APPENDIX 1. Cost Estimates for Mitigation Measures

We estimated the cost of the mitigation measures listed in Table 1 based on a review of the literature and interviews with researchers, manufacturers, and transportation agency personnel (for more detailed review see Huijser et al. 2007a). The costs were calculated for a motorway (2 lanes in each direction) and standardized as costs per kilometer road length. Unless indicated otherwise, all cost estimates were expressed as US$ as reported in the cited work. For our analyses we converted all costs to 2007 US$ using the U.S. Consumer Price Index (U.S. Department of Labor 2008).

Seasonal wildlife warning signs were estimated at US$400 for a large sign, and US$80 for two flashing lights (Sullivan et al. 2004). For these analyses we assumed that one sign and associated flashing lights is installed per km per travel direction. This brings the total costs to US$960 per km (US$1,053 in 2007 US$). The projected life span of the signs and warning lights was set at 10 years.

The purchasing cost for an animal detection system was estimated at US$65,000 per 1,609 m (1 mi) road length (both sides of the road) (Personal communication Lloyd Salsman, Sensor Technologies & Systems, December 2007). However, since roads often have curves and driveways or objects in the right-of-way, the distance between sensors may be shorter than the maximum range of their signal, potentially leading to cost increases. For these analyses we assumed the purchasing costs, including signs and power source or supply, were estimated at US$75,000 per km road length (both sides of the road). The planning costs were estimated at US$50,000 and the installation costs were estimated at US$50,000 per km road length (all in 2007 US$). Maintenance and operation costs were estimated at US$14,800 per km per year (US$10,000 for problem identification and problem solving, parts (US$3,000), vegetation management (US$1,500), and remote access to the system (US$300) (all in 2007 US$). The projected life span of the signs and warning lights was set at 10 years. System removal costs at the end of the life of the system were estimated at US$10,000 per km (in 2007 US$).

Vegetation removal alongside the road, consist of the removal of shrubs and trees to increase visibility for drivers and to reduce the attractiveness for certain species, e.g. moose. The costs were estimated at US$500 per km per year (US$530 in 2007 US$) (Andreassen et al. 2005).

The cost estimates for population culling, relocation and infertility treatment are typically expressed as cost per animal. For the purpose of our cost-benefit analyses we had to translate these costs to costs per km road length. For our analyses we set the treatment area in a zone parallel to, and on both sides, of a road. The width of the zone for each side of the road was based on the diameter of the home range (75 ha) of white-tailed deer in a suburban environment, 978 m (home range size estimated at 43-50-86-144 ha by Kilpatrick and Spohr (2000), Beringer et al. (2002), and Grund et al. (2002)). For both sides of the road this results in a treatment area of 195.4 ha per km road length. Population densities of (suburban) white-tailed deer that are considered a problem have been estimated at 50-88-91 individuals per km^2 (Porter and Underwood 1999, Kilpatrick et al. 2001). Assuming a population density of 70 individuals per km^2, there are 136.8 deer present in 195.4 ha. The cost for culling, relocation, and anti-fertility treatment was set at US$110 (US$132 in 2007 US$), US$450 (US$540 in 2007 US$), and US$1,128 (US$1,296 in 2007 US$) per deer (females only), respectively. The estimate for killing a deer was based on estimates for the use of professional sharpshooters; US$108-US$121-US$194 per deer for conservation officers, park rangers, and police officers, respectively (Doerr et al. 2001). Others estimated these costs at US$91-US$310 per deer (DeNicola et al. 2000). The estimate for relocating a deer was based on estimates by Beringer et al. (2002) (US$387 per relocated deer) and De Nicola et al. (2000) (US$431 or US$400-US$2,931 per deer). The estimate for giving a female deer an anti-fertility treatment was based on estimates by Walter et al. (2002) (US$1,128 per treated deer) (US$1,300 in 2007 US$). Assuming that a population can only be reduced by 50% before the culling, relocation, or anti-fertility treatment efforts become much more labor intensive, the one time culling and relocation of 68.4 deer costs US$9,029 and US$36,936 respectively (reduction of 68.4 deer) (in 2007 US$). Suburban white-tailed deer populations can double their population size every 2-5 years, depending on the circumstances (DeNicola et al. 2000). Assuming a closed population (no immigration from adjacent areas) and a doubling of population size every 3 years, the culling and relocation effort would have to be repeated every 3 years. For the anti-fertility treatment, it was assumed that 80% of the females (80% of 68.4 female deer is 54.7 female deer, assuming an equal sex ratio), would have to be treated annually to stabilize or reduce the population density (DeNicola et al. 2000, Rudolph et al. 2000). This results in an annual cost for anti-fertility treatment of US$71,110 (in 2007 US$). Note that if the population is open to immigration from adjacent areas that the effectiveness for the culling, relocation, and anti-fertility treatment efforts will be much reduced or potentially eliminated. For these mitigation measures there were no estimates available for elk and moose. While the costs of these mitigation measures may be much higher per individual elk and moose, and while these mitigation measures may be less suitable or practical for elk or moose, we used the same costs estimates as for deer.

The costs for 2.4 m (8 ft) high wildlife fencing along US Highway 93 on the Flathead Reservation in Montana varied depending on the road section concerned: US$26, US$38, US$41 per m in 2006 (material and installation combined) (Personal communication Pat Basting, Montana Department of Transportation). A finer mesh fence was dug into the soil and attached to the wildlife fence for some fence sections at an additional cost of US$12 per m (Personal communication Pat Basting, Montana Department of Transportation). For the cost-benefit analyses the cost of wildlife fencing, including a dig barrier, was set at US$47 per m (US$48 in 2007 US$). For both sides of a road this translates into US$96,000 per km road length (in 2007 US$). The projected life span of a wildlife fence was set at 25 years. Fences require maintenance, for example as a result of fallen trees, vehicles that have run off the road and into the fence, and animals that may have succeeded digging under the fence (Clevenger et al. 2002). Maintenance costs were set at US$500 per km per year and fence removal costs were set at US$10,000 per km road length (all in 2007 US$).

Safe crossing opportunities and escape opportunities were not included in the cost estimates for wildlife fencing (see previous paragraph), but they are included in the mitigation measures discussed in the next paragraphs. The safe crossing opportunities and escape opportunities focus on serving large animals (deer size and larger).

For our cost benefit analyses we set the number of safe crossing opportunities at one per 2 km (0.5 crossing opportunity per km) (0.3 per mi). This number is based on the actual number of crossing structures found at three long road sections (two lanes in each travel direction) that have wildlife fencing and crossing structures for large animals: 24 crossing structures over 64 km (0.38 structures per km) (Foster and Humphrey 1995); 24 crossing structures over 45 km (0.53 structures per km) (Clevenger et al. 2002); and (17 crossing structures over 31 km (0.56 structures per km) (Dodd et al. 2007). Note that this number is not based on what may be required to maintain viable wildlife populations in a landscape bisected by roads.

For our cost-benefit analyses we used jump-outs or escape ramps as escape opportunities for large animals. The reported costs for one jump-out are US$11,000 (US$13,200 in 2007 US$) (Bissonette and Hammer 2000) and US$6,250 (2006) (US$6,425 in 2007 US$) (Personal communication Pat Basting, Montana Department of Transportation). We set the costs for a jump-out at US$9,813 (in 2007 US$) with a projected life span of 75 years.

Wildlife fencing in combination with gaps in the fence and crosswalks painted on the road at such gaps was studied by Lehnert and Bissonette (1997). The cost for a wildlife crosswalk across a four lane road (excluding wildlife fencing and escape from right-of-way measures) was US$28,000 (US$36,075 in 2007 US$) (US$18,037 per km) (Lehnert and Bissonette 1997). The projected life span of a crosswalk was set at 10 years. The costs for warning signs (76 cm x 76 cm), one for each travel direction, were set at US$62 per sign with a projected life span of seven years (USA Traffic Signs 2007). For this analyses we included 2 signs per gap (one for each travel direction), resulting in one sign per km. The width of the gap in the fence was set at 100 m (328 ft). However, the length of the fence was not reduced because of the gap as the fence may be angled towards the road to help direct animal movements. The cost for wildlife fencing was set at US$96,000 per km (see earlier section on wildlife fencing). Fence maintenance costs were set at US$500 per km per year, and fence removal costs was set at US$10,000 per km road length. In addition to the gap in the fence a jump-out was provided every 317 m (1,040 ft) (5 per 2 km per roadside; 5 per km; US$49,065 per km).

The cost for purchasing one section of a break-the-beam animal detection system was set at US$8,500 (Personal communication Lloyd Salsman, Sensor Technologies & Systems, December 2007). A gap requires a beam at each side of the road (US$17,000), but the costs for the second beam may be lower as there is only one control station required. The purchasing costs, including signs and power source or supply, were set at US$13,500 per km (in 2007 US$). The planning costs were estimated at US$25,000 and the installation costs were estimated at US$25,000 per km road length (all in 2007 US$). Maintenance and operation costs were estimated at US$11,800 per km per year (US$10,000 for problem identification and problem solving, parts (US$1,000), vegetation management (US$500), and remote access to the system (US$300). The projected life span of the signs and warning lights was set at 10 years. System removal costs were estimated at US$5,000 per km. The width of the gap in the fence with the animal detection system was set at 100 m (328 ft). However, the length of the fence was not reduced because of the gap as the fence may be angled towards the road to help direct animal movements. The cost for wildlife fencing was set at US$96,000 per km (see earlier section on wildlife fencing). Fence maintenance costs were set at US$500 per km per year, and fence removal costs was set at US$10,000 per km road length. In addition to the gap in the fence a jump-out was provided every 317 m (1,040 ft) (5 per 2 km per roadside; 5 per km; US$49,065 per km).

For the purposes of our cost-benefit analyses for wildlife fencing in combination with wildlife underpasses, we provided a wildlife underpass every 2 km (1.2 mi). The cost for an underpass was set at US$500,000 (materials and construction). The cost for an underpass (elliptical culvert, about 7 m wide, 4-5 m high) was based on the US$650,000 paid for three large wildlife underpasses (about 7 m wide, 5 m high) under US Hwy 93 (two lanes) on the Flathead Reservation in Montana in 2006 (US$668,200 in 2007 US$) (Personal communication Pat Basting, Montana Department of Transportation); the CanUS$225,000-CanUS$250,000 (exchange rate 1.36 CanUS$ for 1 US$ in 1996; US$218,731-US$243,034 in 2007 US$) for an underpass (7 m wide, 4 m wide) under the Trans Canada Highway (four lanes) in Banff National Park in 1996 (Personal communication Anthony P. Clevenger, Western Transportation Institute); the US$Can5,400 per m (road width) (exchange rate 1.36 CanUS$ for 1 US$ in 1996; US$5,428 per m in 2007 US$) for elliptical culverts (7 m wide, 4 m high) under the Trans Canada Highway in 1996 (Personal communication Terry McGuire, Parks Canada, unpublished data); and the €30,000-€50,000 per m (road width) (exchange rate 0.80 € for 1 US$ in 2004; US$41,136-US$68,560 per m in 2007 US$) for large underpasses (7-10 m wide) in 2004 in The Netherlands (Kruidering et al. 2005). The planning costs were estimated at US$50,000 per structure (US$25,000 per km) (in 2007 US$). Maintenance and operation costs were estimated at US$2,000 per structure per year (US$1,000 per km per year) (in 2007 US$). The projected life span of an underpass was set at 75 years. Structure removal costs were estimated at US$30,000 per structure (US$15,000) per km) (in 2007US$). The length of the fence was not reduced because of the gap as a result of the crossing structure, as the fence is angled towards the road and ties in with the crossing structure. The cost for wildlife fencing was set at US$96,000 per km (see earlier section on wildlife fencing). Fence maintenance costs were set at US$500 per km per year, and fence removal costs was set at US$10,000 per km road length (in 2007 US$). The number of escape ramps between crossing structures was set at 7 per roadside per 2 km (2 immediately next to a crossing structure (50 m on either side from the center of the structure), and an additional five escape ramps with 317 m (1,040 ft) intervals (7 per km; US$68,691 per km). The escape ramps on either side of a crossing structure are required because of the continuous nature of the wildlife fencing and the assumption that animals will want to cross the road most often at the location of the crossing structures, as that should be one of the most important criteria for the placement of these crossing structures.

For the purposes of our cost-benefit analyses for wildlife fencing in combination with wildlife underpasses and overpasses, we provided a wildlife underpass every 2 km, but every 12th underpass (once every 24 km) was replaced with an overpass. This resulted in 0.46 underpasses and 0.04 overpasses per km (0.29 and 0.02 per mi). The frequency for wildlife overpasses is based on the actual number of overpasses on a long road section (two lanes in each travel direction) that has wildlife fencing and crossing structures for large animals: 2 overpasses over 45 km (1 every 22.5 km) (Clevenger et al. 2002). For the costs of an underpass, see the previous paragraph. The cost for an overpass was set at US$5,000,000 in 2007 US$ (materials and construction). The cost for an overpass (about 50 m wide) was based on the CanUS$1,750,000 for an overpass (52 m wide) over the Trans Canada Highway (four lanes) in Banff National Park in 1996 (Personal communication Anthony P. Clevenger, Western Transportation Institute) (exchange rate 1.36 CanUS$ for 1 US$ in 1996; US$1,701,242 in 2007 US$); the €3,200,000 for an overpass (48 m wide) across the four lane motorway A28 (Leusderheide) in The Netherlands in 2004 (exchange rate 0.80 € for 1 US$ in 2004; US$4,387,866 in 2007 US$) (Kruidering et al. 2005). However, depending on the length (road width) and width of an overpass (15-50 m), and depending on the nature of the terrain, the costs for eight wildlife overpasses in The Netherlands ranged between €1,400.000 and €9,100,000 (exchange rate 0.80 € for 1 US$ in 2004; US$1,919,691-US$12,477,993 in 2007 US$) (Kruidering et al. 2005; Provincie Noord-Brabant 2004). The planning costs were estimated at US$50,000 per structure (US$25,000 per km) (in 2007 US$). Maintenance and operation costs were estimated at US$2,000 per structure per year (US$1000 per km per year) (in 2007 US$). The projected life span of an overpass was set at 75 years. Structure removal costs were estimated at US$350,000 for an overpass (US$14,000 per km) and US$30,000 for an underpass (13,800 per km) (in 2007 US$). Fencing and escape ramp configuration and costs were identical to the previous paragraph.

The costs for an elevated roadway and road tunnel were set at US$60,000,000 and US$115,000,000 per km respectively (in 2007 US$). These estimates are based on a 200 m long elevated road way that cost CanUS$12,500,000 (1.06 CanUS$ for 1 US$ in 2007; US$11,792,453 in 2007 US$) and a 200 m long road tunnel that was constructed for CanUS$24,000,000 (1.06 CanUS$ for 1 US$ in 2007; US$22,641,509 in 2007 US$) in 2007 (Personal communication Anthony P. Clevenger, Western Transportation Institute – Montana State University). The planning costs were estimated at US$1,000,000 per km (in 2007 US$). Maintenance and operation costs were estimated at US$1,000,000 per km per year (in 2007 US$). The projected life span of an elevated roadway and road tunnel was set at 75 years. Structure removal costs were estimated at US$6,000,000 (elevated roadway) and US$11,500,000 (road tunnel) per km.