Fish Friendly Waterway Culverts

WATERWAY MANAGEMENT PRACTICES

Photo 1 – Recessed box culvert

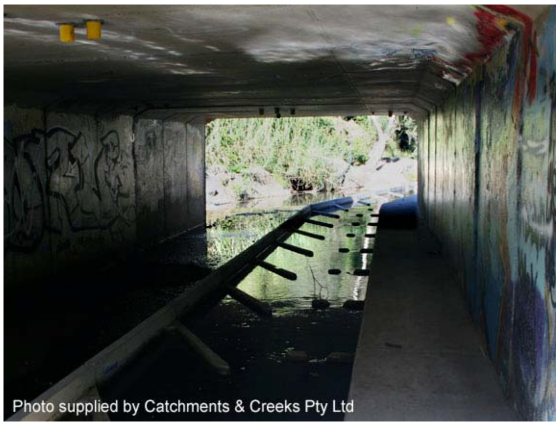

Photo 2 – Baffled fishway

1. Introduction

It is generally recommended that desirable fish passage conditions need to be provided within any waterway culvert located downstream of permanent or near-permanent waters; for example, waterways containing permanent pools, or near-permanent stream flows.

There are basically five different methodologies that exist for the design of waterway culverts. The preferred design method depends on a number of factors, some of which are summarised in Table 1. None of these design method should be considered absolute in their design specification because each culvert and stream will be different and therefore must be assessed on a case-by-case basis.

2. An overview of the five design methodologies

(i) No Slope Method

This design method is possibly best used only when designing single cell pipe culverts located within private property where it can be difficult for landowners to justify the cost of detailed engineering design. In this approach, culverts are placed with zero fall and countersunk below the channel bed a minimum of 20% of the pipe diameter. Natural bed sediments and/or gravels should be allowed to accumulate within the culvert to provide suitable fish passage conditions. The culvert flow area (after the accumulation of bed sediments) should be at least equal to the channel's natural cross section to the elevation of the road crossing.

This design methodology can be problematic on streams with a medium to steep gradient, often resulting in both fish passage and channel erosion problems. Recessing the culvert into the streambed can also initiate a destructive form of head-cut erosion, which can then migrate upstream from the culvert. Therefore this design methodology is best used in circumstances where the natural channel fall is less than 100 mm across the length of the culvert.

(ii) Stream Slope Method

The stream slope method also requires little if any calculation and is also likely to require the installation of a very conservative and thus expensive structure. In this design procedure the culvert is installed at the same slope as the channel's natural bed slope (measured over a distance of at least 50 metres upstream and downstream of the crossing).

One of the benefits of installing the culvert at the same slope as the channel is that the effective flow area through the culvert is more likely to remain constant over time because the gradient of the settled bed sediments is likely to parallel the culvert's obvert (roof).

This design method is possibly best used only when designing single cell pipe culverts located within private property where it is difficult for the landowner to justify the cost of a detailed engineering design.

(iii) Hydraulic Design Method

The hydraulic design methodology can be applied to the design of new culverts as well as the retro-fitting of existing culverts. This design method normally involves the incorporation of baffles to provide both suitable velocity conditions as well as resting areas for migrating fish. The design procedure requires significant knowledge of the size, swimming ability and movement characteristics of the local native fish.

Baffled fishways can be used to provide suitable fish passage conditions for:

- culverts with a gradient exceeding 3%;
- long, high-velocity culverts; and
- sites where fish passage is required during high-velocity flood events.

The design procedure is usually best suited to the passage of medium to large fish, and culverts at least 1.5 m high (for reasons of maintenance access).

Problems associated with the hydraulic design method and the use of baffled fishways include:

- baffled fishways can generate excessive turbulence causing a problem to small fish;
- baffles can wedge large woody debris inside the culvert, and twigs and leaf litter can bridge across the baffles blocking fish passage; and
- some baffle designs can be subject to excessive sediment deposition during flood events.

(iv) Stream Simulation Method

The basis of this design methodology is the creation of near-natural bed conditions through the culvert. To be effective, this design procedure requires two critical culvert attributes:

- a culvert flow area equivalent to the natural channel up to the target water depth; and
- mid-culvert resting areas as appropriate for the culvert length and channel conditions.

The stream simulation method is considered to produce the most diverse fish passage conditions, and thus is a suitable design procedure when there is a wide variation is size and swimming abilities of the target species. This design method is often preferred when the target species include small or juvenile fish.

The stream simulation method can be applied to both low gradient and steep gradient waterways. The incorporation of additional sidewall roughness is recommended in most cases, especially when suitable fish passage conditions are necessary during flood events.

The design procedure relies on the development of suitable boundary layer conditions adjacent the culvert bed and sidewalls. The incorporated roughness units generally need to have a size of between 1 to 3 times the body thickness of the target species.

Problems associated with the stream simulation method include:

- a large and costly culvert is often required;
- limited mid-culvert resting areas; and
- the risk of poor performance due to limited design and construction experience.

(v) Climbing Species Method

The climbing species method relies on the ability of some freshwater fish species to pass obstructions by ‘climbing’ over wetted surfaces. In terms of design, the climbing species method is the least restrictive, but is only useful in high-gradient streams where fish diversity is already limited and those species known to migrate along the wetted surface of obstructions.

This design procedure is likely to be limited to specific waterways such as parts of the upper Snowy Mountains, and certain Tasmanian waterways. Advice on species location and design requirements should always be obtained from the local Fisheries authority.

Problems associated with the design method include:

- most Australian fish are not good climbers; and
- the design methodology is unlikely to satisfy the requirements of the whole fish community.

Table 1 – Guidance on the selection of design methodology [1]

	No Slope Method	Stream Slope Method	Hydraulic Design Method	Stream Simulation Method	Climbing Species Method
Stream gradient:					
low gradient channel bed and tidal streams	✓	✓		✓	
medium gradient channel bed	[2]			✓	
steep channel bed			✓	[3]	[4]
Culvert length:					
short culvert, < 10 m (e.g. single lane crossing)	✓	✓		✓	
medium length culvert, 10 to 20 m (e.g. 2-lane road)				✓	
long culvert, 20 to 30 m (e.g. multi-lane arterial road)			✓	[5]	
very long culvert, > 30 m			✓		
Waterway properties:					
high debris loading (including leaf litter)	✓	✓	[6]	✓	
high sediment loading (including sand-based streams)		✓	[6]	✓	
alluvial, gravel-based streams		✓		✓	
tidal channels	✓	✓		✓	
Critical timing of fish passage:					
during periods of low flow	✓	✓		✓	[4]
during low water levels, < 500 mm water depth		[7]	✓	✓	
during flow less than the 1 in 1 year ARI flood level			✓	✓	
during flood events, 1 in 1 year to 1 in 10 year ARI flooding			✓	[8]	

[1] This table is provided as a guide only. Successful application of any given design methodology depends on the expertise of the designer, and the given site conditions. The preferred design methodology depends on consideration of each issue/condition identified within the table.

[2] Successful application of this design procedure depends on the length of the culvert (the shorter, the better), and the ability of established pool-riffle systems or rock chutes to compensate for the channel gradient lost within the flat culvert.

[3] Successful application of this design procedure depends on other factors such as the available flow area through the culvert, and the timing of critical fish passage/migration.

[4] Fish species likely to utilise this design procedure are likely to exit in steep gradient waterways (e.g. Snowy River, NSW, and the upper catchments of Tasmanian streams). This methodology primarily applies to fish passage during periods of low flow.

[5] The stream simulation method is likely to be most applicable to short and medium length culverts. Successful application to long culverts requires a low gradient channel bed and the timing of critical fish passage to be during periods of low flow. If fish passage is required during minor flood flows, then a baffled fishway may be required (i.e. the Hydraulic Design Method).

[6] Suitability of baffled fishways must be assessed on a case-by-case basis.

[7] Successful application of this design methodology during conditions of deep water (i.e. less than 500 mm) requires a very low channel gradient.

[8] Successful application of this design procedure depends on other factors, such as the available flow area through the culvert.

Table 2 – Guidance on the selection of culvert features [1]

Key: ✓ = Desirable or essential attribute in most circumstances. **D** = Desirable attribute, but not necessarily essential. Suitability depends on other variable and the design method.	Smooth sidewall	Sidewall roughness [2]	Bed roughness [2]	Culvert functioning as a pool	Enhanced lighting conditions
Stream gradient:					
low gradient channel bed and tidal streams	**D**	**D**	**D**	✓	
medium gradient channel bed	**D**	**D**	**D**	[3]	
steep channel bed	✓	✓	✓		
Culvert length:					
short culvert, < 10 m (e.g. single lane crossing)	**D**	**D**	**D**	**D**	
medium length culvert, 10 to 20 m (e.g. 2-lane road)	✓	✓	✓	**D**	
long culvert, 20 to 30 m (e.g. multi-lane arterial road)	✓	✓	✓	[4]	[5]
very long culvert, > 30 m				[4]	✓
Typical size of fish:					
small freshwater fish, < 5 cm	[6]	[7]	✓	✓	
medium freshwater fish, 5 to 15 cm		✓	✓	[8]	
large freshwater fish, > 15 cm		✓	✓		
Critical timing of fish passage:					
during periods of low flow			[9]	[9]	
during low water levels, < 500 mm water depth	✓	✓	✓		
during flow less than the 1 in 1 year ARI flood level	✓	✓	✓		
during flood events, 1 in 1 year to 1 in 10 year ARI flooding	[10]	[10]	[10]		

[1] Information provided as a guide only. Desirable culvert features will vary depending on the interaction between various site conditions.

[2] Bed and sidewall roughness can be provided by various items including rocks and baffles.

[3] Designing the culvert to function as a ‘pool’ may require channel modifications upstream and/or downstream of the culvert to raise the channel bed level to compensate for the flat bed culvert.

[4] Designing the culvert to function as a ‘pool’ is only beneficial if critical fish passage is required during periods of low flow. If critical fish passage is normally during flood flows, then the use of a baffled fishway becomes increasingly important, especially as the culvert length increases.

[5] Necessity of enhanced lighting conditions within the critical fish passage cell depends, in part, on the size (height) of the culvert.

[6] At least one sidewall should be smooth to provide low-turbulent boundary layer conditions to assist the passage of small fish and the juveniles of larger species.

[7] At least one sidewall should be rough to provide a boundary layer of a few centimetres thickness.

[8] Designing the culvert to function as a ‘pool’ is increasing beneficial as the fish size decreases and the culvert length increases.

[9] Suitable fish passage conditions can be provided by either bed roughness or designing the culvert to function as a ‘pool’; however, designing pool-like conditions are preferable wherever practicable.

[10] In addition to providing suitable bed and sidewall roughness, it is essential to provide suitable flow area within the culvert to minimise changes in flow velocity from that of natural conditions.