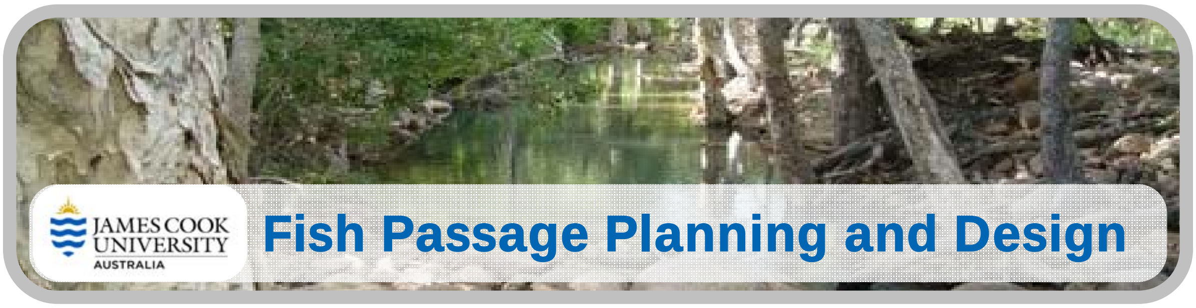

Culvert Fishway Planning and Design Guidelines

Part E – Fish Passage Design: Site Scale

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April 2010 – VER2.0

JAMES COOK UNIVERSITY
AUSTRALIA

James Cook University School of Engineering and Physical Sciences
Culvert Fishway Planning and Design Guidelines
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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*), (*Guidelines Part H – Rock Ramp Fishways for Open Channels*)

These *Guidelines* deal primarily with the ***Concept*** and ***Preliminary Design*** phases of planning and design procedures for road and other infrastructure projects. They apply to design of fish passage facilities to mitigate potential fish migration barrier impacts at new structures, and to remediate migration barriers by retrofit at existing structures (Box E1.1). The focus is on fishway facilities at road culverts but similar approaches apply for provision of fish passage at other waterway structures (e.g. channelised open channel sections, small weirs, control structures).

Box E1.1: Culvert fishway facilities established at Solander Road crossing of University Creek in Townsville to overcome fish migration barriers at existing culvert / causeway structure *(Source: Ross Kapitzke)*

Fish migration barriers at existing structure due to water surface drop and high velocity shallow flow at culvert outlet apron (24/03/05)

Rock ramp / cascade fishway constructed downstream of culvert to raise water levels in downstream channel – apron fishway under construction (17/12/05)

2 SITE SCALE PLANNING AND DESIGN

Planning and design for fish passage at the site scale is undertaken at individual road crossings and other waterway structures where the requirements for fish passage have been identified in road corridor scale assessment studies, in catchment or reach based waterway management programs, or through localised assessments for the waterway and site. Site scale design is informed by fish passage goals established in road corridor scale assessment (*Guidelines Part D – Fish Passage Design: Road Corridor Scale*), by broad scale natural resource management or infrastructure development strategies, or by local factors and site priorities.

Scope, purpose and timing

Site scale planning and design defines fish passage provisions to be made at priority waterway structures adopted in corridor scale assessment or at priority sites identified in other studies. For agencies such as the Department of Transport and Main Roads Queensland, this applies mainly to mitigation measures for potential fish passage impacts at new structures, but it also encompasses remediation measures to overcome fish migration barriers by retrofit at existing structures. Site scale fish passage design is usually undertaken in conjunction with other environmental assessment and design to provide input to waterway and drainage design in the ***Concept***, ***Preliminary Design*** and ***Detailed Design*** phases of road and other infrastructure projects.

Planning and design activities

The major planning and design activities, which are outlined in this *Guideline*, include:

- waterway and habitat assessment – waterway character, fish habitat, migration barriers
- fish species assessment and fish movement characteristics – diversity, swim capabilities
- fish migration barrier evaluation at culvert and adjoining channel sections – hydraulic zones
- objectives, criteria and constraints for fish passage design – design flow, allowable velocities
- fish passage options to meet multipurpose requirements – type, configuration
- design configuration of fish passage facility – fish passage, drainage, utility

Site investigation and characterisation (site assessment)

Site assessment tasks forming part of site scale planning and design may include the following, undertaken through field investigations or as desk top studies:

- catchment and waterway characterisation (e.g. bioregion, climate, ecosystems, landform, contributing catchment, land use, conservation status, institutional arrangements, management plans)
- waterways and flow characteristics (e.g. waterway type, channel form, channel geomorphology, permanence, catchment hydrology, waterway hydraulics, human activities and pressures)
- stream reach condition and fish habitat characteristics (e.g. waterway type, habitat type, crossing location, riparian condition, instream condition, disturbance, human activities and pressures, rehabilitation opportunities)
- road crossings and other waterway structures and fish migration barriers for the stream corridor adjacent to the site (e.g. barrier type, hydraulic barriers, barrier significance, remediation effectiveness, remediation feasibility, barrier location)
- fish community and fish movement characteristics (e.g. diversity, abundance, distribution, life stage, maturity, fish movement group, fish movement direction and timing, fish movement capabilities, fish swim speeds)
- waterway structure configuration (e.g. ownership and use, structure type, configuration, components, associated infrastructure, site and reach characteristics, stream condition)
- hydraulic conditions for waterway structure and adjoining stream reach (e.g. flow frequency, flow hydrograph, stream and culvert flow profile, culvert flow depth, velocity, flow pattern)

3 WATERWAY, HABITAT AND FISH SPECIES ASSESSMENT

For road crossings or other structures on waterways not assessed in terms of waterway character, fish habitat and fish community in road corridor scale or other waterway studies, it is necessary to undertake these assessments as part of the site scale studies for the structure. The approach to waterway, habitat and fish community assessment for site scale planning and design for fish passage at individual structures on a stream, or at a series of structures on a waterway system is outlined in this Chapter. It follows a similar approach to that presented in the road corridor scale assessments outlined in *Guidelines Part D – Fish Passage Design: Road Corridor Scale*, with the waterway and habitat assessment focusing on aquatic fauna connectivity and habitat values within a single waterway rather than multiple waterways that cross the road corridor.

The following sections give some guidance to assessment of waterway characteristics, fish habitat and other fish migration barriers on the stream. The method for assessment of fish community and fish movement characteristics is based on that presented in *Guidelines Part B – Fish Migration and Fish Species Movement Behaviour*. These tasks are illustrated for the Solander Road culvert crossing of University Creek in Townsville, where a prototype fish passage facility was established in 2005 as part of a network of culvert fishways on the stream (Kapitzke 2007c). The Solander Road fish passage design case study is also used in conjunction with the Bruce Highway Corduroy Creek to Tully road project (Kapitzke 2006a; Kapitzke 2007a) to illustrate other sections of this *Guideline*.

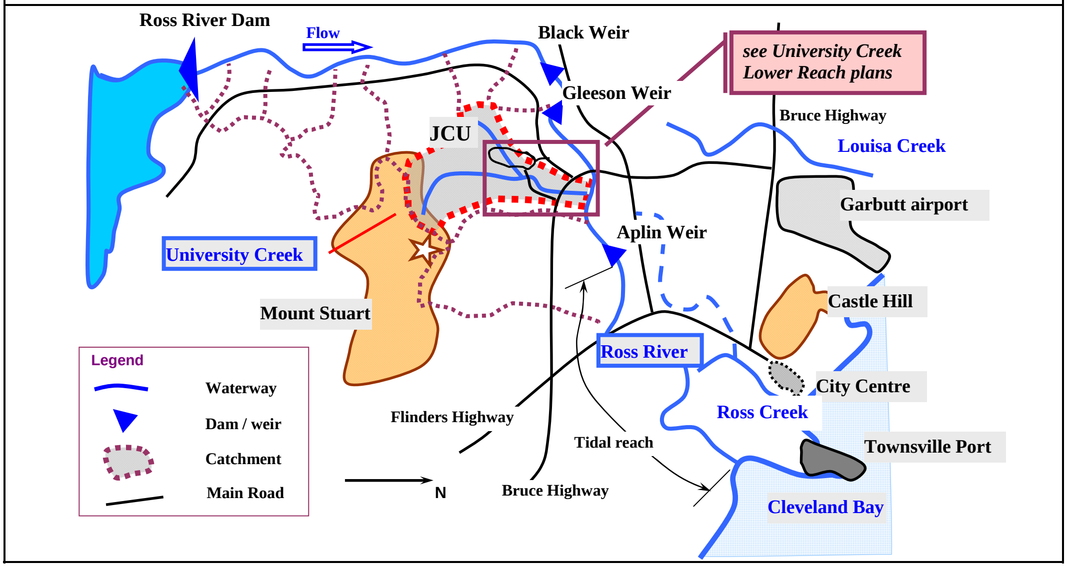
3.1 Catchment and waterway character

Understanding of the character of the waterway and its catchment context is important for site scale design for fish passage at waterway structures. This requires description of the biophysical characteristics of the catchment and waterway (e.g. bioregion, climate, ecosystems, landform, contributing catchment), and identification of relevant socio-cultural factors (e.g. land use, conservation status, institutional arrangements, management plans).

Data category	Example of information to assess
bioregional classification	• wet tropics, brigalow belt, coastal plain
climate	• seasonality, rainfall, temperature
significant ecosystems	• rainforest, wetlands, coral reefs
landform	• upland, floodplain, coastal
contributing catchment	• area, elevation, slope, stream length, tributary systems
land use	• agriculture, forestry, mining, urban
conservation status	• national park, conservation area, environmental reserve
institutional arrangements	• local authority, regional NRM group, land tenure
management planning	• NRM plan, coastal management plan, rehabilitation plans

For example, University Creek is situated in the brigalow belt region in north Queensland and is subject to monsoonal rainfall events and severe wet season flooding. University Creek flows from the eastern slopes of Mount Stuart, and is one of the principal tributaries of Ross River, which discharges into Cleveland Bay in Townsville (Box E3.1). The upper reaches of the creek are located on James Cook University campus and Department of Defence land, where riparian forest and creek-associated vegetation are retained in good condition. The lower reaches in the vicinity of Ross River are subject to disturbance associated with urban development. The riparian corridor has important conservation and amenity value in an area of degraded remnant bushland and urban / residential development, and management planning initiatives have been undertaken to maintain and restore riparian and instream connectivity in the waterway.

Box E3.1: University Creek and the lower reaches of Ross River *(Source: Kapitzke 2007c)*



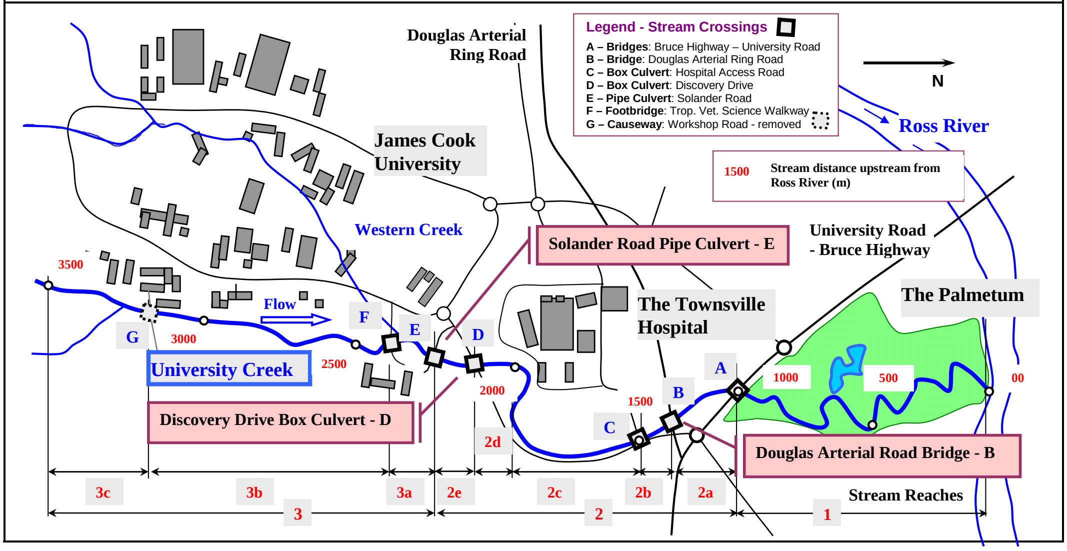
3.2 Waterway and flow characteristics

The nature of the waterway (e.g. waterway type, channel form, geomorphology, permanence), and the flow characteristics (e.g. catchment hydrology, waterway hydraulics) provide the template for assessing fish habitat characteristics of the waterway upstream and downstream of the structure. 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
waterway type	• major stream, flood channel, wetland, constructed drain
channel form	• incised channel, leveed stream, artificial channel
channel geomorphology	• pool / riffle structure, substrate, bank material, stream process
permanence	• perennial, intermittent
catchment hydrology	• flood discharge, streamflow hydrographs
waterway hydraulics	• flow depths, velocities, flow patterns
human activities and pressures	• channelisation, encroachment, river works, infrastructure

University Creek is a small tributary stream, which in its lower reaches flows in a well-formed channel on an alluvial floodplain. The creek has an intermittent flow regime and typically flows in the wet season months of December – April. The steep upper catchment causes rapid stream flow rises, with flows maintained for several weeks following major storm events. An adjoining catchment has been diverted into the main University Creek channel in the vicinity of the JCU campus (Box E3.2), and the lower reaches of the creek are affected by encroachment into the riparian zone, infrastructure crossings of the stream, and invasion of exotic plants.

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

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

- riparian vegetation condition, width and continuity
- instream habitat diversity and pool and riffle integrity

As an example, the lower reaches of University Creek connect directly with permanent habitat in Ross River weir pondages, the upper creek reaches are in good condition, whilst the mid reaches are disturbed and degraded by human activities and pressures (Box E3.3). The upper creek reaches represent significant breeding habitat for the Plotosid Catfish, which are naturally abundant and play a major role in the overall biomass and biodiversity of the Ross River system. University Creek is the only stream in the lower Ross River catchment providing significant suitable spawning habitat for these species.

Box E3.3: Extract from University Creek reach description and habitat characteristics *(Refer Box E3.2; Source: Kapitzke 2006b)*

Reach 1 – Downstream reach within the Palmetum

- narrow channel within landscaped urban parkland, realigned and altered in parts
- riparian vegetation with good canopy cover retained in places, but clearing and exotic plant infestation elsewhere
- permanent pools ponded from Ross River, with gravel, sand and silt substrate, and woody debris and overhanging banks in places
- reasonable quality fish habitat

(Photo: 14/08/04; *Source: Ross Kapitzke*)

Reach 2d – Altered mid-reach at Discovery Drive culvert

- altered and degraded stream with urban development, revetment lining and infrastructure encroaching on the stream corridor
- clearing and disturbance of native riparian vegetation, with stream bank erosion and exotic plant infestation
- disturbed instream channel with altered channel form due to channelisation and infrastructure impacts
- reasonable fish habitat

(Photo: 16/01/04; *Source: Ross Kapitzke*)

Reach 3b – Natural upstream reach on JCU campus

- intermittent stream in forested upland regions, with only minor impacts from encroachment or other pressures
- natural channel with intact and continuous riparian vegetation forming substantial waterway corridor, with limited exotic plants
- coarse boulder / cobble / gravel bed stream with non-permanent pools and good water quality
- excellent seasonal fish habitat

(Photo: 24/03/06; *Source: Ross Kapitzke*)

3.4 Waterway structures and fish migration barriers

The significance of providing for fish passage at a road crossing or other waterway structure on the stream will be influenced by fish passage connectivity between habitat areas upstream and downstream of the site. Existing fish migration barriers at waterway structures downstream of the structure will affect fish migration upstream to the site. Fish migration barriers upstream of the structure will fragment habitat within the waterway, and restrict access for fish to habitat areas further upstream. Information used to define other fish migration barriers on the waterway includes barrier type, barrier significance, ease of remediation, location relative to waterway structure. Examples of the type of information that should be examined for a site scale assessment are presented below. This may require specialist fish passage advice.

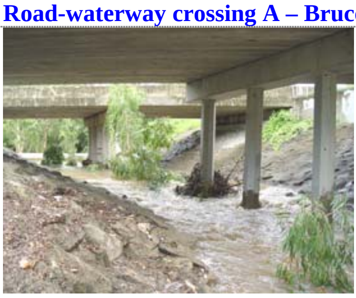
Data category	Example of information to assess
barrier type and configuration	• dam, weir, barrage, grade control, culvert, water quality
hydraulic barriers to fish passage	• water surface drop, velocity, water depth, turbulence
barrier significance	• total, partial, temporal – related to fish species and flows
remediation effectiveness	• compete, restricted, limited
remediation feasibility	• minor constraints, major constraints, limited likelihood
barrier location relative to habitat	• estuarine, lowland, upland, tributary stream, habitat denied

Assessment of other fish migration barriers and their location relative to the extent and quality of fish habitat in the stream, will assist in determining the merit of mitigation of the fish migration barrier at the adopted waterway structure. Mitigation will be most beneficial if the structure represents the most downstream barrier on the stream, but the benefit will be restricted if barriers further upstream prevent access to principal habitat areas.

University Creek in its unaltered condition would have allowed migration of the fish community to all habitat areas upstream, but development of road crossings and other zones of disturbance have obstructed fish migration at several locations. Road bridges on the stream represent some constriction of flow, but no apparent migration barrier. The migration barrier effect of box culvert structures depends on the configuration of the culvert and the hydraulic conditions in the adjoining downstream reaches (Box E3.4). Fish migration barrier remediation has been undertaken at several culvert crossing sites, including the Discovery Drive box culvert and the Solander Road pipe culvert, which prior to remediation, would have severely restricted upstream access to Reach 3 (over 60 % of the prime spawning habitat for the Plotosid Catfish – Box E3.5).

Box E3.4: Extract from University Creek road-waterway crossings and fish migration barriers *(Source: Kapitzke 2006b)*

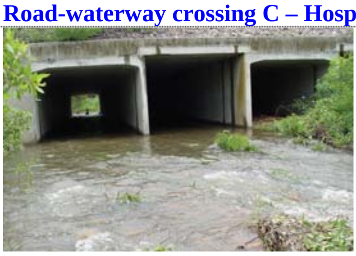
Road-waterway crossing A – Bruce Highway bridge



- dual, double span concrete bridges with concrete rock pitched lining to bridge abutments and stream bed and banks
- bridge piers located within the centre of the stream channel and some vegetation growth constricting flow
- restriction to fish passage for weak swimming species due to high velocities and turbulence at low flows

(Photo: 16/01/04; *Source: Ross Kapitzke*)

Road-waterway crossing C – Hospital access road box culvert



- multi-cell box culvert located within a stream channel pool section
- pooled water and variable sediment deposition in channel base and low culvert velocities at low flows
- no apparent barrier to fish migration at low flows

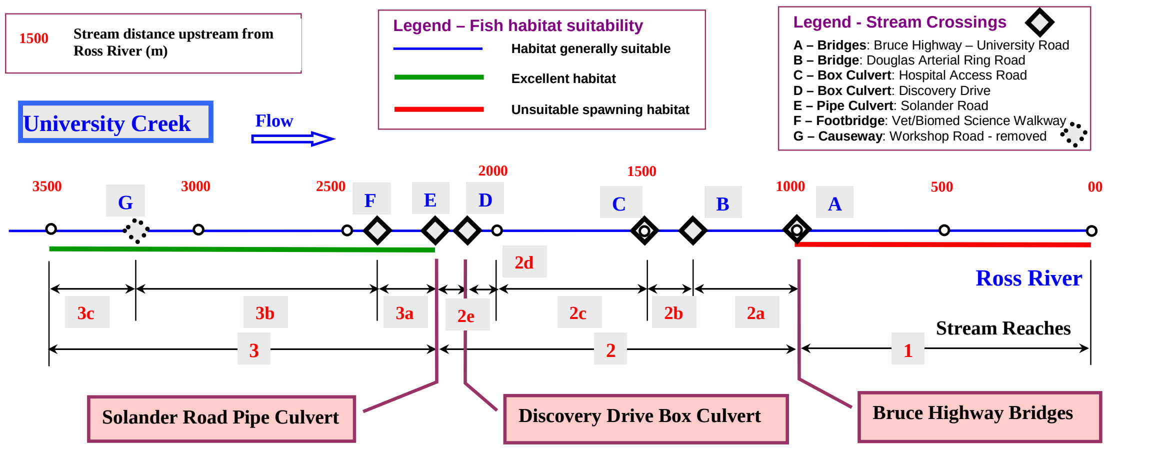
(Photo: 15/01/04; *Source: Ross Kapitzke*)

Road-waterway crossing D – Discovery Drive box culvert

- multi-cell box culvert located upstream of stream riffle section
- regular culvert channel form providing adverse hydraulic conditions for fish at low and medium flows
- barrier to fish migration associated with high velocities, shallow water depth, lack of resting place and excess turbulence
- prototype fishway installed at culvert overcomes migration barrier

(Photo: -/04/00; *Source: Ross Kapitzke*)

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	✓✓	Excellent habitat		
2e	E – Solander Road	2200	100	✓	Degraded	1300	60
2d	D – Discovery Drive	2100	250	✓	Degraded	1400	65
2c		1850	350	✓	Coarse gravel runs	1650	77
2b	C – Hospital Road	1500	150	✓	Sand, gravel runs	2000	93
2a	B – Douglas Arterial Rd	1350	350	✓	Silty sand	2150	100
1	A – Bruce Highway	1000	1000	x ✓	Silty sand, pools	2150	100
Legend	✓✓	Excellent habitat for all species		✓	Habitat generally suitable for all species		
	x ✓	Unsuitable spawning habitat for catfish but habitat generally suitable for all species					

3.5 Fish community and fish movement characteristics

Knowledge of the fish species diversity, abundance and distribution within the waterway, and an understanding of fish movement behaviour for these species will provide the basis for fish passage design at the waterway structure to suit the requirements of the fish community for the stream. The approach to assessment of the fish community and their fish movement characteristics follows the method for road corridor scale assessments outlined in *Guidelines Part D – Fish Passage Design: Road Corridor Scale*, with the focus being on the single waterway rather than multiple waterways that cross the road corridor. This method is in turn based on *Guidelines Part B – Fish Migration and Fish Species Movement Behaviour*.

Information on the diversity, abundance and distribution of the fish community in the waterway can be obtained from specific data for the waterway, or can be inferred from broader scale studies of the catchment and surrounding region, and surveys of similar adjoining catchments. Dedicated fish surveys of the waterway may be required in cases where specific information is required in relation to habitat and connectivity issues for particular species or locations.

Movement characteristics of the fish to be taken into account for fish passage design include spatial movement (upstream, downstream), temporal movement (season, flood stage), and fish swimming capabilities to negotiate flow conditions at the structure. In determining movement behaviour and movement capabilities (e.g. swim speed), conservative approaches can be adopted using default design swim speed values that encompass the complete fish community, or specific swim speed characteristics for particular species can be used where available for design. The method presented in *Guidelines Part D* allows for assessment of fish movement behaviour and 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 fish 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 size and swimming ability. Overall characteristics of the fish community can be assembled in this manner for use in design, or alternatively, specific characteristics for particular fish species, life stage and maturity can be established from the available data in the literature to meet specific design provisions at the structure. Information on fish movement behaviour for the waterway is not commonly obtained directly from local data.

The fish movement categorisation and movement characteristics for the fish community can be used to determine those species facing the most adverse upstream movement conditions at the waterway structure, and fish movement capability groups can be established to define broad fish movement characteristics and swimming capabilities of the fish community for critical movement directions and timings (AUS – adult upstream spawning migration, and JUD – juvenile upstream dispersal migration). Alternatively, specific movement capabilities for design can be established from movement data available for particular species. Information on movement capabilities of the fish is most commonly established from limited general data available in the literature.

As an illustration for the Solander Road fishway project, the fish community surveys for University Creek show a maximum species diversity of 13 native fish in 9 families, recorded in 2003 (Box E3.6). Results of this survey and others in the creek are presented, with fish species grouped by family names and listed alphabetically by common name, with genus and species included. Each species is categorised by fish movement group, in terms of life-cycle, spawning and migration characteristics. An assessment of fish movement characteristics for these species using the method outlined above and presented in *Guidelines Part D*, leads to nominal fish swim speeds for the University Creek fish community, as shown in Box E3.7.

Box E3.6: University Creek fish community *(Source: Kapitzke 2006b; Kapitzke 2007c)*

Common name	Family, genus, species	Life-cycle, spawning and migration (Fish movement group)	Brennan (2000) [1]	Webb (2003)	Webb (2004 – 2007)
Cardinalfishes	**Apogonidae**				
Mouth almighty	*Glossamia aprion*	Potamodromous (P3)		✓	✓
Eels	**Anguillidae**				
Long finned eel	*Anguilla reinhardti*	Catadromous (C1)		✓	✓
Eel-tailed catfish	**Plotosidae**				
Black catfish	*Neosilurus ater*	Potamodromous (P1)	✓	✓	✓
Hyrtl's tandan	*Neosilurus hyrtlii*	Potamodromous (P1)	✓	✓	✓
Glass perchlets	**Chandidae**				
Agassiz's glass perch	*Ambassis agassizii*	Potamodromous (P3)		✓	✓
Grunters	**Therapontidae**				
Banded grunter	*Amniataba percoides*	Potamodromous (P2)		✓	✓
Spangled perch	*Leiopotherapon unicolor*	Potamodromous (P1)	✓	✓	✓
Gudgeons	**Gobiidae: Eleotrididae**				
Empire gudgeon	*Hypseleotris compressa*	Potamodromous (P2) / Catadromous (C2) ?		✓	
Fire tailed gudgeon	*Hypseleotris galii*	Potamodromous (P3)		✓	✓
Purple spotted gudgeon	*Mogurnda adspersa*	Potamodromous (P3)	✓	✓	✓
Hardyheads	**Atherinidae**				

Box E3.6: University Creek fish community *(Source: Kapitzke 2006b; Kapitzke 2007c)*					
Common name	**Family, genus, species**	**Life-cycle, spawning and migration (Fish movement group)**	**Brennan (2000) [1]**	**Webb (2003)**	**Webb (2004 – 2007)**
Fly specked hardyhead	*Craterocephalus stercusmuscarum*	Potamodromous (P4)		✓	✓
Herring	**Clupeidae**				
Bony bream	*Nematolosa erebi*	Potamodromous (P3)		✓	✓
Rainbow fishes	**Melanotaeniidae**				
Eastern Qld rainbowfish	*Melanotaenia splendida*	Potamodromous (P3)	✓	✓	✓
Alien species					
Top minnows	**Poeciliidae**				
Guppy	*Poecilia reticulata*	growth ?			✓
Mosquitofish	*Gambusia holbrooki*	growth ?		✓	✓
Platy	*X maculatus*	growth ?		✓	✓
Mouth brooder	**Cichlidae**				
M mouthbrooder (Tilapia)	*Oreochromis mossambicus*	growth ?		✓	✓
Other					
Burton's haplochromis	*Haplochromis burtoni*	growth ?		✓	✓
		Total No of Species	**5 natives [1]**	**13 natives, 4 exotics**	**12 natives, 5 exotics**
Notes	1	This study focused primarily on Plotosid Catfish – other species may have been present			

Box E3.7: Nominal fish swim speeds for University Creek fish community *(Source: Kapitzke 2007c)*				
Fish movement capability group	**Common length of fish**	**Prolonged speed**	**Burst speed**	**Comment**
AUS – Adult upstream spawning migration (fish movement groups P1, P3)				
Medium size fish species – adults				
Group AUS1 – Eel-tailed Catfish	adults 15 cm - 25 cm	0.45 m/s to 0.75 m/s	0.9 m/s to 1.5 m/s	3 BL/s used for prolonged swim speed (default value) 2 x prolonged speed used for burst swim speed (notional value)
Group AUS2 – Grunters	adults 15 cm - 25 cm			
Small size fish species – adults				
Group AUS3 – Rainbowfish	adults < 10 cm	0.25 m/s	0.5 m/s	3 BL/s used for prolonged swim speed (default value) 2 x prolonged speed used for burst swim speed (notional value)
JUD – Juvenile upstream dispersal migration (fish movement groups C1, C2, P2, P3, P4)				
Medium - large size fish species – juveniles				
Group JUD1 – Eels	adults 60 cm - 100 cm (juveniles to 30 cm)	0.3 m/s to 1.0 m/s	up to 1.4 m/s	prolonged and burst swim speeds based on data for juvenile eels, barramundi and jungle perch
Group JUD3 – Flagtails / Herring	adults 20 cm - 25 cm (juveniles to 10 cm)			
Small size fish species – juveniles				
Group JUD4 – Hardyheads / misc. species	adults < 20 cm (juveniles to 10 cm)	0.1 m/s to 0.3 m/s	0.2 m/s to 0.6 m/s	3 BL/s used for prolonged swim speed (default value) 2 x prolonged speed used for burst swim speed (notional value)
Group JUD5 – Gobies / Grunters / Gudgeons	adults 10 cm - 20 cm (juveniles to 10 cm)			
Group JUD6 – Cardinalfishes / Glass perch / Gobies / Gudgeon	adults < 10 cm (juveniles to 5 cm)			

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) are then 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	• road agency, local authority, private, property boundaries
structure use – past, present, future	• road, bikeway, footpath, services
structure type and integrity	• bridge, box culvert, pipe culvert, causeway
configuration and dimensions	• no of spans / cells, width, length, height, slope, invert drops
structure components	• approach channels, inlet and outlet structures, culvert barrel
associated infrastructure and facilities	• services, grade control, protection works, channelisation
site characteristics	• site topography, downstream erosion, foundations, vegetation
adjoining stream reach	• channel form, substrate, channel width and depth, gradient
stream condition and processes	• natural / degraded channel, erosion / deposition, debris load

For example, in the Bruce Highway Corduroy Creek to Tully road project, provisions for fish passage at road-waterway crossings are made at 5 multi-span bridges on well defined waterways, and 6 multi-cell box culvert structures at flood channel crossings of the road corridor (4 on new road; 2 on existing road). The waterway structures are configured primarily for transport, drainage, and other utilitarian objectives, and provisions for fish passage are incorporated as mitigation measures (new road) or remediation measures (existing road) to address the potential fish barrier effects of the crossings (see Kapitzke 2007a).

The multi-span bridge structures present little obstruction to stream flow or fish movement and typically span the waterway without significant alteration to the stream bed or bank configuration. The box culvert structures are typically 13.2 metres long for the 2 lane road carriageway, and comprise multi-cell 3600 mm culverts, with culvert heights for priority fish passage crossings varying from 1200 mm to 3000 mm. Many of the multi-cell culverts are much wider than the poorly defined waterway channels 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 high 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 in 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 barrier assessment at fish passage flows and for consideration of drainage and utility 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 & discharge	• low flow (e.g. < 1 yr ARI), flood flow (e.g. 50 yr ARI)
flow hydrograph – duration, rise and fall	• low flow (e.g. < 1 yr ARI), flood flow (e.g. 50 yr ARI)
stream flow profile – adjoining reach	• low flow (e.g. < 1 yr ARI), flood flow (e.g. 50 yr ARI)
headwater / tailwater vs discharge curves	• low flow to flood flow
culvert flow profile – head loss, water drop	• low flow (0.5 m depth), medium flow (1.5 m depth)
culvert flow depth, velocity, flow pattern	• low flow (0.5 m depth), medium flow (1.5 m depth)

As outlined in Section 5.3, design flow conditions to be considered for fish passage are low flow (flow up to approx 0.5 m deep – inundating channel bed for defined waterway), and medium flow (flow from approx 0.5 m to approx 1.5 m deep – below low flow channel bench for defined waterway). These flow conditions are expected to correspond to discharges less than the 1 year ARI design flow for the waterway. Drainage design flows for the structure and adjoining stream reach commonly range from 2 year ARI to 50 year ARI, depending on the facility and the design standards applying. In order to establish flow characteristics for the fish passage and drainage design flow conditions at the waterway structure, hydraulic conditions are usually examined for a range of stream flow conditions from very low to flood flows at the site. For the fish migration barrier evaluation, conditions must be examined for all hydraulic zones of the structure from downstream to upstream (see Section 4.3).

Flow frequency data and flow hydrographs for the structure are usually available from hydrologic studies undertaken for road drainage design or other flood studies for the catchment. Data may be available from stream gauging stations on this waterway or from adjacent sites. Stream flow profiles in the reach adjoining the structure and in the culvert or other drainage structure at the site may also be available from road drainage design studies, although these are likely to focus on 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 barrier 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 road are located within generally slow flowing, low gradient waterways with little likelihood of water surface drops at the structures or in adjacent sections of the waterway. The relatively slow floodplain velocities (e.g. 0.3 m/s) are expected to produce tailwater conditions that typically back-up to the waterway crossing without substantial water surface gradient.

For the Solander Road crossing of University Creek, flood frequency information was available from drainage design studies undertaken for other road crossings of the stream. Substantial field monitoring of water surface profiles, flow depths, velocities and flow patterns in University Creek had been undertaken over a period of more than 10 years, and field measurements and observations of velocities, flow depths and flow patterns at the Solander Road culvert and causeway provided good baseline data for fish passage evaluation and design for the crossing.

Field and office studies of flow characteristics for the Solander Road culvert crossing showed adverse hydraulic conditions for fish passage through all hydraulic zones of the structure. This included a water surface drop of about 200 mm at the downstream apron in low flows, shallow flow depths and velocities of up to 4 m/s on the culvert outlet apron, high velocities of more than 4 m/s in the culvert barrel, and lack of resting place for fish at the culvert inlet. The causeway readily overtops in medium flow conditions in the creek, with high velocities and low tailwater conditions causing stream erosion and infrastructure damage and proving impassible for fish.

4.3 Fish migration barrier evaluation for structure

The road crossing or other waterway structure may represent a barrier to upstream fish passage if hydraulic conditions in the structure are more severe than swim capabilities or do not suit 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).

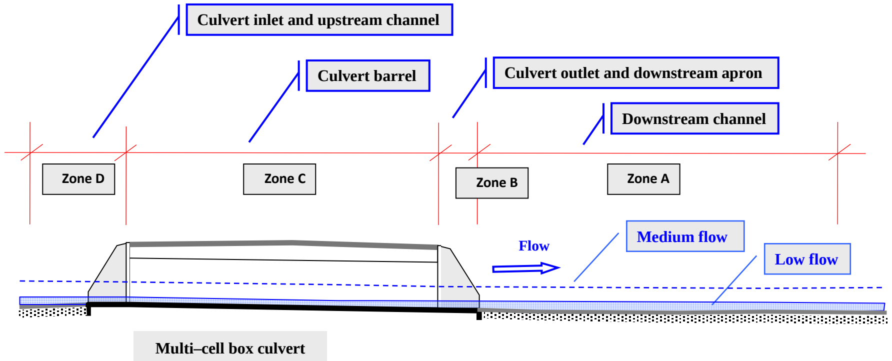
The fish migration barrier effects at the waterway structure depend on the characteristics of the structure (Section 4.1), the hydraulic conditions at the structure (Section 4.2), and the desirable flow characteristics for fish passage at the structure, including the allowable fish swim speeds at the 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 Corduroy 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 medium flow, the critical conditions are high velocities (up to 0.9 m/s) and lack of shelter throughout the structure, and lack of attraction flow at the culvert outlet.

For the multi-span bridge crossings at defined waterways on the Corduroy Creek project, no substantial fish barrier effects are anticipated as stream conditions are not substantially affected by the new bridge structures at the crossings, and overall flow conditions are expected to be similar to natural flow conditions in the waterways. Whereas maximum midstream velocities in excess of fish swim capabilities are estimated for medium flow conditions (up to 1.8 m/s), appropriate treatment of bridge abutments, stream edges and lower terraces within the waterways will create low velocity and sheltered flow conditions on the edge of the stream that will enable fish passage through the sites.

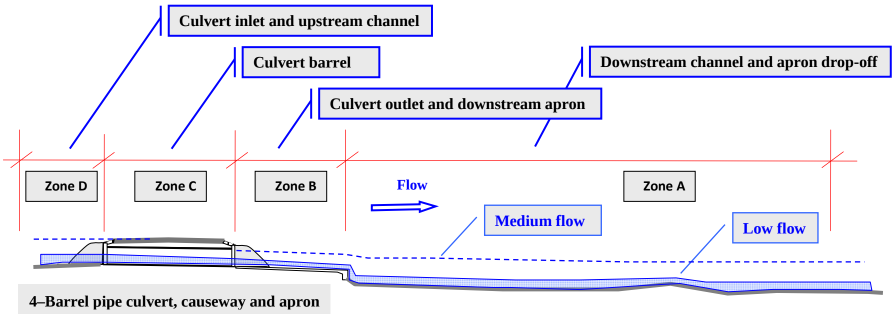
Box E4.1: Corduroy Creek to Tully multi-cell box culverts: Hydraulic zones and fish migration barriers for low and medium flow *(Source: Kapitzke 2007a)*



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	• lack of attraction flow for fish moving upstream to culvert outlet / fishway entrance • no hydraulic barriers anticipated in this Zone due to high tailwater conditions downstream	• wide waterway downstream of the culverts with velocities of ~ 0.1 m/s at low flow • the low velocity flow will not provide a defined path of attraction for fish to move to particular parts of the culvert	• lack of attraction flow for fish moving upstream to culvert outlet / fishway entrance • no hydraulic barriers anticipated in this Zone due to high tailwater conditions downstream	• wide waterway downstream of the culverts with velocities of ~ 0.3 m/s at medium flow • 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	• shallow water depths on downstream apron	• at very low flows, water will spread across the full culvert outlet at depths less than 300 mm – minimum requirement of for fish movement	• high velocities and lack of shelter at culvert outlet and on downstream apron	• 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	• shallow water depths in culvert barrel	• at very low flows, water will spread across the full culvert outlet at depths less than 300 mm – minimum requirement for fish movement	• high velocities in culvert barrel • regular cross section and lack of resting place along culvert barrel	• velocities of ~ 0.5 m/s and ~ 0.9 m/s are beyond fish capabilities for prolonged / burst swim mode • no resting points for fish in the culvert barrel
Zone D: Culvert inlet and upstream channel	• shallow water depths on upstream apron	• at very low flows, water will spread across the full culvert inlet at depths less than 300 mm – minimum requirement for fish movement	• high velocities and lack of shelter at culvert inlet and on upstream apron	• velocities of ~ 0.5 m/s and ~ 0.9 m/s and no resting points for fish are beyond fish capabilities on the upstream apron

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 barrels 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 adverse 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

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

(Photo: 15/01/04; *Source: Ross Kapitzke*)

Zone B: Culvert outlet and downstream apron

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

(Photo: -/02/02; *Source: Ross Kapitzke*)

Zone C: Culvert barrel

- high velocity jet with excess turbulence and no resting points within the culvert barrel for low flows
- high velocity jet with excess turbulence and no resting points within the culvert barrel for medium flows

(Photo: -/02/02; *Source: Ross Kapitzke*)

Zone D: Culvert inlet and upstream channel

- turbulent, high velocity flow at pipe and upstream channel for low flows
- lack of shelter zones upstream of culvert and constricted flow tending to sweep fish back into pipe at low flows
- ponded but constricted flow upstream of culvert with high velocity zones at pipe inlet tending to sweep fish back into pipe at medium flows

(Photo: 15/01/04; *Source: Ross Kapitzke*)

5 OBJECTIVES, CRITERIA AND CONSTRAINTS FOR FISH PASSAGE DESIGN

Provisions that are made for fish passage at the waterway structure must meet multipurpose design requirements related to such things as transport, 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 remediation 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 (e.g. 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 swim speeds for fish 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 Creek 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)	• 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). • The fishway structure should not appreciably increase the upstream water level for the range of discharges up to the design discharge for flooding. • The drainage design flows for the culvert cannot be altered, neither can the requirements for drainage immunity of the road. • 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)	• 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. • 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)	• 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 • 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)	• Development and operation of the fishway should not adversely affect the culvert or other adjacent infrastructure, utilities or landuse. • The fishway should not cause erosion or other damage to the stream and its associated physical and biological features
2 Fish passage	
2.1 Provide for fish passage through the structure during critical seasonal/flood periods, over a range of flow capacities (D)	• Fish passage in streams on the Tully Murray floodplain is mostly required within a low flow (nominal 0.5 m flow depth) to medium flow (nominal 1.5 m flow depth) range during the normal seasonal migration periods. • During high and very low discharges, the likelihood of fish migration in the stream is small, and the requirement for fish passage at the culvert is reduced.
2.2 Provide a continuous fish pathway through the structure with entrance and exit adjacent to the normal fish path (M)	• The structure should provide a continuous pathway to allow fish to pass through the culvert in a satisfactory time without undue or harmful delay. • The structure should provide suitable fishway entrance and exit arrangements that connect fish passage through the structure with the principal fish paths in the adjoining stream. • Fish normally travel along the stream bank, and access through the fishway on both stream banks is preferred. • The spawning ability of some fish species and the health and well being of all migrating fish may be affected if they are delayed or exhausted through flow obstruction or lack of a suitable pathway, entrance or exit for the fishway.
2.3 Provide fish passage for juveniles and adult fish and for species swimming on the stream bed or close to the water surface (D)	• Fishway designs should cater for the various fish swimming abilities and behaviours, according to the size and species of fish. • Fishways should desirably provide passage for the full range of native species in the stream at all lifecycle stages, but may be designed for target species of particular maturity or size in some situations. • To cater for bottom and surface swimming fish, fishway designs should provide suitable hydraulic conditions on or close to the bed and/or the water surface at flow depths up to medium flow conditions.
2.4 Ensure flow velocities and water depths through structure are suitable for fish swim capabilities (M)	• Ensure water velocities and resting areas through the various culvert zones, fishway components and associated transitions between fishway components are suitable for the fish swimming abilities and behaviour. • Fish travelling at prolonged speeds over long distances can negotiate low velocities (estimated range 0.1 – 1.0 m/s for Tully Murray species). Fish travelling at burst speeds over short distances between rest points can negotiate medium velocities (estimated range 0.2 – 1.5 m/s for Tully Murray species). • Water depths commonly decrease with decreasing discharge or increasing slope until the culvert/fishway is inaccessible for fish. • Fish require minimum depths of water for successful passage and for them to swim without harming themselves (reportedly 0.2 – 0.3m).

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
2.5 Prevent adverse flow turbulence through structure and ensure water surface drops at structure outlet and inlet are not excessive (M)	• The structure should not produce excessive flow turbulence that presents barriers to fish passage or causes harm to fish. • Fish can only tolerate a particular level of turbulence without distress, and may experience a lowered immune system if injured. The spawning ability of fish and their health and well being may be affected if they are delayed or exhausted through flow obstruction. • The water surface flow profile through a culvert may drop at the culvert outlet/fishway entrance due to a drop in the stream bed profile at the outlet or due to low tailwater levels in the stream. • The water surface flow profile may also drop at the culvert inlet/fishway exit due to a flow constriction or a drop in the stream bed profile at the inlet. • Australian fish have only very limited ability to jump, or to ascend drops in the water surface.
2.6 Provide attraction flows for fish at the structure outlet / fish entrance (M)	• The structure should provide suitable fishway entrance arrangements that connect the principal fish paths and resting areas in the adjoining stream with fish passage through the structure. • The flow through the structure should enter the stream at a culvert outlet location that attracts the fish to the fishway entrance. Attraction flows must provide a continuous pathway for the fish through the fishway and the culvert. • Fish normally travel along the stream bank, and attraction flows on both stream banks is preferred. • The spawning ability of fish and their health and well being may be affected if they are delayed or exhausted through being unable to find the fishway entrance.
2.7 Ensure suitable flow conditions at the structure inlet to protect fish from downstream flows (M)	• The fish should exit into the stream at a culvert inlet location that enables continued travel upstream, and ensures that they are not swept downstream through the culvert. • Fish normally travel along the stream bank, and suitable exit locations on both stream banks are preferred. • The spawning ability of fish and their health and well being may be affected if they are delayed or exhausted through being swept back downstream and having to negotiate the fishway several times.
2.8 Ensure fish are not obstructed from downstream migration through the fishway (M)	• The culvert / fishway should provide for downstream as well as upstream fish passage. The health and well being of the fish may be affected if they are injured (from turbulent flow, severe drops etc) in moving downstream through the fishway.
2.9 Ensure adequate natural light in the structure to suit passage of the relevant fish species (D)	• Fishways should be installed in culverts that are short enough and of sufficient cross section to provide adequate natural lighting into the structure to cater for various fish behaviours. • Some fish species reportedly require natural daylight patterns to sustain their migration, and are repelled by sudden changes in light levels at darkened tunnels, low culverts and pipes, which create behavioural barriers. • Riparian vegetation in Queensland streams contributes to lowering ambient light levels for native species.
3 Stream processes, riverine habitat and environmental values	
3.1 Maintain natural flow and sediment processes in the waterway (D)	• Development of the fishway facility should not block the stream channel or alter the natural flood and flow regimes for the waterway. • Ensure that sediment delivery through the fishway facility maintains natural sediment transport and deposition processes in the waterway.

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)	• Ensure that development of the fishway facility does not encroach or damage riparian or instream riverine habitat, nor impact terrestrial or aquatic ecosystems, including terrestrial and aquatic fauna well being and movement. • 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)	• 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)	• Endeavour to develop designs for the fishway facility and adjacent aquatic habitat features to restrict abundance, distribution and movement of exotic fish. • 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)	• Fishway components should be constructed from robust materials to withstand environmental conditions in the stream over the expected life of the facility. • 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. • 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)	• The fishway facility should provide for a range of hydraulic, biological and other monitoring, and consideration should be given to providing for monitoring access.
4.3 Ensure development and operation of the facility does not present a public safety problem (M)	• The fishway must not present a public safety risk to people accessing the site.
4.4 Avoid public health problems associated with the facility (M)	• The fishway must not present a public health risk to people, present a fire hazard, or provide a breeding ground for vermin or mosquitoes.
4.5 Maintain or enhance visual amenity at culvert and adjoining site (D)	• The design of the facility should have good aesthetic value that is acceptable to the public.
4.6 Minimise adverse effects on recreational amenity in the adjoining stream (D)	• The fishway facility should have minimal adverse effects on recreational activities in the stream. • Consider the effect of the fishway on recreational activities (eg. swimming, fishing, inner tubing, picnicking) through altered access and stream processes.
4.7 Preserve cultural heritage of site (D)	• Ensure features of cultural significance are identified during development of the facility and appropriate measures are taken to protect these cultural values.

1	**Note**	M = Mandatory	D = Desirable	

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 illustrated 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	• 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.
Legislation and statutory provisions	• The work on the culvert fishway must comply with legislative requirements and regulations related to impact assessment, environmental duty of care, issue of permits and approvals, and environmentally relevant activities (e.g. *Water Act*; *Environmental Protection Act, Fisheries Act, Environmental Protection and Biodiversity Conservation Act*). • A Riverine Protection Permit (RPP) under S266 of the *Water Act 2000* is required where alterations to a watercourse are to be made, including destruction of vegetation, excavation, and/or placing fill in the watercourse. • The *Environmental Protection Policy for Water (EPP Water)* provides a framework for protecting the environmental values of a water body and S31 of *EPP Water* prohibits deposition or release of sediment or other foreign material into the waterway. • The *Fisheries Act* requires that provision be made for fish passage where obstructions to water flow are caused by a waterway structure. • The *Environmental Protection and Biodiversity Conservation Act* relates to environmental impacts of designated activities of national significance.
Institutional arrangements	• Development and operation of the fishway facilities will be undertaken as part of the development for the Corduroy Creek to Tully road by DMR through the Tully Alliance.
Planning, policy and environmental management	• Ensure that fish passage installations on these culverts comply with local authority planning provisions and development planning and environmental management provisions for the region, and are integrated with goals for local and regional natural resource management plans. • Integrate designs, operation and monitoring of these fish passage facilities with other habitat enhancement and fish passage provisions on the Tully Murray floodplain. • Construction activities must comply with environmental management plan provisions in relation to water management, pollution control, erosion and sediment control, workplace, health and safety etc.
Roads, drainage and other infrastructure, underground and above ground services	• The road-waterway culvert structures cannot be changed significantly to incorporate the fishways (e.g. dimensions, bed roughness, configuration, construction materials). The integrity of the road, culvert and other adjoining infrastructure must be protected. • All services crossing the waterways in and adjacent to the culverts (e.g. water pipelines, electricity, communications) will be identified and considered in the road culvert design and will not be affected by the fish passage facilities.
Access for construction	• Access to the culverts will be readily available during development and construction of the road.
Funding and other resources	• Development of the fishway facilities will be incorporated into the Corduroy Creek to Tully road project. Further funding support (technical assistance, maintenance, monitoring) will be required for ongoing operation and management of the facility.
Construction timing and flood management	• It is preferable to develop and install the fishway facilities in the road culverts outside the regular wet season flow periods in the Tully Murray waterways.

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	• all native fish species, life stages and maturity	• all but outlier [(1)] native fish species (e.g. poor swimmers)	• not mandatory for any native fish species
Level 2 – intermediate	• all native fish species, life stages and maturity	• not mandatory for any native fish species	• not mandatory for any native fish species
Level 3 – restrictive	• all but outlier [(1)] native fish species (e.g. poor swimmers)	• not mandatory for any native fish species	• not mandatory for any native fish species
Notes	1 Restricted fish community may be identified on the basis of fish species diversity (e.g. icon species, weak swimming species), or on fish life stage and maturity (adult spawning / juvenile dispersal / adult dispersal / facultative movement for adults and juveniles)		

The fish passage design flow at the waterway structure defines the range of flow conditions in the waterway for which provisions for fish passage are to be made. Three bands of flow (low, medium, high) are adopted, according to nominal flow depth in relation to channel form in a natural waterway (see *Guidelines Part B – Fish Migration and Fish Species Movement Behaviour*). Fish migration in natural conditions is mostly expected to occur in low flow or medium flow, and is least likely to occur during high flow. This is reflected in the fish passage effectiveness criteria (Box E5.4), which provides for passage for all native fish species, life stages and maturity at low flow in the Level 1 and Level 2 criteria, for all but outlier native fish species (e.g. poor swimmers) at medium flow in the Level 1 criterion, and for no native fish species at high flow for either Level 1, Level 2 or Level 3 criteria

Flow bands for fish passage design	
Low flow condition	Flow up to approx 0.5 m deep
	Inundating channel bed for defined waterway
Medium flow condition	Flow from approx 0.5 m to approx 1.5 m deep
	Below low flow channel bench for defined waterway
High flow condition	Flow in excess of approx 1.5 m deep
	Upper channel or overbank flow for defined waterway

The swim speeds and other fish movement characteristics used in design of the fishway are based on the known swim characteristics of the target fish species, life stages and maturity group adopted for that design condition. For the low flow condition in the Level 1 and Level 2 fish passage effectiveness criteria, this would apply for all members of the native fish community present at the site, whereas for the medium flow condition in the Level 2 criterion, swim speeds and fish movement characteristics for all but outlier native fish species would apply.

The design swim speed for the waterway structure will be based on the swim capabilities of the target fish species under the relevant swim mode (burst or prolonged swimming). An envelope is usually applied to the fish swimming capabilities for the various groups of fish species, life stages and maturity and for the particular swimming modes. Fish swim speed information derived for the fish community in the waterway (Section 3.5) can be used where available, or other more specific data for particular species, life cycle stage and maturity may be used at particular structures and for particular situations where closer examination of design criteria and selection of priority species for passage is warranted.

As an illustration for the priority road-waterway crossings for the Bruce Highway Corduroy Creek to Tully road project, the most conservative (Level 1) design criteria for fish passage were adopted as the crossings mostly correspond with the highest fish movement corridor class (see Kapitzke 2007a). High fish passage effectiveness can also be achieved at these waterway crossings because the hydraulic conditions that constitute the fish migration barriers are not severely adverse. The Level 1 criterion provides for passage for all native fish species, life stages and maturity at low flow, for all but outlier native fish species (e.g. poor swimmers) at medium flow, and for no native fish species at high flow. In contrast to this, the Level 2 effectiveness criteria was adopted for fish passage provisions through the pipe culverts in the Solander Road crossing of University Creek (see Kapitzke 2007c). Although the fish habitat / waterway values for University Creek were high, the hydraulic barriers for this structure were severe and the limited opportunities for remediation constrained the fish passage design objectives for the site.

Swim speeds for various fish species, life stages and maturity groups of the Tully-Murray fish community undertaking adult upstream spawning migration (AUS) or juvenile upstream dispersal migration (JUD) were established in an assessment of fish movement characteristics in the road corridor scale studies (see Kapitzke 2006a). This was based on swim speed data for individual species within the species groupings where available from the literature, and was otherwise estimated using generic relationships from the swim behaviour information. The adopted swim speeds for fish passage design for burst and prolonged swim modes for the Tully-Murray fish community are summarised in *Guidelines Part B – Fish Migration and Fish Species Movement Behaviour*). The fish swim speed data for Solander Road crossing of University Creek, which were derived from the Tully-Murray data, are presented in this *Guideline* in Box E3.7. The envelope for the Tully-Murray and University Creek fish communities encompasses a prolonged swim speed range of 0.1 m/s to 1.0 m/s and a burst speed range of 0.2 m/s to 1.5 m/s.

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 following sections outline the approach to identification of component fish passage options to meet design requirements within each of the hydraulic zones of the structure, evaluation to determine the most suitable options for incorporation, and adoption of the preferred fish passage design to provide an integrated solution to the fish migration barrier problems at the site. This is illustrated for the Bruce Highway Corduroy Creek to Tully road project [new – mitigation] (Kapitzke 2007a), and for the Solander Road pipe culvert crossing of University Creek [existing – remediation] (Kapitzke 2007c). Fish passage options to overcome particular fish migration barriers within the hydraulic zones of the waterway structure are outlined in *Guidelines Part C – Fish Migration Barriers and Fish Passage Options for Road Crossings*. Whilst other fish passage design strategies may be appropriate and would be considered in design evaluation (e.g. stream simulation, plain culvert design), the focus here is on the hydraulic design approach (e.g. baffles).

6.1 Fish passage options for various hydraulic zones

The assessment of hydraulic conditions at the waterway structure (Section 4.3) has identified the characteristics of the fish migration barriers that should be overcome for the adopted structure designs. The solution to these fish migration barrier problems must address fish passage requirements for the structure, while satisfying other objectives relating to drainage, environmental protection, amenity and safety for the facility, and addressing the project constraints (Sections 5.1 and 5.2).

Fish passage provisions at the structure must address the particular barrier problems within each of the various hydraulic zones of the structure, and develop an integrated solution that provides for fish passage through the structure from downstream (fishway entrance) to upstream (fishway exit). The fish passage design must provide appropriate conditions for fish passage through each structure zone, while meeting overall requirements for the complete structure. "Thinking like a fish", the fish migration barrier problems and mitigation or remediation options should be addressed for the hydraulic zones, leading from downstream to upstream on the structure.

As outlined in *Guidelines Part C – Fish Migration Barriers and Fish Passage Options for Road Crossings*, one or more culvert fishway components may be required to address fish passage requirements within each zone, within transition sections between the hydraulic zones, and at the inlet and outlet to the waterway structure where it connects to the stream. Options for alternative overall crossing designs to overcome the barrier problems should be considered (e.g. using a bridge instead of a culvert, providing additional culvert cells). Guidance on fish passage measures to overcome the particular fish migration barrier problems within the various structure hydraulic zones is provided in *Guidelines Part C*.

As an illustration for the Bruce Highway Corduroy Creek to Tully road project, several alternative configurations were considered for the fishway facilities at the box culvert waterway crossings on the new road. These options are outlined below, an evaluation is presented in Section 6.2, and the adopted configuration is presented in Section 6.3.

The priority box culvert crossings on the Corduroy Creek project where fish passage provisions are to be made on the new road comprise multiple cell 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 crossing. Culvert heights vary from 1200 mm to 3000 mm.

Hydraulic conditions for these culverts are relatively moderate at the fish passage design flows, and provisions for fish passage are to be made to address potential barriers in the culvert barrels and at the culvert inlet and outlet structures (Section 4.3). As illustrated in *Guidelines Part C – Fish Migration Barriers and Fish Passage Options for Road Crossings*, and as identified above in Chapter 5, the objectives are to provide adequate low velocity and sheltered areas within the culvert barrel and adjoining structures in low flow and medium flow conditions, and to ensure that connectivity for upstream fish movement is provided from the downstream waterway through these fishway zones to the waterway upstream. Attraction flow from the waterway upstream should be directed through the dedicated culvert barrel where fish passage provisions are to be made. Flow connectivity and provision of attraction flows and sufficient water depth for fish movement through the wide shallow culvert is important at low flows.

Alternative configurations for the fishway facilities at the box culvert waterway crossings included the option of lowering one or more of the culvert cells to provide a dedicated low flow channel through the culvert structure. This was not adopted because of the more complex configuration that would be required for the recessed culvert base. Furthermore, the road drainage design requires that the general level for the culvert invert coincides with the waterway bed level, and for low gradient streams on the Tully Murray floodplain it is not practical to provide a local lowering of the stream bed to suit a dedicated recessed culvert cell.

Options were examined for providing fish passage by way of favourable hydraulic conditions in one or more dedicated barrels in the multi-cell culvert. This included fishway components fixed to the base of the culvert, such as the offset baffle pool type fishway design (Kapitzke 2006b), or roughness type fishways incorporating the spoiler baffle or other roughness elements fixed to the base. These options were not considered appropriate for the Corduroy Creek project culvert crossings because of the deep flow low velocity conditions applying for the medium flow design case. The corner “EL” baffle fishway design, which is fixed to the side wall and bottom corner of the box culvert, was considered appropriate for the deeper flow conditions on the basis of field prototype fishway development and testing in the Discovery Drive box culvert in University Creek in Townsville, and hydraulic laboratory model testing of the design (Kapitzke 2007b).

The preferred location for dedicated fishway barrels in a culvert crossing of a well defined waterway channel is typically on the outside edge of the outermost culvert barrels, adjacent to the waterway edge on each side, where fish tend to move in the stream. Because waterway channels are not well defined for the Corduroy Creek project, and because culvert structures are wider than these channels for some crossing sites, several configuration options for location of the dedicated culvert fishway barrels were considered. This included location on the outside barrel for relatively narrow culvert structures and location on a central culvert barrel where the culvert structure is much wider than the waterway. Considerations for flow connectivity through the fishway zones and direction of attraction flows to the fishway entrance at low flows included the provision of nib wall and low flow training walls at the culvert inlet and outlet

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 the facility. Integrated solutions are required to address the fish passage problems and the multipurpose 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 lack of information about the fish community and their movement characteristics, limited knowledge about the appropriate fish passage measure for that application, or lack of understanding of the performance characteristics of the adopted fish passage facility. Implementation, monitoring and evaluation of the fishway at the site will provide an opportunity to develop further understanding of the performance of the fish passage facility in terms of these design objectives.

As an illustration for the Bruce Highway Corduroy Creek to Tully road project, an evaluation of suitability of the adopted culvert fishway design in overcoming the fish migration barrier problems and in meeting the design objectives and constraints for the facility (Boxes E5.2 and E5.3) is presented in Box E6.1. The adopted design is outlined in Section 6.3.

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)*

Drainage, utility and stream integrity

- The corner "EL" baffle fishway design for box culverts, which protrudes 300 mm from the culvert base and lower section of the side wall, does not present a substantial reduction in cross sectional area of flow within the multi-cell 3600 mm wide box culverts, and will not represent a significant obstruction to overall flow capacity of the culvert. The nib wall at the culvert inlet has been placed upstream of the culvert headwall and clear of the culvert opening to avoid flow restriction to the culvert water opening.
- It is likely that only a small amount of sediment will be trapped in the corner baffles on the side of the culvert barrel, and the effect of this on the culvert waterway opening will be negligible. The corner "EL" baffle fishway elements may trap some debris on the edge of the culvert barrel, but large debris blockage of the waterway opening is unlikely
- The corner "EL" baffle fishway will not significantly alter velocities or flow patterns at the culvert outlet due to its minimal effect on flow in the culvert barrel or in the waterway. The fishway will reduce flow velocities locally on the edge of the culvert and is unlikely to adversely affect erosion at the culvert outlet, or downstream sedimentation or turbidity.
- The corner "EL" baffle fishway is unlikely to adversely affect the culvert or other adjacent infrastructure, utilities or landuse. The design of the fishway has maintained the configuration and overall integrity of the culvert, and has protected the existing structure components.
- Operation of the fishway structure is not expected to cause harm to adjacent infrastructure as it is designed to maintain the flow capacity and cause no impact to erosion.

Fish passage

- The priority road-waterway crossings that are adopted for fish passage connect to critical fish habitat areas upstream and downstream of the road during the low flow and medium flow conditions. The corner "EL" baffle fishway is intended to operate at flow depths ranging from about 0.3 m (height of baffle on culvert floor) to the top of the baffles on the culvert side walls.
- The corner "EL" baffle fishway is intended to provide a continuous fish pathway through the structure that is suitable for fish to ascend/descend. Nib wall and low flow training wall structures are provided at the culvert inlet and outlet to direct low flows through the preferred fish pathway in the culvert barrel.
- For road-waterway crossings where the culvert structure has a similar width to the adjoining waterway channel, the corner baffle fishway is established along the outside wall of the outside culvert barrel in order to connect the fish passage flow with the anticipated fish pathway along the stream bank.
- For road-waterway crossings where the culvert structure is much wider than the adjoining waterway channel, the corner "EL" baffle fishway is established in the central culvert barrel in order to align the fish passage flow more directly with the anticipated fish pathway along the stream bank and through adjoining waterway crossing structures.

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 side 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 barrel 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 severe 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 crossing. 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 to adjacent barrels, and avoid being washed back downstream. The fishway exits are located in relatively low energy flow conditions in the waterways 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 minimal 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 flow 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 other 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 vermin. 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, electricity, telephone) will be identified and dealt with as part of the road and drainage construction.

6.3 Adopted fish passage facilities

The adopted fish passage facilities should represent the most suitable option in terms of the design objectives and constraints for the waterway structure. The type, layout and configuration of the crossing and fish passage facility to meet these requirements will usually be developed as part of the preliminary design phase for the project. Design details for fabrication of fishway components (e.g. baffles), and the configuration of fishways and associated features within the structure and adjoining waterway at individual waterway structure sites, will usually be undertaken as part of the detailed design phase. Illustrations of adopted fish passage provisions for the Bruce Highway Corduroy Creek to Tully road project (new – mitigation), and for the Solander Road crossing of University Creek (existing – remediation) are provided below.

6.3.1 Fish passage facilities – Bruce Highway Corduroy Creek to Tully project

For the Bruce Highway Corduroy Creek to Tully road project, where provisions for fish passage were incorporated as mitigation measures for the new road design, the general configuration of the fish passage facilities for the group of 6 priority box culvert waterway structure crossings of the road corridor was undertaken as part of preliminary design (see Kapitzke 2007a). Design details for fabrication of the adopted corner “EL” baffles, and configuration of fishway facilities and adjoining waterway features such as transitions in the low flow channel at each structure location were undertaken in the detailed design phase (Chapter 7).

The adopted fish passage facilities for multi-cell box culverts at priority road-waterway crossings incorporate the corner “EL” baffle fishway within one culvert cell (see *Guidelines Part F – Baffle Fishways for Box Culverts*), with nib wall and low flow training walls at the culvert inlet and 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.

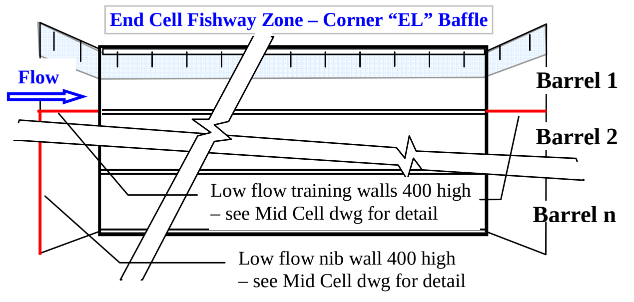
The fishway arrangements for the end cell and mid cell box culvert configurations incorporate the corner "EL" baffle fishway elements at 1800 mm longitudinal spacing, fixed to the culvert base and side walls (Boxes E6.2 and E6.3). The corner baffle units extend onto the culvert inlet and outlet wingwalls 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.

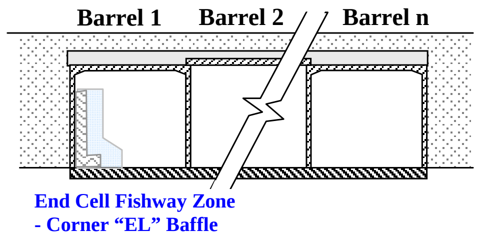
The corner "EL" baffle fishway consists of a series of "L" shaped baffles in the corner of the box culvert cell that protrude a short distance from the culvert wall, and extend up the wall from the culvert floor (see *Guidelines Part F – Baffle Fishways for Box Culverts*). Design configurations (Boxes E6.2 and E6.3) for the corner "EL" baffle fishway, floor baffle, low flow nib wall and training wall for the group of 6 priority waterway crossings provide for the following:

- longitudinal spacing for the corner "EL" baffle units along the culvert barrel of 1800 mm
- corner "EL" baffle unit incorporating a fishway horizontal leg that is 300 mm high above the culvert floor and protrudes 700 mm from the culvert wall, and a fishway vertical leg that protrudes 300 mm from the culvert wall
- corner "EL" baffle unit extending to a nominated height above the culvert invert for each particular culvert, but to within no more than 300 mm of the culvert obvert
- notches for passage of juvenile and small species provided on the horizontal leg of the baffle fishway and at intervals along the fishway vertical leg
- floor baffle units, with notches for passage of juvenile and small species, provided at nominal 1800 mm centres on the inlet and outlet aprons for the mid cell configuration
- low flow nib walls 400 mm high provided at culvert inlets, with notches for flow connectivity and escape of fish from non-fishway cells
- low flow training walls 400 mm high provided at culvert inlets and outlets to connect with the nib walls and the wall of the box culvert cells

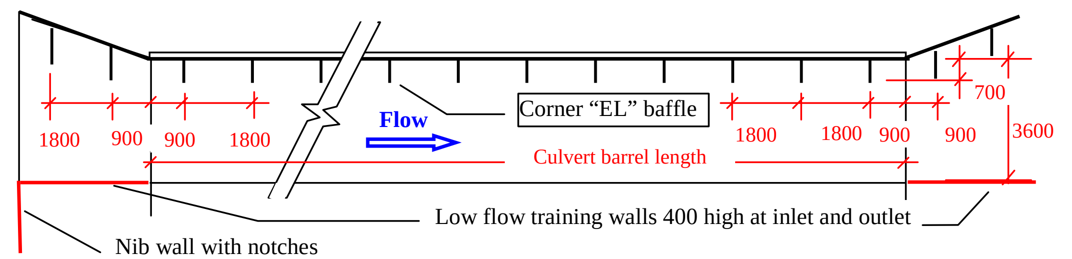
Box E6.2: Bruce Highway Corduroy Creek to Tully road: Corner "EL" baffle fishway for box culverts – End cell configuration *(Source: Kapitzke 2007a)*



Culvert plan showing fishway zones in end cells

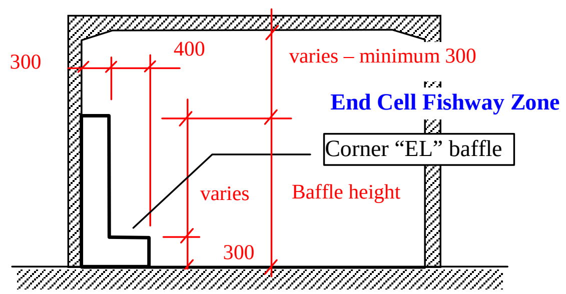


Culvert section showing fishway zones

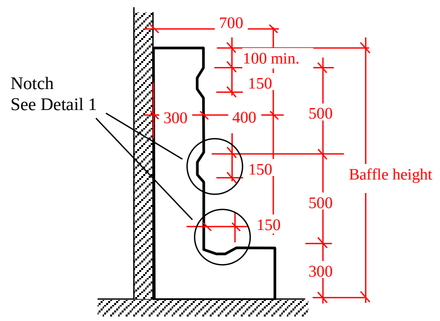


Corner "EL" baffle fishway in end cell – Plan view

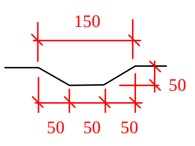
Box E6.3: Bruce Highway Corduroy Creek to Tully road: Corner "EL" baffle fishway for box culverts – Baffle configuration *(Source: Kapitzke 2007a)*



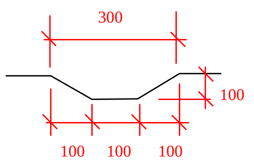
Corner "EL" baffle fishway – Culvert cell looking downstream



Corner "EL" baffle detail

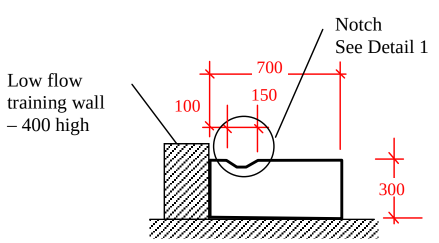


Notch 1 - Baffle



Notch 2 – Nib wall

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 rehabilitate stream bank and bed erosion and infrastructure damage associated with long term degradation of the site. This remediation work was integrated with the fish passage facilities.

The Solander Road culvert presented substantial fish migration barriers in each of the 4 hydraulic zones of the structure (Section 4.3). Remediation of fish migration barriers required careful attention to the requirements within each hydraulic zone and consideration of provisions at transition areas between the defined zones. The adopted fish passage facility includes several prototype fishway components for which designs are not fully established, and which are subject to ongoing design development and testing. Integration of fishway components and provisions for transitions between adjoining hydraulic zones, in particular, requires further attention.

The principal fish migration barrier problems to be overcome included high velocity turbulent flow throughout the culvert, and a water surface drop at the downstream apron slab. As illustrated in *Guidelines Part C – Fish Migration Barriers and Fish Passage Options for Road Crossings*, and identified above in Chapter 5, the remediation objectives for *Zone A – Downstream channel and apron drop-off* are to provide suitable velocity conditions and rest points to enable fish to move upstream to the culvert structure, and to overcome the water surface drop at the downstream end of the apron. The objective for *Zone B – Culvert outlet and apron slab* is to increase flow depths and reduce velocities and turbulence on the apron, and to provide sheltered areas to allow fish to move in a burst and rest pattern up to the region of the pipe barrel.

For *Zone C – Culvert barrel*, the objectives are to reduce overall velocities within the pipe and to provide suitable high flow and low flow conditions including shelter zones to allow fish to move through the pipe to regions upstream of the culvert. For *Zone D – Culvert inlet and upstream channel*, the objective is to allow fish that have passed through the downstream fishway sections to exit the pipe and to move freely away into stream zones where they can continue their upstream migration to suitable habitat areas. Flow continuity through all fishway zones is required, and a continuous fish pathway and attraction flow should be provided to allow fish to move upstream through the fishway from the downstream pools.

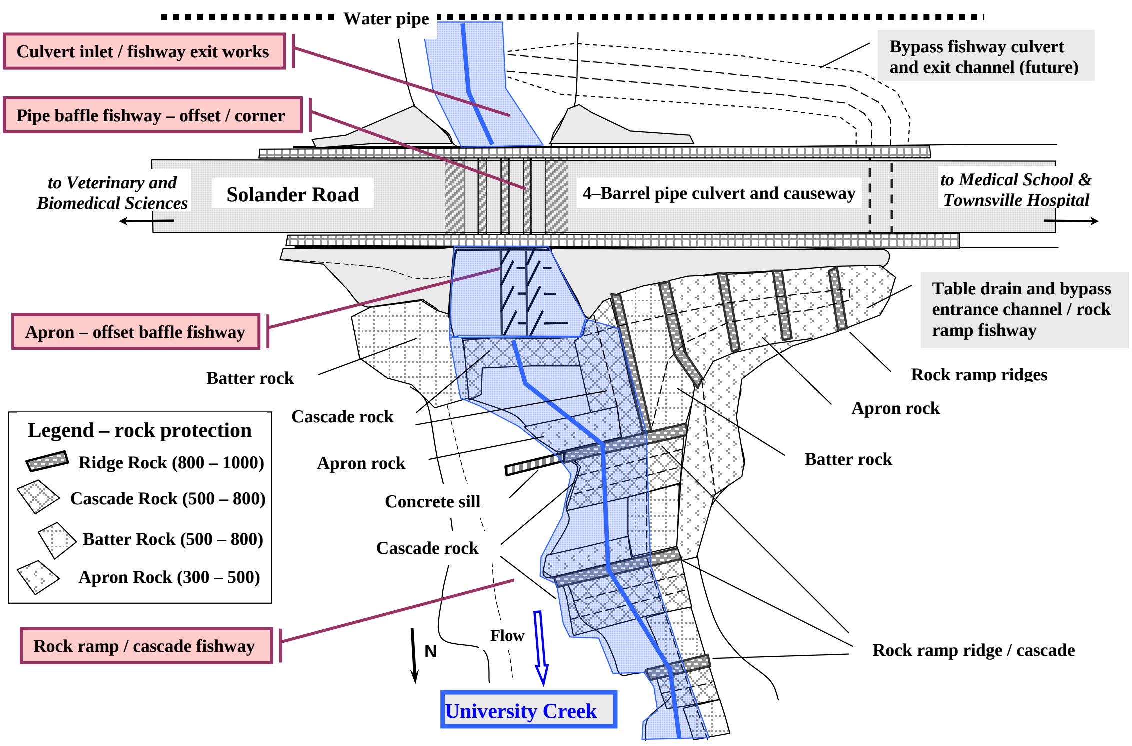
The Solander Road fish passage facility (Prototype Fishway # 3) consists of four major components to overcome fish migration barriers within the various hydraulic zones (Boxes E6.4 and E6.5). This includes the rock ramp / cascade fishway for *Zone A – Downstream channel and apron drop off*, the apron baffle fishway for *Zone B – Culvert outlet and apron slab*, and the offset baffle and the corner “EL” baffle fishways for pipe culverts in *Zone C – Culvert barrel*. Some minor culvert inlet / fishway exit works have been incorporated into *Zone D – Culvert inlet and upstream channel*, and provision has been made for a future bypass fishway for culverts and causeways to be developed through the road embankment adjacent to the Solander Road culvert.

The rock ramp / cascade fishway in Zone A downstream of the crossing (see *Guidelines Part H – Rock Ramp Fishways for Open Channels*) extends over the full width of the low flow channel, which crosses over from the right bank at the culvert outlet, to the left bank where the rock ramps are located further downstream. The culvert apron baffle fishway devices in Zone B are located on the left side of the culvert, downstream of pipe barrel Nos 1 and 2. These pipe barrels in Zone C incorporate the offset baffle and corner baffle fishways (see *Guidelines Part G – Baffle Fishways for Pipe Culverts*). The pipe inlet / fishway exit works in Zone D are provided upstream of pipe barrel Nos 1 and 2, and the proposed future bypass fishway connects with the downstream and upstream channel sections, also on the left abutment.

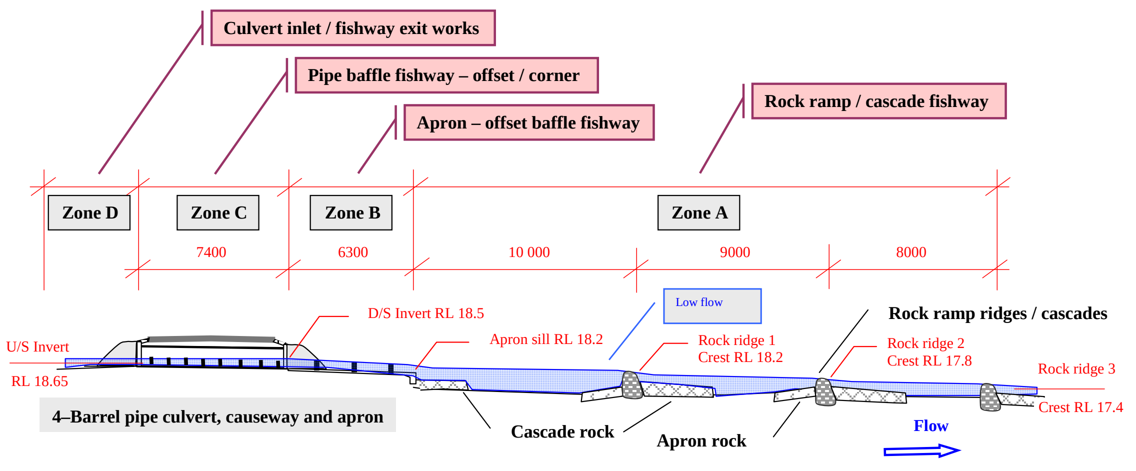
The fish passage facilities within Zones A – D and the future bypass fishway have been integrated with environmental remediation and downstream erosion control and culvert protection works to assist with the long term integrity of the fishway, road crossing, and riverine corridor. The remediation work has included stabilisation of undermined culvert and causeway structure foundations, placement of batter rock on the edges of the stream channel and within the road table drains and return flow channels downstream of the culvert, and placement of apron /

bench rock on the stream banks adjacent to the culvert structure, batter rock and causeway overflow areas (Boxes E6.4 and E6.5).

Box E6.4: Configuration of Solander Road prototype fishway facility and environmental remediation – general arrangement *(Source: Kapitzke 2007c)*



Box E6.5: Configuration of Solander Road prototype fishway facility and environmental remediation – longitudinal section *(Source: Kapitzke 2007c)*



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 medium flow 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 into 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.

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April 2010 – VER2.0