WILDLIFE FUNNEL FENCING

Fencing that serves to funnel wildlife toward passage structures is critical to promoting highway passage (Romin and Bissonette 1996, Forman et al. 2003, Dodd et al. 2009). For larger animals (e.g., elk, deer), fences also are important in promoting highway safety through reduced incidence of wildlife-vehicle collisions (Dodd et al. 2007*a*, 2009). In fact, without ungulate-proof fencing along reconstructed sections of State Route 260, elk and mule deer use of large wildlife underpasses was limited (most animals continued to cross at grade) and the incidence of wildlife-vehicle collisions increased dramatically (Dodd et al. 2007*b*); after fencing, passage through underpasses increased nearly 5 fold, elk permeability increased 60%, and elk-vehicle collisions declined 85%. Further, Dodd et al. (2007*a*) found that funnel fencing resulted in the greatest benefit in increased deer and elk crossings associated with relatively marginal underpasses, thus having implications on achieving wildlife use of existing structures through retrofitting.

Ungulate-proof fencing ranging in height from 6.5 to 8 ft has been effective in reducing the incidence of wildlife-vehicle collisions, especially when used in conjunction with passage structures (Romin and Bissonette 1996, Forman et al. 2003, Dodd et al. 2007*a*, 2009). Though effective in reducing collisions, fencing alone in the absence of passage structures contributes to a barrier effect and fragments populations and habitats (Forman et al. 2003). Ward (1982) reported a more than 90% reduction in mule deer collisions with vehicles where underpasses and fencing were applied in Wyoming. Woods (1990) and Clevenger et al. (2001) reported 94−97% reductions in wildlife-vehicle collisions involving several species in Alberta with passages and fencing.

Though studies have found fencing to be effective, some mixed results have been reported (Falk et al. 1978), especially where animals cross at the ends of fencing, resulting in zones of increased incidence of wildlife-vehicle collisions (Feldhamer et al. 1986, Woods 1990, Clevenger et al. 2001). The primary drawbacks of fencing are that it is costly and requires substantial and continuous maintenance to remain effective (Forman et al. 2003), and there may also be some impact to visual aesthetics along highway corridors. Therefore, a balance needs to be achieved in the application of fencing to ensure effectiveness of passage structures against construction cost and long-term maintenance requirements. Dodd et al. (2009) and Gagnon et al (2009) both reported substantial economic benefit associated with funnel fencing realized from the reduced incidence of wildlife-vehicle collisions, thus helping justifying the upfront costs associated with fencing. Fencing may be a necessary component in meeting project objectives and conditions in promoting sensitiver, threatened and endangered species (e.g., desert tortoise, flat-tailed horned lizard) highway passage and reduced vehicle-related mortality.

Most highway fencing applications in Arizona to date have been associated with maintaining rights-of way (ROW) free of livestock, using various barbed-wire (cattle) and woven wire (sheep) fence applications (Detail A). The application of funnel fencing and various alternatives is relatively new, and relatively few different designs have been implemented to date. However, with effective evaluation and monitoring, valuable insights have been obtained. The types and applications of fencing and alternatives considered here include:

- Standard game fence (see Detail A)
- Standard wildlife fence (see Detail B)
- Retrofit right-of-way (ROW) fence
  - ROW fence raised with 10 foot T-posts (see Detail C)
  - ROW fence raised with extension sleeves (see Detail D)
  - Electric fence (experimental)
- Elk rock alternative to fence (see Detail E)
- Special status reptile fencing
  - Desert tortoise (see Detail F)
  - Flat-tailed horned lizard (see Detail G)

WILDLIFE FUNNEL FENCING AND ALTERNATIVE DESCRIPTIONS

Standard Game Fence

The standard barbed-wire game fence is but one of several applications of ROW fencing (Detail A). Game fence is a 4-wire fence 3.5 feet high, with a smooth bottom wire 16 inches above ground designed to limit livestock (cattle) access to highway ROW while facilitating wildlife passage. The spacing of the barbed-wire strands are intended to prevent livestock encroachment while allowing wildlife (e.g., deer, elk) to jump over the fence without foot entanglement, or to gain passage by crawling under the fence (e.g., pronghorn, young deer and elk). Standard game fence is not intended for nor is it effective in funneling ungulates and other wildlife species to wildlife passage structures.

Standard Wildlife Fence

Designed to withstand the impact of falling small trees and limbs that occur with fence erected in Arizona's "high country" ponderosa pine forests, as well as the force exerted by large elk pushing against it, standard wildlife fence is both stout and costly. This fence design (Figure 1; Detail B) was engineered to minimize maintenance while being highly effective at funneling large ungulates (elk, deer, etc.) toward passage structures. This 8-foot high fence is constructed with 12½ gauge fence fabric strung on 10-foot T-posts spaced 20 feet apart and metal line posts in concrete spaced no more than 120 feet apart. Even with other fence applications along highway corridors, the standard wildlife fence design has been used in conjunction with passage structures due to the concentration of animals at these sites.

Standard wildlife fence costs approximately $50/lineal foot (State Route 260 in 2007), or $528,000/mile for both sides of a highway. Unfortunately, this fence's high cost can be an impediment to its wide application of in conjunction with passage structures.

Figure 1. Standard 8-foot wildlife fence erected at a wildlife underpass along State Route 260. Note the woven wire, T-posts space 20 feet apart and metal support posts.

Retrofit Right-Of-Way Fences

Retrofitting of existing, sound ROW fence has been done on State Route 260 and is currently being considered for Interstate-17. In the State Route 260 applications, the existing ROW fence was raised from 3.5 to 7.5−8 feet in two manners to create an elk funnel fence directing animals to wildlife passage structures. This fencing is considered "semi-permeable" as smaller animals (coyotes, white-tailed deer, etc.) can pass through the standard game fence portion of the retrofitted fencing, generally crawling under the smooth bottom wire. To prevent such passage, additional modification to the existing ROW fence would be necessary using woven wire.

On State Route 260, engineered modifications were made to the design in Detail C whereby the existing angle-metal corner braces were not replaced, but were raised and strengthened (Figure 2). Also, the amount of concrete poured at each in-line support post was reduced. These changes contributed to making this application particularly cost effective, the primary attraction with this design. These retrofit applications cost approximately $12/lineal foot or $126,000/mile for both sides of a highway, a quarter of the cost of the standard wildlife fence.

Extended ROW Fence with T-posts and Barbed-Wire. With this fencing type, the existing barbed-wire ROW fence is extended upward to 7.5−8 feet using new 10-foot T-posts and barbed wire (Figure 2; Detail C). Existing ROW fence corner braces must be extended upward with new angle supports welded or bolted to the existing upright and bedded in concrete (Figure 2). This retrofit application has the widest applicability and is the most cost-effective. In the 2.5 years that this fence type has been in place along State Route 260, it has held up very well and presented no maintenance issues.

Extended ROW Fence with T-post Sleeves and Barbed-Wire. In this application, the existing ROW fence is extended upward to 7.5−8 feet using T-post sleeve extensions and barbed wire (Figure 3; Detail D). On State Route 260, sleeves were mass produced at a machine shop, yet their cost still exceeded that of new 10-foot T-posts. However, this application is attractive on rocky and/or steep slopes where it may be difficult to install new T-posts.

Electric Fence (Experimental). Along State Route 260, ElectroBraid™ braided electric rope fence with imbedded copper wire was used to raise the existing ROW fence to 8 feet. Electrified rope was affixed to 10-foot fiberglass poles with an electrified "kicker" attached to the ROW fence T-posts (Figure 4). Fencing was powered by a 12-volt solar panel system on one side of the highway and by 110-v power drop on the other; both applications proved reliable and no safety issues (fence is UL™ approved) were encountered (Gagnon et al. 2009). This fence is experimental in nature, and similar applications elsewhere have proven effective (Seamens and VerCauteren 2006). One advantage of electric fence is that wildlife species prone to climbing over other fencing types (e.g., black bear) are deterred from doing such with electrified fence.

Figure 2. Application of retrofitted ROW fencing using 10-foot T-posts and barbed wire to extend the fence to 7.5−8 feet, with a metal in-line support posts for strength (left). Exiting ROW fence corner braces were raised and supported with new angle braces bolted to the upright and bedded in concrete (right). Fencing retrofitted on State Route 260.

Figure 3. Application of retrofitted ROW fencing using T-post sleeve extensions and barbed wire to extend the fence to 7.5−8 feet, with a metal in-line support post for strength (left). Close-up of the T-post sleeve extending the existing T-post upward with bolts securing T-posts in place (right). Fencing retrofitted on State Route 260.

Figure 4. Application of modified ROW fence raised to 8 feet with ElectroBraid™ braided rope electric fence and fiberglass posts, with an electrified "kicker" mounted on the outside of ROW fence T-posts. Fencing retrofitted on State Route 260.

Elk Rock Alternative to Fence

Elk rock was designed as an alternative to fencing along State Route 260, primarily to eliminate the need for continuous maintenance (Figure 5, Detail E). It entails boulders 18−24" in diameter laid into a rip-rap swath approximately 12−20 feet wide to create a barrier to ungulate and other animal movement, thus deterring their crossing of the highway and funneling them toward passage structures. A critical element of the application is that no gaps be left between the boulders such that animals may pick their way through and ultimately establish travel routes; where such is done, elk rock proved to be an effective alternative to fencing (Dodd et al. 2007*a*). Such an application is especially attractive where large amounts of rock material must be disposed of during construction activities, and it also presents an attractive visual alternative to fencing (Figure 5). On the down side, the high costs of hauling and arranging the boulders into tight swaths with heavy equipment and operators is an expensive proposition, costing as much as $65/lineal foot or approximately $686,000/mile for both sides of a highway.

Figure 5. Application of "elk rock" rip-rap in a swath to deter ungulate passage into the highway ROW. In this instance along State Route 260, elk rock was tied into a wildlife underpass.

Special Status Reptile Fencing

Fencing to funnel special status reptiles toward passage structures or to limit access to highways to reduce mortality from vehicles presents a special challenge, as these species can either crawl or dig under fencing. As such, mesh-type fencing for the desert tortoise (Mojave population is a federally threatened species and Sonoran population under review) and the flat-tailed horned lizard (protected under a 1997 conservation agreement) must be buried to prevent crawling or digging under fence. However, where properly implemented, this fencing can dramatically reduce mortality from vehicles; on State Route 86, tortoise deaths from vehicles were reduced by 75% after fencing.

The U.S. Fish and Wildlife Service-approved tortoise exclusion fence specifications (Detail F) stipulate using 36-inch wide rolled 1-inch horizontal by 2-inch vertical welded mesh wire that is buried at least 12 inches below the surface. The remaining 22−24 inches of mesh wire above ground is either attached to existing ROW fence or to new T-posts spaced no further than 10-feet apart. Where burying fence is not practical due to rocky or other hard substrate, an alternative approach is to bend the wire mesh 90 degrees in the direction of approaching tortoises to create a 14-inch wide apron upon which at least 4 inches of soil and rock material is placed (Detail F).

For highways within the range of the flat-tailed horned lizard, the *Flat-tailed Horned Lizard Rangewide Management Strategy* (Flat-tailed Horned Lizard Interagency Coordinating Committee 2003) recommends funnel or barrier fencing that employs the application of 36 inch wide rolled hardware cloth with ¼-inch mesh (Detail G). The hardware cloth should be buried 6 inches below the ground surface with the 30 inches of mesh above ground attached to existing ROW fence or new T-posts with barbed wire strung at heights of 15 and 30 inches.

FUNNEL FENCING IMPLEMENTATION CONSIDERATIONS

A variety of factors must be addressed when erecting funnel fencing adjacent to highways.

Extent of Fencing

There are no clear guidelines for the extent of funnel fencing required in association with highway construction projects. However, the application of limited wing fencing in association with passage structures along State Route 260 did not yield desired results in terms of facilitating wildlife use of structures, promoting highway permeability, or reducing wildlife-vehicle collisions (Dodd et al. 2007*a*, 2009). Short of fencing an entire highway corridor and linking multiple passage structures, the preferred approach (Clevenger et al. 2001), sufficient amounts of fencing must be erected to ensure animals are successfully funneled to passage structures, unrestricted access to attractive habitats (e.g., wet meadows, streams) is eliminated, wildlife-vehicle collision issues are adequately addressed, and potential "end-run" effects are not created (see below).

Terminating Fencing

An important consideration of any fencing project that limits at-grade highway crossings by wildlife and funnels animals along the fencing parallel to the highway is the manner in which the ends of the fencing are terminated. Where funnel fencing does not end at a passage structure, an "end run" effect can occur where animals cross around the end of the fencing, potentially causing a concentrated wildlife-vehicle collision zone (Feldhamer et al. 1986, Woods 1990, Clevenger et al. 2001). Thus, the extent of funnel fencing may need to be extended to an appropriate site where the fence can be tied into another passage structure, a large canyon, or cut slope. In the absence of an appropriate location to terminate retrofitted fence along State Route 260, an animal detection system and wildlife crosswalk were installed to alert motorists (Gagnon et al. 2009).

Securing Lateral Access Points

Where funnel fencing along highways crosses lateral road access points, some type of measure is needed to prevent wildlife encroachment through the fence into the fenced corridor. Depending on the lateral road standard and traffic volume, various approaches can be taken. In low volume situations, gates may be appropriate. On State Route 260, 6-foot Powder River gates with barbed-wire stringers across the top, mounted on metal posts provided gated access while precluding wildlife encroachment into the fenced ROW (Figure 6). Signs were erected on the SR 260 gates alerting users to close the gates to maintain highway safety.

Figure 6. Modified 6-foot Powder River gate installed on a lateral access along State Route 260. Gate was raised to 8 feet with a barbed-wire stinger above the top rail to preclude animals from entering the fenced ROW. Note the sign imploring users to close the gate.

Cattle guards present an option for securing higher volume roadways while preventing wildlife encroachment should a gate be inadvertently left open; however, they are costly. Elk and deer can readily jump over single-width cattle guards, necessitating that double-wide cattle guards be installed as was done on a lateral access road off State Route 260 (Figure 7; Gagnon et al. 2009). As an alternative to cattle guards, electrified mats (ElectroMats™) constructed of recycled plastic decking material into which electrical conducting bars are mitered have shown promise in various applications in Alaska, New Mexico (Interstate-40) and even a lateral road off State Route 260. An electric mat is planned for implementation across State Route 260 to secure the

Figure 7. Double-wide cattle guard installed at a lateral access point along State Route 260 to prevent elk encroachment into the fenced ROW.

wildlife crosswalk, and this approach is being considered for on- and off-ramps associated with an enhancement project along Interstate-17. Mats are laid flush with the pavement surface and are attached to large cross members bedded in concrete (Figure 8). They may be powered by AC (power drop) or DC (small solar panels) power, and can be turned off during the day or have crosswalk-type push button switches installed to minimize conflicts with crossing pedestrians. They do not need to be wider than a standard cattle guard due to animal aversion to approaching or jumping them associated with the electrical current.

Figure 8. Electrified mats (ElectroMats$^{TM)}$ installed along lateral access roads as an alternative to gates and cattle guards on a low volume access road off State Route 260 (left) and an on-ramp on Interstate-40 in New Mexico.

Right-of-Way Fencing in Conjunction with Passage Structures

Ideally, there should be no standard game fence along the ROW at the mouths of passage structures, presenting an unobstructed approach and view to and through the structures for animals; funnel fencing is tied into bridge/underpass abutments or culvert headwalls. In the event that standard game fence must be retained along the ROW at the mouths of passage structures, primarily to limit livestock access through structures, lengths of PVC pipe affixed to the top 2 stands of barbed-wire can be used to minimize damage from animals jumping the fence while moving to and from the passage structure (Detail H).

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Table 1. Summary of the various wildlife funnel fencing types and alternatives available for use on highway fencing projects to funnel large ungulates (e.g., elk and deer) toward passage structures, their relative rating for several evaluation criterion, and an overall applicability rating.

Funnel Fencing Type	Evaluation Criterion for Funnel Fencing and Alternatives				
	General Effectiveness	**Relative Cost**	**Retrofit Applicability**	**Maintenance Requirements**	**Overall Applicability**
Standard wildlife fence	High	High	Low	Low	Moderate
Retrofit ROW barbed-wire fencing	High	Moderate	High	Moderate	High
Retrofit ROW electric fencing	High	Moderate	Moderate	Moderate	Moderate
Elk rock alternative to fencing	Moderate	Highest	Low	Lowest (None)	Low