Culvert Fishway Planning and Design Guidelines

Part E – Fish Passage Design: Site Scale

Ross Kapitzke
James Cook University
School of Engineering and Physical Sciences

April 2010 – VER2.0

James Cook University School of Engineering and Physical Sciences
Culvert Fishway Planning and Design Guidelines
Part E – Fish Passage Design: Site Scale

Contents

James Cook University School of Engineering and Physical Sciences
Culvert Fishway Planning and Design Guidelines
Part E – Fish Passage Design: Site Scale

1 INTRODUCTION

For individual road crossings or other waterway structures where provisions for fish passage are to be made, designers, managers and scientists require information on the design requirements for fish passage at the structures, and an understanding of fishway configuration options and performance in order to establish the type, layout and configuration of the fishway facility.

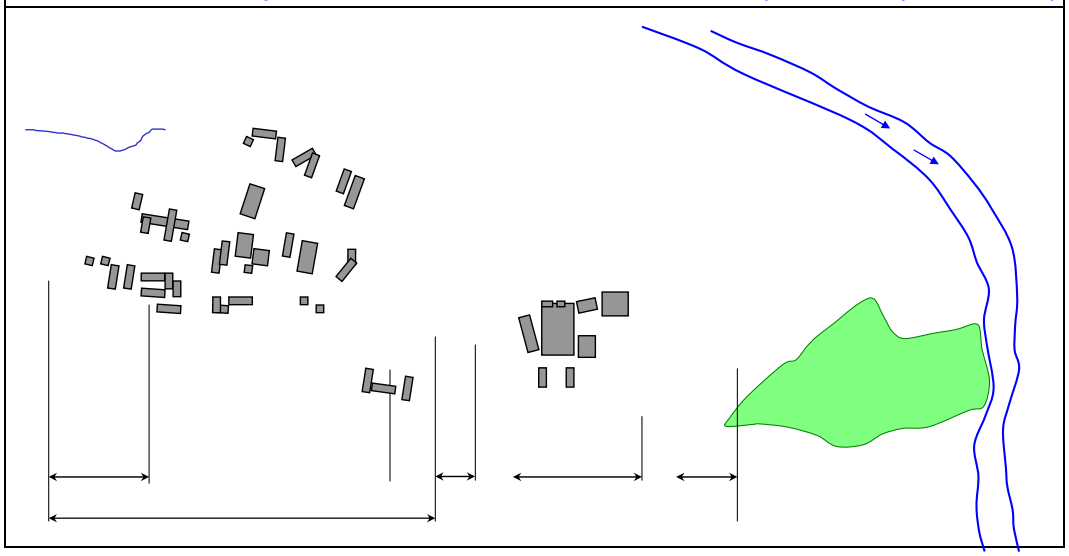
These Guidelines Part E deal with fish passage design at the site scale, and aim to:

- present methods for assessment of waterway characteristics and hydraulic conditions, and evaluation of fish migration barriers at the waterway structure site
- outline objectives, criteria and constraints for fish passage design to meet multipurpose requirements
- evaluate fishway configuration options and performance in terms of fishway hydraulics, attraction flows, effectiveness and overall suitability of the fishway
- describe the layout and configuration of the adopted fishway facility, including fish passage devices and waterway structure and adjoining waterway features to provide for fish passage
- illustrate site scale design for fish passage through the University Creek Solander Road and Bruce Highway Corduroy Creek to Tully case study projects

The information from Guidelines Part E is used in other parts of these Guidelines to:

- guide the design configurations of various fishway devices (Guidelines Part F – Baffle Fishways for Box Culverts), (Guidelines Part G – Baffle Fishways for Pipe Culverts), (

Box E3.2: University Creek lower reaches – JCU to Ross River (Source: Kapitzke 2007c)



3.3 Stream reach condition and fish habitat characteristics

The condition of the stream reaches and the location, extent and nature of the fish habitat areas within the waterway affect the fish community in the stream, and assist in defining the value of providing for fish passage at particular waterway structures. Information used to describe reach condition and fish habitat for the stream includes waterway type, habitat type, riparian condition, instream condition, disturbance, and rehabilitation potential. Reconnaissance level assessment based on aerial photo and mapping data, and review of available stream condition reports (where available) supplemented by field inspection is usually appropriate. Examples of the type of information that should be examined for a site scale assessment are presented below. This may require specialist advice on fish habitat and aquatic fauna connectivity.

Data category	Example of information to assess
waterway type	x freshwater stream, saline wetland, constructed wetland
habitat mapping	x regional ecosystems, terrestrial fauna, aquatic fauna
fish habitat type	x spawning, growth, refugial
structure location relative to habitat	x estuarine, lowland, upland, tributary stream
riparian condition	x native vegetation, continuous or fragmented corridor
instream condition	x structural diversity, aquatic vegetation, water quality
integrity and disturbance	x channel form, flow connectivity, isolation, ecosystem function
human activities and pressures	x agriculture, wetland drainage, exotic animals and plants
rehabilitation opportunities	x riparian corridor, aquatic habitat, connectivity, stream process

Methods for undertaking fish habitat assessment of a waterway typically examine the instream and riparian habitat condition of the waterway on the basis of ratings for a number of physical and ecological parameters for the stream reaches. Reach delineation is usually based on tributary systems, landform, channel condition, road crossings, waterway structures and other land marks. The suggested method for reach condition and fish habitat assessment in site scale studies is based loosely on that of Russell and Hales (1997). The following principal elements are considered in the habitat assessment where information is available for the stream reaches:

- x general waterway type and channel form
- x extent and quality of permanent or intermittent water

Box E3.5: University Creek reach lengths and suitable habitat upstream of road crossings (Source: Kapitzke 2007c)

Reach	Road crossing at U/S extent			Habitat suitability		Suitable habitat length	
	Road-stream Crossing	Dist U/S Ross R	Reach length		Description	Cumulative length U/S	% habitat U/S
3		3500	1300	q q	Excellent habitat		
2e	E – Solander Road	2200	100	q	Degraded	1300	60
2d	D – Discovery Drive	2100	250	q	Degraded	1400	65
2c		1850	350	q	Coarse gravel runs	1650	77 E – Solander R8 25.0

swim speeds for the defined fish community, through categorisation of fish movement behaviour and use of the best available data on fish movement characteristics for the fish community.

The fish movement group and movement behaviour categorisation outlined in Guidelines Part D enables ready evaluation of the range of species that are likely to be migrating through waterway reaches adjoining the road crossing, the life stage and maturity of the fish at the time of movement, the direction of movement, the time of movement in relation to seasonal flow and flood stage in the stream, and the fish species

4 ROAD CROSSING AND FISH MIGRATION BARRIER CHARACTERISTICS

The hydraulic characteristics of the road crossing or other waterway structure and the movement capabilities of the fish community attempting to pass through the site, define the extent to which the structure represents a fish migration barrier. Evaluation of the fish migration barrier characteristics of the site requires knowledge of the configuration of the drainage structure and the hydraulic characteristics of the structure and adjoining stream reach. Fish migration barrier effects (e.g. high velocities, water surface drop) can then be identified within the various hydraulic zones of the structure according to the fish movement capabilities (e.g. swim speed).

The following sections outline waterway structure aspects and hydraulic characteristics to be examined in site scale planning and design, and describe the method for establishing fish migration barrier effects within hydraulic zones. This is illustrated for road-waterway structures for the Bruce Highway Corduroy Creek to Tully road crossing of the Tully Murray floodplain (Kapitzke 2007a), and for the Solander Road crossing of University Creek (Kapitzke 2007c). Fish migration barrier types are outlined in Guidelines Part C – Fish Migration Barriers and Fish Passage Options for Road Crossings

4.1 Waterway structure configuration

Site scale planning and design for fish passage at a road crossing or other waterway structure is based on specific information that defines the structure (e.g. ownership and use, structure type, configuration, components) and describes it within the context of the stream reach (e.g. associated infrastructure, site and reach characteristics, stream condition). This applies to new and existing structures identified in road corridor scale or other prioritisation studies where provisions for fish passage are to be made. Examples of the type of information that should be examined for a site scale assessment are presented below.

Data category	Example of information to assess
structure ownership and land use	x

passage crossings varying from 1200 mm to 3000 mm. Many of the multi-cell culverts are much wider than the poorly defined waterway channel at the site, and entail channel widening and transitions in bed width at the culvert inlet and outlet to connect to the adjoining waterway and to other waterway structures on the existing road and rail line.

At the Solander Road crossing of University Creek on the James Cook University campus in Townsville, the existing pipe culvert and causeway structure provides vehicle, pedestrian and cycle access over the creek. The overall remediation goals for the site include environmental remediation and stream rehabilitation downstream of the crossing, and provision for fish passage through retrofit of the existing structure without major modification (see Kapitzke 2007c). The Solander Road crossing comprises a 4-barrel 1200 mm diameter pipe culvert on a single lane road, with a barrel length of 7.2 metres, and a slope of approximately 1 in 50 or 2 %. A concrete apron at the culvert outlet falls away a further 300 mm over its 6.3 m length (longitudinal slope of 1 in 20 or 5 %), and an erosion hole up to 1 metre deep has developed at the downstream end of the apron. The road embankment forms a causeway that spreads flow across the creek floodplain, leading to erosion and environmental degradation of the downstream channel as a result of severe hydraulic conditions associated with afflux and return flow to the channel.

4.2 Hydraulic conditions for waterway structure and adjoining stream reach

Flow conditions at the waterway structure and the adjoining stream reach determine the hydraulic characteristics and associated fish migration barrier effects of the structure. Hydraulic information for the site is required for both assessment at fish passage flows and for consideration of drainage and safety functions of the waterway structure and fishway in larger drainage flows. Examples of the type of information that should be examined for site scale assessment of a road crossing or other waterway structure are presented below.

Data category	Example of information to assess
flow frequency – ARI &6 - to	

the larger stream flows. Culvert flow depths and velocities for the fish passage design flows can be estimated from these results and from theoretical hydraulic calculations, but should take account of the various roughness conditions that may apply for the culvert barrel, and the range of tailwater conditions that may apply in the stream. For example, back-flooding of the culvert outlet may occur under some flow conditions where downstream structures or sediment deposits in the stream bed drown out a water surface drop that might otherwise occur at the culvert outlet.

Hydraulic monitoring and site observations provide valuable information on flow characteristics within the various hydraulic zones of the structure, including flow depth measurements, velocity measurements with a current meter, and photo and video observations of flow patterns and characteristics. Local observations and measurements can be correlated with rainfall data obtained from automatic rainfall recording stations within and adjacent to the catchment, and other stream flow characteristics obtained from other sites on the stream.

For example, for the Bruce Highway Corduroy Creek to Tully road crossing of the Tully-Murray floodplain, a first level assessment of hydraulic conditions in the box culvert waterway crossings obtained from flood modelling undertaken for road drainage design indicated average velocities through the culverts of up to 0.5 m/s for the 5 year ARI design drainage flow. More detailed assessment of hydraulic conditions for the priority fish passage culverts was undertaken by evaluating flows through these waterways on the basis of field observations and measurements of the flow event associated with Tropical Cyclone Larry on 24/03/06. Simple calculations based on waterway areas, velocities and flow continuity were used to transpose field measurements at existing road and rail crossings of these waterways to the box culvert crossings of the new road. Velocities at the priority fish passage culverts on the new road and existing road ranged from 0.1 – 0.9 m/s for the fish passage design flows of 0.5 m and 1.5 m flow depth (see Kapitzke 2007a).

In addition to velocities and flow depths within the culvert barrels, flow conditions at culvert inlets and outlets and adjoining channel sections were also evaluated for their effects on fish passage. Tailwater conditions for the culverts, and flow characteristics of waterways upstream and downstream of the crossings may influence barrel effects for fish passage at the sites (e.g. due to water surface drop). All box culvert crossings on the Tully Murray floodplain for the new

behavioural characteristics of fish attempting to pass through. Fish migration barrier effects are considered in terms of high velocity, reduced flow depth, lack of resting place, excess turbulence or water surface drop (see Guidelines Part C – Fish Migration Barriers and Fish Passage Options for Road Crossings) under low flow and medium flow design conditions (Section 5.3).

The fish migration barrier effects at the waterway structure depend on the characteristics of the structure (Section 4.1), the hydraulic conditions at the structure (Section 4.2), and the desirable flow characteristics for fish passage at the structure, including the allowable fish swim speeds at the fish passage design flows (Section 5.3). Consideration is given, not only to hydraulic conditions within the main culvert barrels, but also to conditions throughout the waterway crossings and other structures, to enable fish passage through all hydraulic zones from downstream to upstream at the structure.

In terms of velocity barriers to fish passage in hydraulic zones of the waterway structure such as the culvert barrel, the capacity of fish to overcome these velocity conditions for the range of design flows within the culverts is assessed for fish swimming in either prolonged or burst swim modes (see Guidelines Part C – Fish Migration Barriers and Fish Passage Options for Road Crossings). Fish passage through a culvert in prolonged swim mode will require fish swim capabilities to exceed culvert flow velocities, or provision of a dedicated fishway zone within the culvert where flow velocities are suitably less than the prolonged swim speed for these species. Other than for short culverts with low flow velocities, a fish swimming in burst swim mode will commonly be unable to swim through a road culvert without resting at intermediate points. Fish will attempt to use a burst and rest swim pattern to pass through culverts where the culvert flow velocity is close to or greater than the prolonged swim speed, or where the culvert length exceeds that which can be negotiated in one action in burst swim mode. Movement through the culvert using a burst / rest pattern requires regularly placed rest locations that are typically not present within plain culvert barrels, but can be attained within sheltered zones in culvert fishways.

As an illustration for the Bruce Highway Cordury Creek to Tully road project, fish passage through the box culvert waterway crossings was assessed in the low flow and medium flow conditions, and the fish migration barrier problems were evaluated for each of the 4 hydraulic zones (Zones A – D), leading from downstream to upstream in the structure (Box E4.1). The hydraulic characteristics for these zones are described, along with the rationale for their identification as fish migration barriers in the low flow and medium flow conditions. This shows that the critical conditions for low flow are shallow water depths throughout the structure and lack of attraction flow for fish moving upstream to the culvert outlet / fishway entrance. For

Box E4.1: Corduroy Creek to Tully multi-cell box culverts: Hydraulic zones and fish migration barriers for low and medium flow (Source: Kapitzke 2007a)

Hydraulic zones (fish moving from downstream to upstream)	Low flow (flow up to approx 0.5 m deep, inundating channel bed for defined waterway)		Medium flow (flow from approx 0.5 m to 1.5 m deep, below low flow channel bench for defined waterway)	
	Fish migration barrier problems	Rationale	Fish migration barrier problems	Rationale
Zone A: Downstream channel	x lack of attraction flow for fish moving upstream to culvert outlet / fishway entrance x no hydraulic barriers anticipated in this Zone due to high tailwater conditions downstream	x wide waterway downstream of the culverts with velocities of ~ 0.1 m/s at low flow x the low velocity flow will not provide a defined path of attraction for fish to move to particular parts o the culvert	x lack of attraction flow for fish moving upstream to culvert outlet / fishway entrance x no hydraulic barriers anticipated in this Zone due to high tailwater conditions downstream	x wide waterway downstream of the culverts with velocities of ~ 0.3 m/s at medium flow x the low velocity flow will not provide a defined path of attraction for fish to move to particular parts of the culvert
Zone B: Culvert outlet and downstream apron slab	x shallow water depths on downstream apron	x at very low flows, water will spread across the full culvert outlet at depths less than 300 mm – minimu requirement of for fish movement	x high velocities and lack of shelter at culvert outlet and on downstream apron	x velocities of ~ 0.5 m/s and ~ 0.9 m/s and no resting points for fish are beyond fish swim capabilities on the downstream apron
Zone C: Culvert barrel	x shallow water depths in culvert barrel	x at very low flows, water will spread across the full culvert outlet at depths less than 300 mm – minimu requirement for fish movement	x high velocities in culvert barrel	

For the Solander Road crossing of University Creek, the hydraulic characteristics of the crossing typify many pipe culverts / causeways and present the elements of many classic fish migration barriers at road-waterway crossings (Box E4.2). For low flow and medium flow conditions at the crossing, high velocities in the culvert barrel and on the downstream apron exceed fish swimming capabilities in prolonged or burst swim mode. Major water level drops downstream of the culvert outlet at low flow, turbulence at the pipe outlet in low and medium flow, and lack or resting place throughout the structure present severe hydraulic conditions for fish passage.

Box E4.2: Solander Road crossing of University Creek: Hydraulic zones and fish migration barriers (After: Kapitzke 2007c)

Zone A: Downstream channel and apron drop-off

- x turbulent, high velocity flow in part of downstream channel at low flows
- x water surface drop, plunging jet and turbulence at end apron at low flows
- x turbulent, high velocity flow in downstream channel at medium flows
- x water surface drop and hydraulic jump downstream of the apron

(Photo: 15/01/04, Source: Ross Kapitzke)

Zone B: Culvert outlet and downstream apron

- x high velocity shallow jet across apron slab from pipe outlet to apron drop off at low flows
- x high velocity turbulent flow across apron slab from pipe outlet to downstream channel at medium flows

(Photo: -/02/02, Source: Ross Kapitzke)

d o w n s t r e a m

(Pho 1 T/

5 OBJECTIVES, CRITERIA AND CONSTRAINTS FOR FISH PASSAGE DESIGN

Provisions that are made for fish passage at a waterway structure must meet multipurpose design requirements related to such things as stream, drainage, fish passage and amenity for the structure and fishway facilities. This will involve either mitigation measures to address potential fish migration barrier problems at new structures (e.g. incorporating rock ramps downstream of the crossing for raised tailwater), or remedial measures to overcome fish passage problems as retrofits for existing structures (e.g. fitting baffles within the culvert barrel). The goals for the mitigation or remediation projects are to address the conventional utilitarian and infrastructure related design objectives for the structure, while providing for the fish passage and other objectives. Several waterway structure and fish passage design options may be available to address the design goals, requiring evaluation of options prior to adoption (see Chapter 6).

Criteria for many fish passage design objectives (design flows, allowable velocities) are not established at this stage of development of fish passage technology for small waterway structures. Design, development and testing of fishway facilities with well established design goals and monitoring and evaluation programs will assist with establishing design criteria and performance characteristics for the fishways. These design objectives, and the evaluation of the suitability and likely performance of prospective fish passage design options (Chapter 6) provide the framework for performance monitoring and evaluation of the fishway facility against design criteria.

The following sections define multipurpose objectives and the rationale for their adoption in relation to fish passage provisions at a waterway structure. The design criteria relating to these objectives are presented, to the extent to which they are defined for the fish passage work, and possible constraints on planning, design and implementation of the facilities are outlined. Specific criteria for fish passage design flow and velocities for the waterway structure are discussed. This is illustrated for the provision of fish passage at road-waterway crossing structures for the Bruce Highway Corduroy Ck to Tully road project (Kapitzke 2007a).

5.1 Objectives and rationale for fish passage provisions

Multiple objectives to be considered in the planning, design and implementation of fish passage facilities for the road crossing or other waterway structure fall under the broad groupings: Drainage, utility and stream integrity; Fish passage; Stream processes, riverine habitat and environmental values; Operation and safety, amenity and cultural heritage (Box E5.1).

An illustration of design objectives and associated comments, criteria and rationale for these objectives within the various groupings is presented in Box E5.2, based on fish passage provisions at box culvert waterway crossings for the Bruce Highway Corduroy Creek to Tully road project. Design options for the fish passage facilities, and a preliminary evaluation of their suitability in meeting these design objectives are presented in Chapter 6.

Box E5.1: Multipurpose design requirements for fishway facilities at waterway structure

Drainage, utility and stream integrity	Fish passage	Stream processes, riverine habitat and environmental values	Operation and safety, amenity and cultural heritage
Ensure flow capacity and operation of waterway and structure maintained so flooding and drainage function not adversely affected (M)	Provide for fish passage through the structure during critical seasonal / flood periods, over a range of flow capacities (D)	Maintain natural flow and sediment processes in the waterway (M)	Minimise need for ongoing maintenance of fishway facility (D)
Minimise debris and sediment obstruction from the fishway facility (D)	Provide a continuous fish pathway through the structure with entrance and exit adjacent to the normal fish path (M)	Protect riparian and instream habitat, terrestrial and aquatic ecosystems (M)	Provide for physical and biological monitoring of the fishway facility (M)

Box E5.1: Multipurpose design requirements for fishway facilities at waterway structure			
Drainage, utility and stream integrity	Fish passage	Stream processes, riverine habitat and environmental values	Operation and safety, amenity and cultural heritage
Minimise effect of erosion at structure outlet and on sedimentation in downstream reaches (D)	Provide fish passage for juveniles and adult fish and for species swimming on the stream bed or close to the water surface (D)	Ensure stream water quality is not degraded (M)	Ensure development and operation of the facility does not present a public safety problem (M)
Prevent flood and erosion damage to the structure, other infrastructure and utilities, adjoining land or stream (M)	Ensure flow velocities and water depths through the structure are suitable for fish swim capabilities (M)	Control exotic animals and plants (D)	Avoid public health problems associated with the facility (M)
	Prevent adverse flow turbulence through the structure and ensure water surface drops at structure outlet and inlet are not excessive (M)		Maintain or enhance visual amenity at structure and adjoining site (D)
	Provide attraction flows for fish at the structure outlet / fish entrance (M)		Minimise adverse effects on recreational amenity in adjoining stream (D)
	Ensure suitable flow conditions at the structure inlet to protect fish from downstream flows (M)		Preserve cultural heritage of site (D)
	Ensure fish are not obstructed from downstream migration through the fishway (M)		
	Ensure adequate natural light in the structure to suit passage of the relevant fish species (D)		
Legend	D Desirable Objective	M Mandatory Objective	

Box E5.2: Design objectives, criteria and rationale for fishway facilities at box culvert waterway crossings – based on the Corduroy Creek to Tully road project (After: Kapitzke 2007a)	
Design objective	Criteria, comment and rationale
1 Drainage, utility and stream integrity	
1.1 Ensure flow capacity and operation of waterway and structure maintained so flooding and drainage function are not adversely affected (M)	x The fishway structure (baffles, spoilers etc.) should not significantly reduce the culvert hydraulic capacity at the design discharge for flooding (e.g. 20 yr ARI). x The fishway structure should not appreciably increase the upstream water level for the range of discharges up to the design discharge for flooding. x The drainage design flows for the culvert cannot be altered, neither can the requirements for drainage immunity of the road. x The fishway facility should be configured to ensure that low flow drainage functions in the culvert and adjoining waterway are maintained.
1.2 Minimise debris and sediment obstruction from the fishway facility (D)	x The structure should not significantly restrict the culvert waterway opening, and should be configured to minimise debris and sediment accumulation and to shed debris where possible. x Severe debris accumulation may obstruct fish passage.

Box E5.2: Design objectives, criteria and rationale for fishway facilities at box culvert waterway crossings – based on the Corduroy Creek to Tully road project (After: Kapitzke 2007a)	
Design objective	Criteria, comment and rationale
1.3 Minimise effect of erosion at structure outlet and on sedimentation in downstream reaches (D)	x The fishway structure should not significantly increase flow velocities or alter flow patterns at the culvert outlet that may lead to downstream erosion and sedimentation x The intention is to reduce adverse erosion, sedimentation and turbidity effects downstream.
1.4 Prevent flood and erosion damage to the structure, other infrastructure and utilities, adjoining land or stream (M)	x Development and operation of the fishway should not adversely affect the culvert or other adjacent infrastructure, utilities or landuse. x The fishway should not cause erosion or Bo

Box E5.2: Design objectives, criteria and rationale for fishway facilities at box culvert waterway crossings – based on the Corduroy Creek to Tully road project (After: Kapitzke 2007a)	
Design objective	Criteria, comment and rationale
3.2 Protect riparian and instream habitat, terrestrial and aquatic ecosystems (M)	x Ensure that development of the fishway facility does not encroach or damage riparian or instream riverine habitat, or impact terrestrial or aquatic ecosystems, including terrestrial and aquatic fauna well being and movement. x In order to prevent structure fragmentation, leaching of contaminants, or other damage to aquatic environments, the fishway structure should only be constructed from suitable robust materials that are adequately secured to the culvert.
3.3 Ensure stream water quality is not degraded (M)	x Ensure that development of the fishway does not degrade stream water quality at or downstream of the structure due to release of point source or diffuse pollutants.
3.4 Control exotic animals and plants (D)	x Endeavour to develop designs for the fishway facility and adjacent aquatic habitat features to restrict abundance, distribution and movement of exotic fish. x Ensure that the fishway development does not spread or enhance exotic plants such as woody weed infestations.
4 Operation and safety, amenity and cultural heritage	
4.1 Minimise need for ongoing maintenance of fishway facility (D)	x Fishway components should be constructed from robust materials to withstand environmental conditions in the stream over the expected life of the facility. x The fishway facility should provide ready access to, and ease of removal of fishway and monitoring facility components, particularly when not in operation during the dry season. x The structure should be configured to minimise accumulation of sediment and debris, and be suitable for cleaning during wet and dry seasons.
4.2 Provide for physical and biological monitoring of the fishway facility (M)	x The fishway facility should provide for a range of hydraulic, biological and other monitoring, and consideration should be given to providing for monitoring access. g

5.2 Constraints on planning, design and implementation

Planning, design and implementation of the culvert fishway facilities will be constrained by a number of factors (e.g. land tenure, legislation, infrastructure, services, timing), which must be addressed for the project. These constraints are detailed in Box E5.3 for the Bruce Highway Corduroy Creek to Tully road project, and a preliminary evaluation of the suitability of the fish passage design options in meeting these constraints is presented in Chapter 6.

Box E5.3: Constraints for design and implementation of fishway facilities at box culvert waterway crossings for the Corduroy Creek to Tully road project (After: Kapitzke 2007a)

Constraints	Description
Land tenure and ownership of road and culvert	x The culvert infrastructure and adjoining land will be contained within road reserves acquired by Department of Main Roads (DMR) for the Corduroy Creek to Tully road.

5.3 Design criteria for fish passage provisions

The suitability of fish passage provisions at a road crossing or other waterway structure depends on the adopted fish passage design objectives and criteria for the structure, and the extent to which the proposed fishway facilities meet these design objectives. Design objectives and criteria for site scale fish passage design may devolve from fish passage provisions established in road corridor scale studies (see Guidelines Part D – Fish Passage Design: Road Corridor Scale), or will be established for particular waterway structures according to the fish habitat values of the waterway and the fish passage goals for the site.

The principal design criteria for fish passage are established by considering the desired fish passage effectiveness of the structure, the fish passage design flows and the design swim speeds and other fish movement characteristics of the fish community (see Guidelines Part B – Fish Migration and Fish Species Movement Behaviour). In terms of fish passage effectiveness, a conservative approach would aim to provide for 100% effectiveness in passage for the complete native fish community over the full range of fish migration flows in the waterway. A more restrictive approach with reduced fish passage effectiveness would aim to provide passage for a reduced diversity of fish species, life stage and maturity, and / or a reduced range of flow conditions. Three levels of fish passage effectiveness are adopted (Levels 1 – 3), with associated bands of flow conditions and target fish community, which will allow the desired fish passage provisions at the waterway structure to be chosen (Box E5.4).

The fish passage effectiveness band for the waterway structure, and associated fish passage design flows and swim speeds for the target fish community, are chosen by the designer on a discretionary basis, taking into account the following:

- fish movement corridor class (Class A – Class C)
- aquatic fauna connectivity / fish passage goals (high – low)
- fish migration barrier hydraulic conditions for waterway structure
- feasibility of overcoming the fish migration barrier at the structure

The Level 1 criterion would normally apply for the most valuable waterways / fish habitat, for situations where fish passage goals are high, for road crossings or other waterway structures where the hydraulic conditions that constitute the fish migration barriers are not severely adverse, and where it is readily feasible to overcome the fish migration barrier. The Level 2 (intermediate) criterion would apply for high value or medium value fish waterways / fish habitat, for situations where fish passage goals are medium to high, for waterway structures where the hydraulic conditions that constitute the fish migration barriers are not severely adverse, and where it is feasible to overcome the fish migration barrier. The Level 3 (restrictive) criterion would apply for low value fish movement corridors, for situations where fish passage goals are low to medium, for waterway structures where the hydraulic conditions that constitute the fish migration barriers are not severely adverse, and where it is feasible to overcome the fish migration barrier.

Box E5.4: Fish passage effectiveness levels and design criteria for provision of fish passage at waterway structures			
Fish passage effectiveness	Fish passage provisions for design flow conditions – upstream migration		
	Low flow (flow up to approx. 0.5 m deep)	Medium flow (from appr. 0.5 m to approx 1.5 m deep)	High flow (flow in excess of approx. 1.5 m deep)
Level 1 – conservative	x all native fish species, life stages and maturity	x all but outlier[(1)] native fish species (e.g. poor swimmers)	x not mandatory for any native fish species
Level 2 –			

6 FISH PASSAGE DESIGN AND EVALUATION OF OPTIONS

A number of options may be available for fish passage facilities to overcome the fish migration barriers (Section 4.3) at a road crossing or other waterway structure. An evaluation of the suitability of these options in meeting the multipurpose requirements and design objectives for the facility (Section 5.1) should be undertaken in order to establish the preferred design for the structure. This will apply to new projects where mitigation measures can be incorporated into the design of the structure, and to existing projects where remediation measures may be applied as retrofits to the site. The identification of fish passage options will commonly be undertaken in the concept design phase of the project, whilst the evaluation of options and adoption of the preferred design will commonly be undertaken in project preliminary design / feasibility design.

The priority box culvert crossings on the Condur Creek project where fish passage provisions are to be made on the new road comprise multiple 3600 mm span culverts, several relatively wide 8 and 9-cell culvert structures, and other narrower crossings comprising 5-cell structures (see Kapitzke 2006a; Kapitzke 2007a). The culverts are typically located within wide shallow waterways on the floodplain, but many of the structures, particularly the 8 and 9-cell structures that are up to 35 m wide, are much wider than the local low flow channels at the crossings, and channel widening and transitions in bed width are provided at the culvert inlet and outlet to connect to the adjoining waterway and other waterway crossing structures. The culvert invert, which has a common level across the full structure width without recess of the culvert bed for any particular culvert cell, is typically chosen to be close to the bed of the waterway at the

6.2 Evaluation of suitability of fish passage design options

The suitability of the fish passage options (Section 6.1) in overcoming the hydraulic barriers to fish passage at the waterway structure (Section 4.3), and in meeting the design objectives and constraints for the site (Sections 5.1 and 5.2), should be evaluated for each fish passage component within the structure. Comparisons can be made between alternative fish passage measures to establish the most suitable design for each facility. Integrated solutions are required to address the fish passage problems and the multiple objectives for the waterway structure.

Some of the fish passage design objectives and criteria may not be adequately established for the waterway structure and fishway facility due to a

Box E6.1: Evaluation of suitability of culvert fishway designs in meeting design objectives and constraints for the Corduroy Creek to Tully road project (After: Kapitzke 2007a)

- The corner "EL" baffle fishway is intended to provide suitable hydraulic conditions on or close to the bed and through the water column up to the top of the baffle. The baffles for the corner baffle fishway are extended up the culvert wall with the intention of providing for fish passage at the water surface for flow depths of 1.5 m or more through the culvert. The presence of surface swimming fish in the Tully Murray waterways are unknown.
- The corner "EL" baffle fishway provides a zone of reduced velocity along the culvert wall, and provides shelter zones and flow recirculation behind the baffles that attract upstream fish movement. The corner "EL" baffle fishway has been provided along the entire length of the culvert barrels with short sections in the transition zone at culvert inlet and outlet.
- Nib wall and low flow training wall structures that have been provided at the culvert inlet and outlet direct low flows through the preferred fish pathway in the culvert barrel and help maintain minimum water depths through the fishway. Shallow notches in the nib wall at the culvert inlet across culvert barrels without the baffle fishway provide attraction flow and a pathway for fish to exit these barrels and pass upstream through the notches.
- The corner "EL" baffle fishway is not expected to create excessive turbulence due to its minimal effect on flow in the culvert barrel, and the tendency for energy dissipation due to the roughness effect of the fishway along the culvert wall.
- The tailwater conditions at the Tully Murray waterway crossings commonly provide slow moving flow that backs up to the culvert outlet, thereby eliminating a water surface drop at the culvert outlet/fishway entrance. Lowered tailwater conditions that are present or may occur at particular crossing sites over time can be addressed through provision of rock ramp or other grade control structures downstream of the crossings. No significant drop or drawdown occurs in the water surface at the culvert inlets due to the low velocities through the culvert waterways.
- The corner "EL" baffle fishway has been extended out of the barrel at the culvert inlet, which will improve the flow conditions for fish to exit the fishway. The nib wall and low flow training wall structures at the culvert inlet will assist fish to move upstream away from the inlet into adjacent barrels, and avoid being washed back downstream. The fishway exits are located in relatively low energy flow conditions in the waterway upstream of the culverts.
- The corner "EL" baffle fishway is not likely to obstruct downstream fish passage as it provides clear fish pathways in either direction. The fishway will slow water velocities through the culvert and will create a greater diversity of flow patterns, which should assist fish in moving downstream. The nib walls at the culvert inlet will obstruct downstream fish movement through the affected barrels during low flow conditions, but access will be available through the culvert barrel with the fishway.
- These Corduroy Creek to Tully road culverts are relatively short with well illuminated ends and large barrel cross section area (multi-cell 3600 mm wide), which is most likely large enough to provide adequate natural light without presenting a behavioural barrier to migrating fish. The inherently high natural light levels in the region provide relatively good illumination for these types of culverts.
- Overhanging vegetation in the vicinity of the culvert ends will simulate natural stream conditions and assist with transition of light intensity from the open stream to inside the culvert. The corner "EL" baffle is a low profile fishway that will not reduce natural light penetration.

Stream processes, riverine habitat and environmental values

- The fishway facilities do not alter stream discharge or flow regime through the sites, and will not affect stream sediment processes as they are expected to provide no obstruction to the transport of stream sediments downstream through the box culverts.
- Development of the fishway facility will not have any additional impact on riparian vegetation and stream condition beyond that associated with the road and waterway crossing developments. No adverse impacts on aquatic ecosystem function are anticipated. The fishway facilities will augment habitat restoration and fish passage initiatives within the Tully Murray floodplain, and will enhance conservation values and biodiversity in the region.
- Best practice environmental management provisions during construction of the fishway will ensure that spread of exotic plants and animals is controlled, and that no spills or pollution will occur to affect water quality in the stream.
- Fishway elements are unlikely to cause damage if dislodged, and can likely be retrieved and replaced in the fishway. No adverse environmental effects are anticipated from leaching or corrosion of any of the fishway components.
- The extent to which the fishway design will assist or restrict upstream passage of exotic fish species is unknown. The fishway is designed to allow passage of the complete native fish community, and will not preferentially advantage passage of exotic fish species. The fishway is located entirely within the culvert barrel and waterway structure and will not affect exotic plants in the stream.

Operation and safety, amenity and cultural heritage

- The fishway structure is readily accessible within the culvert barrels and the components are of simple construction that can be readily cleaned of debris or sediment after events, and removed if necessary. Access to the top of the culvert will be available at the culvert inlet and outlet, and access for monitoring within the culvert barrel will be available in low flow conditions.

Box E6.1: Evaluation of suitability of culvert fishway designs in meeting design objectives and constraints for the Corduroy Creek to Tully road project (After: Kapitzke 2007a)

- The culvert fishways are not likely to be accessed by the public and do not present a safety concern as they are low profile structures protruding from the culvert base and walls in a regular pattern without substantial obstruction to movement or threat to falling or tripping.
- The baffle fishways are to be fabricated from robust steel and inert materials, which are to be attached firmly to the base and walls of the culvert, and the structure is unlikely to fragment and pollute the stream. The fishway is an open structure, which is unlikely to pond water or harbour mosquitoes. Debris that may be trapped in the fishway can be removed and is unlikely to present a fire hazard.
- The culvert fishway is not readily visible to the public and does not present a public eyesore. The fishway is neatly integrated with the culvert infrastructure, and has the positive visual characteristics of a robust technical facility with environmental benefits.
- The fishway is not expected to adversely affect recreational activities in the adjoining stream such as fishing or picknicking. Recreational fishing should improve in adjoining waterways as a result of improved fish migration and reduced interference with fish lifecycles. Swimming is unlikely to take place in the vicinity of the culvert and the slow flowing nature of the culvert and fishway in low flow conditions is unlikely to provide a safety threat for recreational activities.
- There are no apparent matters of cultural significance at the sites that will be affected by the fishways.

Land tenure, institutional, infrastructure and other constraints

- Approvals or waivers for riverine protection permits under S266 of the Water Act 2000 will be sought from Department of Natural Resources and Water, and for permits under the Fisheries Act from Department of Primary Industries and Fisheries.
- Planning, design and development of fish passage facilities for the road-waterway crossings has been incorporated into environmental reviews, environmental impact assessments, and environmental management plans for the road project.
- Best practice environmental management provisions during construction of the fishway will ensure that water management, pollution control and other environmental measures are employed to avoid point source or diffuse pollution of the stream, or other environmental harm associated with construction.
- The fishway and associated protection works do not adversely alter the structure of the multi-cell box culverts and adjacent waterway reaches, nor threaten the integrity of the road and other adjoining infrastructure.
- All underground or above ground services (e.g. pipelines, elect

outlet. For narrower culverts on the new road (typically less than 6 cells) where waterway width upstream and downstream approximates the width of the culvert, the culvert end cell is adopted as the dedicated fishway barrel (Box E6.2). For wide culverts on the new road (typically 8 and 9 cells wide) where the width of the waterway upstream and downstream is much less than the width of the culvert, the dedicated fishway cell is located in or adjacent to the culvert mid cell. The outside culvert cell is adopted for culvert crossings on the existing road, which are single bay structures comprising up to 5 culvert cells with a total structure width of less than 12 m.

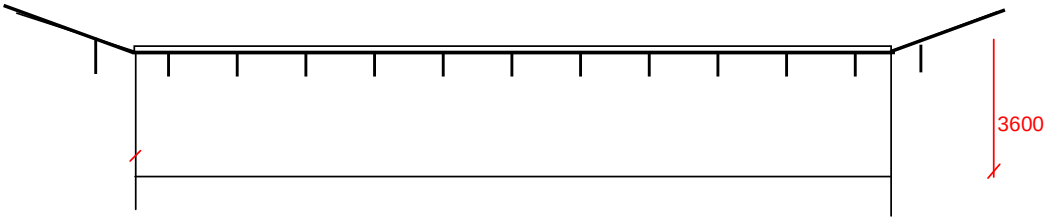
The fishway arrangements for the end cell and mid cell box culvert configurations incorporate the corner “EL” baffle fishway elements at 1800 mm longitudinal spacing, fixed to the culvert base and side walls (Boxes E6.2 and E6.3). The corner baffle units extend onto the culvert inlet and outlet wingwalls for the end cell arrangement, and low profile floor baffle units are provided as extensions of the fishway outside the barrel onto the culvert inlet and outlet aprons for the mid cell design. Notches are provided in the corner baffle and floor baffle units to assist the passage of juvenile and small fish species close to the culvert side wall.

Low flow nib walls (400 mm high) are located at the culvert inlet to direct shallow flows into the dedicated fishway barrel, and low flow training walls (400 mm high) connect these nib walls to the wall of the box culvert cells at the culvert inlet, and extend over the outlet apron on the downstream side of the culvert. Notches (100 mm deep) are provided in the nib walls at the culvert inlet to provide flow connectivity through the non-fishway cells, and to allow upstream passage for fish that move into the relatively calm conditions in the non-fishway cell, and might otherwise be trapped downstream of the nib wall. Flow through the notches provides attraction flow for these fish to pass upstream through the notch.

The corner “EL” baffle fishway consists of a series of “L” shaped baffles in the corner of the box culvert cell that protrude a short distance from the culvert wall, and extend up the wall from the culvert floor (see Guidelines Part F – Baffle Fishways for Box Culverts). Design configurations (Boxes E6.2 and E6.3) [illegible]

Box E6.2: Bruce Highway Corduroy Creek to Tully road: Corner "EL" baffle fishway for box culverts – End cell configuration (Source: Kapitzke 2007a)

Culvert plan showing fishway zones in end cells	Culvert section showing fishway zones



Corner "EL" baffle fishway in end cell – Plan view

Box E6.3: Bruce Highway Corduroy Creek to Tully road: Corner "EL" baffle fishway for box culverts – Baffle configuration (Source: Kapitzke 2007a)

Corner "EL" baffle fishway – Culvert cell looking downstream	Corner "EL" baffle detail

Notch details		Floor baffle detail

6.3.2 Fish passage facilities – University Creek Solander Road pipe culvert

For the Solander Road pipe culvert crossing of University Creek, where provisions for fish passage were incorporated as remediation measures for the existing culvert / causeway, fish passage options for the waterway crossing were examined in a concept design study for the project, and fishway design configurations were established as part of detailed design (see Kapitzke 2007c). Remediation at the crossing included stream protection work downstream to

7 FISHWAY DETAILED DESIGN AND IMPLEMENTATION

The concept design and preliminary / feasibility design phases of a project establish the fish passage design provisions for the road crossing or other waterway structure and the general layout and configuration of the fish passage facilities at the structure. More specific design aspects for the fish passage devices and other miscellaneous features of the fish passage facilities will commonly be established in the detailed design phase. This may include design details for fabrication of fishway components (e.g. baffles), and the configuration of fishways and associated features within the structures and adjoining waterways at the adopted sites.

Detailed engineering design and tender documents are often produced in the detailed design phase, and maintenance and monitoring plans may also be developed. Detailed designs are used for refining project costing, and in some cases may form the basis for seeking planning permissions and licences. Construction of the fishway and drainage structure should conform with design requirements, and operation and maintenance provisions should be made to ensure satisfactory long term performance of the facility. Provisions should also be made for physical and biological monitoring to allow evaluation of performance in relation to design objectives.

The following information illustrates detailed design and construction aspects for the corner “EL” baffle fishways for box culverts in the Bruce Highway Corduroy Creek to Tully project (Kapitzke 2007a). Design details for baffle fabrication, including evaluation of construction materials, were established as part of detailed design for this project. Specific configurations of fishway devices and associated culvert and waterway features at individual road crossing sites (baffle heights within culvert cells, configuration of dedicated fishway barrels, nib walls and low flow training walls) were also established in this phase. This fishway configuration aspect is often undertaken as part of the concept or preliminary design phases for these type of projects.

The corner “EL” baffles for box culverts in this project are fabricated from galvanised steel. Alternative materials such as other metals, precast concrete, composite fibre, or high density recycled materials could be considered for baffles such as this. If concrete or an alternative material with an appreciable thickness (100 mm or more) was used for this type of installation, the upstream face of the baffle units could be profiled to assist in debris shedding. The heights of the baffle tops above the culvert invert for each crossing were established from the anticipated flow depths in the culverts under the median low design condition (flow approx 1.5 m deep in adjoining defined waterway). The tops of the baffles were maintained at least 300 mm below the culvert obvert, multiples of 300 mm were adopted for baffle height intervals, and baffle heights were standardised between culverts where possible to reduce variations in baffle configurations.

The configuration of the dedicated fishway barrel, and the nib walls and low flow training walls for each of the adopted fish passage waterway crossings has been determined on the basis of drainage configurations leading to and out of the culvert, and the road infrastructure and other features adjacent to the culvert structure. For the standard end cell fishway installation at culverts on the new road, the corner “EL” baffles are fixed to the outside culvert wall and extend onto the culvert inlet and outlet wingwalls. The nib wall is located at the upstream edge of the inlet apron slab, and the low flow training walls are aligned parallel to and as an extension of the culvert walls. The standard mid cell fishway installation at culverts on the new road has a similar nib wall arrangement, and the training walls also extend parallel to the culvert walls.

Non-standard configurations have been used at several culvert sites to suit the adjoining waterway and infrastructure. This includes skewing the low flow training walls away from the line of the culvert walls in order to open up the low flow waterway connection between the dedicated fishway cell and the adjoining stream channel. At another site immediately adjacent to a waterway crossing on the existing road, the low flow training walls at the inlet to the culvert fishway are skewed away from the line of the culvert walls and connected directly to the outlet of the dedicated fishway cell in the corresponding culvert on the existing road.

8 BIBLIOGRAPHY

Kapitzke, I.R. 2006a, Bruce Highway Corduroy Creek to Tully planning study Provisions for fish passage – Road corridor scale Assessment Tasks 1A, report to Maunsell Australia and Department of Main Roads.
Kapitzke, I.R. 2006b, Discovery Drive offset baffle fishway for box culverts (Prototype Fishway # 1): Case study project design and prototype monitoring report to April 2005, report to Dept of Main Roads.
Kapitzke, I.R. 2006c, Douglas Arterial Project rock ramp fishway for open channels (Prototype Fishway # 2): Case study project design and prototype monitoring report to April, 2005, report to Dept Main Roads.
Kapitzke, I.R. 2007a, Bruce Highway Corduroy Creek to Tully High School Provisions for fish passage – Preliminary Design Assessment Tasks 1B and 2, report to Maunsell Australia and Dept of Main Roads.
Kapitzke, I.R. 2007b, Discovery Drive corner baffle fishway for box culverts (Prototype Fishway # 4): Case study project design and prototype monitoring report to April, 2006, report to Dept of Main Roads.
Kapitzke, I.R. 2007c, Solander Road pipe culvert fishway (Prototype Fishway # 3): Case study project design and prototype monitoring report to April 2006, report to Department of Main Roads.
Russell, D.J. and Hales, P.W. 1997, Fish resources and stream habitat of the Liverpool, Maria and Hull Catchments, prepared by Northern Fisheries Centre Cairns.

Ross Kapitzke
James Cook University
School of Engineering and Physical Sciences
April 2010 – VER2.0