EVALUATION OF DESERT BIGHORN SHEEP OVERPASSES ALONG
US HIGHWAY 93 IN ARIZONA, USA

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ABSTRACT
More than 20 years ago planning began for the improvement and realignment of US Highway 93 (US 93) near Hoover Dam on the Arizona-Nevada border. In those early planning stages Arizona Game and Fish Department (AGFD) and other stakeholders expressed concern for existence the Black Mountain desert bighorn sheep (Ovis canadensis nelson) herd, the largest contiguous population remaining in the southwest. The impending realignment, widening and increased traffic would block sheep from food, water, mates and lambing grounds and restrict genetic interchange, threatening the herd’s existence. Further, sheep-vehicle collisions would increase, reducing both motorist and sheep safety. On September 11, 2001, commercial truck traffic across Hoover Dam was stopped because of terrorism concerns, and Federal Highway Administration (FHWA) and Arizona Department of Transportation (ADOT) began the upgrade of the first 2 miles (3 km) of US 93 to bypass the dam. Concurrently, final planning for the adjacent 15 miles (24 km) was expedited to ensure its completion by the time the Hoover Dam Bypass opened. Construction for both sections included complete realignment near Hoover Dam and upgrading the 17 miles (27 km) to a four-lane divided highway. To address concerns for the local sheep population, a Technical Advisory Committee (TAC) was formed. Also concurrently, an evaluation of three wildlife underpasses built for desert bighorn sheep along State Route (SR) 68 showed minimal use by desert bighorn sheep and pointed to the need for better designs. In the absence of data, overpasses seemed likely the best option for this species. Given this sparse information, combined with results from monitoring wildlife crossings on SR 260 for other species, the TAC understood the importance of proper placement and design for successful wildlife crossings. Therefore, in 2004, AGFD/ADOT/FHWA initiated a study along US 93 to identify exactly where sheep crossed Hwy 93. Ultimately, GPS movement data revealed three locations to construct desert bighorn sheep overpasses. With their completion in fall of 2010, these overpasses linked by fencing to four bridges and numerous culverts reestablished wildlife connectivity across Hwy 93.
Following overpass construction, AGFD, funded through ADOT Research Center, began evaluation of the overpasses. The objectives of our study were to evaluate: 1) wildlife use of overpasses, bridges, culverts and escape ramps, 2) post-construction sheep-vehicle collision rates, and 3) highway permeability for sheep. To meet these objectives we used video surveillance and still camera systems to assess wildlife movement and behavior associated with the overpasses, culverts, escape ramps and cattle guards. We also continue to collect wildlife-vehicle collision data to compare with pre-construction levels. Additionally, we placed GPS collars on sheep to evaluate overpass and funnel-fencing use. On February 1, 2011, we recorded the first crossings of a wildlife overpass by desert bighorn sheep. Sheep continue to use the three overpasses and we’ve recorded more than 1000 crossings Sheep-vehicle collisions are below pre-construction levels. We will provide detailed results of wildlife crossing use and sheep-vehicle collisions from the first two years of the US 93 evaluation.

INTRODUCTION

Direct and indirect highway impacts have been characterized as some of the most prevalent and widespread forces altering natural ecosystems in the U.S. (Noss and Cooperrider 1994, Trombulak and Frissell 2000, Farrell et al. 2002). The direct impact of collisions with motor vehicles is a significant source of mortality affecting wildlife populations. An estimated 500,000 (Romin and Bissonette 1996) to 700,000 (Schwabe and Schuhmann 2002) deer (Odocoileus spp.) alone are killed annually on U.S. highways. Wildlife-vehicle collisions cause human injuries and deaths, tremendous property damage and substantial loss of recreational opportunity and revenue associated with sport hunting (Reed et al. 1982, Schwabe and Schuhmann 2002), and disproportionately affect threatened and endangered species (Foster and Humphrey 1996).

Forman (2000) and Forman and Alexander (1998) estimated that highways have affected >20% of the U.S. land area through habitat loss and degradation. Perhaps the most pervasive impact of highways on wildlife is barrier and fragmentation effects resulting in diminished habitat connectivity and permeability (Noss and Cooperrider 1994, Forman et al. 2003). Highways block animal movements between seasonal ranges or other vital habitats (Trombulak and Frissell 2000). This barrier effect fragments habitats and populations, reduces genetic interchange (Epps et al. 2005, Riley et al. 2006), and limits dispersal of young (Beier 1995), all serving to disrupt viable wildlife population processes. Long-term fragmentation and isolation renders populations more vulnerable to stochastic events that may lead to extinctions (Hanski and Gilpin 1997).

Wildlife passage structures have shown tremendous benefit in promoting wildlife passage for a variety of wildlife species (Farrell et al. 2002, Clevenger and Waltho 2003, Dodd et al. 2007a), by reducing the impact of roadway traffic on wildlife movements versus those that would occur during at-grade crossings (Gagnon et al. 2007a,b). Wildlife crossings, in conjunction with fencing have reduced the incidence of wildlife-vehicle collisions while promoting permeability (Clevenger et al. 2001, Dodd et al. 2007b,c, Dodd and Gagnon 2011).

Desert bighorn sheep occur throughout much of northern Mexico and the southwestern U.S. and are distributed in naturally fragmented populations (Krausman and Leopold 1986, Bleich et al. 1990, 1996, Andrew et al. 1999). Population persistence as it relates to bighorn sheep population size is a controversial topic (Berger 1990, Krausman et al. 1993, 1996, Berger 1999, Wehausen 1999). In general, no specific population size ensures population persistence (Thomas 1990), but small bighorn sheep populations (Berger 1990) occupying marginal or comparatively poor habitat, or small patches of suitable habitat (Gross et al. 1997, McKinney et al. 2003) may require management intervention to ensure long-term persistence. Habitat patch size may be the primary correlate of bighorn sheep population performance and persistence (Gross et al. 1997, Singer et al. 2001, McKinney et al. 2003), but factors other than patch size may influence extinction and colonization (Fleishman et al. 2002). As such, bighorn
conservation efforts should emphasize preventing habitat fragmentation and loss and restoring habitat (Fahrig 1997).

Throughout the Southwest, including Arizona, most populations of desert bighorn sheep are small (<100) and isolated (Krausman and Leopold 1986). Berger (1990) concluded that desert bighorn populations with fewer than 50 individuals tend to go extinct, but that extirpation of populations is not caused by food shortages, weather, predation, or interspecific (e.g., with cattle, burros, etc.) competition. Desert bighorn sheep populations may be fragmented and isolated by anthropogenic influences such as highways, fences, railroads, agricultural developments, canals, and housing developments (Leslie and Douglas 1979, Gionfriddo and Krausman 1986, Rodriguez et al. 1996, McKinney and Smith 2007). Traditional management techniques such as habitat protection and improvement and maintenance of dispersal corridors are important in conservation of bighorn sheep populations (Schwartz et al. 1986). However, Beier and Loe (1992) suggested preservation of natural wildlife movement corridors and creation of new corridors may not preserve connectivity if the location of these corridors are not scientifically based. Though wildlife passage structures have been widely used in North America to enhance permeability and reduce wildlife-vehicle collisions for a range of wildlife species, limited information exists on the efficacy of passage structures in promoting permeability for desert bighorn sheep populations. Evaluation of underpasses by Bristow and Crabb (2008) indicated little use by sheep, particularly ewes, leading to the incorporation of overpasses on US 93 with their locations defined by GPS movements to overcome potential design and placement issues.

To gain adequate insight into the efficacy of overpasses in promoting habitat connectivity for desert bighorn sheep, long-term monitoring is essential to determine adaptation of sheep to the newly built structures over time. Along SR 260 in central Arizona, elk and deer did not immediately use certain structures possibly due to their design or placement (Dodd et al. 2007a). However, after a 4 year period of monitoring, most structures were used by elk and deer regularly and in fact structure use increased over time (Gagnon et al. 2011). Had researchers drawn final conclusions from only a couple years of monitoring, recommendations and implementation of future structures would have been severely limited. The expectation is that long term monitoring of the structures will provide data to validate their design and justify the investment.

BACKGROUND AND STUDY AREA

U.S. Highway 93 (US 93) is the primary transportation route between Phoenix and Las Vegas, Nevada, and has been congressionally designated as one leg of the CANAMEX (Canada to Mexico) Trade Corridor upon which commercial and non-commercial traffic is projected to increase dramatically in the future. US 93 currently crosses Hoover Dam (Milepost [MP] 0) on the Colorado River 70 miles northwest of Kingman, Arizona, and 20 miles (32 km) southeast of Las Vegas. The study area extends between US 93 MP 0 and 17, with a large majority of the Lake Mead National Recreation Area, and small portions of Bureau of Reclamation at the dam site and BLM lands at the far southern extreme. Construction of a new US 93 highway alignment has been ongoing since 2003 between MP 0 and 2 to bypass Hoover Dam to address traffic volume congestion and security issues; the overall project was completed and the highway reopened in October 2010. US 93 traffic volumes on the new bridge over the Colorado River, included as part of the Hoover Dam bypass project were forecast at 9,300 AADT in 1997 and are anticipated to increase to 16,400 by 2017 (Hoover Dam Bypass EIS; ADOT). US 93 from MP 2-17 was recently reconstructed from a 2-lane to a 4-lane divided highway with a standard median width (108 ft (32 m) centerline to centerline).

The sheep population on the proposed study area is a sub-unit of the largest extant desert bighorn sheep population in Arizona, encompassing the Black Mountains, and has served as a source herd for numerous reintroductions of bighorn into several sites in Arizona and the Southwest. Elevations within the study area range from 637 ft (194 m) at the Colorado River to 4,957 ft (1510 m) on Mount Wilson. This
topography is well suited to desert bighorn sheep and includes rugged mountainous terrain with steep talus slopes and cliffs to dry washes among rolling hills (Cunningham and Hanna 1992). The sheep population here provides enjoyment through wildlife watching on the study site and along the Colorado River, as well as providing recreational opportunity to those who hunt sheep in the area. Desert bighorn sheep have been a focal species of concern during all planning efforts for the reconstruction of US 93.

As planning progressed for the reconstruction of US 93 and the preferred alignment alternative was selected, McKinney and Smith (2007) conducted an assessment of bighorn sheep trans-highway movements relative to the proposed reconstruction plans. They focused on identifying potential locations for future passage structures to enhance highway permeability for sheep and to reduce the incidence of wildlife-vehicle collisions. Potential fragmentation of the desert bighorn population on the eastern side of the study area from the larger population in the Black Mountains to the west was of particular concern. McKinney and Smith (2007) instrumented 36 desert bighorn with Global Positioning System (GPS) receiver collars, funded with the assistance of ADOT and the Federal Highway Administration, from 2004-2006 and obtained more than 73,000 fixes. They documented 5 areas corresponding to ridgelines where sheep concentrated their movements and three of these locations were ultimately selected for wildlife overpasses. These recommendations were incorporated into the 2008 Preliminary Bridge Selection Report for US 93 MP 2-17, which also included two new mainline bridges (Table 1, Figures 1 and 2) for DESERT BIGHORN SHEEP passage. Concurrently, funnel-fencing, escape ramps and installation of double-wide cattle guards were identified in the 2008 Environmental Assessment Reevaluation for US 93, Hoover Dam to Milepost 17. The project team used this information to complete planning and begin construction in early 2009. Construction of all wildlife crossings and funnel-fencing wrapped up on March 15, 2011.

Table 1. US 93 Bridge and Wildlife Crossing Structures Implemented with Highway Reconstruction between MP 3 and MP 17*.

<table>
<thead>
<tr>
<th>Structure Name</th>
<th>Structure Type</th>
<th>Milepost</th>
<th>Length ft (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wildlife Crossing #1</td>
<td>Overpass</td>
<td>12.2</td>
<td>202.0 (61.6)</td>
</tr>
<tr>
<td>Devils Wash Bridge Northbound (NB)</td>
<td>Bridge</td>
<td>8.0</td>
<td>290.0 (88.4)</td>
</tr>
<tr>
<td>Devils Wash Bridge Southbound (SB)</td>
<td>Bridge</td>
<td>8.0</td>
<td>268.8 (81.9)</td>
</tr>
<tr>
<td>Wildlife Crossing #2</td>
<td>Overpass</td>
<td>5.1</td>
<td>202.0 (61.6)</td>
</tr>
<tr>
<td>White Rock Canyon Bridge SB</td>
<td>Bridge</td>
<td>4.2</td>
<td>216.5 (66.0)</td>
</tr>
<tr>
<td>White Rock Canyon Bridge NB</td>
<td>Bridge</td>
<td>4.2</td>
<td>213.8 (65.2)</td>
</tr>
<tr>
<td>Wildlife Crossing #3</td>
<td>Overpass</td>
<td>3.3</td>
<td>202.0 (61.6)</td>
</tr>
</tbody>
</table>

*Source: ADOT 2008
The US 93 project is located in the northwestern corner of Arizona along a 17-mile (27 km) stretch of roadway near Hoover Dam that included the reconstruction of Hoover Dam Bypass (MP 0-2) and a separate project that includes MP 2-17. For this study we evaluated the latter stretch of US 93, including the three overpasses and two bridges along with select culverts linked with 7’ (2.1 m) woven wire fence (Figure 1).

Figure 1. US Highway 93 study area showing landownership, mileposts (red numbers), 0.1-mile segments (black numbers), and location of bridges and wildlife overpasses.
Figure 2. Aerial and ground view of wildlife crossings along US Highway 93 near Hoover Dam, AZ. This includes the overpasses at MP 3.3 (top), MP 5.2 (second from top), MP 12.2 (middle), and White Rock bridge at MP 4.0 (second from bottom) and Devils Wash bridge (MP 8.0 (bottom).
METHODS
With the extensive desert bighorn sheep research conducted along US 93 by Cunningham and Hanna (1992) and McKinney and Smith (2007), our proposed research focuses on evaluating the effectiveness of the proposed US 93 wildlife overpasses. This evaluation will add greatly to our understanding of desert bighorn sheep-highway relationships and the effectiveness of passage structures to promote permeability (McKinney and Smith 2007). The specific objectives and associated procedures of our proposed US 93 research project include:

1) Investigation of wildlife-vehicle collision patterns and rates along US 93.

2) Evaluation of wildlife use of overpasses the two bridges, escape ramps and select culverts using video camera and Reconyx© still camera surveillance.

Wildlife-vehicle collision patterns
Collisions along US 93 cause significant mortality for desert bighorn sheep in the vicinity of Hoover Dam (Cunningham and Hanna 1992, Figure 3). ADOT constructed passage structures and ungulate-proof fencing intended to reduce sheep-vehicle collisions. Given the reduction in traffic, particularly semi-trailer trucks, during the restricted access period to Hoover Dam, we compared the post-construction collision rate to that documented prior to 9-11-2001 before truck traffic was diverted. We used two methods to document sheep-vehicle collisions. First, AGFD Region III, Department of Public Safety (DPS) highway patrolmen and ADOT maintenance personnel submitted sheep/vehicle collision records. Second, we searched the highway corridor for evidence of wildlife-vehicle collisions every two weeks. The database included non-duplicate records with date, time, location of the sheep-vehicle collision (to the nearest 0.1 mile), sex of the animal(s) involved when known, and the reporting agency. We compared the collision numbers to 11 sheep-vehicle collisions/year (Cunningham and Hanna 1992).

Wildlife use of structures
Factors that influence wildlife crossing use have been reported for many species, but not desert bighorn sheep. Monitoring the three overpasses adds to our general knowledge when designing future bighorn sheep crossings, as well as for other species in that habitat type. For this study, we evaluated crossing structure use with an array of video and rapid-fire still cameras (Table 2, Figure 2 and 3). These structures included all overpasses and bridges from MP 2-17, along with select culverts, escape ramps and cattle guards (Table 2). Complex camera and trigger arrays detected approaching and crossing animals used to calculate passage rates (Dodd et al. 2007). Passage rates are calculated as a ratio of crossings to
approaches to provide an unbiased comparison of structure use. To minimize premature conclusions in this report, the Research Teams limited our results to structure use only. Passage rate analysis will be reported on following the ensuing long-term monitoring project (Gagnon et al. 2011). In the event of a video system failure, rapid-fire still cameras were used at the overpasses to document crossing wildlife. Still cameras were also installed at the culverts, escape ramps, and cattle guards.

Table 2. Structures monitored with video and/or still frame cameras within the study area.

<table>
<thead>
<tr>
<th>Structure name</th>
<th>Milepost</th>
<th>Video camera #</th>
<th>Still camera #</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wildlife Crossing #1 (overpass)</td>
<td>12.2</td>
<td>X</td>
<td>1</td>
</tr>
<tr>
<td>Devils Wash Bridge</td>
<td>8.0</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Wildlife Crossing #2 (overpass)</td>
<td>5.1</td>
<td>X</td>
<td>1</td>
</tr>
<tr>
<td>White Rock Canyon Bridge</td>
<td>4.2</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Wildlife Crossing #3 (overpass)</td>
<td>3.3</td>
<td>X</td>
<td>1</td>
</tr>
<tr>
<td>Culvert 13.1</td>
<td>13.1</td>
<td></td>
<td>1</td>
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<tr>
<td>Culvert 6.0</td>
<td>6.0</td>
<td></td>
<td>1</td>
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<tr>
<td>Culvert 5.1</td>
<td>5.1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Escape Ramp Overpass #1 NW</td>
<td>12.2</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Escape Ramp Overpass #2 NW</td>
<td>5.1</td>
<td>X</td>
<td></td>
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<tr>
<td>Escape Ramp 3.3 NW</td>
<td>3.3</td>
<td></td>
<td>1</td>
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<tr>
<td>Escape Ramp 3.3 NE</td>
<td>3.3</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Escape Ramp 3.3 SW</td>
<td>3.3</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Escape Ramp 3.3 SE</td>
<td>3.3</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Escape Ramp Kingman Wash</td>
<td>2.2</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Escape Ramp Sugar Loaf NE</td>
<td>1.1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Kingman Wash SE Cattle Guard</td>
<td>2.2</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Kingman Wash SW Cattle Guard</td>
<td>2.2</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 3. During construction of the wildlife overpasses AGFD worked with ADOT and FNF Construction to incorporate these seamless state-of-the-art video surveillance systems into the overpass infrastructure.
RESULTS
Wildlife-vehicle collision patterns
In the first two years following construction, we documented seven sheep-vehicle collisions, all between MP 0-4, which included two rams and five ewes (Table 3). Therefore we realized a 45% collision year one and an 82% reduction in year two compared to the baseline of 11 sheep-vehicle collisions/year (Cunningham and Hanna 1992). The highest percentage of collisions occurred in July (43%) and November (29%).


<table>
<thead>
<tr>
<th>Date</th>
<th>Mile Post</th>
<th>Sex</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/14/2011</td>
<td>2.2</td>
<td>Male</td>
</tr>
<tr>
<td>7/15/2011</td>
<td>2.0</td>
<td>Female</td>
</tr>
<tr>
<td>7/18/2011</td>
<td>3.1</td>
<td>Female</td>
</tr>
<tr>
<td>10/29/2011</td>
<td>0.9</td>
<td>Female</td>
</tr>
<tr>
<td>11/25/2011</td>
<td>0.8</td>
<td>Male</td>
</tr>
<tr>
<td>5/1/2012</td>
<td>3.1</td>
<td>Female</td>
</tr>
<tr>
<td>11/12/2012</td>
<td>0.8</td>
<td>Female</td>
</tr>
</tbody>
</table>
We suspect the collisions were the result of sheep circumventing the ungulate-proof fencing in three possible ways: 1) passing through holes in the fence, 2) jumping up escape ramps (the wrong direction), and 3) jumping over single-wide cattle guards at the Kingman Wash traffic interchange. We are currently collaborating with ADOT to restrict this access points.

**Wildlife use of structures**

We observed 1742 sheep using overpass structures and 179 using bridges to cross from one side of US 93 to the other (figure 5). Rams used all overpasses relatively equal while ewes and lambs used Overpass #3 most. Over time, use of structures vary, however use of bridges remains relatively low (Figure 6). Eight other species utilized the overpasses, most notably coyote (*Canis latrans*). We did not document any cougar (*Puma concolor*), major predator of desert bighorn sheep at the overpasses.

![Figure 5. Desert bighorn sheep using various large wildlife crossings along US Highway 93 in Arizona. Ewes and lambs (upper left) and a ram (upper right) cross US 93 via overpass structures and sheep use White Rock Canyon (lower left) and Devils Wash (lower right) bridges to cross under US 93.](image-url)
Figure 6. Graph depicting 1,921 desert bighorn sheep crossing US Highway 93 via three overpasses and two bridges from March 2011 to March 2013.

Culverts
We documented 199 sheep approaching the three monitored culverts. Four sheep (2%) successfully crossed US 93 using one of these structures at MP 6.0. The typical observed sheep behavior was an approach to the structures followed by a retreat. On a few occasions, sheep entered the culvert and quickly exited, leaving the area without crossing (Figure 7), perhaps because of traffic noise overhead.

Figure 7. This sequence of photos shows a typical failed attempt of a desert bighorn sheep ram to cross under US Highway 93 using the culvert at MP 6.0

Escape ramps
We documented 150 sheep at the 8 escape ramps we monitored. Of the sheep that used the escape ramps, 322 of 337 (96%) used them in the proper direction while 44 of 1312 (3%) traversed them backwards and accessed the ROW (Figure 8). Throughout the project, research team personnel added PVC to reduce sheep movements in the wrong direction (Figure 8). However, no sheep have used monitored ramps to enter the ROW since May 3, 2012 when the research team adjusted the PVC and metal pipes that had been added to prevent sheep from ROW access to a height of 16 inches (0.4 m). In addition, the added bar does not appear to prevent sheep from using the ramps to exit the ROW. Since May 3, 2012, 96% of sheep that approach the ramp from the ROW side exit the ROW via the ramp. ADOT Maintenance began replacing all PVC with adjustable metal pipes in January 2012.
Figure 8. Progression of modifications to eliminate desert bighorn sheep from entering the right of way via escape ramps while continuing to allow exiting along US Highway 93 in Arizona. Sheep entering ROW via escape ramp without modification (upper left), failed attempt at access to ROW with low visibility smooth wire modification (upper right) and a sheep successfully exiting the ROW via escape ramp under (lower left) and over (lower right) a bar provided as a visible obstruction. Once the bars were included and adjusted to approximately 16” (0.4 m), sheep use of the ramps in the wrong direction ceased and proper use continued.

**Kingman Wash cattle guards**

After construction was completed on US 93, we observed sheep in the ROW near the Kingman Wash Traffic Interchange on several occasions. The Research Team observed that sheep were walking the concrete edge of the cattle guard vault. To close off this access point, ADOT extended the fence into the cattle guard and added a “painted cattle guard” to the ROW side of the existing cattle guard. We continued to see sheep in the ROW and monitored the two southern-most Kingman Wash cattle guard and noted sheep continuing to enter the ROW area by leaping the cattle guard (Figure 9). They landed on the “painted cattle guard”. The cattle guards at the Kingman Wash Traffic Interchange remain a concern, so we are working with ADOT to block these access points.
**DISCUSSION**

Preliminary analysis of sheep-vehicle collisions suggested that ungulate-proof fencing along with wildlife crossings have limited the number of sheep-vehicle collisions along US 93. When compared to Cunningham and Hanna’s (1992) sheep-vehicle collision rate of 11/year, we found a 45% and 82% reduction in collisions during years one and two, respectively. We believe the addition of PVC at the escape ramps accounted for the reduction in collisions between years one and two as sheep movement in the wrong direction was eliminated. ADOT is working to replace the PVC with an adjustable metal pole. Aside from the escape ramps, we determined sheep entered the ROW through holes in the fence and single-wide cattle guards at the Kingman Wash Traffic Interchange. This information has allowed us to close gaps in the fence and we are now considering and “electrified” cattle guards at the Kingman Wash Traffic Interchange. Once all issues are addressed, we believe effectiveness of mitigation measure will exceed the 82% reduction realized in year two.

Our video and rapid-fire still camera systems enabled us to document the use of all three overpasses 1,742 times by sheep including rams, ewes, and lambs. These preliminary results, when compared to Bristow and Crabb (2008) who documented only 32 ram crossings of wildlife underpasses on nearby SR 68, indicate that wildlife overpasses are highly effective for promoting sheep permeability. Preliminary results also indicated that the use of all 3 wildlife crossing structures has increased sharply during the last few months monitored, which indicates that sheep are becoming more accustomed to the structures and use will continue to increase. This upward trend is similar to that found for elk by Gagnon et al. (2011), who found that elk used passing structures in increasing numbers as time passed. However, this increase may be due to seasonal or behavioral parameters that can only be identified through long-term monitoring. We also found that sheep will pass under large-span bridges, but at significantly reduced frequencies relative to overpass utilization. We have only documented the use of a culvert by four sheep to successfully cross US 93.

Our long-term evaluation of the US 93 wildlife crossings and fencing will include assessments of permeability through calculation of passage rates similar to those for elk and Coues’ white-tailed deer (*Odocoileus virginianus couesi*) completed by Dodd et al. (2007b) and Dodd and Gagnon (2011). This assessment will allow for comparison of the ability of desert bighorn sheep to cross the highway before...
during and after construction. Currently, approximately 38 desert bighorn sheep are collared along US 93 and these collars are collecting a location every two hours for two years. Further, our video surveillance assessment will take into account unsuccessful crossings and determine passage rates and crossing probabilities per Dodd et al. (2007a) and Gagnon et al. (2011). These passage rates will be used to compare success of overpasses of different size while controlling for species distribution. This long-term analysis is crucial to determining if wider more expensive 100’ (30 m) overpasses are necessary or if the less expensive 50’ (15 m) overpasses are adequate.

RECOMMENDATIONS
Although we will hold final recommendations until the completion of the long-term monitoring study, there are a few preliminary recommendations that need to be considered in the event that DOT’s move forward with projects involving desert bighorn sheep prior to completion of our long-term evaluation. Currently, overpasses appear to promote desert bighorn sheep habitat connectivity better than underpasses. However, given the preliminary nature of these findings, planners should consult local wildlife experts for the most recent findings and recommendations to ensure their sustained validity. Whatever measures are considered as mitigation to reduce collisions and enhance connectivity, post-construction monitoring should be considered to evaluate efficacy of those measures.

ACKNOWLEDGEMENTS
This project was funded by the Arizona Department of Transportation’s (ADOT) Research Center, the Arizona Game and Fish Department (AGFD) and the Federal Aid Wildlife in Restoration Act, Project W-78-R supporting AGFD research. We commend ADOT for its proactive commitment to promoting wildlife connectivity and highway safety. The Federal Highway Administration also was instrumental to the funding and support of the project. We sincerely thank the Arizona Desert Bighorn Sheep Society for their financial support to help bridge the gap between during construction and long-term post-construction monitoring. Lake Mead National Recreation Area and Bureau of Land Management Kingman Office were instrumental in both successful implementation of mitigation measures and support of the ongoing research projects.

BIOGRAPHICAL SKETCHES
**Jeff Gagnon** has worked for AZGFD since 1998, currently as a Research Biologist focusing primarily on wildlife-highway interactions throughout Arizona, including State Route 260 and US Highway 93 wildlife crossing projects. Jeff received his B. S. and M. S. from Northern Arizona University where he studied the effects of traffic volumes on elk movements associated with highways and wildlife underpasses.

**Chad Loberger** is a research biologist for the Arizona Game and Fish Department working on projects related to wildlife-highway relationships. Current research focuses on large ungulates interacting with Interstates 17 and 40, and U.S. 93. He obtained his M.S. in biology from Northern Arizona University.

**Scott Sprague** has worked as a Research Biologist for AZGFD since 2002, focusing on wildlife-highway interactions. He received his B. A. from Colgate University and M. S. from Northern Arizona University where he studied the effects of roads on genetic interchange of pronghorn populations in northern Arizona.

**Mike Priest** obtained his B. S. in Biology with a Fish and Wildlife Management emphasis from Northern Arizona University. He has worked for AZGFD for four years on various projects, focusing on large mammal research.
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Estomih Kombe completed his graduate research at Arizona State University and in 1995 joined ADOT Research Center as a Project Manager for transportation research projects. Estomih has been involved with several collaborative wildlife-highway research projects with AGFD. Prior to this, Estomih was a member of the academic staff of the Faculty of Engineering at the University of Dar Es Salaam in Tanzania, where he taught Project Management and Industrial Safety classes.

Ray Schweinsburg has been a research program supervisor with the department for 20 years. He received his Ph.D. from the University of Arizona and currently focuses on enhancing wildlife habitat connectivity throughout Arizona.

LITERATURE CITED


