Appendix C—Example Infrastructure Designs, Costs, and Schedules

There is extensive scientific literature on the effectiveness and economic benefits of various infrastructure designs as mitigation for wildlife vehicle collisions, including signs, lighting, visibility, animal detection systems, traffic controls, crossing guards, escape structures, undercrossings, overpasses, and fencing (e.g., Arizona Department of Transportation, Dodd et al. 2012, Forman et al. 2003, Gagnon et al. 2009, Huijser et al. 2008, 2009, Kintsch and Cramer 2011). Fencing combined with crossing structures are by far the most effective, reducing collisions of deer and carnivores by 80% or more in many cases. Funnel fencing, modifications to undercrossing approaches, and vegetation management and restoration can improve use of undercrossings that previously were used only marginally. Wildlife warning signs and reduced speed limits have not proven very effective in preventing wildlife vehicle collisions but could improve traffic safety.

Phased reconstruction along the highway will allow before-and-after comparisons of animal use and roadkill and adaptive management of the infrastructure plan; it will also allow animals to change their routes during construction. Moreover, long-term maintenance funding must be budgeted to ensure that the initial construction funding is cost-effective and that the function for wildlife linkage across the highway is not diminished with time.

Fencing

Caltrans, in coordination with CDFW and FWS, will determine type and location of fencing. In this document, we specify two types of fencing, both of which should be used to direct animals to crossing structures, and should consider landscape condition and topography as well as the home range size of the target species:

1. ROW fencing (funnel fencing, exclusion fencing, or “species protection fences,” Caltrans 2013b) should be impermeable to keep wildlife off the highway; fence height and design are specific to the target species (Table C-1, Figures C-1a,b). For example, there may be the need for extra reinforcements at the bottom (for small animals) and top (for mountain lions and deer) of the ROW fencing.

2. Secondary fencing between public and private land is a less costly alternative to discourage animals from entering private lands, and may be sufficient along some stretches of the highway.

While chain link fencing is often used for access control in developed areas, it is very expensive for use in large projects. In rural areas such as Jamul and Dulzura, fences can be metal, galvanized wire mesh on posts of either wood (more esthetically pleasing) or metal (more durable, probably 20-30 year life span). Wire mesh fencing should be placed on the side of the poles facing away from the road so that animals inside the fence are less likely to loosen the fence from the poles. Fencing should tie directly into crossing structures.

In specific areas where the topography is not suitable for culverts or undercrossings and where wildlife are likely to cross the road at-grade, wildlife escape structures should be built into the fence to allow animals that penetrate the fence to get off the road (Figures C-2a,b). These structures should be sited in the field, approximately 0.5 mi apart, depending on number and spacing of undercrossings, at locations to be determined by landscape features and additional wildlife movement monitoring.

1. For ROW fencing, use impermeable 8 ft high (height dependent on location, slope, and target species) mesh fence, with smaller mesh sizes or hardware cloth along the bottom where needed to prevent small mammals and herpetofauna from entering the highway and to block vehicle-generated sparks from entering habitat areas. Where deer and lions are not target species, fence heights can be lower (e.g., 6 ft).

2. In areas where mountain lions are a focal species (based on pre-construction monitoring), use a 3-5-strand barbed wire overhang to deter them from climbing the fence.

3. At the bottom of the ROW fence, secure a skirt of 18-24 inches of fence buried in a trench underground or extending from the base of the fence 20-36 inches and anchored to prevent wildlife digging.

4. A coyote roller is a free-rolling tube on bearings, attached to the top of a fence, so that the coyote can't get traction to climb over.

Table C-1—ROW fence design by target species (also see Figure C-1 and Attachment 1).

Structure	Lions	Deer	Medium	Small	Herps
Fence height[1]	10-12 ft	8-9 ft	3-4 ft	±1.3 ft	±1.3 ft
Mesh size	6x6 in.	6x6 in.	6x4 in.	0.5x0.5 in.	0.25x0.25 in.
Dig barrier[2]	2-3 ft	-	2 ft	2 ft	4-6 in.
Overhang	2-strand barbed wire	-	-	-	-
Short concrete wall	-	-	-	-	18-48 in.

[1] Height depends on slope; higher fences are required for places where animals approach the fence from above.

[2] Rolled hardware cloth

Source: compiled from Huijser et al. 2008

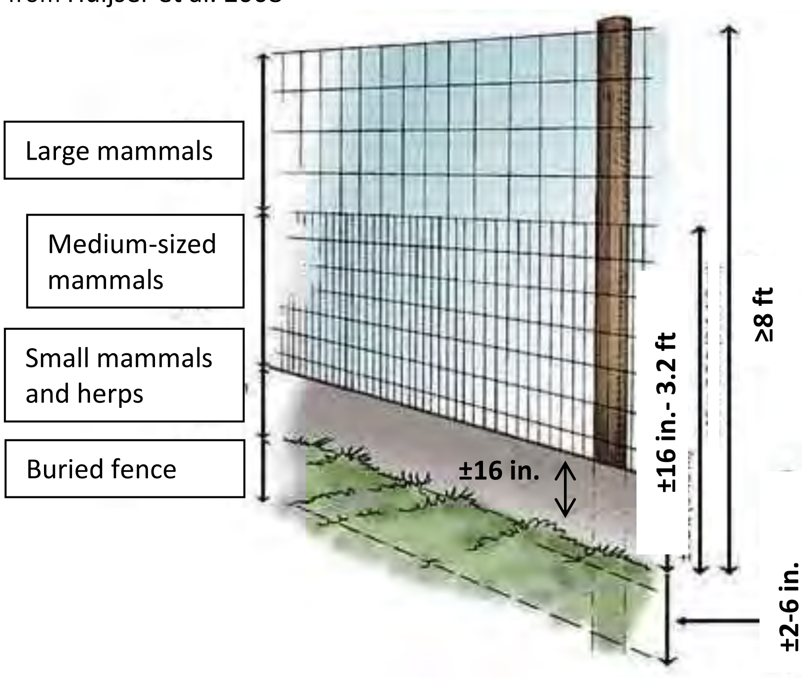


Figure C-1a—Schematic drawing of a large-mammal ROW fence in combination with smaller mesh and/or barriers at the bottom for smaller species (Source: Huijser et al. 2008, from Kruidering et al. 2005).

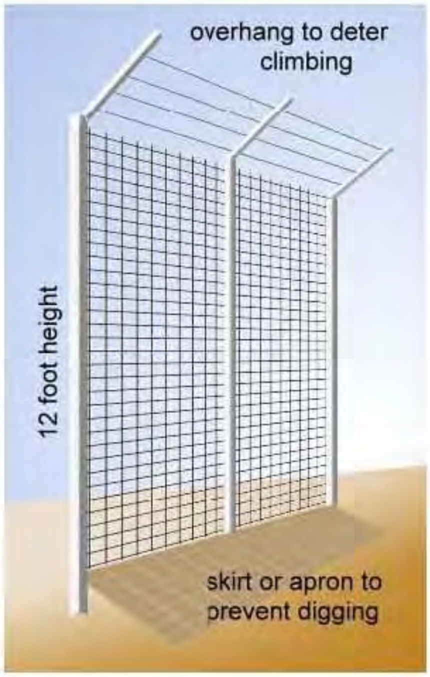


Figure C-1b—Example fence design to deter climbing (e.g., for mountain lions).
Source: Vickers and Huber 2012.

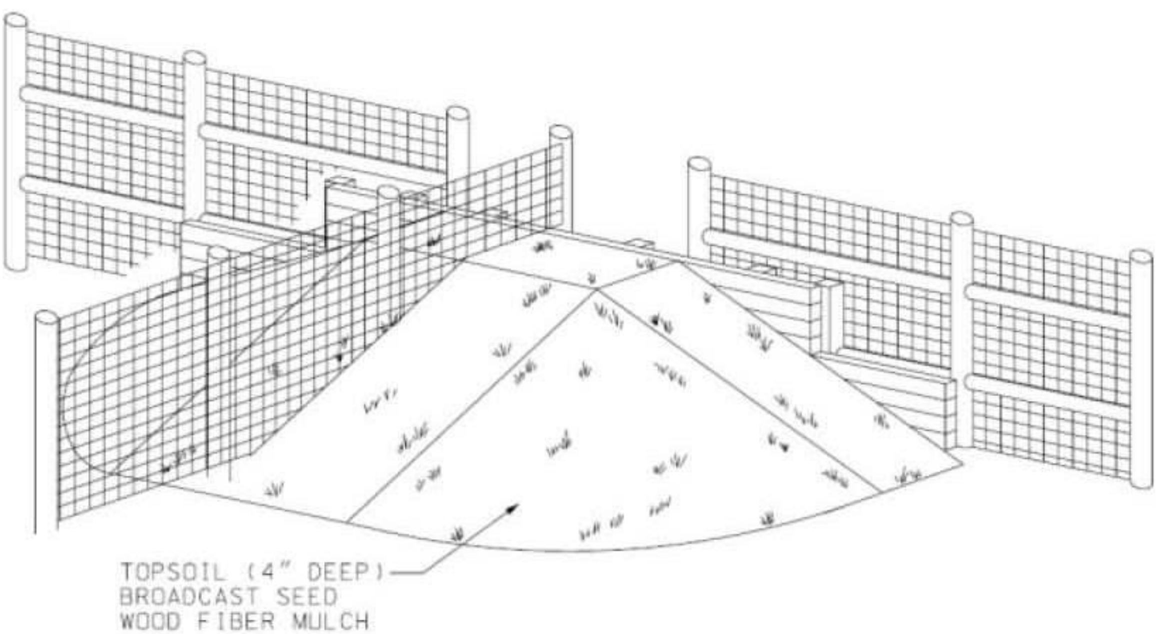


Figure C-2a—Example jump-out design for deer and other wildlife; consists of an earthen berm or ramp that slopes up from the highway, with a drop on the other side of the ROW fence.
Source: Caltrans 2007.

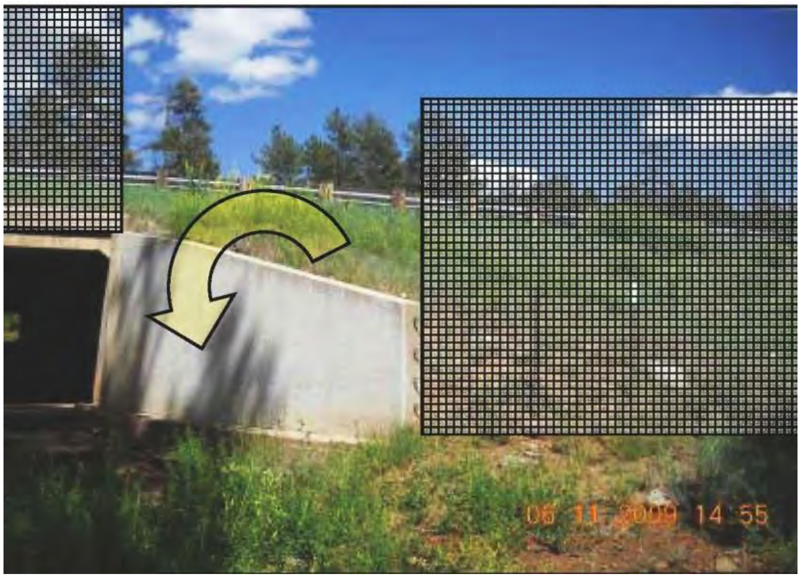


Figure C-2b—Lower cost escape structure. Source: AZDOT wildlife escape measures.

Undercrossings

Openness is important to achieving a high probability of successful crossings. The length of the crossings along SR-94 currently do not exceed 30 ft, thus minimizing the distance an animal has to travel and maximizing the visibility through the underpass; this increases the likelihood that animals can see the other side of the highway through the underpass. However, as Caltrans has plans to widen the highway in areas, the openness ratio of each undercrossing must be considered, as the length of the crossing corresponds to the width of the roadway (Caltrans 2007, 2009). Table C-2 provides examples of recommended dimensions for undercrossings designed for different species.

The openness ratio of an undercrossing is defined as a structure's (height x width)/length (the distance of an underpass perpendicular to the road). A large openness ratio (i.e., >0.75) provides more natural lighting and is recommended to allow an animal to see all the way through a crossing structure to the other side (e.g., Cain et al. 2003, Clevenger and Waltho 2005). In addition to the openness ratio, however, one must consider brightness, distance to safety from predators, traffic volume and noise, vegetation cover, and similarity to natural environmental conditions. Where undercrossings also support water flow, it is important to have a ledge or shelf that animals can use to stay above the water level (Figures C-3a—C-3d).

Dodd et al. (2007a) suggest that all bridges include natural 2:1 slopes approaching the undercrossing, to enhance openness, rather than rip-rap or other concrete material. If rip-rap is used, it should be covered with a material that animals can more easily traverse. Mitigate the vehicle noise impact on bridges or large box culverts by using rubberized asphalt or installing "Rhino Liner" type material on the underside of the bridge.

In drainages subject to high flows, a piece of woven wire can be placed across the channel, upstream from the culvert, to collect debris during floods so that the debris does not clog the culvert and impede movement.

Construction is typically a concrete bridge span, steel beam span, box culvert, or arch made of prefabricated concrete or corrugated steel, without a bottom or with a bottom covered by natural substrate >6 in. deep.

Table C-2—Types of undercrossings for target species (source: Huijser et al. 2008, AZDOT 2008).

Type	Example Dimensions	Walkway w/i Underpass[4]
Open-span vehicle bridge	40-45 ft wide X 12-17 ft high	7-10 ft wide
Large-mammal undercrossing (arched culvert)[1]	26 ft wide X 17 ft high	7-10 ft wide
Medium mammal undercrossing (box culvert)[2]	3-10 ft wide X 2-8 ft high	2-3 ft wide
Small animal pipe[3]	1-3 ft diameter	1-2 ft wide

[1] Large mammals = deer, lions; underpass is an arched culvert or box culverts; deer prefer overpasses but will use undercrossings with large cross-sectional areas and an openness ratio of ≥0.75 (height x width/length).

[2] Medium mammals = weasels, skunks, bobcats, fox, coyote, badger, jackrabbits.

[3] Small animals = cottontail rabbits, rodents, herpetofauna.

[4] Underpasses that also accommodate waterflow should include walkways for terrestrial species (see Figure D-3).

Figure C-3a—Bridge with channel that allows water to flow seasonally.
Source: M.Huijser et al. 2008.

Figure C-3b—Arched culvert with a ditch on left that allows water to flow seasonally.
Source: M.Huijser et al. 2008.

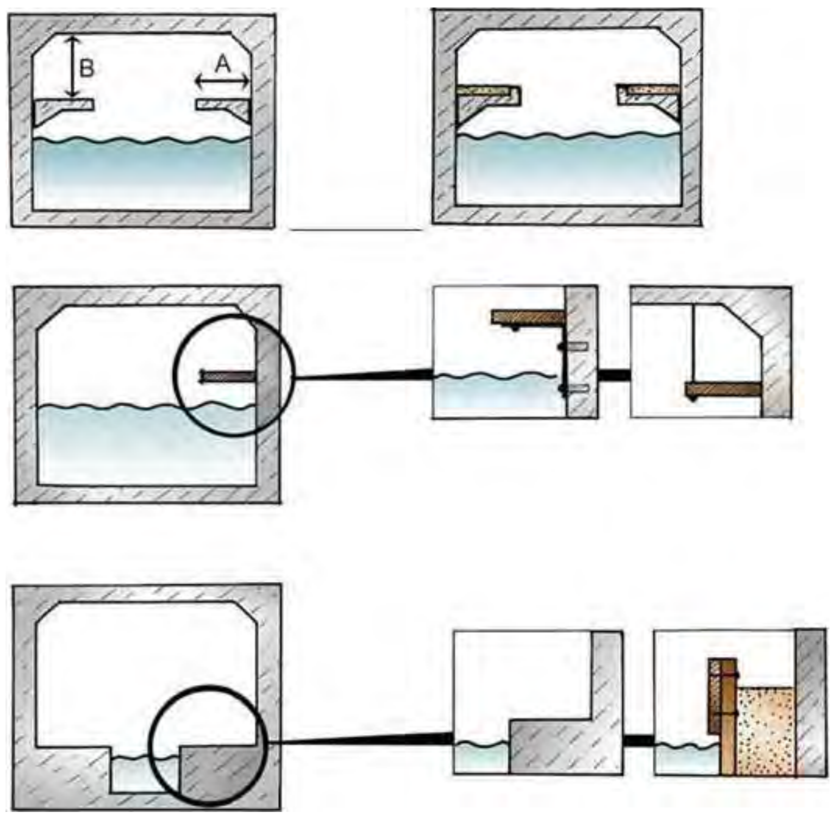


Figure C-3c—Walkway or "shelf" designs for small-and medium-sized mammals in box culverts.
Source: M.Huijser et al. 2008, from Kruidering et al. 2005.

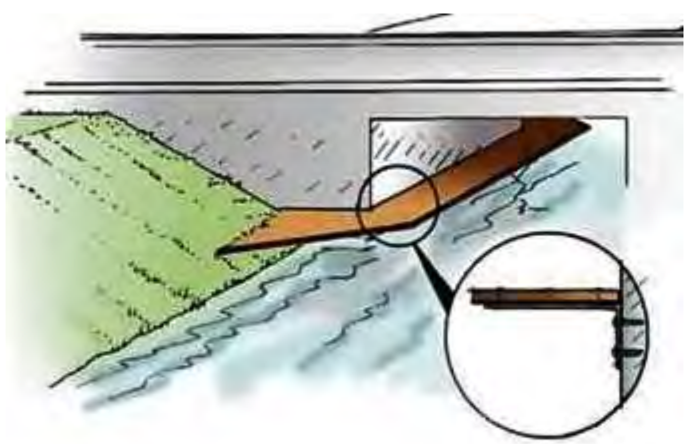


Figure C-3d—Connection of walkway to adjacent bank.
Source: M.Huijser et al. 2008, from Kruidering et al. 2005.

Pre-cast concrete or pre-formed metal structures are effective and typically less expensive (e.g., $110,000 in 1997) than bridges (Lotz et al. 1997). These modular structures can consist of a combination of cast in-place concrete footings, precast arch elements, headwalls, and/or wingwalls. They are designed for a specific site and can be used to span from 12-102 ft (BEBO Arch Systems), with minimal long-term maintenance. Corrugated pipes also are relatively inexpensive and easy to install. See examples Figure C-4 and http://www.conteches.com/products/bridges-and-structures/precast/bebo-bridge.aspx.

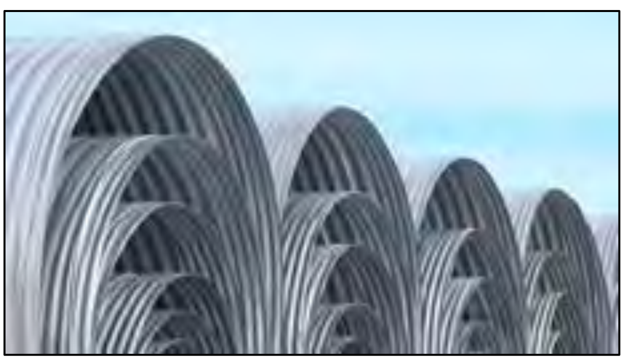


Figure C-4—Examples of pre-cast concrete and pre-formed metal structures.

Special Considerations for Amphibians and Reptiles

Like other species, amphibians and reptiles need light to see and pass through tunnels. But in addition, amphibians especially need moisture in their passages, so the tunnel should be open at top and fitted with an iron grate, to allow light, rain, and air to equilibrate ambient temperatures and moisture conditions. The tunnel should have a detritus and leafy substrate which is not prone to flooding (e.g., a wildlife "shelf") and situated at the base of the slope coming off the road grade (Tracey et al. 2014, http://www.aco-wildlife.com/home/).

Where larger culverts are also used as undercrossings for small mammals and herps, place rocks, log, natural debris, or pipes inside the culverts to provide cover (Figure C-7) (Tracey et al. 2014).

Drift fencing, or exclusion fencing, sunk into the ground 3-4 in. is needed to direct small animals toward the tunnels, and wing walls should angle out from each end of the tunnel at ~45° for 100-300 ft, more for larger animals (Figure C-8).

Figure C-7—Structural elements inside culverts to provide cover for small animals.
Source: Clevenger and Huijser 2011.

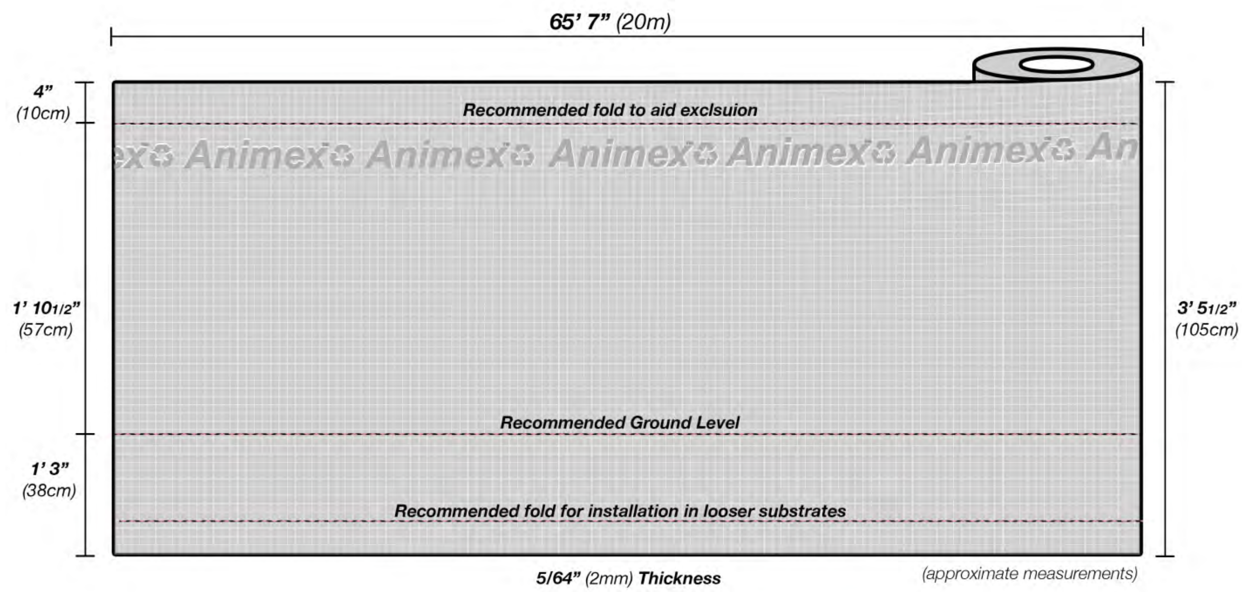


Figure C-8—Examples of small animal exclusion fencing (frogs, lizards, salamanders, toads, snakes, small mammals). Source: http://animexfencing.com/; Clevenger and Huijser 2011.

Overcrossing or Wildlife Overpass

Sight lines and widths are the most important considerations for effective overcrossing designs, with the ends of the structure being wider than the middle portion (Kintsch and Cramer 2011). Clevenger et al. (2002) recommend that the narrowest portion of the parabolic-shaped structure be 230 ft wide for a multiple-species overpass; however, existing overcrossings of some two-lane roads are <200 ft wide (Huijser et al. 2008). Some literature refers to landscape bridges that are wider (>330 ft) than wildlife overpasses, with a soil depth of 5-8 ft that is taken from adjacent habitat (Clevenger and Huijser 2011). Construction is typically a steel truss or concrete bridge span or pre-fabricated cast-in-place concrete arches or corrugated steel). The overpass should be exclusively for wildlife, with human use prohibited (see example Figure C-9).

Figure C-9—Example of overcrossing.
Source: www.bluevalleyranch.com

Example Infrastructure Costs and Schedule

Costs for wildlife infrastructure are site-specific and species-specific, depending on terrain, mobilization, size of the project (economies of scale), and types of equipment used (e.g., jack and bore vs cut and cover). Another cost consideration is maintaining traffic flow on an existing roadway during construction. Moreover, costs in the scientific literature are not comparable because of differences in target species, construction dates, and whether costs include labor for installation. Attachment 1 provides 3 years of costs for Caltrans projects statewide.

Fencing and Jumpouts

Costs for fencing depend on material and mesh size (for specific target species), terrain, height and depth below ground, as well as requirements to withstand high winds (Table C-3; see

Attachment 1). Costs for jump-outs vary widely, depending on structure. Jump-outs can be as simple as lowering the height of one section of fence.

Table C-3—Example costs for fencing and jump-outs.

Type	Material	Cost	Source
UNIT COSTS[1]			
Fence	8'Wire mesh (4")	\$100/LF[3]	Siepel 2015
Fence	"Ungulate-proof"	\$30/LF[3]	Nordhaugen 2009
Fence	Wire mesh	\$33/LF[3]	Caltrans 2013 District 11
Fence	Barbed wire	\$12/LF[3]	Caltrans 2013 District 11
Fence	Chain link	\$20-\$22/LF[3]	Caltrans 2012 District 11
Fence with posts	Wire mesh, metal post	\$45/LF[3]	Caltrans 2013 District 11
Gate (pedestrian)		\$3,000	Siepel 2015
Gate	4 ft chain link	\$756-\$1,238	Caltrans 2012, 2013 District 11
Gate	4 ft chain link, vinyl clad	\$2,000	Caltrans 2013 District 11
Gate	8 ft chain link	\$1,000-\$1,380	Caltrans 2012, 2013 District 11
Gate	10 ft chain link	\$850-\$880	Caltrans 2012, 2013 District 11
Jump-outs	Wildlife escape ramp	\$8,000	Siepel 2015
Wildlife guard	Electric mat	\$8,000	Siepel 2015
Wildlife guard	Metal guard	\$60,000-\$80,000	Siepel 2015
TOTAL COSTS[2]			
Fence, mountain lions	Hwy 241, Orange County	\$1 million/mile	W. Vickers, pers. comm.
Jump-outs	various	\$7,207-\$15,267[4]	Huijser et al. 2008
Jump-outs, ungulates and mountain lions	SR-77, Arizona Hwy 241, Orange County	\$40,000-\$50,000 each	Nordhaugen 2009, W. Vickers, pers. comm.

[1] Unit Costs for materials may vary based on quantity ordered, contractor, location, terrain, and type of equipment used for installation; does not include installation.
[2] Total Costs include installation.
[3] LF = linear foot
[4] Corrected by 15.3% inflation rate between 2008-2015 in San Diego County

Wildlife Crossings

Table C-4 provides some examples from the literature, wildlife crossing handbooks, Caltrans contracts across the state, and personal communication from scientists and engineers. Also see Attachment 1 for unit costs.

Table C-4—Example costs for undercrossings and overpasses. Add 15.3% due to inflation in San Diego County over the period 2007-2015.

Type	Material	Size	Cost[1]	Source
UNIT COSTS[1]				
Vehicle bridge, open span		40' x 16'	$10-12,000/ft	Caltrans 2007
Box culvert		12' x 16'	$36,632/linrst gy	Siepel 2015
Box culvert	Concrete	10' x 8'	$575/ft	Caltrans 2007
Box culvert	Class 1 concrete		$565-$1,380/cu m	Caltrans 2009
Box culvert	Class 2 concrete		$620-$3,630/cu m	Caltrans 2009
Concrete pipe	Reinforced concrete	7'	$650/linear ft	Caltrans 2013
Steel pipe	Corrugated steel	4'	$150/linear ft	Caltrans 2013
Elliptical culvert	Corrugated metal	23' x 13'	$1,100/ft	Caltrans 2007
Overpass		170' wide	$6,890/ft	Caltrans 2007
TOTAL COSTS[2]				
Arch culvert SR-91, Orange County			$8 million	Pers. comm. W. Vickers
Overpass, 101, Orange County			$25-50 million	Pers. comm. W. Vickers
Box culvert 13x13			$10-12 million	Pers. comm. W. Vickers
Undercrossing	Prefabricated concrete with head and wing walls	32' wide x 12' high x 190' long	$615,790	Nordhaugen 2009
Undercrossing	Prefabricated concrete	50' wide x 12' high x 190' long	$729,680	Nordhaugen 2009
Overpass	Prefabricated concrete	72' span x 26' rise	$2,622,500	Nordhaugen 2009
Tunnel, SR-91 Riverside County	Prefabricated concrete	12' x 37' arch	$4.9 million	L. Correa, WRCRCA pers. comm.
Bridge, SR-91, Riverside County	SR-91, Riverside County		$20 million	L. Correa, WRCRCA pers. comm.

[1] Unit Costs may vary based on quantity ordered, contractor, location, terrain, and type of equipment used for installation.
[2] Total Costs include labor for installation, but do not include design, engineering, mobilization, traffic control, erosion control, surveying and layout

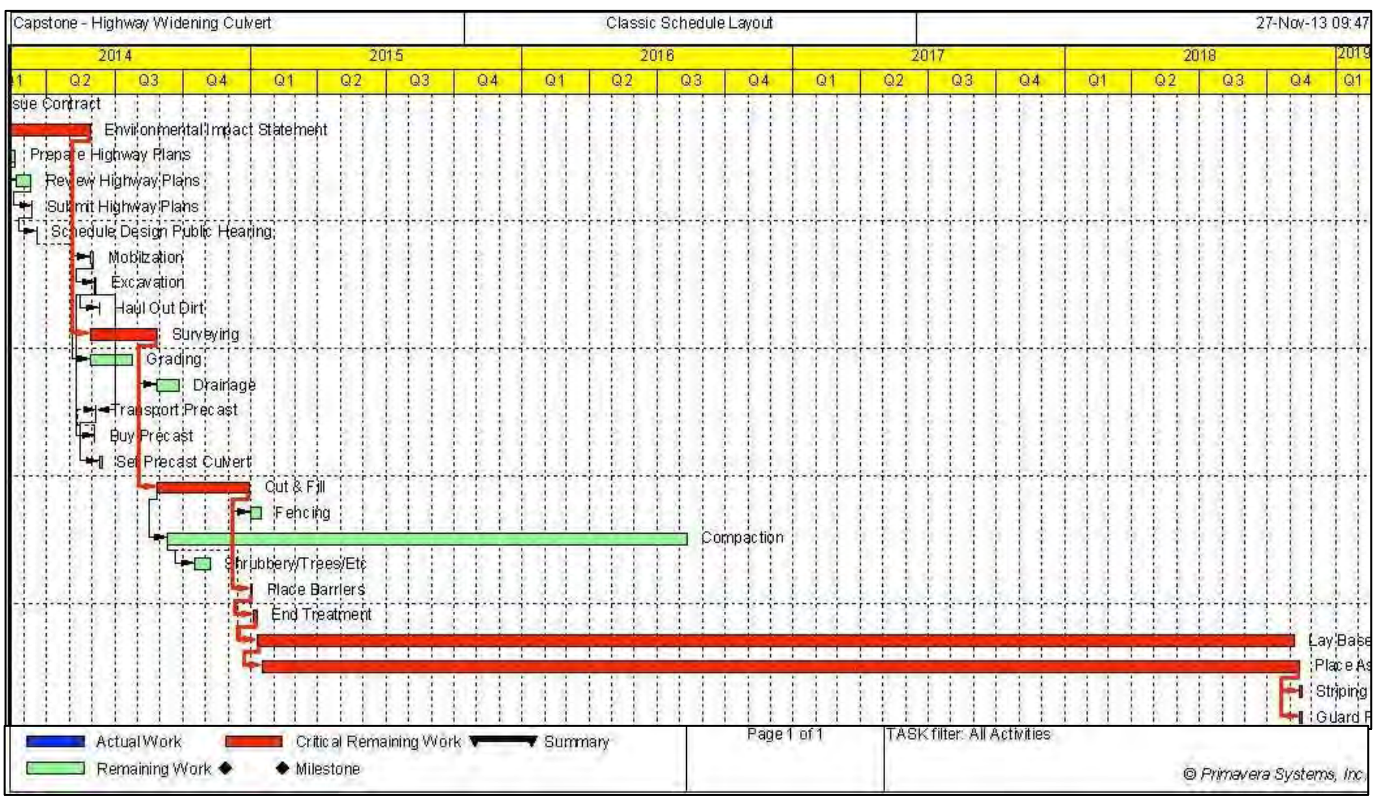
Box Culvert for Segment 3

San Diego State University engineering students designed a precast concrete box culvert with wing walls specifically for the location in Segment 3 (Map 3) at the bottom of the hill on the SR-94 curve that bisects the San Diego National Wildlife Refuge (see Appendix D). The 15x20 ft box culvert is intended to support large and small mammals, birds, and herpetofauna. The culvert has an openness ration of 1.20. The bottom of the culvert will be covered with soil from the area, and is designed to accommodate flow from a 100-year storm. The culvert is designed to extend underneath 4 lanes of highway (64 ft).

Table C-5—Approximate costs of Segment 3 box culvert (SIMBA Engineering 2013).

Item	Cost
Transportation: Traffic management, construction signs, excavation, aggregate base, asphalt	$2,370,330
Structural: Precast concrete box culvert	$100,000
Environmental: Fencing, planting erosion control	$1,181,968
Total Project	$3,752,298

Table C-6—Approximate construction schedule (SIMBA 2013).



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Attachment 1—Unit Cost Examples

http://www.dot.ca.gov/hq/esc/oe/awards/