine all of these factors are expected to produce the best fencing DVC-reduction effectiveness.

Other more general conclusions can also be reached from the similarities in the study results. One, more information is needed about the importance and need of a particular fencing height. Fencing heights other than 8-feet (2.44-meters) (if cost effective) needs to be evaluated. Two, the location of the fencing may have an impact on its effectiveness. In one study it was found that the number of roadside white-tailed deer carcasses was the highest when the fencing was on the edge or within 75 feet (22.9 meters) of the woods. This pattern was especially obvious if there were grazing opportunities within the ROW. Three, the length of the exclusionary fencing is important. Several of the researchers had problems with deer going around the ends of their installations. One study suggested that the areas of “high” deer activity and/or DVCs be determined (through observation of animals and/or carcasses), and that the fencing should be installed at least 1/2-mile (0.8- kilometers) beyond that area. It was also suggested that wildlife crossings should be installed in these areas, if possible, every one mile (1.6 kilometers). These suggestions are based on their observations of how deer move parallel to the exclusionary fencing. Finally, the topography adjacent to the fencing must be considered, and the locations where it effectively makes the fencing shorter should be adjusted.

The other subjects discussed in this summary included DVC modeling, one-way gates, earthen escape ramps, electric fencing, and the benefit-cost of fencing installations. Two studies were found that showed a relationship between the existence of fencing and whether that segment would be a “high” DVC section or not. The results, however, contradicted each other. The use of the one-way gates in the study installations also seemed to vary, and in one study earthen escape ramps were used 8 to 11 times more than the one-way gates along the same roadway segments. However, several studies have shown that the installation of electric fencing can reduce crop damage. The installations were also considered to be cost effective in some cases. The electric fencing considered was often shorter than 8 feet (2.44 meters) in height, and sometimes only consisted of one strand of wire. Concerns related to the installation of electric fencing typically include cost, vegetation management around the fence, power, and maintenance. The use of electric fence along a ROW has not been studied, but its feasibility could be the subject of future research. Finally, a study was summarized that attempted to determine the number of deer that needed to be killed along a roadway segment to make the benefit-cost ratio of a fencing installation greater than one. It was suggested that for a conservative benefit-cost ratio of 1.35, 8-foot (2.44-meter) fencing on one side of the roadway, both sides of the roadway, and on both sides combined with a wildlife crossings, the roadside deer carcass numbers would need to be 8, 16, and 24 deer killed per mile (1.6 kilometer) per year, respectively.

Ultimately, the study results described in this summary are the outcome of different methods of data collection, amounts of data, and analysis approaches. Few, if any, of the studies are statistically rigorous (as measured by current safety data analysis standards), and the documentation necessary to completely understand the strengths and weaknesses of the declared results are often not available. However, and again unlike most of the DVC countermeasure research considered in this toolbox, there were two fencing studies that did recognize and document the weaknesses of their evaluative approach (e.g., the problems with typical before-and-after and control/treatment site DVC comparisons). There were also some attempts to control for and/or quantify the variability inherent in the data and comparison sites. A proper experimental design and statistically rigorous approach to DVC reduction evaluations would reveal an estimate of the actual impact of particular fencing designs. In other words, the observed impacts of the exclusionary fencing studies described in this summary might decrease by some amount. It is recommended that future fencing evaluations incorporate currently accepted safety data analysis approaches.

References

1. Carbaugh, B.T. *Activity and Behavior of White-Tailed Deer (Ococoileus Virginianus) Along an Interstate Highway in a Forest Region of Pennsylvania*. Dissertation. The Pennsylvania State University, State College, PA, 1970.

2. Peek, F.W., and E.D. Bellis. Deer Movements and Behavior Along an Interstate Highway. In the *Highway Research News*. Number 36. Highway Research Board, Washington, D.C., 1969, pp. 36 to 42, 1969.

3. Bellis, E.D., H.B. Graves, B.T. Carbaugh, and J.P. Vaughn. *Behavior, Ecology, and Mortality of White-Tailed Deer Along a Pennsylvania Interstate Highway*. The Pennsylvania State University Institute for Research on Land and Water Resources. Research Publication Number 71, Pennsylvania State University, State College, PA, October 1971.

4. Bellis, E.D., and H.B. Graves. Highway Fences as Deterrents to Vehicle-Deer Collisions. In the *Transportation Research Record 674*, Transportation Research Board, National Research Council, Washington, D.C., 1978. pp. 53 to 58.

5. Falk, N.W. *Fencing as a Deterrent to Deer Movement along Highways*. Dissertation. The Pennsylvania State University, State College, PA, November 1975.

6. Tubbs D.M. *Ecology and Behavior of White-Tailed Deer (Odocoileus Virginianus) Along A Fenced Section of a Pennsylvania Interstate Highway*. Dissertation. Pennsylvania State University, State College, PA, December 1972.

7. Feldhamer, G.A., J.E. Gates, D.M. Harman, A.J. Loranger, and K.R. Dison. Effects of Interstate Highway Fencing on White-Tailed Deer Activity. *Journal of Wildlife Management*, Volume 50, Number 3, 1986, pp. 497 to 503.

8. Reed, D.F., T.N. Woodard, and T.D.I. Beck. *Regional Deer- Vehicle Accident Research*. Report Number FHWA-CO-RD-79-11, Colorado Division of Wildlife, Denver, Colorado, November 1979.

9. Reed, D.F., T.D. Beck, and T.N. Woodard. Methods of Reducing Deer-Vehicle Accidents: Benefit-Cost Analysis. *Wildlife Society Bulletin*, Volume 10, 1982, pp. 349 to 354.

10. Bashore, T.L., W.M. Tzilkowski, and E.D. Bellis. Analysis of Deer-Vehicle Collision Sites in Pennsylvania. *Journal of Wildlife Management*, Volume 49, Number 3, 1985, pp. 769 to 774.

11. Puglisi, M.J., J.S. Lindzey, and E.D. Bellis. Factors Associated With Highway Mortality of White-Tailed Deer. *Journal of Wildlife Management*, Volume 38, Number 4, 1974, pp. 799 to 807.

12. Woods, J.G. *Effectiveness of Fences and Underpasses on the Trans-Canada Highway and Their Impact on Ungulate Populations Project*. Canadian Parks Service, Natural History Division, Calgary, Alberta, Canada, March 1990.

13. Ludwig, J., and T. Bremicker. Evaluation of 2.4-Meter Fences and One-Way Gates for Reducing Deer-Vehicle Collisions in Minnesota. In the *Transportation*

Research Record 913, Transportation Research Board, National Research Council, Washington, D.C., 1983, pp. 19 to 22.

14. Reed, D.F., T.M. Pojar, and T.N. Woodard. Use of One-Way Gates by Mule Deer. *Journal of Wildlife Management*, Volume 38, Number 1, 1974, pp. 9 to 15.

15. Ward, A.L. Mule Deer Behavior in Relation to Fencing and Underpasses on Interstate 80 in Wyoming. In the *Transportation Research Record 859*, Transportation Research Board, National Research Council, Washington, D.C., 1982, pp. 8 to 13.

16. Hubbard, M.W., B.J. Danielson, and R.A. Schmitz. Factors Influencing the Location of Deer-Vehicle Accidents in Iowa. *Journal of Wildlife Management*, Volume 64, Number 3, July 2000, pp. 707 to 713.

17. Meyer, E., and I. Ahmed. Modeling of Deer-Vehicle Crash Likelihood Using Roadway and Roadside Characteristics. In the *Proceedings of the Transportation Research Board Annual Meeting*. Transportation Research Board, National Research Council, Washington, D.C., January 2004.

18. Clevenger, A.P., B. Chruszcz, and K.E. Gunson. Highway Mitigation Fencing Reduces Wildlife-Vehicle Collisions. *Wildlife Society Bulletin*, Volume 29, Number 2, 2001, pp. 646 to 653.

19. Bissonette, J.A. and M. Hammer. *Effectiveness of Earthen Return Ramps in Reducing Big Game Highway Mortality in Utah*. Utah Cooperative Fish and Wildlife Research Unit Series 2000, Utah State University, Logan, UT, November 2000.

20. Tierson, W.C. Controlling Deer Use of Forest Vegetation with Electric Fences. *Journal of Wildlife Management*, Volume 33, Number 4, October 1969, pp. 922 to 926.

21. Palmer, W.L., J.M. Payne, R.G. Wingard, and J.L. George. A Practical Fence To Reduce Deer Damage. *Wildlife Society Bulletin*, Volume 13, Number 3, 1985, pp. 240 to 245.

22. Porter, W.F. A Baited Electric Fence for Controlling Deer Damage to Orchard Seedling. *Wildlife Society Bulletin*, Volume 11, Number 4, 1983, pp. 325 to 327.

23. Hygnstrom, S.E. and S.C. Craven. Electric Fences and Commercial Repellents for Reducing Deer Damage in Cornfields. *Wildlife Society Bulletin*, Volume 16, Number 3, 1988, pp. 291 to 296.