DESIGN ELEMENTS OF WILDLIFE CROSSING STRUCTURES

A LITERATURE REVIEW

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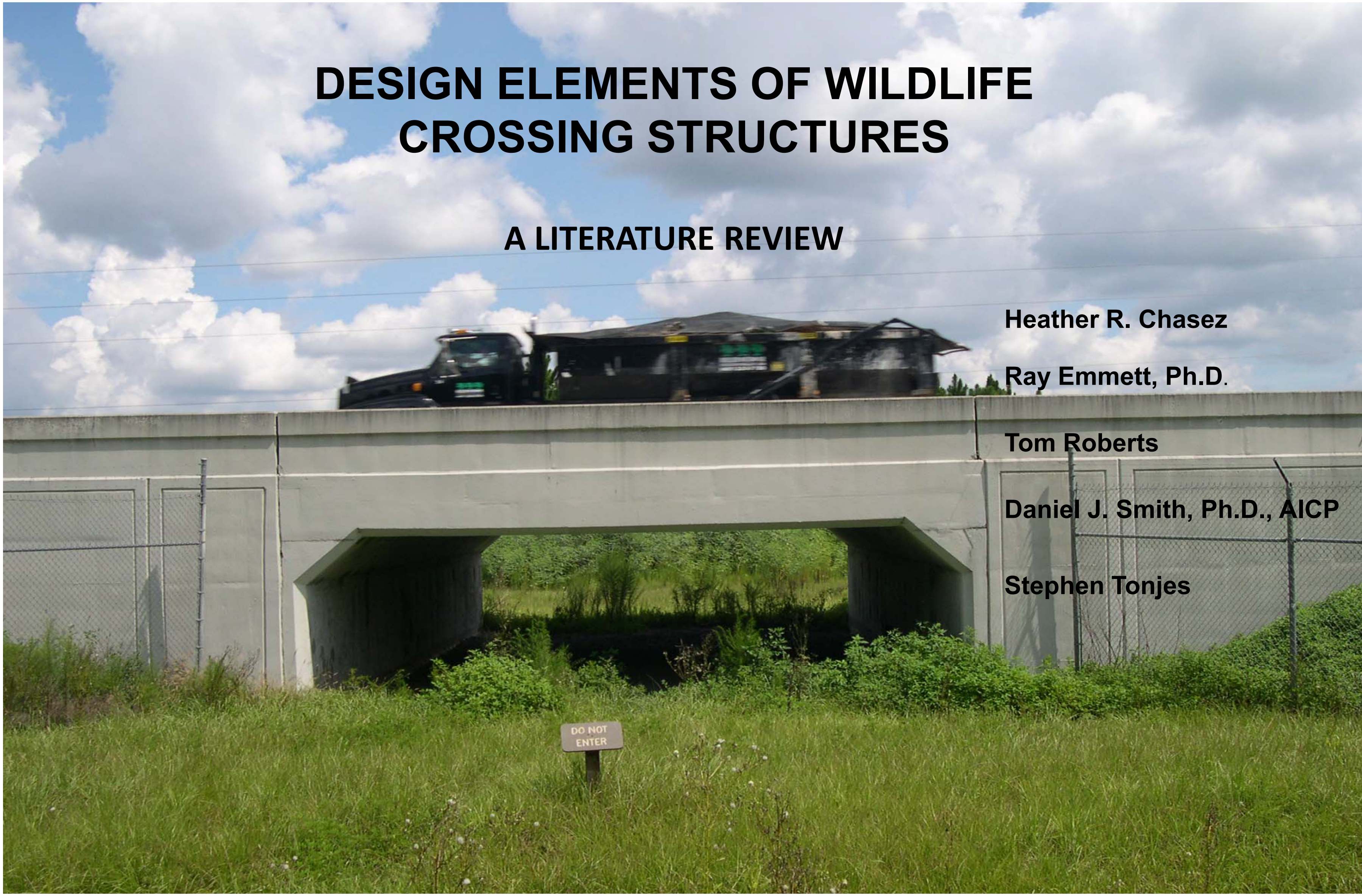

INTRODUCTION

This review will be updated from time to time. If you want to be informed whenever updates become available, please contact Stephen Tonjes at the FDOT District 5 Environmental Management Office, 719 S. Woodland Blvd., DeLand, FL 32720, telephone 386-943-5394 or e-mail stephen.tonjes@dot.state.fl.us.

These recommendations are for the use of transportation professionals in evaluating and designing crossing structures. Their relevance to a particular project will depend on the target species, local and regional geography, and other factors. These recommendations should not be viewed as a complete manual, but instead as a general guide.

Small oversights during design and construction can virtually eliminate the usefulness of wildlife passages; therefore, engineers and environmental professionals should collaborate throughout the design and the construction phases, and every project should make provisions for maintenance, and for monitoring of wildlife use after construction.

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SECTION 1:

CROSSING STRUCTURES

category	sub-category	# of lanes	type/ shape	material	substrate/ drainage	median features	height (ft)	width (ft)	length (ft)	animal class	animal size	species	comments/ recommendations	citation
crossing structures	culvert							smallest 2, largest 3.28	smallest 26.2, largest 121.4				all had species use	Ascensao, F. et al (2006)
crossing structures	culvert		circular				1.64 - 3.28	1.64 - 3.28		mammal	small	marten and others	facilitate passage	Clevenger, A.P. (1999)
crossing structures	culvert		rectangular	concrete or polymer concrete	above water table so no flooding but not too far off ground as to be accessible		2, if tunnel is longer than 66 then up to 5	3.28, if tunnel is longer than 66 then up to 6.56	shortest possible	herptile	small	amphibians	distance between tunnels 262.5 - 328 ft, some species, such as the spotted salamander was noted to use a pipe with D- 0.66 ft as well as some other species.	Puky, M. (2003), Jackson, S. (1996), Brehm, K. (1989)
crossing structures	culvert		circular	concrete or polymer concrete	above water table so no flooding but not too far off ground as to be accessible		3.28, if tunnel is longer than 66 then up to 6.56	3.28, if tunnel is longer than 66 then up to 6.56	shortest possible	herptile	small	amphibians	distance between tunnels 262.5 - 328 ft, some species, such as the spotted salamander was noted to use a pipe with D- 0.66 ft as well as some other species	Puky, M. (2003), Jackson, S. (1996), Brehm, K. (1989)
crossing structures	culvert		circular				3.28 - 4.92	3.28 - 4.92		mammal	medium	e.g., coyote	facilitate passage	Clevenger, A.P. (1999)
crossing structures	culvert		circular				5.9	5.9	118 - 262.5	general	small	mustelids, amphibians, reptiles and mammals	selectively utilized	Mata, C. et al (2005)
crossing structures	culvert		rectangular				6.56	6.56 - 9.84	115 - 164	general	small	mustelids, amphibians, reptiles and mammals	adapted structure, selectively utilized	Mata, C. et al (2005)
crossing structures	culvert						6.56	6.56 - 9.84		general	small	anurans, water voles and ophidians	adapted culvert (openness index- 0.05-0.19), high rate of use	Mata, C. et al (2003)
crossing structures	culvert		circular				5.9	5.9		general	small	lacertids, rats, mammals, and mustelids	high rate of use; openness index - 0.04-0.09	Mata, C. et al (2003)

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crossing structures	culvert		box				12	12			large		or larger	Bond, M. (2003)
crossing structures	culvert		circular				1	1				small animals	install parallel to lg. box culvert for small animals, upstream end should be a few inches higher	Bond, M. (2003)
crossing structures	culvert		box or round, small					5 or less at widest dimension		general	small	pika, western jumping mouse, pacific water shrew, bushy-tailed woodrat, cascade frog, larch mt. salamander, alligator lizard, western skink, rubber boa	recommended dimensions for small crossings	Ehinger, W. et al (2006)
crossing structures	culvert								43	mammal	small-large	hare, coyote, martin, weasel, red	carnivores and small mammals utilized	Clevenger, A.P. (2002)
crossing structures	culvert									mammal	small		mixed size class is recommended and to be placed in frequent intervals of 150-300m	Clevenger, A.P. (2002)
crossing structures	culvert									mammal	small-medium	red foxes, wildcats, striped skunks, raccoons	generally favored structures of cool, wet conditions	Servheen, C. et al (2003), Foster, L.R. et al (1995), Land, D. et al (1996), Rodriguez, A. et al (1997)

category	sub-category	# of lanes	type/ shape	material	substrate/ drainage	median features	height (ft)	width (ft)	length (ft)	animal class	animal size	species	comments/ recommendations	citation
crossing structures	culvert						7.87 - 19.7	7.87 - 19.7		mammal	large	ungulates, carnivores	not used though large enough, probably due to lack of suitable substrate and low openness ratios, observed prefererences included open structures with high openness ratios	Servheen, C. et al (2003), Groot Bruinerink, G.W.T.A. et al (1996), Foster, L.R. et al (1995), Land, D. et al (1996), Reed, D.F. et al (1975), Ruediger, B. (2001)
crossing structures	culvert		2- square boxes	concrete	partially submerged	grate	7.87	7.87	144.3	general	small-large	snakes, turtles, alligators, small-medium mammals	greatly decreased the mortality especially for large species	Dodd Jr, K.C. (2004)
crossing structures	culvert		2- square boxes	concrete	partially submerged	grate	5.9	5.9	144.3	general	small-large	snakes, turtles, alligators, small-medium mammals	greatly decreased the mortality especially for large species	Dodd Jr, K.C. (2004)
crossing structures	culvert		4- circular	concrete	partially submerged	grate	2.95	2.95	144.3	general	small-large	snakes, turtles, alligators, small-medium mammals	greatly decreased the mortality especially for large species	Dodd Jr, K.C. (2004)
crossing structures	culvert		shelves									deer mice, short tailed weasels, striped skunks, raccoons	adding shelves for animals to use when water is in the culvert has been highly successful	Foresman, K. (2003)
crossing structures	culvert		"vole tubes"									voles, weasels	adding small tubes for animals that prefer small closed spaces has been highly successful	Foresman, K. (2003)

category	sub-category	# of lanes	type/ shape	material	substrate/ drainage	median features	height (ft)	width (ft)	length (ft)	animal class	animal size	species	comments/ recommendations	citation
crossing structures	culvert		elliptical	metal			13.1	23					In Banff National Park	Clevenger, A.P. (2002)
crossing structures	culvert		box tunnel	concrete			8.2	9.84					In Banff National Park	Clevenger, A.P. (2002)
crossing structures	culvert						9.84 min.			mammal	large	lg. carnivores, ungulates	recommended	Smith, D. (2003)
crossing structures	culvert			added a concrete pad at the level of the culvert	rocks were removed and banks cut and supported by stone-filled wire cages.					herptile	small	turtles	culverts were too steep, retrofits were initiated	New Jersey, Sussex county: Robert Bird, NJDOT, 609-530-4239
crossing structures	culvert		drainage pipes and box culverts										41 to 72" dia.	Virginia, Great Dismal Swamp: Sandy Snead, VDOT, 804-225-4491
crossing structures	culvert		created ledge inside culvert	rock						general	small-medium	mammals, amphibians	animals have been observed using the ledge; wall wide enough for small-med mammals geenrally high enough to remain dry	Oregon, Suislaw River: Tom Murtagh, ODOT, 503-657-2000
crossing structures	culvert		added ledge during construction							general	small-medium	mammals, amphibians		Rhode Island, Slater Mill Park: Emilie Holland, RIDOT, 401-222-2023
crossing structures	culvert			cobbled concrete	natural substrate								at bottom of culvert with underlying cobbled concrete	Bond, M. (2003)
crossing structures	habitat												should accommodate aquatic, riparian, terrestrial components	Ehinger, W. et al (2006)
crossing structures	lighting												prohibit street lighting to encourage use	Bond, M. (2003)

category	sub-category	# of lanes	type/ shape	material	substrate/ drainage	median features	height (ft)	width (ft)	length (ft)	animal class	animal size	species	comments/ recommendations	citation
crossing structures	overpass							52.5 center, 65.62 ends		ungulate		red deer, other	had low use index among species, except red deer which used it exclusively. Other species opted for different crossing structures	Mata, C. et al (2003)
crossing structures	overpass							164					In Banff National Park	Clevenger, A.P. et al (2002)
crossing structures	overpass							11 to 2,854					general range of widths at ends	Evink, G. (2002)
crossing structures	overpass							295 at ends, 230 in center					typical of European structures	Clevenger, A.P. et al (2002), Wieren, S.E. et al (2001), Jackson, S.D. et al (2002)
crossing structures	overpass							100 to 165					most overpasses in the world	Knapp, K.K. et al (2004), Forman, R.T.T. et al (2003)
crossing structures	overpass							66 or less					had significantly less mammal use	Knapp, K.K. et al (2004), Forman, R.T.T. et al (2003), Rodriguez, A. et al (1997)
crossing structures	overpass							164 to 197					seem to be adequate	Knapp, K.K. et al (2004), Forman, R.T.T. et al (2003), Rodriguez, A. et al (1997)
crossing structures	overpass												generally quieter than underpasses	Iuell, B. et al (2003), Jackson, S.D. (2000)
crossing structures	overpass			earthen berms placed on structure									in Banff National Park; to reduce light and noise	Clevenger, A.P. et al (2002)
crossing structures	overpass											arboreal species	planting of continuous canopy over structure	Bank, F.G. et al (2002)

category	sub-category	# of lanes	type/ shape	material	substrate/ drainage	median features	height (ft)	width (ft)	length (ft)	animal class	animal size	species	comments/ recommendations	citation
crossing structures	overpass			diverse vegetation and temporary debris									should be vegetated with a wide variety of vegetation. Temporary material such as old x-mas trees can be used to provide temp shelter until permanent cover in place	Hardy, A. (2006)
crossing structures	overpass		Dutch hourglass design					center, 98 ends 262		mammal	large		design with these widths, considered best design for the Netherlands	Knapp, K.K. et al (2004), Forman, R.T.T. et al (2003)
crossing structures	overpass		hourglass or square shape					100, width at narrowest point- at least					recommended dimensions	Knapp, K.K. et al (2004)
crossing structures	overpass	4						180					minimum recommended	Carr, T. et al (2003)
crossing structures	overpass	2						50					minimum recommended	Carr, T. et al (2003)
crossing structures	overpass									ungulate	large	deer	overpass bridge effect index- (width) x (height)^1/2/(length). Deer may be fearful of some overpasses, this formula may help to increase deer use. In Colorado deer were found less afraid of using overpasses with BEIs of 0.34 and 0.65. In Utah a structure with a BEI of 0.26 was functional.	Knapp, K.K. et al (2004), Reed, et al (1979)

category	sub-category	# of lanes	type/ shape	material	substrate/ drainage	median features	height (ft)	width (ft)	length (ft)	animal class	animal size	species	comments/ recommendations	citation
crossing structures	overpass			raised berms	will create artificial ridges and valleys								recommended these be constructed extending the length of the crossing. 3 berms, one on each edge and one in the middle	Hardy, A. et al (2006)
crossing structures	overpass												the most effective have a wide visual angle and short passage length	Groot Bruinderink, G.W.T.A. et al (1996)
crossing structures	streams		box culvert or bridge underpass				6			mammal	large	mt. lions, bear, deer, coyote, wolf, elk, bobcat	openness index - 0.75 min. prefer 0.9; recommendations for mammals (at least 1.5 ft at shoulder and 2 ft in length w/o tail)	Bates, K. (2003)
crossing structures	streams		box or pipe culvert				3, minimum			mammal	small-medium	javelina, skunk, raccoon, fox, rabbit	openness index - 0.75 min., placed with frequency (e.g., on a 1/2 mile section of roadway, 1 every 500 to 1,000 feet); recommended for med mammals (animals 0.5 to 1.5 ft at shoulder, 1.25 to 2 ft in length)	Bates, K. (2003)
crossing structures	streams		box or pipe culvert, small				1	1 to 4		mammal	small	squirrels, prairie dogs, rats, voles, mice	structure placement - every 150-300 ft recommended for sm. animals	Bates, K. (2003)
crossing structures	streams		pipe culvert, small		moist substrate or sandy soil	open grate to allow rain, light and air	1, at least	1, at least		herptile	small	frogs, toads, salamanders, turtles, lizard, snakes, tortoises	recommended placement: every 150 to 300 ft	Bates, K. (2003)
crossing structures	streams		ledge culvert		should meet WDFW stream simulation specifications								add large wood debris and terrestrial bench	Ehinger, W. et al (2006)

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crossing structures	streams		culvert		should be laid at same slope as stream, but bury 1/6 of the dia. to provide substrate								recommendations to promote animal use	WDFW (2003)
crossing structures	streams		culvert		natural bottom sediment							fish and wildlife	span entire stream and adjacent dry land, highly recommended	Carr, T. et al (2003)
crossing structures	streams		made culverts larger		buried the concrete bottom by placing natural streambed materials and stockpile cobble on top					fish		trout	slowed water down so fish can swim freely	New York, Rt 10: Steve Camissa, NYDOT, 607-721-8164
crossing structures	streams		2-barrel box culvert		added a 6" lip to one barrel to direct water during low level periods into one side					fish			this allows spawning fish and young fry to move freely	North Dakota, Turtle Creek, NDDOT, 701-250-4343
crossing structures	subtrate				soil floor/ natural vegetation						large		large animals preferences for over and under crossings	Knapp, K.K. (2004), Olbrich, P. (1984) in Putman, R.J. (1997), Ward, A.L. (1982)
crossing structures	subtrate				native soils								maximize continuity of native soils	Ehinger, W. et al (2006)

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crossing structures	subtrate				organic soil, woody debris					general	small	invertebrates, amphibians, reptiles, mammals	addition of organic matter in soil, decomposer habitat, moisture retention through dry periods. Things such as coarse, woody debris and legacy structures- large logs, root wads and rocks	Ehinger, W. et al (2006)
crossing structures	subtrate				organic litter						small	macro-imvertebrate	increasing litter near and within the structures may increase usage	Ehinger, W. et al (2006)
crossing structures	underpass						6.9, at least	wide	short	ungulate			open passage with clear view of habitat	Hardy, A. et al (2006) Clevenger, A.P. et al (2005), Gagnon, J.W. et al (2005), Barnum, S.A. (2003)
crossing structures	underpass						8.2 or above			ungulate	large	mule deer	preferred below grade crossing structures even when there was a choice to cross at-grade	Barnum, S.A. (2003)
crossing structures	underpass		box tunnel	concrete			9.84	9.84	100	ungulate	large	mule deer	deer always initially reluctant, but then use. Artificial lighting had no effect good or bad. Larger more open underpass with a minimum of 4.3m height and width and shortest length is recommended	Reed, D.F. (1975)
crossing structures	underpass						12.1	9.84		ungulate	large	deer	recommended dimensions	Hardy, A. et al (2006), Donaldson, B.M. (2005)
crossing structures	underpass				earth floor		13.1	13.1	short	ungulate	large	red, roe, fallow deer	ratio of aperture size to overall length is critical (height x width)/length	Olbrich, P. (1984) Cited in Putman, R.J. (1997)

category	sub-category	# of lanes	type/ shape	material	substrate/ drainage	median features	height (ft)	width (ft)	length (ft)	animal class	animal size	species	comments/ recommendations	citation
crossing structures	underpass						6.5					general, except deer	typical height of underpasses used by wildlife, but can range up to 13-16 ft	Knapp, K.K. et al (2004), Forman, R.T.T. et al (2003)
crossing structures	underpass						6.9			ungulate	large	white-tailed deer	were observed using in Florida	Knapp, K.K. et al (2004), Foster, L.R. (1995)
crossing structures	underpass						7 to 8	20 to 25		ungulate	large	deer	recommended minimum dimensions for deer underpass	Knapp, K.K. et al (2004)
crossing structures	underpass						8	23, at least		ungulate	large		recommended dimensions	Knapp, K.K. et al (2004), Forman, R. et al (2003), Foster, L.R. et al (1995), McGuire, T.M. et al (2000)
crossing structures	underpass												bridge undercrossings are preferable	Bond, M. (2003)
crossing structures	underpass									ungulate	large	fallow deer	lighted underpasses were avoided. Structures painted light-gray were more readily used than ones painted black or dark gray	Kruger, H.H. and Wolfel, H. (1991).
crossing structures	underpass		box culverts or small bridges				5 (min) to 12 (max) vertical clearance	5 (at least), up to 100		mammal	medium	river otter, mountain beaver, porcupine, hoary marmot, cascade red fox, bobcat, American marten, coyote, snowshoe hare, fisher	recommended dimensions for medium sized structure	Ehinger, W. et al (2006)

category	sub-category	# of lanes	type/ shape	material	substrate/ drainage	median features	height (ft)	width (ft)	length (ft)	animal class	animal size	species	comments/ recommendations	citation
crossing structures	underpass		bridge spans				16, but includes room for 4 ft of snow depth			mammal	large	mule deer, rocky mountain elk, black bear, grizzly bear, mt. goat, gray wolf, Ca. wolverine, Canada lynx	recommended dimensions for large structures	Ehinger, W. et al (2006)
crossing structures	underpass		machinery tunnel		earth floor		13.1	29.5		ungulate	large	mule deer	more extensively used than concrete box tunnel (9.84 ft x 9.84 ft; concrete floors)	Hardy, A. et al (2006), Ward, A.L. (1982)
crossing structures	underpass						6.56 - 13.1	49.2					recommended dimensions	Hardy, A. et al (2006), Iuell, B. et al (2003)
crossing structures	underpass		bridge				35	50	45	ungulate	large	deer, elk	the minimum height require for this project is 20 ft, due to elk use	Brown, D.L. (1999)
crossing structures	underpass							> 98.4 mouths				deer	used in the Netherlands, have been highly successful.	Putman, R.J. (1997)
crossing structures	underpass						120 or less						use vertical walls within the structure to maximize habitat connection	Ehinger, W. et al (2006)
crossing structures	underpass									mammal	small		max. distance between crossings recommended at 1,066 ft, corresponding to 75% use by sm. mammals	Smith, D. (2003)

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crossing structures	underpass												openness ratio is important because the animal perceives the opening on the other end as being smaller, and this ratio is an indicator of how large the opening is, the larger the ratio the more likely they are to enter	Ehinger, W. et al (2006)
crossing structures	underpass									ungulate	large	mule deer	in Colorado they were reluctant to use structures with an openness value 0.31, but more apt to use structures with openness values between 4.6 and 5.6	Knapp, K.K. et al (2004), Reed, D.F. et al (1979), Ward, A.L. et al (1982)
crossing structures	underpass									ungulate	large	red, fallow and roe	red deer and fallow deer did not use structures with an openness index of < 1.5; roe deer would not use those < 0.75	Knapp, K.K. et al (2004), Olbrich, P. (1984) in Putman, R.J. (1997)
crossing structures	underpass						8.2 to 13.1, min			ungulate	large	red deer, roe deer, wild boar	recommended min height: 13.1 ft red deer, 9.84 ft roe deer, and 8.2 ft wild boar	Groot Bruinderink, G.W.T.A. (1996)
crossing structures	underpass									ungulate	large	red, fallow, row, mule deer	suggested openness indices 0.6 for mule deer, 0.75 for roe deer and 1.5 for red and fallow deer	Knapp, K.K. et al (2004)
crossing structures	underpass									mammal	small-large	deer, though also used by sm-lg carnivores	generally favored more natural lighting, vegetation, substrate, and moisture	Servheen, C. et al (2003)

category	sub-category	# of lanes	type/ shape	material	substrate/ drainage	median features	height (ft)	width (ft)	length (ft)	animal class	animal size	species	comments/ recommendations	citation
crossing structures	underpass		open construction machinery underpass							ungulate	large	mule deer	OI = 1.07, has substantially more use than other underpasses studied, including a similar one with an OI = 0.72; difference may be due to surrounding habitat differences	Gordon, K. et al (2003)
crossing structures	underpass		arch or bridge span over water		open bottom with natural substrate					general		fish and wildlife	for box culvert/pipe arch or pipe culvert embed at least 1 ft and at least 25%, respectively. Span channel a min. of 1.2 times the bankful width, openness ratio at least 0.25.	River and Stream Continuity Steering Committee (2004)
crossing structures	underpass		arch or bridge span over water		open bottom with natural substrate		6, minimum height preferred, or 4 when conditions prohibitive						optimal: span at least 1.2 times the bankful width with sufficient head room for dry passage, min. openness ratio of 0.75 if inhibiting conditions present, min. openness ratio 0.5.	River and Stream Continuity Steering Committee (2004)
crossing structures	underpass												should be open enough for light to be seen on other side	Hardy, A. et al (2006)
crossing structures	underpass												should be perpendicular to road	Hardy, A. et al (2006)
crossing structures	underpass		fine mesh ledge for inside of culvert; rain gutter sized tubes attach to underside										ramps exit to the side of the culvert mouth; tubes allow smaller animal passage. Shelf can be purchased from Roscoe Steel; a shelf long enough to extend under a 4-lane highway costs < $5,000.	Foresman, K. (2006)

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crossing structures	underpass												crossing usage increases with the age of the structure	Knapp, K.K. (2004), Reed, D.F. et al (1975), Land, D. et al (1996), Clevenger, A.P. (2000)
crossing structures	underpass		expanded bridge				9.84	36					In Banff National Park	Clevenger, A.P. (2002)
crossing structures	underpass		open-span bridge	concrete			9.84	36					In Banff National Park	Clevenger, A.P. (2002)
crossing structures	underpass							8.86 at least		general	small-large		to maintain 75% crossing rate	Smith, D. (2003)
crossing structures	underpass						4.92 or lower			general	small	small mammals, herpetofauna	used more frequently, maybe because predators did not also use	Smith, D. (2003)
crossing structures	underpass		bridge				11.5 min.			mammal	large	lg. carnivores, ungulates	recommended	Smith, D. (2003)
crossing structures	underpass		rectangular		natural soil					general	all		preferences	Smith, D. (2003)
crossing structures	underpass									mammal	small-large		make crossings as wide and open as possible with vegetation and stumps or logs	Carr, T. et al (2003)
crossing structures	underpass										small-medium		additional structures should be at intervals of 820 ft to accommodate species with small home ranges	Ehinger, W. et al (2006), Clevenger, A.P. et al (2001) (2002)
crossing structures	underpass		3 extended/ stabilized railroad ties underneath railroad tracks							general	small	reptiles, amphibians, mammals	animals have been observed using structures; Note: ballasts removed to a depth of 9 inches with concrete guidewalls keeping the ballast out of the path way.	Massachusetts: Lars Carlson, 617-994-4354

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crossing structures	underpass											general	short as possible length, bundle lanes where feasible	Ehinger, W. et al (2006)
crossing structures	underpass			vegetation, logs, stumps						mammal	small		should be within passages	Carr, T. et al (2003)

SECTION 2:

FENCING AND OTHER BARRIERS

category	sub-category	height (ft)	length (mi)	material	mesh size	design features	animal class	animal size	species	comments/recommendations	citation
fencing and other barriers	directional					should be designed to funnel to crossing	ungulate	large	deer		Putnum, R.J. (1997)
fencing and other barriers	directional					trenches			amphibians	used in europe to direct amphibians into culverts	Bank, F.G. et al (2002)
fencing and other barriers	directional					double pipe method where a trench directs amphibians into a drop inlet and into a pipe leading to other side	herptile	small	amphibians	reported to be more effective than a single pipe where they can move either way	Bank, F.G. et al (2002)
fencing and other barriers	directional							large		found tracks following a great distance parallel to the fence leading to the culvert	Ascensao, F. et al (2007)
fencing and other barriers	directional			mesh barrier fencing	0.625"		general	small	reptiles, amphibians, mammals	will funnel animals to crossing	Massachusetts: Lars Carlson, 617-994-4354
fencing and other barriers	directional		1	wire fencing			herptile	small	turtles	installed along the road to channel the turtles	New Jersey, Sussex county: Robert Bird, NJDOT, 609-530-4239
fencing and other barriers	ends	8				use of wing pattern at end of fencing with suggested length of 150 ft				Fencing should not end in a habitat that is good for wildlife	Hardy, A.R. et al (2006)
fencing and other barriers	ends	8				end at natural deterrents like bridges or steep grades.				Fencing should not end in a habitat that is good for wildlife	Hardy, A.R. et al (2006)
fencing and other barriers	ends					extend a far length	ungulate	large	deer	to deter "end-running"	Putnum, R.J. (1997)
fencing and other barriers	ends					need angling, or use electric fence or cobblestone				to deter crossing at these points	Hardy, A.R. et al (2006), wildlife crossing toolkit
fencing and other barriers	ends					directing away from the highway or toward a natural barrier				is effective at the fence ends to reduce collisions	Ehinger, W. et al (2006), Clevenger, A.P. et al (2002)
fencing and other barriers	ends					mesh or cattle guards may be effective	ungulate	large		but small mammals can slip through and become trapped	Hardy, A. et al (2006), Iuell, B. et al (2003)

category	sub-category	height (ft)	length (mi)	material	mesh size	design features	animal class	animal size	species	comments/recommendations	citation
fencing and other barriers	ends					fencing should extend past the point of suitable habitat				to discourage end running	Carr, T. et al (2003)
fencing and other barriers	ends					improved highway lighting, lower speed zones, signs				have been effective in preventing collisions at fence ends, along with a turnaround style fence	Ehinger, W. et al (2006), Clevenger, A.P. et al (2002)
fencing and other barriers	escape mechanisms					employ one-way gates	ungulate	large	deer	for animals stuck on roadway	Putnum, R.J. (1997)
fencing and other barriers	escape mechanisms					breaks or ramps in curbs	herptile	small	amphibians	allow amphibians to exit roadway	Bank, F.G. et al (2002)
fencing and other barriers	escape mechanisms	8				one-way gates	general	large		necessary when tall fences are used along a highway	Reed, D.F. et al (1974)
fencing and other barriers	escape mechanisms					e.g., ramps on the side of the road				should be included for stream culverts	Bates, K. (2003)
fencing and other barriers	escape mechanisms									should be included in any fencing structure	Carr, T. et al (2003)
fencing and other barriers	escape mechanisms					one way gates placed within fenced stretches of roadway			large mammals, deer	to give escape to animals stuck on roadway, need to keep maintained or could become stuck open	Brown, D.L. et al (1999) , Bank, F.G. et al (2002)
fencing and other barriers	escape mechanisms					earthen ramps				allow access over the fence to animals trapped on ROW	Bank, F.G. et al (2002)
fencing and other barriers	escape mechanisms					sloped ramps that stretch from roadway to top of fence, most effective when placed at v-shaped funnels in fence	mammal	large	deer and others	with vegetation cover, have been shown to be 8-11 times more effective than one-way gates for ungulates, quoted cost in 2006- $6,000 per ramp	Hardy, A.R. et al (2006), Bissonette, J.A. et al (2000), Ehinger, W. et al (2006)
fencing and other barriers	fence	6, at least								recommended height	Bond, M. (2003)
fencing and other barriers	fence	7.2 to 7.9					ungulate	large	deer	have been shown to prevent jumping	Hardy, A.R. et al (2006), Iuell, B. et al (2003), Wildlife Crossing Toolkit

category	sub-category	height (ft)	length (mi)	material	mesh size	design features	animal class	animal size	species	comments/recommendations	citation
fencing and other barriers	fence	7.87				buried with a 4.92 ft apron extending into the ground at a 45 degree angle					Clevenger, A.P. et al (2002)
fencing and other barriers	fence	7.87	6.7			used along with underpass	ungulate	large	deer	Decreased road kills from 40-60 to almost 0.	Hardy, A.R. et al (2006), Ward, A.L. (1982)
fencing and other barriers	fence	8			wire strands 6" to 8" apart	vertical stays every 12" and at least 12.5 wire gauge twisted or tied, t-posts with 3" well piping every 100 ft	ungulate	large	deer/elk		Brown, D.L. (1999)
fencing and other barriers	fence	8, at least					ungulate	large	deer		Carr, T. (2003)
fencing and other barriers	fence	8.2	0.31			should flank each structure	general	large	bear and other wildlife		McCown, W. (2004)
fencing and other barriers	fence	8.53 to 9.19					ungulate	large	red deer, roe deer and moose	european structures use this size	Bank, F.G. et al (2002)
fencing and other barriers	fence	10 to 12		high tensile wire with wooden or metal post		need to be buried for some species	general	large	deer, elk, bear, mt. lion, coyote, bobcat, rabbit, marten, badger	needed for large and med animals	Ehinger, W. et al (2006), Falk N.W. et al (1978), Clevenger, A.P. et al (2001), Groot Bruinderink, G.W.T.A., et al (1996)
fencing and other barriers	fence					should be installed on the outside of the poles				keeps larger animals from separating it from the poles	Bank, F.G. et al (2002)
fencing and other barriers	fence									fencing will need maintenance	Ehinger, W. et al (2006)
fencing and other barriers	fence					aesthetics				to minimize visual impacts of fencing place fences outside of the visual corridor, when in visual corridor, construct out of painted materials matching landscape, use small fences posts, and plant small shrubs and other vegetation.	Ehinger, W. et al (2006)

category	sub-category	height (ft)	length (mi)	material	mesh size	design features	animal class	animal size	species	comments/recommendations	citation
fencing and other barriers	fence			metal		using metal post instead of wood	carnivore	large	bear	may keep animals from climbing	Hardy, A.R. et al (2006)
fencing and other barriers	fence	8		woven wire or chain link			mammal	large	mt. lion, bear, deer, coyote, wolf, elk, bobcat		Bates, K. (2003)
fencing and other barriers	fence	3 to 6					mammal	small-medium	javelina, skunk, raccoon, fox, rabbit		Bates, K. (2003)
fencing and other barriers	gaps	8				use cattle grates				if driveways or roads are within fencing limits.	Hardy, A.R. et al (2006)
fencing and other barriers	gaps					riprap and cattle guards				although cattle guards are not effective for all species	Ehinger W. et al (2006), Clevenger, A.P. et al (2002)
fencing and other barriers	gaps					cattle guard	ungulate	large	deer	10ftx12ft sufficient to deter deer	Reed, D.F. et al (1974)
fencing and other barriers	gaps					fencing should be tied to stream culvert, tops bend in				to elimiinate gaps	Bates, K. (2003)
fencing and other barriers	over/under					mesh should be buried from 20 to 40cm				prevents digging under fence	Bank, F.G. et al (2002)
fencing and other barriers	over/under					90 degree lip or outrigger	carnivore	large	bear/cougar	may prevent fence climbing	Clevenger, A.P. et al (2001)
fencing and other barriers	over/under					bury bottom or have flush with ground				to keep animals from crawling under	Clevenger, A.P. et al (2001)
fencing and other barriers	over/under					fine mesh on bottom	general		bear/small mammals	may prevent climbing or small animals from penetrating	Hardy, A.R. et al(2006)
fencing and other barriers	over/under					bury fence several feet	carnivore	med	coyotes, badgers	so animals cannot dig	Carr, T. et al (2003)

category	sub-category	height (ft)	length (mi)	material	mesh size	design features	animal class	animal size	species	comments/recommendations	citation
fencing and other barriers	over/under			barb wire		add strands to top of fence				to keep animals from climbing	Carr, T. et al (2003)
fencing and other barriers	over/under			wood		placed on top of deer fencing	ungulate	large	deer	less fatalities because they can judge height better	Wyoming, WYO 135: Rod Vaughn, WDOT, 307-772-2004
fencing and other barriers	over/under	2				welded wire installed onto bottom of ROW fence	herptile	small	desert tortoises	has reduced deaths by 75%	Arizona, Tohono Reservation: Bruce Eilerts, ADOT, 602-712-7398
fencing and other barriers	over/under					wide mesh fencing	carnivore	large	bear	will climb	Clevenger, A.P. et al (2001)
fencing and other barriers	small animal barrier	3.281		concrete		wall	herptile	small	turtles	smooth, vertical surface with overhanging, inward lip and turned back ends	Aresco, M.J. (2003)
fencing and other barriers	small animal barrier				0.78" to 1.57"	placed on the bottom half or third				european fencing usually has this size mesh	Bank, F.G. et al (2002)
fencing and other barriers	small animal barrier			concrete		low wall with lip or mesh	herptile	small	amphibians/ reptiles	will stop movement	Hardy, A. R. et al (2006), Griffin and Pletscher (2006), Iuell et al (2003), Evink (2002), Carr T et
fencing and other barriers	small animal barrier					mesh screens over drainage inlets	herptile	small	amphibians	to keep amphibians out of pipes	Bank, F.G. et al (2002)
fencing and other barriers	small animal barrier	3		heavy guage pony wire		placed in a 1ft deep trench with rebar-stick post weaved into the wire then attached to existing ROW fencing	herptile	small	stinkpots, red-eared slider, ornate boxes	not a single turtle death since installation, fence is located halfway up embankment leaving plenty of nesting space	Arkansas, Rixey Bayou: John Fleming, State Highway and Transportation Dept., 501-569-2522
fencing and other barriers	small animal barrier	0.5		2"x8" composite plastic boards		inserted into trench leaving only 6" exposed. The boards were laid in a "V" pattern with each arm being 30 ft long.	herptile	small	boreal toads	few toad carcasses have been noted and more egg masses behind barrier. Chemically treated wood could not be used because copper and arsenic would leach into ground water poisoning frogs and eggs	Colorado, SH 40: Jeff Peterson, CDOT, 303-512-4959

category	sub-category	height (ft)	length (mi)	material	mesh size	design features	animal class	animal size	species	comments/recommendations	citation
fencing and other barriers	small animal barrier	3		chain-link		12" buried into ground, at the edge of the ROW. A "turnaround" was constructed by adding a 90 degree angle corner attached to a second 45 degree angle corner	herptile	small	gopher tortoise	this road is frequently monitored and not a single gopher tortoise casualty has been recorded	Mississippi, SR 63 Bypass: Chuck Walter, MDOT, 601-544-6511
fencing and other barriers	small animal barrier			guardrail		placed angling toward a pipe culvert and staked down with rebar	herptile	small	salamanders, frogs, toads		New York, Labrador Hollow: Timothy Baker, NYDOT, 315-448-7366
fencing and other barriers	small animal barrier		0.265	wood		barrier of 2" x 8" lumber and sign posts was constructed	herptile	small	turtles	to funnel turtles into existing culverts; nesting habitat was constructed on adjacent land	New York, Rt. 21: Mary Papin, NYDOT, 585-272-3407
fencing and other barriers	small animal barrier				0.125"	"hardware cloth" was attached to the ROW fencing with 12" of wire below the ground	general	small		animals cannot burrow underneath or puncture the fabric. No road kill reported on bypass since installation	Iowa, Eddyville Bypass (US 63): Ron Ridnour, IDOT, 515-239-1613
fencing and other barriers	small animal barrier			plastic	0.157" or less		herptile	small	amphibians	buried 20-24" with top of fence angled down and ends turned back with no gaps; no vegetation on fencing	Puky, M. (2003), Jackson, S. (1996), Brehm, K. (1989)
fencing and other barriers	small animal barrier	3 to 4		strong mesh					squirrels, prairie dogs, rats, voles, mice		Bates, K. (2003)
fencing and other barriers	small animal barrier	1.5 to 2.5		galvanized tin, aluminum flashing, plastic, vinyl, concrete or fine mesh		includes 6" overhanging lip	herptile	small	frogs, toads, salamanders, turtles, lizard, snakes, tortoises		Bates, K. (2003)
fencing and other barriers	small animal barrier		2.1	wall		an extended wall was added with a lip	general	small-medium		keeps species from climbing the wall and many larger species walk down it to the culvert instead of crossing the road	Florida, US 441: Pete Southhall, FDOT, 386-961-7470

category	sub-category	height (ft)	length (mi)	material	mesh size	design features	animal class	animal size	species	comments/recommendations	citation
fencing and other barriers	small animal barrier	3.6		concrete wall		6" overhanging lip	general	small-large	snakes, turtles, alligators, small-medium mammals	on both sides of road 29.5 - 36 ft from roadway; greatly decreased mortality especially for larger species	Dodd Jr, K.C. (2004)
fencing and other barriers						3.281 ft offset between concrete barriers				a decrease in road kill has been noted	California, Bruce April, COT, 691-688-0107

SECTION 3:

APPROACHES AND TRANSITION ZONES

category	sub-category	approach length (ft)	approach slope	drainage	cover type	denseness of cover	animal class	animal size	species	comments/ recommendations	citation
approaches/ transition zones	berms/slopes		use vertical walls, not fill slopes							to prevent loss of habitat at places of elevated highway	Ehinger, W. et al (2006)
approaches/ transition zones	cover				vegetation		ungulate	large	deer/elk	palatable veg. and salting station leading down to crossing; plant undesirable species near road	Brown, D.L. et al (1999), Bank, F.G. et al (2002)
approaches/ transition zones	cover				natural surfaces, rocks, vegetation, woody material, debris piles					used at European over/under passes	Carr, T. et al (2003), Bank, F.G. (2002)
approaches/ transition zones	cover				vegetation					use same as surrounding habitat	Smith, D. (2003)
approaches/ transition zones	cover				herbaceous vegetation		general	small	mammals and herptiles	all animals preferred presence of; veg, height was a significant factor to improve cover from predators	Smith, D. (2003)
approaches/ transition zones	cover					dense				recommended: maximize habitat cover at entrances	Ehinger, W. et al (2006)
approaches/ transition zones	cover				vegetation	dense	ungulate	large	deer	more readily use underpasses with entrances and exits secluded with vegetation	Ulbrich, P. (1984) and Putman, R.J. (1997)
approaches/ transition zones	cover				vegetation	open	ungulate	large	moose	removal of vegetation on either side of a railway decreased deaths by 56%	Jaren, V. et al (1991)
approaches/ transition zones	cover				vegetation	open	ungulate	large	deer	vegetation away from roads reduces accident rates by keeping deer away from road and increase driver visibility	Putman, R.J. (1997) and Waring, G.H. et al (1991)

category	sub-category	approach length (ft)	approach slope	drainage	cover type	denseness of cover	animal class	animal size	species	comments/ recommendations	citation
approaches/ transition zones	cover				vegetation, logs, stumps		mammal	small-medium	genets, weasels, hedgehogs, carnivores and other mammals	vegetation at culvert entrances seemed to promote crossing rate	Ascensao, F. et al (2007), Rodriguez, A. et al (1996), Mata, C. et al (2005), McDonald, W. et al (2004), Brudin III, C. et al (2003), Bond, M. (2003), Smith, D. (2003)
approaches/ transition zones	cover				vegetation				birds, butterflies, fox squirrel, deer, etc.	established high maintenance, transitional and natural zones for their mowing schedule, natural areas are never mowed; has increased wildlife use on more than 30,000 acres within the state.	Arkansas, statewide: Phillip Moore, State Highway and Transportation Dept., 501-569-2281
approaches/ transition zones	cover					open	mammal	small-medium	badgers, foxes, lagomorphs	prefer more clear passages	Ascensao, F. et al (2007)
approaches/ transition zones	cover				vegetation		ungulate	large	deer	in corridor - planted palatable vegetation (*Melilotus officinalis* and *Medicago lupulina*); on roadside - removed palatable vegetation and replaced with non-palatable	Brudin III, C. et al (2003), Ehinger, W. et al (2006), Bank, F.G. et al (2002)
approaches/ transition zones	cover					open	mammal	small		open roadside habitat has been shown to be important for movement	Clevenger, A.P. et al (2001)
approaches/ transition zones	cover				vegetation		ungulate	large	deer	thorny plants, no mast carrying trees along the roadside to deter deer, cover and permanent opening to forest area should be as far as possible from the road	Groot Bruinderink, G.W.T.A. et al (1996)

category	sub-category	approach length (ft)	approach slope	drainage	cover type	denseness of cover	animal class	animal size	species	comments/ recommendations	citation
approaches/ transition zones	cover				coarse woody debris and legacy structures		general	small	invertebrates, amphibians, reptiles, mammals	things such as large logs, root wads and rocks	Ehinger, W. et al (2006)
approaches/ transition zones	cover				vegetation		mammal	small	squirrels, prairie dogs, rats, voles, mice	provide low stature natural veg. at entrance and approach	Bates, K. (2003)
approaches/ transition zones	distance to habitat						mammal	small		distance from structure determined use, structures need to be close	McDonald, W. (2004)
approaches/ transition zones	distance to habitat	12 to 16.4								recommended from adjacent habitat to structure	Smith, D. (2003)
approaches/ transition zones	distance to habitat									use minimal clearing widths	Ehinger, W. et al (2006)
approaches/ transition zones	habitat quality				vegetation		general	large	bear and other wildlife	an 820-1640 ft wide forest strip leading to each structure should remain uncut	McCown, W. (2004)
approaches/ transition zones	habitat quality				vegetation	dense				recommended to restore vegetation along riparian zones leading to entrance, provide cover to shield entrance but still allow habitat on other side to be visible	Hardy, A. (2006)
approaches/ transition zones	habitat quality				presence of water feature		ungulate	large		water accumulation near the roadway, e.g., ditches can be an attractant for some species, esp. ungulates	Groot Bruinderink, G.W.T.A. et al (1996)
approaches/ transition zones	substrate				organic litter		macro-invertebrate			increasing near and within crossing structures may increase usage	Ehinger, W. et al (2006)

category	sub-category	approach length (ft)	approach slope	drainage	cover type	denseness of cover	animal class	animal size	species	comments/ recommendations	citation
approaches/ transition zones	substrate				organic matter		general	small	invertebrates, amphibians, reptiles, mammals	addition of organic matter to soil, improves decomposer habitat, moisture retention through dry periods	Ehinger, W. et al (2006)
approaches/ transition zones	substrate						herptile	small	frogs, toads, salamanders, turtles, lizard, snakes, tortoises	low natural material	Bates, K. (2003)
approaches/ transition zones	wildlife trails									cut trails leading to the crossing, and add bait such as salt licks along them	Ehinger, W. et al (2006)

SECTION 4:

ANIMALS

category	sub-category	design issue	animal class	animal size	species	comments/recommendations	citation
animals	behavior	escape	mammal	small		will crawl under fence gaps	Clevenger, A.P. et al (2001)
animals	behavior	escape	ungulate			will jump over sagging fence, push through opening or crawl under gaps as little as 9 inches high	Hardy, A. et al (2006), Falk, N.W. et al (1978)
animals	behavior	human and domestic disturbance	ungulate	large	deer	shy of human disturbance so don't like open areas during daylight. Most road crossing in open areas happens at night with peaks at dawn and dusk with movement to and away from feeding. In well-wooded areas crossing is both day and night.	Putman, R.J. (1997)
animals	behavior	predation	general			studies not indicating predators using crossings to trap prey, perhaps there are just chance encounters but not generally a pattern.	Forman, R.T.T. et al (2003), Little, S.J. et al (2002)
animals	cover	vegetation	carnivore	small	weasels	preferred vegetative cover at openings	Clevenger, A.P. et al (2001)
animals	cover	vegetation	mammal	small-medium	lagomorphs, badgers, foxes, dogs	prefer more open land cover areas	Ascensao, F. et al (2007)
animals	cover	vegetation	ungulate	large	deer	More readily use underpasses with entrances and exits secluded by vegetation. Can take from 6 months to 3 years to become accustomed to using.	Olbrich, P. (1984) in Putman, R.J. (1997)
animals	environmental	light and moisture	herptile	small	amphibians	maintaining light and moisture levels similar to surrounding habitat may increase crossing effectiveness	Carr, T. et al (2003)
animals	environmental	light and temperature	herptile	small	reptiles	preferred intermediate passages in which they moved between sun-warmed and shaded surfaces	Rodriguez, A. et al (1996)
animals	environmental	moisture	herptile	small	amphibians	observed using structures during rain	Ascensao, F. et al (2007)
animals	environmental	moisture and temperature	herptile	small		culvert material can create conditions that direct what species use them. the metal or concrete may keep cool and wet attracting water reptiles and amphibians although some prefer dry conditions	Mata, C. et al (2005), Foresman, K.R. (2004), McDonald, W. et al (2004), Barnum, S.A. (2003), Servheen, C. et al (2003), Rodriguez, A. et al (1997)
animals	environmental	moisture and temperature	herptile	small	amphibians	prefer moist conditions, culverts instead of open underpasses, avoid dry passages and sudden temp	Hardy et al (2006), Mata et al (2005), Clevenger and Waltho (1999)
animals	environmental	noise	carnivore	medium	coyotes	increase in noise was deterrent to crossing use	Clevenger, A.P. et al (2001)
animals	environmental	noise	general		general	traffic noise can deter the use of crossing structure	Clevenger, A.P. et al (2005), Evink, G.
animals	environmental	noise	mammal	small	snowshoe hare, red squirrel	increased noise and road width are deterrents	Clevenger, A.P. et al (2001)
animals	environmental	noise and lights	general		general	design to minimize intensity of noise and light from traffic	Ehinger, W. et al (2006)
animals	environmental	noise, vibration	invertebrate	small		very sensitive to road noise	Hagood, S. (2002)
animals	home range	area requirements	carnivore	large	black bear	avg. male home range in ONF- 94.3km^2, female- 20.48km^2	McCown, W. (2004)

category	sub-category	design issue	animal class	animal size	species	comments/recommendations	citation
animals	home range	structure spacing	carnivore	large	black bear	male home range 5.4 km radius, in a 9.3 km stretch of road, 2 structures would be adequate	McCown, W. (2004)
animals	road design	geometry	carnivore	large	black bear	Road strikes against bears happened more often at low elevations, also the higher degree of curvature the higher the mortality rate	McCown, W. (2004)
animals	road design	width	carnivore	medium	coyotes	increase in road width was deterrent to crossing use	Clevenger, A.P. et al (2001)
animals	structure preferences	openness	carnivore	small	martens	preferred crossings with low clearance and high openness ratios	Clevenger, A.P. et al (2001)
animals	structure preferences	openness	carnivore	small	weasels	had pos. correlation with height, neg. with openness	Clevenger, A.P. et al (2001)
animals	structure preferences	openness	carnivore	medium	otters	recommended crossing is a continuous, natural bank above the high flow level using either widespan bridges,	Philcox, C.K. et al (1999)
animals	structure preferences	openness	carnivore	large	black bear	no preference between over and underpasses	Hardy, A.R. et al (2006), Clevenger, A.P. et al (2002)
animals	structure preferences	openness	carnivore	large	bear and cougars	prefer constricted structures (long, narrow with low openness ratio), maybe due to species requirements for	Clevenger, A.P. et al (2005)
animals	structure preferences	openness	carnivore	medium	bobcats and coyotes	used a variety of sizes from large spanning bridges to smaller pipe culverts	Ng, S.J. et al (2004)
animals	structure preferences	openness	carnivore	large	cougars	prefer underpasses	Knapp, K.K. (2004), Forman, R.T.T. et al (2003), Gloyne, C.C. et al (2001)
animals	structure preferences	openness	general			smaller species generally like smaller passages, larger species larger passages	Mata, C. et al (2005)
animals	structure preferences	openness	general	small	small carnivores, small mammals, amphibians, reptiles	prefer narrow openings/smaller structures	Mata,C. et al (2005), Foresman, K.R. (2004), Clevenger, A.P. et al (1999), McDonald, W. et al (2004), Rodriguez, A. (1996)
animals	structure preferences	openness	general	small	reptiles, lagomorphs and small mammals	prefer shorter passages, avoid long passages	Ascensao, F. et al (2007), Yanes, M. et al (1995), Rodriguez, A. et al. (1996), McDonald, W. (2004), Mata, C. et al (2005)
animals	structure preferences	openness	mammal		ungulate and carnivore	structural openness and closeness to town were the 1st and 2nd most significant variables of crossings in Banff	Knapp, K.K. et al (2004), Clevenger, A.P. (2000)
animals	structure preferences	openness	mammal	small-large	American marten, weasel, hare, red squirrel, deer mice, voles	prefer small culverts with low openness ratios because predation rate may be higher in large tunnels.	Clevenger, A.P. et al (2002) and (2001)

category	sub-category	design issue	animal class	animal size	species	comments/recommendations	citation
animals	structure preferences	openness	mammal	small-large	lagomorphs, red foxes and large canids	prefer large over and under passes	Mata, C. et al (2005)
animals	structure preferences	openness	mammal	large	deer, wild boar and wolves	prefer large over and under passes	Mata, C. et al (2005)
animals	structure preferences	openness	ungulate	large	deer	prefer over but will use under	Clevenger, A.P. et al (2002), Hardy, A. et al (2006), Forman, R.T.T. et al (2003)
animals	structure preferences	openness	ungulate	large	deer	overpass use was less than underpass use	Putman, R.J. (1997)
animals	structure preferences	openness	ungulate			prefer open area structures (short, high and wide)	Clevenger, A.P. et al (2005)
animals	structure preferences	sight line	carnivore	small	weasels	through culvert visibility was not important	Clevenger, A.P. et al (2001)
animals	structure preferences	sight line	general			Overpasses and underpasses with a clear view of the habitat across the roadway are more readily used	Clevenger, A.P. et al (2002)
animals	structure preferences	sight line	mammal	small	snow-shoe hares	through culvert visibility is important	Clevenger, A.P. et al (2001)
animals	structure preferences	sight line	mammal		lagomorphs and carnivores	inhibited by low visibility	Clevenger, A.P. et al (2002) and (2001)
animals	structure preferences	sight line	mammal	large	mt. lion, bear, deer, coyote, wolf, elk, bobcat	need open field of view	Bates, K. (2003)
animals	structure preferences	substrate	general		general	overpasses with concrete floor not used much by wildlife	Putman, R.J. (1997)
animals	structure preferences	substrate	general	small	reptiles, lagomorphs and carnivores	detritus pits deterred reptile, rabbit and carnivores from using the crossings	Yanes, M. et al (1994)
animals	structure preferences	substrate	ungulate	large	deer	prefer earth floors to concrete floors	Putman, R.J. (1997)
animals	tolerance	human and domestic disturbance	carnivore			crossing use strongly related to distance to nearest major drainage, although human act. still more of a factor	Knapp, K.K. et al (2004), Clevenger AP (2000)
animals	tolerance	human and domestic disturbance	general		general	to maximize crossing use, human and domestic predator use must be minimized	Smith, D. (2003)
animals	tolerance	human and domestic disturbance	general		general	initially the structures dimensions are major crossing factor but as the structures get older human use becomes more important	Clevenger, A.P. et al (2002)

category	sub-category	design issue	animal class	animal size	species	comments/recommendations	citation
animals	tolerance	human and domestic disturbance	general		general	nearby human activity can significantly reduce crossing use	Knapp, K.K. et al (2004), Clevenger, A.P. et al (2000)
animals	tolerance	human and domestic disturbance	general		except deer	human use was a deterring factor in animal use whether it be distance to development or direct human use	Clevenger, A.P. et al (2000)

SECTION 5:

TRAFFIC

category	sub-category	# of lanes	traffic volume	noise levels	animal class	animal size	species	comments/recommendations	citations
traffic	noise				general		general	traffic noise can deter the use of crossing structure	Clevenger, A.P. et al (2005), Evink, G. (2002)
traffic	noise and lights				general		general	design to minimize intensity of noise and light from traffic	Ehinger, W. et al (2006)
traffic	siting of structure				general		esp. carnivores	incorporated culverts into their paths and movements regardless of traffic level.	Ascensao, F. et al (2007)
traffic	visual disturbance				mammal	small-large	mule deer, coyotes, mountain lion, bobcat, fox, American marten, rabbits and small mammals	Preferred to use high quality below-grade crossings instead of crossing at grade, when they had a choice.	Barnum, S.A. (2003)
traffic	volume				mammal	small	marten, snowshoe hare, red squirrel	passage increased with traffic volume	Clevenger, A.P. et al (2001)
traffic	volume				carnivore	medium	coyotes	increased traffic volume was deterrent to crossing use	Clevenger, A.P. et al (2001)

SECTION 6:

ALTERNATIVES

category	sub-category	animal class	animal size	species	comments/recommendations	citation
alternatives	at-grade crossings	ungulate	large	deer	general design- 7.5ft exclusionary fencing leading to opening, keeping a 3ft fence within the gap. Opening approx. 30ft from road. Within the 30ft was a dirt path and round cobblestones. On pavement crosswalk edged by cattleguards. mule deer death decreased by 37 - 42% but no statistical evidence that it works.	Knapp, K.K. (2004), Lehnert, M.E. (1997)
alternatives	chemical repellents	ungulate	large	deer	make a scent fence. Some studies find it effective, some do not.	Putman, R.J. (1997)
alternatives	chemical repellents				may help, but lots of maintenance to keep scent fresh	Bank, F.G. et al (2002)
alternatives	chemical repellents	ungulate	large	red, roe, sika deer, moufflon	research showed that scent fencing had no effect on these species	Groot Bruinderink, G.W.T.A. et al (1996)
alternatives	remote animal detection systems				thermal sensor triggers flashing sign when animal is present to warn motorists	Carr, T. et al (2003)
alternatives	remote animal detection systems				thermal sensor determines animal presence and reduces speed limit; used on a road in Switzerland and significantly decreased mortailty	Bank, F.G. et al (2002)
alternatives	remote animal detection systems	ungulate	large	deer	an infrared camera senses wildlife within a 1km range and triggers a sign alerting motorist, operational day and night; found to successful track wildlife, no habituation, is portable	Newhouse, N. (2003)
alternatives	roadside reflectors	ungulate	large	deer	visual barrier reflectors are better than flash mirrors because animals habituate to them. Visual barrier reflector creates a continuous barrier of light. Red and blue-green visual barrier types may be most effective. Studies on red reflectors have found to be effective in some studies and ineffective in others.	Putman, R.J. (1997), Bank, F.G. et al (2002)
alternatives	roadside reflectors	ungulate	large	white-tailed deer, mule deer, fallow, roe, red deer	use of 90 degree Swareflex reflectors did not have effect on number of road kills	Groot Bruinderink, G.W.T.A. et al (1996), Waring, G.H. et al (1991), Romin, L.A. et al (1992), Olbrich, P. (1984) in Putman, R.J. (1997)
alternatives	roadway lighting				did not show effectiveness in reducing mortality, had neg. impacts on nesting birds in Netherlands extending several meters from road	Bank, F.G. et al (2002)
alternatives	signs				standard signing not useful; pairing sign with speed limit sign or flashing lights seem to increase effectiveness	Bank, F.G. et al (2002)
alternatives	speed bumps				slows motorists to increase reaction time and avoid collisions	Carr, T. et al (2003), Bond, M. (2003)
alternatives	tall, mast lighting	volant	small	bats	Insects fly higher so bats fly higher keeping them out of traffic	Indiana, Lanesville Rest Area: Lyle Sadler, INDOT, 317-233-6972
alternatives	ultrasound				no evidence of mortality reduction	Bank, F.G. et al (2002)
alternatives	warning signs	ungulate	large	elk	Heightened awareness of crossing animals	Arizona, SR 260: Bruce Eilerts, ADOT, 602-712-7398, Bond M (2003)

SECTION 7:

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