

**EVALUATION OF BEST
MANAGEMENT PRACTICES
FOR MITIGATING IMPACTS
OF HIGHWAYS ON STREAM
AND WILDLIFE ECOLOGY**

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Prepared for

Highway Research Center
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JULY 2003

Evaluation of best management practices for mitigating impacts of highways on stream and wildlife ecology

(First Progress Report)

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July 11, 2003

[Abstract]

Transportation, like many other human activities, affects the environment such as air and water quality as well as wildlife habitat. Serious environment problems may arise when a road/highway intercepts the natural pathways of streams or wetlands, which play critical roles in accommodating regional habitats for both aquatic and terrestrial wildlife and in facilitating biological life cycles. Disruption of streams by transportation activities often results in upsetting the existing processes that maintain regional populations and ecological balances. Published field data show that highway operations have caused unprecedented habitat loss and degradation, habitat fragmentation and road kills.

Over the last thirty years, new laws and regulations have emerged to mitigate the impacts of transportation projects on the ecosystem. Powered by the Clean Air Act (CAA) and Clean Water Act (CWA), more and more stringent legislations have been promulgated to regulate specific environmental issues associated with transportation. In light of ever tightening environmental regulations, selection of best management practice (BMP) is no longer dictated solely by practical feasibility. Overall environmental soundness including wildlife ecology and environmental sustainability is also influencing the permitting process.

Engineered animal passage structures have been widely employed to facilitate the movement of certain terrestrial and amphibian species across highways and thus to mitigate the adverse impacts of highway activities on the wildlife ecology. This report summarizes and examines various engineered passage structures such as wildlife overpass, wildlife underpass, upland culvert, oversized stream culvert and bridge, viaduct, and fencing. Discussion pertaining to their suitability, design and dimensions was offered. Environmental factors such as location, noise, temperature, light and moisture, which may affect the effectiveness of these passage systems, are also discussed in this report.

For aquatic species, our study indicated three fish passage design options: no slope option, hydraulic design option and stream simulation option. Design guidelines for bridges were also discussed.

Preliminary cost analysis revealed that some of the most effective techniques for facilitating wildlife movement (e.g. overpasses) are also quite expensive. A practical strategy for mitigating highway impacts on wildlife movement may dictate that expensive elements be reserved for areas that are identified as important travel corridors or connection between areas of significant habitats, while inexpensive elements be used at appropriate areas throughout the highway alignment.

The information will help road designers with selecting BMPs for mitigating transportation impacts on the environment.

[Key Word] BMP, highway, ecology, fragmentation, mitigation, overpass, road kill, underpass, wildlife.

1. Introduction

Roads and numbers of motorized vehicles increased enormously during the twentieth century. In 2000, it was estimated that United States contained 6.36 millions km of roads occupying 8.1 millions hectares (Highway Statistics, 2001) and these numbers for Canada in 1995 were 0.9 millions km and 1.2 millions hectares; In 1990, the European Commission presented a major plan for improving so-called Trans-Europe Network (TEN), this program entailed an enormous expansion of motorway, waterway and high-speed railway links, the total length of motorway was scheduled to grow from 43,000 km to 58,000 km (Bekker, 1998). By 1998, Australia had built approximately 870,000 km of roads and yielded more than 3.1 million of its rural area to roads (Straker, 1998). Total length of roads in the Great Britain was approximately 371,914 km by 1999. The total area of land taken up by these roads in 1991 was about 0.32 millions hectares, about 1.4% of its total land area (Spellerberg, 2002).

As more and more roads are constructed, the associated impacts on the human and environmental health become increasingly an environmental concern. Highway activities can cause severe human's health and safety problems such as traffic accidents, air pollution from exhaust, noise pollution, water contamination, soil pollution. In addition, highway projects also directly or indirectly damage the stream and wildlife ecology near highways. Studies in Canada, for example, indicate a correlation between traffic intensity and lower density of calling anurans and between the density of paved roads within 1-2 km of wetland and the diversity of wildlife in that wetland (Fahrig, 1995).

Various new laws and regulations have emerged to mitigate the impacts of transportation projects on the ecosystem during the last thirty years. The following environmental laws/regulations are among the most encountered and should be aware of by transportation designers and practitioners:

- National Environmental Policy Act (NEPA), Public Law No. 91-190. 1970
- Clean Water Act of 1977, Section 401 and 404.
- Endangered Species Act of 1973, as amended, 16 USC 1531 et seq.
- Coastal Zone Act Reauthorization Amendments of 1990-section 6217.
- Coastal Resources Management program-October 1987.
- Federal Coastal Zone Management Act of 1972, P.L. 92-583, as amended.
- Section 4(f) Evaluation and Approvals for Federally- Aided Highway Projects with Minor Involvement with Public Parks, Recreations Lands, Wildlife and Waterfowl Refuges and historic Sites, December 23, 1986-49 USC303.
- Migratory Bird Treaty Act.
- Fish and Wildlife Coordination Act

Since Congress adopted the National Environmental Policy Act (NEPA) in 1969, the Federal Highway Administration (FHWA) has established various policies and procedures to help meet its social, economic, and environmental responsibilities while accomplishing its transportation mission. The FHWA Environmental Policy Statement (EPS) is a formal expression of FHWA's commitment to protection and enhancement of the environment. The FHWA provides the policy

grounds and associated procedures for development of environmentally sound projects. It is clear from the FHWA environmental policy that environmentally sound transportation system is the ultimate goal, and it is the responsibility of state transportation agencies to meet these standards.

Powered by the National Environmental Policy Act (NEPA), Clean Water Act (CWA) and Clean Air Act (CAA), more and more stringent legislations have been promulgated to regulate specific environmental issues associated with transportation. For instance, the Fish and Wildlife Coordination Act (FWCA) requires conservation, maintenance, and management of wildlife resources for any project that involves impoundment, diversion, channel deepening or other modification of a stream or other water bodies. In light of ever tightening environmental regulations, selection of a BMP is no longer driven only by practical feasibility. Overall environmental soundness including wildlife ecology is also influencing the permitting process.

Although various engineered structures such as wildlife overpasses, underpasses, and upland culverts have been practiced, an integrated guideline regarding their application and performance is lacking. Some of the most effective techniques for facilitating wildlife movement (e.g. overpasses) are also quite expensive. To maximize the use of limited resources in transportation agencies and to help agencies comply with regulatory requirements, an improved decision-making process is needed to guide state DOT designers and practitioners on selecting the most economical and effective mitigating strategies.

The objectives of this project are:

- To update our knowledge base on the BMPs used for mitigating transportation impacts on the stream and wildlife ecology, and
- To present recommendations/guidelines for transportation designers and practitioners on selecting the BMPs.

2. Impacts of Highway on Wildlife

A large body of literature data has revealed the tremendous impacts of massive road constructions and heavy highway operations on the wildlife ecology. Some most well documented effects are summarized as follows.

2.1. Direct habitat loss

The most direct damage of road development to wildlife is occupation of land or area, which serves as the habitat of animals and plants. Wildlife was forced to find a new place for habitat and foods, which often results in large quantities of death. In the Netherlands, the loss of habitat during 1980-1993 due to construction of rural sealed roads was 0.18 million hectares, constituting an annual loss of 0.04% of rural land (Cuperus et al.,1999). A recent study by the National Research Council (1997) estimates that approximately 20 million acres or 8.1 million hectares of natural habitat has been converted to US highways, streets, and adjacent rights-of-way. This represents approximately 1% of the contiguous United States or an area about the size of South Carolina. The number did not include private roads, parking areas and driveways.

The variability in habitat delineation across the nation makes it very difficult to follow wildlife trends. However, using a macro-habitat perspective of landscape features, Flather et al. (1999) described the decreasing trend in wildlife associated with the habitat loss in the United States. Landscape structure that influences the distribution and abundance of wildlife is primarily affected by vegetation cover and how the land is used by humans (Forman 1995; Janetos 1997). Vitous et al. (1997) identified human land use as the primary force changing biological diversity. The cumulative effect of the land-use change has resulted in a number of critically endangered ecosystems (where the presettlement extent of system is reduced by more than 98%) (Noss and Petter, 1995). Of the studied habitats, six were in the Rocky mountain region, seven in the northern and pacific coastal regions, and nine in the south. May (1990) concluded that this has resulted in efforts to save the few remaining individuals of endangered species to avoid extinction, as reflected by the Endangered Species Act of 1973.

The impacts of direct habitat loss on wildlife may vary with the area that a highway transects. Some habitats such as “critical habitats” for endangered species could be more important than disturbed habitats in urban setting. Uniqueness and importance for wildlife are factors that need to be considered early in transportation planning to avoid and/or minimize impacts to wildlife. Special cautions should be exercised to include habitat loss as a significant part of environmental studies when road projects pass through public lands such as park, wildlife refuge, forests and wilderness area (Harper-Lore, 2002).

2.2. Degradation of habitat quality

Road development can cause serious deterioration in quality of both terrestrial and aquatic habitats. Erosion from poorly constructed or rehabilitated sites can lead to slope movement causing downstream siltation, thereby ruining spawning beds for fish; Constriction of flows at water crossings can make the current too fast for some species; Alterations of flood cycles, tidal flows, and water levels can upset trophic dynamics by affecting the life cycle of plankton, and have corresponding damaging effects on the rest of the food chain. The cumulative effects of modification of aquatic habitats through impoundment, channlization, dredges along with sediments and water pollution has resulted in dramatic declines of the North America naiad fauna in last century (UN, 1999).

The presence of motor vehicles often causes contamination of the soil, air and water adjacent to the road. In the case of surface water, well beyond the immediate surroundings, chronic contamination can be a serious problem for animal species, especially those at top of the food chain because of bioaccumulation of the pollutants generated through various road development activities (WHO, 1993).

Noise associated with road development and usage can also impact wildlife habitats. Forest interior birds, ovenbird, redheaded woodpecker, cuckoo, owl and hawks have specific habitat requirement that can be affected by highway noise (Forman and Deblinger, 1998). Rejjenn et al (1995b) showed evidence that in woodland, noise is probably the most critical factor in causing reduced density of birds close to road and also the most critical factor in open land. For example, the population of meadow birds, which are of international importance, in the western part of the

Netherlands was estimated to have decreased by 16% because of the denser network of extremely crowded main roads near their habitat.

In addition to direct land occupation, the pollution and other general disturbance by highway operation may extend to 30 m, sometimes even 100 m, from the road edge. Recent research showed that some of the adverse environmental effects may extend several hundreds of meters away from the road. Forman and Deblinger (1998) described a so-called “road effect zone”, whose size and extent may vary from area to area. They estimated that such effect zones may account for 15 to 20% of the land in the United States.

2.3. Fragmentation of habitat and population

Highways often constrain or destroy the living activities of both terrestrial and aquatic animals and result in fragmentation of habitat and population due to following facts:

- Highway structures (median strip, fences, etc.) can split existing habitat or population into fragments;
- Road development alters the habitat topography, deteriorating habitat living conditions for animals;
- Heavy traffic volume virtually exacerbates the barrier function of highways. Studies indicated that an average daily traffic (ADT) of 10,000 could completely block animal movement for a number of species (FHWA-PL-02-011).

Highway fragmentation of vital habitat can jeopardize the local population of wildlife. For instance, in Glacier National Park in Montana, construction of US Highway 2 interrupted the habitat of mountain goats that have to cross the highway to access to an important mineral lick (Singer and Doherty, 1985). During wet seasons/years when much of their habitat is flooded, wildlife to the south of I-75 in the Big Cypress Swamp and adjacent environs in Florida has to rely on the wildlife crossing to move into the dry habitat to the north of the highway (Evink 1990, Evink 1996). Fowle (1996) observed that by separating aquatic habitat and upland nesting habitat for turtles, or terrestrial habitat and aquatic breeding sites for amphibians, highway could pose significant adverse impacts on local population of those species. Diaz et al.(2000) hypothesized that the combined effects of fragmentation and predation in small remnants of forests had led to extinction of the forest lizard *Psammodramus algirus* in fragments smaller than about 90 hectares. Recolonization seemed to be prevented by the very limited dispersal abilities of these lizards.

Wildlife populations suffer when fragmented by roads. Dispersal of individuals between populations is important for gene flow, movement of individuals to maintain small populations, and decolonization of areas where species has been extirpated (Shaffer 1985; Dodd 1990; Gibbs 1993; Fahrig and Merriam 1994).

Road crossing can also fragment habitat for fish and other aquatic animals (Furniss et al. 1991; Ruediger and Ruediger 1999). Such separation can result in the inability of individuals to find each other for reproduction. This is especially true for species that are shy of roads or do not cross high traffic roads, such as the wolf and grizzly bear (Gibeau 1996; Paquett and Callahan 1996). Pronghorn antelope (Bruns 1997) and mountain lions (Van Dyke et al. 1986) have also shown reluctance to cross roads. In Germany, genetic difference was observed in common frogs in places where roads were barriers (Reh and Seitz 1990).

Wildlife species composition changes due to avoidance of roadway by some animals (Lyon 1983). Most recent research indicates that road avoidance has been demonstrated for bobcats (Lovallo and Anderson 1996), wolves (Thber et al., 1994), grizzly bear (McLellan and Shackleton 1988), and black bears (Brody and Pelton 1998). In western North Carolina, a study of black bears by Brody and Pelton (1989) found that these bears almost never crossed an interstate highway. Of the roads the bears did cross, those of low traffic density were crossed more frequently. Avoidance of areas adjacent to roads was apparent in a study of bird breeding and nesting in Netherlands (Illner 1992; Reijnen 1995; Reijnen and Thissen 1997). Species, which are most vulnerable to local and regional extinction following habitat fragmentation, include naturally rare species, wide-ranging species, interior species, and species with low reproductive capacity (Meffe and Carroll, 1994).

2.4. Road kill

Road-related mortality represents the most visible and direct effect on wildlife. Road mortality has impacted significantly some species such as white-tailed deer, black bear, Florida panther and so on. Additionally, wildlife-vehicle collisions are a serious safety problem for human in North America, Europe and Japan. Cook & Paggett (1995) estimated the cost at \$ 1.2 million per year nationwide in property damage and human injury associated with deer vehicle collision (DVC).

Recent studies indicate that road mortality (motorist safety and wildlife species impacts) has been a global concern.

In Australia, for example, the number of frogs and reptiles killed annually on roads has been estimated at around five millions. A wildlife information and rescue service has estimated that up to 12 million native animals are killed on Australian roads each year. In the Netherlands, Jonkers and De Vries (1977) estimated that the yearly average number of animal traffic casualties at 653,000 birds and 159,000 mammals. In the UK, an estimated 10 million of birds were killed on roads every year (Spellerberg, 2002). Deer are particularly at risk. Romin and Bissonette's report (1996a) provided a comprehensive account of deer mortality on highway (Table 1). Table 1 also shows that between 1982 and 1991 the number roadkills has increased considerably in most states.

Road kill is perhaps the greatest, directly human related source of wildlife mortality throughout the United States and worldwide. For some species its impacts are significant at population level (Natasha 1998). Farhig et al (1995) after a detailed study of effects of traffic on amphibian density concluded that road kills could be contributing to worldwide declines in amphibian population. For some endangered species, road kills are also thought to be an important contributing factor to mortality (Spellerberg, 2002).

Table 1: State-wise changes in deer mortality on USA highways from 1982-1991 (from Romin and Bissonette, 1996)

State	No. deer killed (year)		Actual Count made?	Percent ^a Change
	Lowest year	Highest year		
Alabama	no data			
Alaska ^b	57-77/year			
Arizona	no response			
Arkansas	3,603(1990)	4,200 (1989)	no	(14)
California	15,000/year		no	
Colorado	5,202(1983)	7,296 (1991)	no	40
Connecticut	1,429(1982)	2,423(1986)	yes	70
Delaware	103(1982)	268(1991)	yes	160
Florida	no data			
Georgia	50,000/year		no	
Hawaii	no response			
Idaho	no data			
Illinois	2,797(1982)	15,560(1991)	yes	456
Indiana	2,858(1982)	12,671(1991)	yes	343
Iowa	4,805(1982)	9,248(1988)	yes	92
Kansas	2,492(1982)	3,536(1991)	yes	41
Kentucky	1,490(1982)	4,677(1990)	yes	214
Louisiana	1,500/year		no	
Maine	2,000(1080's)	3,000(1990's)	no	75
Maryland	no response			
Massachusetts	no data			
Michigan	18,045(1982)	44,374(1991)	no	146
Minnesota	11,471(1982)	16,280(1991)	yes	42
Mississippi	no data			
Missouri	4,779(1982)	9,519(1987)	yes	99
Montana	no data			
Nebraska	1,261(1982)	3,341(1991)	yes	42
Nevada	no response			
New Hampshire	455(1982)	1,000(1990)	yes	120
New Jersey ^c	455(1982)	10,496(1986)	yes	20,202
New Mexico	no data			
New York	7,269(1984)	10,978(1991)	yes	51
North Carolina	5,000-8,000/year		no	

Table 1(contd.)

State	No. deer killed (year)		Actual Count made?	Percent ^a Change
	Lowest year	Highest year		
North Dakota	2,500(1980's)	3,000(1990's)	no	20
Ohio	8,587(1982)	20,215(1991)	yes	135
Oklahoma ^d	450(1985)	495(1983)	yes	(9)
Oregon	no data			
Pennsylvania	24,648(1983)	43,002(1990)	yes	75
Rhode Island	no response			
South Carolina	840(1982)	3,689(1991)	yes	339
South Dakota	2,166(1982)	3,363(1991)	yes	55
Tennessee	no response			
Texas	(19,000/year)			
Utah	1,826(1980-81)	5,502 (1988-89)	yes	201
Vermont	1,105(1982-83)	1,514(1990-91)	yes	37
Virginia	1,446(1982)	3,427(1990)	yes	137
Washington	no response			
West Virginia	3,844(1985)	9,515 (1991)	yes	148
Wisconsin	28,878(1982-82)	76,626(1989-90)	yes	165
Wyoming	987(1988)	1,756(1982)	yes	(44)

a. Values in parentheses are decreases.

b. Highest yearly estimate was use to calculate total deer killed in 1990.

c. Actual counts through 1988-1989, estimated 10,000 deer/year from 1989-1992.

d. Record keeping discontinued after 1985 due to unreliable efforts.

3. Engineered Mitigation Strategies

To mitigate the habitat fragmentation and road kills caused by highway construction, various wildlife passages have been constructed across the highway to connect the habitat and facilitate the movement of wild species across the highway. For example, various engineered tunnels have been widely used to help mitigate the fragmentation of habitat in Europe, Australia, Canada and the USA. Some of the most commonly used engineered structures are summarized and discussed as follows.

3.1. Wildlife Overpasses

The overpass approach has been considered quite successful for the largest spectrum of animals (USDOT and FHA, 2002). Figures 1-2 show two common overpasses used in New Jersey (TRB, 2002) and Germany (TRB, 2002). The presence of habitat and structure on overpasses allows for use by everything from insects to large carnivores. The most effective overpasses range in width from 50 m wide on each end narrowing to 8-35 m in the center, to structure up to 200m wide. Pfister et al (1999) observed that structures at least 60 m (196.8 ft) wide were more effective than overpasses narrower than 50 m (164 ft), especially for larger mammals. It was noted that animal

behavior on the overpasses was more normal on the wider structures. Soil on these overpasses ranging in depth from 0.5 – 2 m, allows for the growth of herbaceous vegetation, shrubs and small trees. As guidance for soil depth for plants on overpasses, the Germans use 1/3 m for grass, 2/3 m for shrubs, and 1.5 to 2 m for trees (USDOT and FHA, 2002). Some overpasses contain small ponds fed by rainwater. Sometimes board fence are used along the edge of an overpass to prevent traffic noise and lights from disturbing wildlife.



Figure 1. Overpass being used by deer and Other wildlife in New Jersey (91.46m wide)



Figure 2. Vegetated overpass in German approximately 50 m wide.

Primary advantages of overpasses relative to underpasses are that they are less confining, quieter, maintain ambient conditions of rainfall, temperature and light, and can serve both as passage ways for wildlife and intermediate habitat for small animals such as reptiles, amphibians and small mammals. They are probably less effective for semi-aquatic species, such as muskrats (*Ondatra zibethica*), beavers (*Caster canadensis*) and alligators (*Alligator mississippiensis*). By providing intermediate habitat, overpasses may provide the only feasible means for allowing various species of animals to cross highways. The major drawback is that they are rather expensive.

France was the first European country to use overpasses (USDOT and FHA, 2002). In 1991, France had 125 overpasses in place and continues to use them as principal structures for habitat connectivity and motorist safety. Some overpasses are quite large, such as the 800-m-wide overpass at Forest Hardelot (France). Germany had 32 overpasses, with 8 additional ones under construction and 20 more planned in 2002, with a width ranging from 8.5m to 870 m. The Switzerland had more than 20 overpasses with widths from 3.4 m to 200 m by 2002, and is continuing to build new overpasses (USDOT and FHA, 2002).

Although wildlife overpasses has been largely a European phenomenon, application in the U.S. has been growing. Table 2 listed a number of major structures in Florida, Hawaii, New Jersey and Utah. The New Jersey overpasses, among the first in the United States, were completed in 1985 at a cost of \$12 million. The two overpasses were designed to provide connectivity across I-78 (a six-lane highway) at an approximately 2-mile stretch that crossed the Watchung Reservation in Union Country. Although no formal research has been conducted, deer have been observed using the crossing and the health of local population indicates the success of the overpasses (TRB, 2002).

Table 2. State use of structural measures for wildlife
(NCHRP, Synthesis 305, 2002 , pp30-31)

State	Bridge Extensions	Wildlife Underpasses	Wildlife Overpasses	Culverts	Fencing	Other
Alaska	Yes-for moose	No	No	Yes-fish passage	Yes	No
Arkansas	No	Yes-three 4' x 4' box culverts on I-440 east of Little Rock	No	No	No	No
California	Yes-10% for wildlife and river restoration	Yes-SR-71 San Bernardino for bobcat and coyotes Tool road-deer and other wildlife	Planning use for antelope	Yes-for passage of San Joaquin kit fox	Yes-for Desert Tortoise and deer	Modified bridges for bats, amphibian and fish passage; median barrier design and interchange decommission
Colorado	No	Yes-Borthoud Pass, 7' x 8' and 3' x 4'; Muddy Pass, two 8' x 12' planned; SR19, North of Silverton, 8' x 12' and 7' x 8' planned. Planned dimensions may change for final	No	No	Yes-various areas of state	No
Connecticut	Yes-Route 7, Brookfield	Yes-Route 6 proposed	Yes-Route 6 proposed	Yes-for fish passage	Yes-Route 6 proposed	Yes-nesting boxes for falcons
Florida	Yes-Wakiva River for bear and 13 bridges on I-75 for Florida panther, etc.	Yes-I-75, 23 8' high x 120' long bridges; SR-29, three 8' high x 24' wide box culverts and one 8' high x 120' long bridge; SR-46, one 8' high x 24' wide box culvert; US-1 Florida Keys, two crossings for Key deer planned	Yes-I-75 in Marion County	Yes-US-1 in Florida Keys for crocodiles; Payne's Prairie US-441 for reptile and amphibians	Yes-I-10 and other locations for deer, I-75, SR-29, and SR-46 for crossings	Yes-barrier wall on Payne's Prairie for reptiles and amphibians, nest boxes for blue birds, nesting platforms for osprey, poles to keep birds off bridges, motorist education signs, speed bumps with signing, reduced speed limit, reduced lighting for sea turtles
Georgia	Yes-for wildlife in several locations	No	No	Yes-for fish passage	Yes-for black bear	No
Hawaii	Yes-projects on Kauai	Yes-projects on Kauai	Yes-on Kauai	Yes-on Kauai	Yes-on Kauai	No
Iaho	Yes	No	No	Yes-for fish passage	Yes-for ungulates	No
Illinois	Yes	No	No	Yes-for small mammals	Construction for snakes & plants	No
Iowa	Yes-Hardin County US-20 Iowa River Bridge	No	No	Yes-baffles, Dubuque County, Iowa-32	Yes-Jones County, US-151 barrier fence for herps	No
Kansas	No	Yes-wildlife/ livestock on I-70 west of Topeka; US-75 south of Topeka; US-69 Marnis des Cygnes	No	Yes-US-69 Marnis des Cygnes, 20 th St. Lawrenceworth	Yes-US-69 Marnis des Cygnes	No
Kentucky	Yes-US-60 for Copperbelly water-snake. Henderson Union	Yes-Deer crossing in design US-68 Land Between the Lakes, in design	No	No	No	Yes-numerous bridge designs for muskels

Table2 (Continued)

State	Bridge Extensions	Wildlife Underpasses	Wildlife Overpasses	Culverts	Fencing	Other
Maine	No	Yes-cattle culverts rehabilitated in Dixfield; Sangerville for wildlife	No	Yes	Yes-numerous locations	Yes
Michigan	Yes-US-131 over Little Muskegon River for deer	Yes-large culvert for deer on M-6	No	Yes-small mammals on I-475 and herps	Yes-deer on M-6	No
Minnesota	No	No	No	No	Yes-deer	No
Mississippi	Yes-Hinds and Rankin County Airport Parkway	Yes-Hinds and Rankin County Airport Parkway	No	Yes	Yes	No
Missouri	Yes	Yes	No	Yes	Yes	Yes-median ballooning for Ozark bears
Montana	Yes-US-93	Yes-US-93 and Goat Lick at Glacier National Park	Yes-US-93	Yes-for herps, small mammals, and fish	Yes-til interstate fence is small mesh for small mammals	Yes-preserving and reestablishing vegetation for grizzly linkage zone
Nebraska	Yes	No	No	Yes-turtles	Yes-for turtles	No
Nevada	Yes	Yes	No	Yes	Yes	No
New Hampshire	Yes-NH-101 for wildlife	Yes	No	Yes-wildlife, salamanders	No	Yes-bird houses
New Jersey	Yes-I-295/195 Mercer County	Yes-Route 31, Hunterdon County	Yes-I-78, Union County	Yes-various locations around state	Yes-various locations around state	No
New York	Yes-Rte 155-Albany, Taconic State Parkway	Yes-Northway, Albany to Plattsburgh	No	Yes-Rte 21, Cinnidagua Lake, Long Island	Yes-Montezuma Refuge	Yes-culvert baffles, fish ladders, cul barriers
Ohio	Yes-for wetlands	No	No	No	No	No
Oregon	Yes-many	No	No	Yes-many	Yes	No
South Carolina	Yes-Carolina Bays Parkway and Conway Bypass, Horry County	Yes-Carolina Bays Parkway and Conway Bypass, Horry County	No	Yes-Carolina Bays Parkway and Conway Bypass	Yes-same projects	No
South Dakota	No	Yes	No	Yes-US-18 for turtles and elsewhere for fish and Topaka shiner	No	No
Texas	No	No	No	Yes-for ocelots, Houston toads, and small aquatics	Yes-drift fence for Houston toad	Yes-use old signs for bat habitat under bridges
Utah	No	Yes-many highways and freeways	Yes-see deer overpass	Yes	Yes-with the crossings	Yes-funded osprey platforms
Virginia	Yes	Yes	No	Yes	Yes	Yes-falcon nesting boxes
Washington	Yes	Yes-I-90	No	Yes-fish passage	Yes-elt; along I-90	Yes-deer reflectors and motion-activated signs
Wisconsin	No	No	No	Yes-Butler's garter snake, Waukesha County, in design	No	Yes-nests for barn and cliff swallow during maintenance
Wyoming	No	Yes-deer underpass, Nugget Canyon SW Wyoming and modified culverts throughout Wyoming	No	Yes-for fish and Wyoming toad	Yes-alter design for big game crossings	No

3.2. Wildlife Underpasses

Wildlife underpasses are constructed through bridges (up to 30 m wide, 3-5 m high) and/or large culverts over dry land and sometimes land and water as shown in Figures 3-4. The target species of this structure are medium-sized and large mammals although smaller animals can also use it. The length and height of these large culverts and bridges varies with the wildlife expected to use them. Vegetations, stump and piles of debris often provided under large crossing structure as cover for smaller animals. These structures provide relatively unconfined passage for wildlife with plenty of light and air movement, but generally too dry for some species of amphibians. Wildlife underpasses with open median provide a certain amount of intermediate habitat for small mammals, reptiles and amphibians. However, open median design is much noisier than continuous bridges and may be less suitable for species that are sensitive to human disturbance. While less expensive than overpasses, wildlife underpasses are also fairly costly.

Twenty-three states reported using underpasses for wildlife (Table 2). Some species being addressed included bobcat and coyote in San Bernardino, California; Deer in most states and goats at Glacier national Park, Montana (Figure 3).



Figure 3. Snowslide gulch bridge for goats on Highway 2 near Glacier national Park, Montana (3m high x 3m wide x 11m long)



Figure 4. One of 23 wildlife underpasses on I-75 (Alligator Alley) in Southern Florida California (36.5m high x 2.44m high)

Florida used 2.44m high and 7.32m wide box culverts for a variety of species in central and south Florida (TRB, 2002). Depending on the remoteness of the area of use, these concrete boxes can be either cast in place or pre-cast for shipment to the site. Fencing associated with these crossing was 3.04 m in height with three strands of barbed wire on an outrigger. A wide variety of species use the culverts, including the Florida panther and black bear (Land and Lotz 1996; Roof and wooding 1996).

Wyoming conducted a research on a wildlife crossing (6.08 m wide, 9.12 m long and 3.35 m high) on US-30 through Nugget Canyon between Kemmerer and Cokeville and found that approximately 2,000 animals (elk, mule deer and antelope) had used the crossing (Gordon, 2002B). North Carolina is constructing three underpasses for black bears at a new location, US-64 near Outer Banks in Washington County. The dimensions will be approximately 38 m wide, 2.4-3 m high and 100 m long (Van Manen et al. 2002).

3.3. Upland Culverts

A culvert is a closed conduit primarily used to convey water from one area to another, usually from one side of road to the other side. Culverts can be divided into two functional types: Stream Culvert (also called Stream Crossing) and Upland Culvert (also called Runoff Management). The first culvert type, stream culvert, is required where the roadway crosses a stream channel to allow pass downstream. The second type culvert, upland culvert, is the one that is strategically placed to manage and route roadway runoff along, under, and away from roadway. However here in section 3.3 and 3.4, upland culvert and stream culvert will be used as animal passages.

Not all species of wildlife readily use stream or river corridors for travel routes. Therefore, a comprehensive approach to the maintenance of habitat connectivity must include structures allowing overland movement between wetlands and uplands. Figures 5 shows one of the upland culverts incorporated with fine mesh fence for amphibians in the Netherlands. Figure 6 shows one of the culverts designed for small and medium-sized mammals in Banff National Park. Movements to and from wetlands are particularly important for amphibians, reptiles and other small animals. Wildlife overpasses and underpasses (see above) may provide upland passage for larger species. Relatively small amphibian and reptile tunnels may be a cost effective means for mitigating highway impacts where roads and highways are located between wetland and upland habitats. Box culverts are generally preferable over pipes. Larger culvert will generally accommodate more species than smaller ones. Open-top culverts can be expected to provide more light and moisture, and will be more effective for facilitating amphibian's movements. Although there is evidence that amphibian and reptile tunnels are effective when used with two-lane roads, it is not known how effective they will be for facilitating passage beneath highways of four or more lanes. Guidance structures are usually needed to direct target animals to culvert under the roads (see details in Fencing below)

Upland culvert systems were observed in most of the European countries and culverts are placed in known areas of amphibian movement to alleviate mortality on roadways. The Dutch, for example, are using concrete pipes, metal pipes, or rectangular concrete tunnels approximately 0.4 to 2.0 m in diameter in conjunction with fine mesh fencing for amphibians and reptiles, as well as other small animals.



Figure 5. Fine mesh fence and culvert for small mammals in Europe.



Figure 6. Box culvert used by wildlife in Banff National Park

Table 2 reports that a number of states in the US are using culverts in different applications for a variety of species. Florida, Montana, New Hampshire, Texas, and Wisconsin are using culverts for reptiles and amphibians. Nebraska and South Carolina are using them for turtles.

3.4. Oversize Stream Culverts and Bridges

Where roads and highways cross rivers and streams, expanded bridges that can provide upland corridors adjacent to waterway can provide passageways for many species of riverine wildlife, as well as other species that may utilize stream corridors for travel. Higher bridges with wider areas for passage underneath tend to be more successful than low bridges and culverts

Where culverts are used to cross streams and small rivers, oversize culverts, large enough to allow for wildlife passage, maybe used. Again, box culverts generally provide more room for travel than large pipes. Efforts to provide natural substrate, including large flat rocks as cover for small animals, will enhance their use by some species. Construction of benches on one or both sides of stream to allow dry passage during normal high water periods will also enhance these structures. The optimum size for this structure is not known but, generally, the larger the more effective. Given sufficient height, these culverts can even allow larger mammals, such as deer, bear and other species that ordinarily follow riparian corridors for movement, to pass safely under roads. Proper sizing of the culvert depends on site-specific considerations and hydraulics, but including the natural streambed and as much adjacent upland as possible proves most successful. Culverts are less expensive than expanded bridges, but also less effective.

A number of states reported uses of specialized culverts and bridges in streams for uninterrupted or improved fish passage (Table 2). In Washington, there are 4,463 sites where state highways cross fish-bearing streams. Of these locations, more than 500 “problem sites” were identified. These were sites where the drop of the culvert’s outfall was too high, existing water velocities are too great, or water depth was too shallow for adequate upstream fish passage. The state transportation agency is fixing these culverts using a “priority Index System”, which considers potential habitat improvements. These efforts have been documented by Carey and Wagner (1996). Oregon has a similar program to retrofit culverts to increase the value and accessibility of upstream habitat.

Stream restoration is also becoming a part of transportation projects. Harman and Jennings (2002) describe restoration project in North Carolina that used the natural channel in the design technique. The project was to improve water quality and habitat, reduce stream bank erosion, and enhance floodplain functions. Enhancement to stream was provided during Maine Turnpike construction for two high-quality trout stream crossings to improve productive habitat and the carrying capacity of the streams. Log flow deflectors were provided to increase the depth and velocity of the main channel, create pools, scour fine sediments, and divert water flow from eroding banks. Submerged woody debris and boulders were placed to provide additional habitat. Log bank undercut structures were provided to stabilize stream banks (Farrell and Simmons 2002).

Fish passage structures in urban streams are also becoming better understood. Hegberg et al. (2002A and B) discussed related hydrologic and resource issues and presented approaches on the hydraulic design and analysis. Recommendations for evaluation of target fish species characteristics, site-

specific base flow hydrology, and hydraulics of structures are provided. They also present a list of procedures for design of the passage structures.

To address the specifics of culvert design and placement, the Pacific Northwest National Laboratory in the state of Washington started a culvert testing for juvenile salmonid passage (Pearson et al. 2002). Full-scale models will be used to look at hydraulic conditions (velocity, turbulence, and water depth) associated with various culvert designs under various slopes and flow regimes.

States are also considering freshwater mussels in construction of bridges and culverts. Savidge(1998) described erosion control measures, elimination of direct drainage from bridges, and structural features on several projects in North Carolina that were the result of protected mussel species. Reutter and Patrick (2002) reported on measures taken for mussels in a bridge replacement on Allegheny River 80.5 km north of Pittsburgh, Pennsylvania. The assessment included a construction/demolition option evaluation, hydraulic and hydrologic analyses, and the development and implementation of a mussel relocation program with subsequent monitoring of success.

3.5. Viaducts

Viaducts are areas of elevated roadway that span valleys and gorges. Figures 7 and 8 provide a general view of two viaduct structures (TRB, 2002). They are different from bridges in that they are typically higher and cross-streams and rivers as well as adjacent valley habitats. Viaducts provide relatively unrestricted passage for riverine wildlife and species that utilize riparian areas for movement. The height of viaducts allows for maintenance of vegetated habitat beneath the structure and provides a sense of openness that is required for many species.

Most existing viaducts were constructed because it was the best or most esthetic way to cross a valley or ravine from an engineering standpoint rather than to accommodate wildlife. However, consideration and design for wildlife are increasing, especially in Europe. There are three viaducts (593m, 160m and 265m in length, respectively) used in Slovenia on the Ljubljana-Trieste highway. These viaducts are being successfully used by brown bear, wolf and a number of ungulates.

Based on the survey in Table 2, none of the states reported using this concept for wildlife connectivity. Although there are numerous viaducts in the United States and Europe, wildlife movement was not the primary motive in their development. However, wildlife connectivity could be one of the multiple considerations resulting in a viaduct.



Figure 7. Viaduct on Highway 241 in southern California



Figure 8. Viaduct on the Ljubljana-Trieste Highway in Slovenia

3.6. Fencing

Fencing for large and medium-sized mammals is required for underpass and overpass system to be effective. Standard fencing may not be effective for some species (black bear, coyotes), but manipulations of wildlife trails and vegetation can also be used to guide animals to passage ways and learning may enhance their effectiveness for these species over time. Fencing for large animals must also include one-way gates or earthen ramps to prevent animals that get onto roadways from being trapped between fences on both sides of road. Fencing for small mammals, reptile and amphibians must be specifically designed to prevent animals from climbing over and through, or tunneling under the fencing. Short retaining walls (Figure 9) can provide relative maintenance-free barriers for reptiles, amphibians and small mammals (USDOT and FHA, 2002). Table 2 shows that 28 of 34 responding states use all kinds of fences to protect different animals from highway disturbing.



Figure 9. Short wall to keep reptiles and amphibians from road

4. Design Guidelines

4.1. Design considerations

Placement. Placement of passage structures can be very important for some species, even relatively mobile species. Travel distance (to reach a passage way) is especially important for small animals. Mammals are generally capable of learning to use underpass or overpass system and may transfer that knowledge to succeeding generation (Ford 1980, Singer and Doherty 1985, Land and Lotz 1996, Paquet and Callaghan 1996). This is unlikely to be the case with reptiles and amphibians. The learning ability may result in improving mitigation success over time for more mobile species even for underpass that is not placed at traditional crossing points. Even so, many people consider placement to be the single most important factor affecting the success of passage structure (Podlucky 1989, Foster and Humphrey 1995, Rodriguez et al. 1996, Rosell et al. 1997). However, few methodological approaches to determine the placement of mitigation passages along road corridors have been explored. The following three methods are most often used in passage structure design:

- (1). The location of wildlife passage is derived from information on the spatial distribution of wildlife-vehicle collisions primarily where road kill density are highest (Evink, 1996). Databases such as Wars200-Wildlife Accident Reporting System (Sielecki, 2000) and the Washington State

DOT deer kill database (Carey, 2002) are being developed by transportation agencies to identify wildlife accident prone locations and wildlife accident trends, direct wildlife accident mitigation effort and evaluate the effectiveness of wildlife accident mitigation techniques.

(2). The other method for locating passages might utilize data obtained from radio-monitoring of animal movements or tracking surveys along roads (Kohbler and Adamic 1999, Scheick&Junes 1999). Florida and Montana DOTs are financing these radio-telemetry studies for important species in important ecological areas of their states (Waller and Servheen ,1999; Eason and McCown, 2002). But not all transportation planners and land managers have the luxury of possessing data on animal movements, their crossing location and road-kill location or the time to initiate studying to acquire these data because infrastructure-planning decisions are usually made over a short period of time.

(3). Modeling habitat linkages with a geographic information system (GIS) is another means of determining optimal placement of wildlife crossing structures because basically, this method associates characteristic of topography (e.g. Elevation, slope, greenness, wetness and so on) with activity of an animal (Clevenger et al, 2002). Briefly, this method relates the frequency of the activity of a certain animal to the combination of various topographical characteristics of its surroundings based on field observation and literature. The highway area which has the same or similar topography with highest activity frequency of the animal will have the highest probability for this animal to cross. In planning mitigation passages for this kind of animals, the wildlife habitat linkage placement can be easily identified by comparing the topography of planning area with the conclusion. This method represents a useful tool for resource and transportation planners charged with determining the location of mitigation passage for wildlife when baseline information is lacking and when time constraints do not allow for data collection before construction.

Size. It is difficult to determine critical size thresholds for passage structures because these size thresholds undoubtedly vary from species to species. For some species openness-the size of underpasses is more important than absolute size (Foster and Humphrey, 1995). Tunnel layouts that allow animals to see the opposite end of a wildlife passage were positively correlated with utilization for some species (Rosell, 1997). In general, bigger is better. However, some species such as old world badgers and some small mammals may prefer small underpasses. Based on studies of ecoducts in Europe, some have recommended that wildlife overpass be at least 50m wide (Keller and Pfister, 1997).

Light. Some species are hesitant to enter underpasses that lack sufficient ambient light (Jackson,1996). Conversely, there is evidence that species that are sensitive to human avoid areas that are artificially lit (Beier, 1995). Maintenance of natural lighting through the use of overpasses, large underpasses or open-top (grated) underpasses may help address these concerns.

Moisture. Maintenance of wet substrate is important for some amphibian's species. Shrews are often more active (or more mobile) on rainy nights and also may prefer wet substrates for traveling. Underpasses at stream crossings will probably suffice for species that utilize riverine or riparian habitat. However, many amphibian species do not use riparian or riverine areas for migration and the presence of flowing water may deter usage by these species. Open-top (grated or slotted) underpasses do provide sufficient moisture for crossings that lack flowing water. Alternatively, innovative storm water systems might be designed for closed-top systems that would provide enough

water to maintain moist travel conditions without creating flooded or stream-like conditions. Proper drainage is important, because some wildlife species are less likely to use structures when they contain standing water (Rosell et al 1997, Santolini et al 1997).

Temperature. Small underpasses may create temperature disparities (inside vs. outside) that can deter use by amphibians (Langton 1989b). Large underpasses or open-top systems that allow more airflow may help address this concern.

Noise. Traffic noise can be a problem for some mammals, especially those sensitive to human disturbance. Certain underpasses designs (those with expansion joints and those with uncovered medians) can be quite noisy (Foster and Humphrey 1995, Santolini et al 1997). Open-top designs would be inappropriate for species that are sensitive to traffic noise. Overpass systems that incorporate tree and shrub buffers along the edges appear to be much quieter than underpass systems.

Substrate. Some animals feel more secure utilizing crossing systems if they provides sufficient cover. For example, rows of stumps in an underpass appear to facilitate use by small mammals (Linden 1997). Maintaining or replicating streambed conditions within over-sized culverts may facilitate use by salamanders, frogs, small mammals and aquatic invertebrates, thereby maintaining habitat continuity in the area of stream crossings. Certain species (e.g. *Mountain pygmy possums*, *Burramys parvus*) with very specific substrate requirements may require special attention at wildlife crossing (Manserrgh and Scotts 1989).

Approaches. Characteristics of the approaches to underpasses or overpasses may affect their use by some species. Forested species, such as black bears (*Ursus americanus*), prefer well vegetated approaches. Other species, such as mountain goats, appear to prefer approaches that provide good visibility. At Glacier National Park, mountain goats have apparently shifted movement patterns away from a traditional crossing point rather than utilize an underpass that offers poor visibility on the approaches (Pedevillano and wright 1987). The presence of covers on the approaches, in the form of vegetation, rocks and logs, may enhance use by a variety of small and mid-sized mammals (Rodriguez et al 1996, Rosell et al 1997, Santolini et al 1997). However, vegetation at the entrance of an underpass may deter some mammals that are wary of conditions that provide ambush opportunities for predators.

Fencing. Although some species may utilize underpasses or overpasses systems without fencing. Some forms of fencing do appear to be necessary for most species. Fences help guide animals to passage systems and prevent wildlife from circumventing the system. Mountain lions moving along stream corridors have been observed to leave stream valleys and cross over highways rather than utilize large culverts (Beier, 1995). This has also been observed for two species of turtles in Massachusetts. Ungulates commonly seek to avoid underpasses and will generally use them only if other access cross the highway is barred (Ward, 1982). In Banff national Park an elaborate system of multiple arched fences is used to deter wildlife from walking around fences. However, some species are relatively good at circumventing fences by climbing over (black bears) or digging under (coyotes, *Canis latrans*, and badgers) standard fencing. Standard fencing is also ineffective for small animals.

If mitigation objectives are defined too narrowly, mitigation projects can create as many problems as they solve. An obvious example of this is the use of fencing along highways to reduce wildlife road mortality, often for human safety reasons. When these fences are installed without crossing structures, they can compound the fragmentation effects of highway on populations and habitat. In designing wildlife passages, it is important to remember that different structures are not designed for use by a broad range of wildlife, a project that facilitates passage for one species might constitute an absolute barrier for another.

Wildlife overpass, underpass, upland culvert and viaduct are passage structures for terrestrial and amphibian species. As discussed above, these structures are widely used in North America, Europe and Australia for mitigating highway impacts on the wildlife ecology. However, there have not been standard design criteria for these passage structures so far (Spellerberg, 2002) because different species of animal may need different passage structure and no study of comprehensive effectiveness of passage structure was conducted so far.

4.2. Design of fish passages

Fish passage design is very important and complicated because:

- Well-designed fish passage is necessary for life cycle of some migrating fish species such as wild salmon and sea-run trout, which need upstream habitat for spawning. Poorly-designed passage, for example, will wash them back downstream because of the stream velocity in the culvert or outfall drop is too high.
- Fish passage design involves more disciplines including engineering, hydrology and biology.

Selected structures for fish passage are summarized as follows.

4.2.1. Road-Crossing Culverts

The Washington Department of Fish and Wildlife (1999) provided a manual for the design of permanent new, retrofit, or replacement road crossing culverts that will not block the migration of salmonids. Passage design for other fishes can also consult this manual. There are three design options provided in this manual. A general flow chart of the culvert-design process for fish passage is shown in Figure 10.

The no-slope design option results in reasonably sized culverts without requiring much in the way of calculations. The hydraulic design option requires hydrologic and open channel hydraulic calculations, but it usually results in smaller culverts being required than no-slope design option. Smaller culverts may trap more debris, however, so a factor of safety must be applied. The hydraulic design option is based on velocity, depth and maximum-turbulence requirement for a target species and age class. The stream-simulation design option involves constructing an artificial stream channel inside culvert, thereby providing passage for any fish that would be migrating through the reach. It is difficult in most situations, if not impossible, to comply with velocity criteria for juvenile fish passage using the hydraulic design option. The no-slope and stream-simulation design, on the other hand, are assumed to be satisfactory for adult and juvenile passage: thus, they

tend to be used more at sites where juvenile fish passage is required. Application of the no-slope design option is most effective for relatively short culverts at low-gradient sites. Following is a brief introduction to no-slope design option. More about hydraulic design and stream –simulation design option might be found at www.wa.gov/wdfw/hab/engineer/cm/ (Design of road culvert for fish passage, 2003)

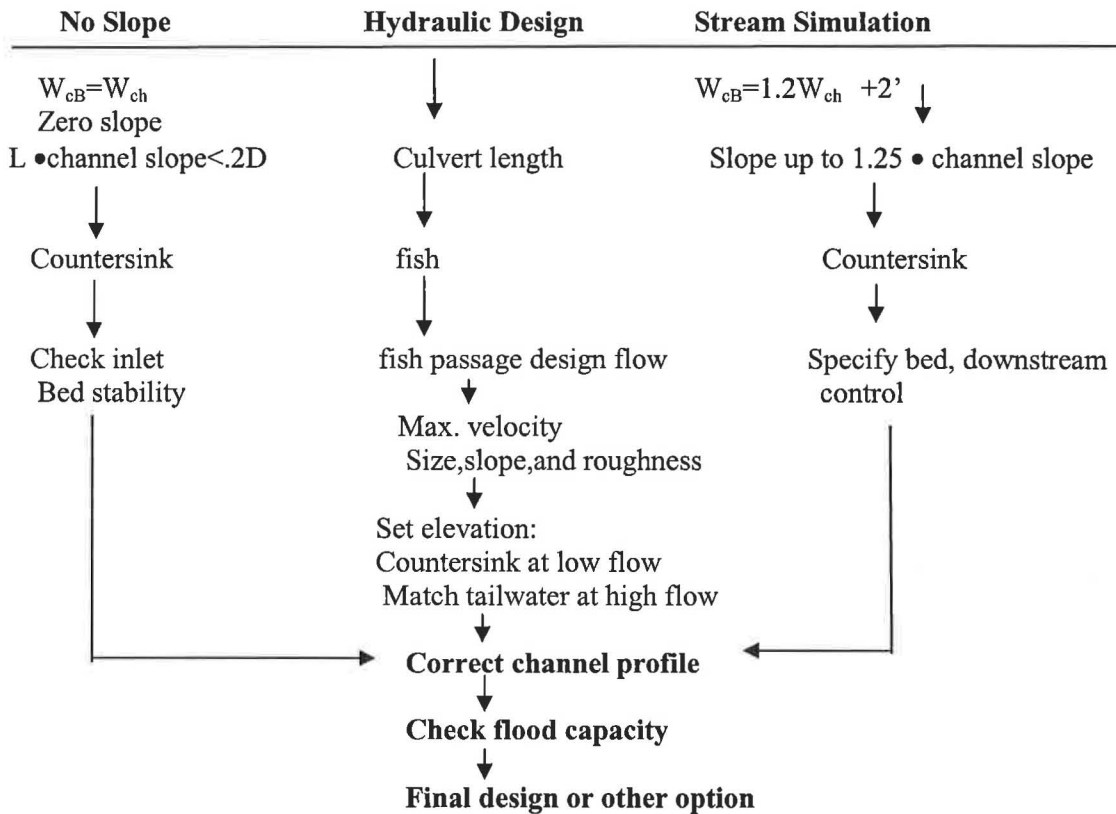


Figure 10 Culvert design process

(Note: W_{cB} = Width of culvert bed W_{ch} = Bankful width of channel L = Length of culvert
 D = Diameter of culvert)

No-Slope Design Option. Successful fish passage can be expected if the culvert is sufficiently large and is installed flat, allowing the natural movement of bedload to form a stable bed inside the culvert. The No-Slope Design Option creates just such a scenario. A no-slope option is defined by a culvert with:

- Width equal to or greater than the average channel bed width at the elevation the culvert meets the streambed.
- A flat gradient,
- The downstream invert is countersunk below the channel bed by a minimum of 20% of the culvert diameter or rise,
- The upstream invert is countersunk below the channel bed by a maximum of 40% of the culvert diameter or rise,

- The possibility of upstream headcut has been taken into account and,
- There is adequate flood capacity.

Generally, the no-slope design option might be applied in the following situations

- New and replacement culvert installations,
- Simple installations: low to moderate natural gradient or culvert length (generally, 3% slope),
- Passage required for all species,
- No species design expertise or survey information required.

Information needed for the no-slope option includes:

- The average natural channel bed width,
- The natural channel slope,
- The elevation of natural channel bed at the culvert outlet,
- The evaluation of potential headcut impacts upstream of the culvert.

A reasonable upper limit of no-slope design option is to use it at sites where the product of channel slope (ft/ft) and the culvert length (ft) doesn't exceed 20% of the culvert diameter or rise. It should be noted that this limitation can be overcome by understanding and accounting for the implications of constricting the upstream end of the culvert with accreted bed or by installing a larger culvert. Any culvert shape can be used (round, pipe-arch or elliptical), but it must be countersunk a minimum of 20 % at downstream end and a maximum of 40 % at upstream end (see Figure 11).

The no-slope design option is, therefore, limited by slope and length. If a site does not comply with this limitation, the size of culvert (D) can be increased: the slope (S) can be decreased, or another design option should be used.

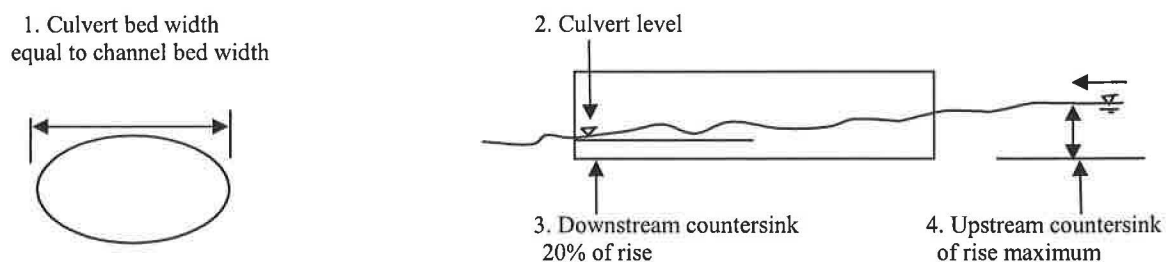


Figure 11. No Slope Option

4.2.2. Bridges

Where the design process leads away from a culvert as a viable crossing structure, bridges should be considered. This is particularly the case where the stream width exceeds 20 feet or stream slope is greater than about six percent, or when the movement of large debris is frequent. Crossing that is subject to debris flows needs special consideration. Alternatives in such a situation include fords,

temporary bridges, bridges with high clearance and moving the road to where its crossing is less problematic.

While general considerations regarding the use of bridges at crossing are discussed in this design guideline (www.wa.gov/wdfw/hab/engineer/cm/), their actual design details are not provided. An experienced bridge design engineer is required for such an undertaking.

For the purpose of this guideline, a bridge is any crossing that has separate structural elements for the span and its abutments. Unencumbered by the dimensional limitations of culverts, a bridge can be large enough that the structure does not significantly affect the flood hydraulic profile. Piers and abutments can be drilled or buried deeply enough that there is very little risk of failure.

Like culverts, however, bridge designs must also comply with regulations; in this case, regulations addressing water crossings and the creation of new channels (WAC220-110-070 and 220-110-0800). And, just as in the case of culverts, bridge design must begin with consideration for habitat impact. Properly designed bridges are superior to culverts in terms of habitat preservation and restoration; however, mitigation measures may still be necessary to compensate for impacts from construction, bank armoring or other habitat losses caused by the presence of the bridge.

The channel created or restored beneath the bridge must have a gradient, width, floodplain and configuration similar to the natural existing natural channel upstream or downstream of the crossing. Where possible, habitat components normally present in these channels should also be included. In high-gradient situations, the stream-simulation width criteria may be used to determine channel width under the bridge.

Bridge-span calculations should begin with a consideration of required channel width and floodplain requirements and proceed to side-slope. Abutments should be placed at an angle that leads to natural stability. Large riprap retaining walls that encroach on the channel should be avoided. Wac220-110-070 states that abutments, piers, piling, sills, approach fills, etc. should not constrict the flow so as to cause any appreciable increase (not exceed 0.2 feet) in backwater elevation (calculated at the 100-year flood) or channel wide scour and should be aligned to cause the least effect on hydraulics of water course. The purpose of the criteria is to limit the effect of bridge on the upstream channel, especially in channels with significant gravel bedload.

When an undersized culvert is removed and replaced with a bridge, some upstream channel instability is likely. This can be due to stored sediment above the culvert and /or channel incisions below the culvert. The result is excessive drop through the area of the crossing. The designer should carefully consider the channel headcut and regrade factors (see the discussion addressing channel regrade in chapter 7, Channel Profile at www.wa.gov/wdfw/hab/engineer/cm/). Some sort of grade control, temporary or permanent, may be necessary to ensure channel and habitat integrity.

5. Toward a Practical Strategy

To mitigate highway impacts on wildlife we must focus on reducing the impact of roadways on local populations and preserving ecological processes related to landscape continuity and metapopulation dynamics. Mitigation strategies that focus too much on preserving local populations may be too

expensive to be fully implemented, given the large numbers of species involved. A practical strategy for mitigating highway impacts should first focus on the landscape level, using the most effective techniques available to maintain landscape continuity and metapopulation dynamics within the designated “connectivity zones”. In addition to the maintenance of some level of ecosystem function, cost-effective techniques should be practically employed throughout the highway alignment to maintain local wildlife populations.

According to Jackson et al (1998), a practical strategy for mitigating highway impacts on wildlife should include:

- Avoidance of highway fencing and Jersey barriers when not used in association with wildlife passage structures.
- Use of small (e.g. 2'x2' minimum) amphibian and reptile passages wherever roadways pass along the boundary between wetlands and uplands.
- Use of oversized stream culverts and bridges at stream crossings.
- Selective use of viaducts instead of bridges at important stream or river crossing.
- Use of landscape-based analyses to identify “connectivity zones” where mitigation efforts can be concentrated to maintain ecosystem processes.
- Selective use of wildlife overpasses and larger underpasses within “connectivity zones.”
- Monitoring and maintenance plans to ensure that mitigation system continue to function over time and that knowledge gained from these projects can be used to further refine our mitigation techniques.

6. Concluding Remarks

Traditionally, highway impacts to wildlife have been viewed in terms of road mortality and threats to selected populations of animals. Viewing this issue from a landscape ecology perspective, it is clear that highways have the potential to undermine ecological process through the fragmentation of wildlife populations, restriction of wildlife movements, and the disruption of gene flow and metapopulation dynamics.

Due to the complex nature associated with the natural ecological systems, selection and design of engineered structures are rather complicated. With the growing application of engineered structures worldwide, our knowledge base is also growing. This report provides up-to-the-date knowledge pertaining to selected key structures widely used to protect the wildlife ecology for both terrestrial and aquatic animals. The information provided herewith should be helpful to transportation designers to select BMPs for mitigating road impacts on ecological integrity.

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