Culvert Fishway Planning and Design Guidelines

Part C – Fish Migration Barriers and Fish Passage Options for Road Crossings

Ross Kapitzke
James Cook University
School of Engineering and Physical Sciences

April 2010 – VER2.0

James Cook University School of Engineering and Physical Sciences
Culvert Fishway Planning and Design Guidelines
Part C – Fish Migration Barriers and Fish Passage Options for Road Crossings

Contents

1

James Cook University School of Engineering and Physical Sciences
Culvert Fishway Planning and Design Guidelines
Part C – Fish Migration Barriers and Fish Passage Options for Road Crossings

1 INTRODUCTION

2 FISH MIGRATION BARRIERS AT ROAD-WATERWAY CROSSINGS

Fish migration barriers at road crossings and other waterway structures commonly occur as a result of adverse hydraulic conditions at box culverts, pipe culverts and causeways, but may also occur at bridge crossings and other constructed waterways, where channelisation, grade control or other structures sometimes produce adverse conditions for upstream fish movement. In addition to hydraulic barriers at road-waterway crossings and open channel sections that are the focus of these *Guidelines*, other barriers to fish movement in the catchment may be associated with the following physical or behavioural barriers, which are not specifically addressed here:

- hydraulic and physical barriers at dams, weirs, flood gates, tide gates, or control structures
- barriers associated with pipelines, footings, or other infrastructure in the waterway
- physical barriers due to sediment or debris blockages at waterway structures
- altered streamflow regimes in waterways changing cues to migration
- modified stream and aquatic habitat due to ponding, channelisation or vegetation removal
- poor water quality or other environmental degradation in the stream such as weed blockage
- natural barriers such as waterfalls or rapids

The following sections describe the principal types of hydraulic barriers to upstream fish passage at conventional road-waterway crossings and open channel sections, and outline methods for evaluating velocity barrier effects in culverts in terms of waterway conditions and fish swimming capabilities. Some discussion of other barriers related to lack of attraction flow, debris or sediment blockage, downstream passage, structure drown-out, and light barriers is also provided. Fish passage design approaches and fishway concepts for road-waterway crossings are discussed in Chapter 3. Fishway configuration options are outlined in Chapter 4, and the application and performance characteristics of various fishway components are presented in Chapter 5. The method for evaluating fish migration barriers and for design of fish passage facilities at a waterway structure are outlined in *Guidelines Part E – Fish Passage Design: Site Scale.*

2.1 Hydraulic barriers to fish migrat ion at road-waterway crossings , p008 T08 n ba(es produce pon

x

x131 0 TD25 008 Tp131eto lshe 1.11

x

x

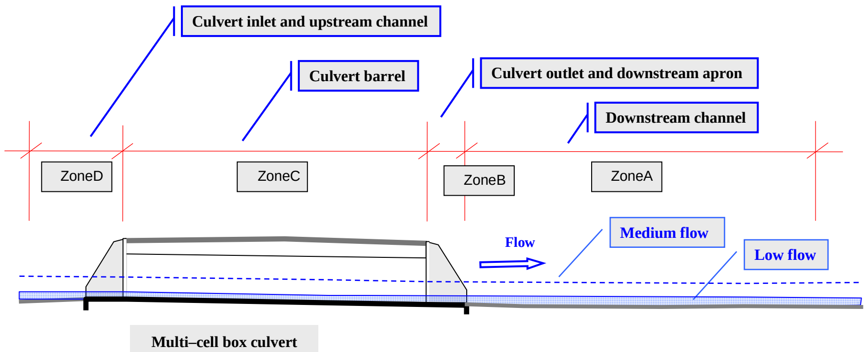
Fish migration barriers due to adverse hydraulic conditions in road crossings (e.g. box culverts, pipe culverts, causeways) may occur within any of the various drainage structure components such as the inlet and outlet structures, the culvert barrel, and the overtopping section of the roadway. The upstream and downstream sections of the stream channel adjoining the crossing may also represent fish migration barriers if the waterway structure and associated channel are configured to produce adverse conditions such as high velocities, turbulence, or water surface drops. Consideration of fish migration barriers at the crossing should be given, not only to hydraulic conditions within the culvert barrels, but to conditions throughout the structure and adjoining waterway, to enable fish passage through all hydraulic zones from downstream to upstream at the structure (see *Guidelines Part E – Fish Passage Design: Site Scale*).

Hydraulic conditions affecting fish passage through the waterway structure must be considered over a range of stream flows to encompass the design flow range for fish passage (see *Guidelines Part B – Fish Migration and Fish Species Movement Behaviour*). This includes the low flow condition (flow up to approx 0.5 m deep – inundating channel bed for defined waterway), and medium flow condition (flow from approx 0.5 m to approx 1.5 m deep – below low flow channel bench for defined waterway). Whereas velocities in culvert barrels will usually be greater at the medium flow condition than at low flow, barriers such as water surface drops at culvert outlets and shallow flow depths on outlet aprons may occur at low flows rather than at the higher flows.

The hydraulic barriers to fish migration that commonly occur in various hydraulic zones within typical road-waterway crossing structures are illustrated and described below (Boxes C2.1 and C2.2). Principal hydraulic barrier types and their common occurrence within box culvert, pipe culvert and causeway structures are shown in Box C2.1, along with typical configuration, flow profiles and hydraulic zones for these crossings. Box C2.2 identifies typical locations and configurations of these hydraulic barriers to fish migration and describes them in terms of hydraulic characteristics and effects on fish movement within these zones.

Box C2.1: Common occurrence of principal hydraulic barriers to fish migration within culvert zones at road-waterway crossings *(Source: Ross Kapitzke)*

Hydraulic barrier type	Zone D: Culvert inlet and upstream channel	Zone C: Culvert barrel	Zone B: Culvert outlet and downstream apron	Zone A: Downstream channel
High velocity	9	9	9	9
Shallow water depth	9	9	9	
Lack of resting place	9	9	9	
Excess turbulence	9	9	9	9
Water surface drop	9		9	9



Example culvert configuration, flow profiles and hydraulic zones: Box culvert

Box C2.2: Type and characteristics of principal hydraulic barriers to fish passage at road-waterway crossings *(Photo source: Ross Kapitzke)*

Fish may use prolonged speeds for continuous passage through low velocity culverts without the need for resting areas, but barriers occur when prolonged swim speed capabilities for fish are exceeded in plain culverts, where flow conditions are commonly more severe than those in natural channels. For example, a fish with a prolonged swim speed of 0.5 m/s can readily traverse the length of a regular 15 m long culvert when the culvert flows at less than 0.3 m/s (swim time < 2 minutes), but would be unable to swim through this culvert when the culvert flow velocity is close to 0.5 m/s (swim time > 200 minutes). Fish passage through a culvert in prolonged swim mode will therefore 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 (culvert flow < about 0.5 m/s).

Fish cannot normally maintain burst speeds long enough to navigate the entire length of most culverts. For example, a fish swimming in burst swim mode at 1.0 m/s would travel a maximum of 10 m against a culvert flow of 0.5 m/s (swim time < 20 secs), and would be unable to swim through a 15 m long culvert without resting at intermediate points (swim time > 30 secs). Fish will therefore 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 (swim time > 200 minutes), or where the culvert length exceeds that which can be negotiated in one action in burst swim mode (swim time > 20 secs). Movement through the culvert using a burst / rest pattern requires regularly placed rest locations along the culvert length, and takes advantage of low water velocities and rest points such as those attained in sheltered zones created by placement of baffles and other elements in culvert fishways.

In evaluating fish migration barriers due to velocity conditions at a culvert or other waterway structure, the fish migration barrier effects should be assessed for the range of flow velocities within the structure, and for fish swimming in either prolonged or burst swim modes through the length of the structure or over short distances between rest points (for example, maximum 2 m spacings between baffles for culvert fishway). The swim speeds required of fish to negotiate these distances under the prevailing velocity conditions can be compared with the estimated swim capabilities of the fish community for the waterway in either prolonged or burst swim modes. This identifies whether the waterway structures represent a barrier to fish passage, and establishes the limit of flow velocities that are negotiable by these species for the distances to be travelled through the structures. The method of assessment of hydraulic barrier effects of culvert velocity on fish passage outlined here uses a rudimentary approach, and fish movement success against these flows may depend on other aspects of fish behaviour other than fish swim speed (e.g. tolerance to turbulence, minimum required water depth).

As an illustration for the Bruce Highway Corduroy Creek to Tully road project, the suitability of velocity conditions for fish passage through the box culvert waterway structures was assessed for the low flow and medium flow conditions, and has been used to assess fish migration barrier effects for these structures (see *Guidelines Part E – Fish Passage Design: Site Scale*). Fish swim speeds required to negotiate the full culvert length of 15 m (Mode 1) or the length between rest points of 2 m (Mode 2) for the prolonged and burst swim modes are tabulated in Box C2.3. These swim speeds are compared with estimated swim capabilities of the Tully Murray fish community (Kapitzke 2007a) to establish the limit of culvert flow velocities negotiable by these species, and whether the culvert barrels represent a barrier to fish passage.

Box C2.3: Fish swim speeds required to negotiate culvert barrel in burst or prolonged swim mode
(*After: Kapitzke 2007a*)

	Fish swim speed required to negotiate full or partial culvert length			
	Mode 1 – full culvert length - 15 m (L)		**Mode 2 – length between rest points - 2m (L)**	
Culvert velocity (V_c)	**Prolonged speed (S_p)[1]**	**Burst speed (S_b)[2]**	**Prolonged speed (S_p)[1]**	**Burst speed (S_b)[2]**
0.2 m/s	~ 0.2 m/s	0.95 m/s		

2.3 Other barriers to fish migration at structures

In addition to the principal hydraulic barriers to upstream migration at road crossings and other waterway structures (high velocity, reduced flow depth, lack of resting place or shelter, excess turbulence, water surface drop), a number of other fish migration barriers may also apply. These barriers may relate to lack of attraction flows, debris or sediment blockage, downstream passage, waterway structure drown-out, and light barriers. Some information on considerations for these fish migration barrier effects is provided in Box C2.4.

Little information is available on the movement capabilities and behavioural characteristics of Australian freshwater fish species to overcome the principal hydraulic barriers to fish migration (Section 2.1) and the other barriers outlined here. Most published data on swimming ability of fish relates to species form the northern hemisphere, and data on swim speed, jumping ability, minimum water depth requirements, and tolerance to turbulence and light levels are lacking for most Australian native fish species (see *Guidelines Part B – Fish Migration and Fish Species Movement Behaviour*). The rudimentary approaches that are presently used for fish migration

3 FISH PASSAGE DESIGN APPROACHES AND FISHWAY CONCEPTS

The fish passage design approach for road crossings and other waterway structures may be influenced by the type of structure causing the fish migration barrier, the severity of the barrier problem, the values and goals for overcoming the ba fishways in that they typically function to combat high velocities and other hydraulic barriers through a culvert rather than water level drop across a weir. Nevertheless, components of weir fishway design can often be adapted to culvert fishway conditions. The configuration of culvert structures also provides ready opportunities to use fishway devices to modify adverse flow conditions within the culvert barrel and adjoining zones of the structure.

Requirements for culvert fishway design for Australian conditions are different in many ways from those pertaining in other areas. Furthermore, a negative experience related to fishway design for dams and weirs in the mid to late part of the 20th century provides a lesson for Australia to avoid the trap of merely transplanting imported culvert fishway design approaches from other regions. Prior to development of methods that suited Australian conditions, fish passage technology for dams and weirs in Australia was, in its early stages, set back significantly by disillusionment at the failure of translocated inappropriate designs from the northern hemisphere (see Thorncraft and Harris 2000). Fish passage design for culverts and other road-waterway crossings in Australia is fortunately still in an embryonic stage that is not substantially corrupted by translocation of inappropriate methods. The opportunity should therefore be available over time to develop, adapt and establish the appropriate method for Australia.

The design approach, fishway configuration options and fishway components outlined below are supported by the culvert fishway R & D so far undertaken through concept design development, prototype implementation and testing, hydraulic laboratory modeling and case study application. Further development, testing and application will lead to complementary and enhanced methods, and allow refinement of the approaches and techniques for the work undertaken. Design and development of culvert fishway technology for Australian conditions has so far shown that it is not necessary or appropriate:

x

The natural stream channel option can only be achieved through mitigation design for a new structure or in situations where a bridge is already provided at an existing site. The plain culvert option with moderate hydraulic conditions may be able to be achieved for a new development, or relied on where favourable conditions apply for remediation at an existing site. The options for modifications to achieve favourable hydraulic conditions in association with conventional drainage structures may be applied through mitigation design and remediation design.

The following categorisation of fish passage strategies provides a useful framework for considering and addressing fish migration barrier problems at road-waterway crossings (Box C3.1). Much of this is based on work in Canada by Chris Katopodis of Department of Fisheries and Oceans Canada (DFO) and in Washington State USA by Ken Bates of Washington Department of Fish and Wildlife (WDFW). Four basic approaches to fishway design are used (*stream simulation*, *plain culvert*, *hydraulic*, and *hybrid* designs), relating primarily to treatment within the culvert barrel. In addition to this, a number of fishway components may be required to address fish passage requirements through each hydraulic zone of the structure (see Chapter 4).

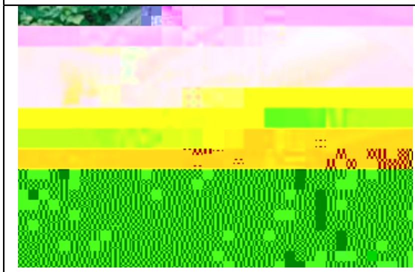
Box C3.1: Design strategies for culvert fishway barrel treatment *(After: Kapitzke 2003)*

Stream simulation

- The principle of the stream simulation or nature-mimicking approach is to pattern the fishway after streams bearing similar fish species, and to preserve natural stream characteristics through the culvert for biologically significant discharges
- The stream simulation concept uses stream dimensions to size the culvert, and rock within the culvert barrel to resemble natural stream substrate. The preferred culvert size is to maintain the average channel width and cross sectional area for the fish passage design discharge
- The approach approximates natural stream morphological features, and places considerable emphasis on retaining as many qualities of the original stream channel as possible
- Stream simulation design reflects an ecosystem approach to fish migration and fish habitat management, whereas hydraulic designs and other fishway types may be less suited for small or very large fish due to velocity, turbulence and space limitations
- The stream simulation approach may be more economical than plain culvert designs where large cross section areas are needed to maintain acceptable water velocities for fish passage
- Stream simulation culverts may be satisfactory for small fish passage flows but stream substrate may be dislodged and the culvert structure will most likely be overtopped for larger flood flows
- Stream simulation is more readily achieved with bridges and arch culverts supported by footings, as these structures allow retention of natural stream properties at the crossing and do not normally hinder fish passage unless significant channel constriction occurs

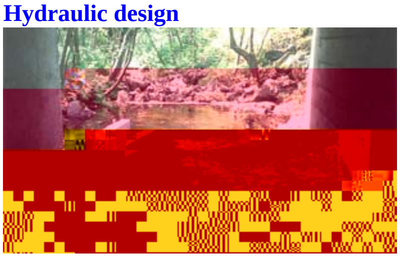
Box C3.1: Design strategies for culvert fishway barrel treatment *(After: Kapitzke 2003)*

Plain culvert



- Providing water velocities in plain culverts low enough for fish to negotiate the culvert length without rest is a difficult task
- Water velocities in culverts are usually much higher and more uniform than those in natural channels, where channel form and substrate complexity provide diverse flow conditions for fish
- The maximum permissible culvert length for a particular maximum water velocity depends on the endurance time for which the target fish size and species can travel at or above that velocity
- Unless inherently deep and slow flowing water is present at the site due to ponding from downstream, designing plain culverts to meet restrictive velocity criteria is generally not practical or economical, particularly for weak swimmers migrating during periods of high stream flow
- Where the plain culvert fishway design is used, it is necessary to provide low culvert velocities at the fish passage design flow, and to ensure sufficient water depth for fish passage through the culvert

Hydraulic design



- In the hydraulic design, arrangements of baffles, blocks or other structures are attached to the culvert base or walls to enhance fish passage
- Water depths in the culvert are increased, velocities are reduced, and other flow conditions are altered locally or throughout the structure

3.3 Hydraulic design approach for culvert fishways

The stream simulation approach using a bridge or an arch culvert to span the waterway and retain natural stream channel form and substrate conditions often provides the best solution to overcome fish migration barrier problems at a road crossing (Box C3.2). The bridge or arch culvert option may not always, however, be technically feasible or economically justified. The hydraulic design approach using baffles and other fishway devices (Box C3.3) usually provides a viable solution, particularly where costs and major site constraints related to the stream channel and conventional waterway drainage infrastructure exist (e.g. limited space, channel encroachment, existing culvert). Nature-like fishways such as rock ramps are often used in conjunction with baffle fishway designs to meet overall fish passage requirements for the crossing (Box C3.3).

elaborate configurations that may require complete removal and replacement using the nature-like approach

- more effective at providing suitable hydraulic conditions than a plain culvert, which requires large culvert cross section and ponded flow cond

The “ideal” culvert describes an impractical combination of design parameters that is seemingly developed through a conservative grab bag of desirable criteria, which fail to address realistic multipurpose requirements relating to transport, drainage, amenity etc. for the site.

Many fish passage approaches often deal only with velocity and other hydraulic barriers within the culvert barrel, thereby failing to identify hydraulic barriers in other zones of the waterway structure or acknowledging the need to address fish passage requirements throughout the whole structure. Fundamental hydraulic assessments and computational models (e.g. Fish Xing) are often designed to compare culvert velocities with fish movement capabilities within the culvert barrel. These techniques may be inadequate, however, if they fail to evaluate hydraulic conditions at the culvert inlet and outlet or in the adjoining stream channel. Water surface drops and other adverse hydraulic conditions in these structure zones often also represent barriers to fish movement (including varying effects with varying flow).

4 FISHWAY CONFIGURATION OPTIONS FOR ROAD CROSSINGS

The configuration of fish passage facilities at a road crossing or other waterway structure is established on the basis of the fish migration barrier characteristics of the structure (Chapter 2) and the fish passage goals and other multipurpose requirements for the site. A number of fishway configuration options comprising several fish passage devices may be considered, both for new projects where mitigation measures to overcome potential barriers are required, and for existing projects where remediation measures are used to address existing barrier problems.

This Chapter 4 outlines fishway configuration options that can be considered as part of the fish passage design process at a waterway structure (see *Guidelines Part E – Fish Passage Design: Site Scale*). These fishway options incorporate various fish passage components configured to meet fish passage design requirements within the various hydraulic zones of the structure, as outlined below. Whilst other fish passage design strategies may be appropriate (e.g. stream simulation, plain culvert design), the focus here is on the hydraulic design approach (e.g. baffles).

Illustrations of particular fish migration barrier characteristics, fish passage design requirements, and fishway components to overcome these hydraulic barriers are given for the Bruce Highway Corduroy Creek to Tully box culvert and the Solander Road pipe culvert case study projects. The applications and characteristics of the various fishway components that may be used in these bew[(This5.84 0 TD

Box C4.2: Key principles and design configuration options to meet fish passage requirements for road-waterway crossings	
Design aspect / parameter	**Design consideration, comment and rationale**
Waterway structure / fishway configuration within stream	
Stream geomorphic	

Box C4.2: Key principles and design configuration options to meet fish passage requirements for road-waterway crossings

Design aspect / parameter	Design consideration, comment and rationale
Bridge abutments, stream edges and terraces	x desirable to maintain the natural form of the stream channel and banks in order to retain channel complexity and provide habitat and flow diversity to suit fish passage along the waterway edges x minimise disturbance of the channel bench and lower stream terraces or

Box C4.2: Key principles and design configuration options to meet fish passage requirements for road-waterway crossings	
Design aspect / parameter	**Design consideration, comment and rationale**
Tailwater level for fishway components	
Tailwater level at structure outlet / fishway entrance	x downstream flow conditions should produce tailwater levels at the culvert outlet that drown out the fishway entrance to a water level at or above the flow profile within the fishway under fish passage design flow conditions x raised tailwater conditions are intended to overcome a water surface drop and to avoid adverse hydraulic conditions associated with local acceleration or formation of a hydraulic jump in the vicinity of the entrance to a fishway x raised tailwater conditions in low gradient culvert structures may also improve conditions within the culvert barrel as a result of maintaining a minimum depth of flow and reducing velocities through the structure
Tailwater level at rock ramp grade control structures	

Box C4.2: Key principles and design configuration options to meet fish passage requirements for road-waterway crossings	
Design aspect / parameter	**Design consideration, comment and rationale**
Hydraulic conditions to suit fish passage	
Fish movement path through fishway structure	x where possible, configure fishway components along the outside edge of the

Box C4.2: Key principles and design configuration options to meet fish passage requirements for road-waterway crossings	
Design aspect / parameter	**Design consideration, comment and rationale**
Self cleaning of sediment and debris	x bed load material such as boulders and gravel is often flushed out of baffle fishways during flood flows along with debris that accumulates in low velocity areas (Engel 1974; Katopodis 1981) x the box culvert offset baffle and corner “EL” baffle fishways, and pipe culvert corner “Quad” baffle fishway demonstrate good self cleaning characteristics for sediment and debris (see *Guidelines Part F – Baffle Fishways for Box Culverts* and *Guidelines Part G – Baffle Fishways for Pipe Culverts*) x the open channel nature-like rock configuration of rock ramp fishways that is submerged in high flows are conducive to through passage of sediment and debris without substantial blockage of the fishway structure
Maintenance requirements	x frequent inspection and maintenance of baffled culverts is essential to remove debris accumulation and to ensure hydraulic capacity and fish passage capability is retained (Bates et al. 2003) x in ramp type fishways, ongoing monitoring and maintenance is essential to ensure they retain their desired hydraulic and fish passage characteristics x adjustment, replacement or supplementation of rock work may be required in rock ramp fishways to deal with rocks that may move during stream flows, and cleaning and removal of sediment or debris may be required to ensure satisfactory operation

4.3 al ctorfoptions

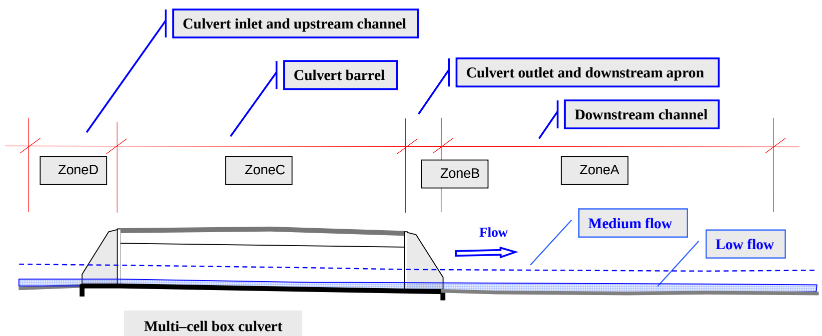
- minimise debris accumulation and sediment deposition within the culvert barrels and provide for ready cleaning and maintenance of the waterway structure

These fish passage requirements have been addressed in the culvert fishway designs for the site, which has involved identification of options and evaluation of suitability of a number of fish passage components within the various zones of the waterway structure. The adopted fishway facilities and their suitability in meeting fish passage requirements for the site are outlined below for each of the hydraulic zones leading from downstream (Zone A) to upstream (Zone D). The adopted fishway configuration for the structures is presented in Box C4.4, and the characteristics of individual fishway component types (baffles) are outlined in Chapter 5. The following material is based principally on the project case study report (Kapitzke 2007a).

Box C4.3: Principal hydraulic barriers to fish passage within culvert zones at Bruce Highway Corduroy Creek box culvert crossing of Tully Murray floodplain *(After: Kapitzke 2007a)*

Hydraulic barrier type	Zone D: Culvert inlet and upstream channel	Zone C: Culvert barrel	Zone B: Culvert outlet and downstream apron	Zone A: Downstream channel
High velocity	9 Ò	9 Ò	9 Ò	
Shallow water depth	9 Ñ	9 Ñ	9 Ñ	
Lack of resting place	9 Ò	9 Ò	9 Ò	
Excess turbulence				
Water surface drop				

Legend Ñ Low flow condition Ò Medium flow condition



There are no specific requirements to provide fish passage facilities for *Zone A – Downstream channel and apron drop-off*, as hydraulic conditions do not present a barrier to upstream fish movement in this zone (Box C4.3). Relatively high tailwater conditions provide adequate water depth in low flow conditions, and the requirement to provide suitable attraction flow to lead fish to the culvert outlet from the downstream channel is addressed by providing the low nib walls and training walls to direct low flows through the structure and to concentrate flow at a defined outlet location (Box C4.4). This low flow channel is provided in the end cell for some structures and in the mid cell for other larger structures.

Fish passage requirements for *Zone B – Culvert outlet and downstream apron*, *Zone C – Culvert barrel*, and *Zone D – Culvert inlet and upstream channel* are addressed by providing the corner "EL" baffle fishway within one dedicated culvert cell, and the nib wall and low flow training wall configurations at the culvert inlet and outlet to direct low flows through the adopted cell (Box C4.4). These baffles, which are located on the outside wall of the end cell for some structures and in the mid cell for other larger structures, address the requirements to provide suitable hydraulic conditions (velocity, shelter) through the structure in medium flow conditions. Velocity, shelter and turbulence are satisfactory during low flow, and nib wall and training wall facilities provide suitable water depth by concentrating flow through the dedicated culvert cell.

The low flow nib walls (400 mm high) extend across the non-low flow cells at the culvert inlet and direct shallow flows into the dedicated fi

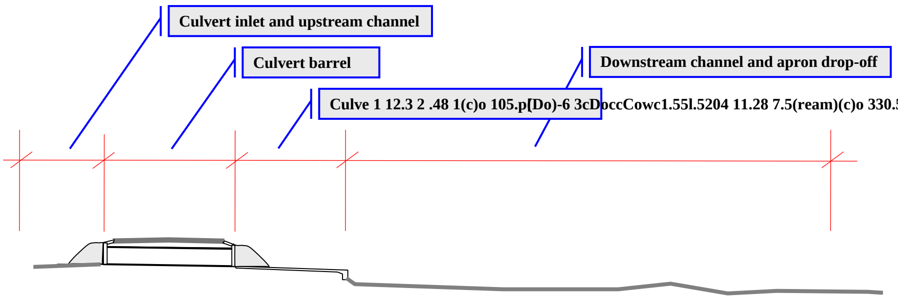
The fish passage requirements for the Solander Road crossing have been addressed in the culvert fishway designs for the site, which has involved identification of options and evaluation of suitability of a number of fish passage components within the various zones of the waterway structure. The adopted fishway facilities and their suitability in meeting fish passage requirements for the site are outlined below for each of the hydraulic zones leading from downstream (Zone A) to upstream (Zone D). The adopted fishway configuration for the structure is presented in Box C4.6, and the characteristics of individual fishway component types (baffles, rock ramp cascades) are outlined in Chapter 5. The following material is based principally on the project case study report (Kapitzke 2007c).

The adverse hydraulic conditions for upstream fish passage extend through all zones of the waterway structure at this site (Box C4.5). Because the conditions are severe in medium flow conditions, particularly through the culvert barrel and at the culvert outlet, the design goals focus on overcoming hydraulic barriers in low flow conditions. The fish passage facilities comprise components within each of the waterway structure zones, with the need for careful configuration of fishway devices to provide for integrated function of the facility to provide for fish passage upstream through all zones. Requirements for erosion protection and environmental remediation of the site are also to be integrated into the fish passage facilities.

Box C4.5: Principal hydraulic barriers to fish passage within culvert zones at Solander Road pipe culvert causeway crossing of University Creek *(After: Kapitzke 2007c)*

Hydraulic barrier type	Zone D: Culvert inlet and upstream channel	Zone C: Culvert barrel	Zone B: Culvert outlet and downstream apron	Zone A: Downstream channel
High velocity	9 Ñ Ò	9 Ñ Ò	9 Ñ Ò	9 Ò
Shallow water depth			9 Ñ	
Lack of resting place	9 Ñ Ò	9 Ñ Ò	9 Ñ Ò	
Excess turbulence	9 Ñ Ò	9 Ñ Ò	9 Ò	9 Ñ Ò
Water surface drop				9 Ñ

Legend Ñ Low flow condition Ò Medium flow condition



For *Zone A – Downstream channel and apron drop-off*, the requirements to overcome excess turbulence and the water surface drop at the downstream end of the culvert apron are addressed by providing the rock ramp cascade fishway in the channel (Box C4.6). This provides a series of pools and low riffle type structures to suit upstream fish passage in the stream and raises the tailwater level at the downstream end of the apron during low flow. The rock ramp cascades are integrated with rock protection works that provide for erosion control and site remediation.

Fish passage requirements for *Zone B – Culvert outlet and downstream apron* are addressed by providing the offset baffle fishway on the culvert downstream apron slab (Box C4.6). This baffle structure increases flow depth on the apron slab, and provides diverse flow conditions during low flows that provide low velocities, resting areas, attraction flows and continuous flow paths for fish moving upstream to the pipe culvert outlet.

Within *Zone C – Culvert barrel*

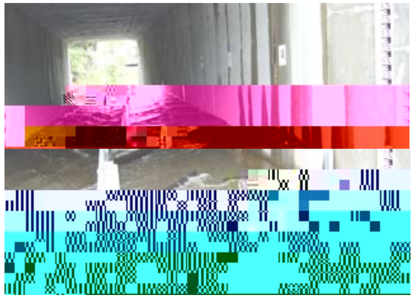
Box C4.6: Solander Road pipe culvert fishway configuration *(Source: Kapitzke 2007c)*

General arrangement showing fishway components and protection works

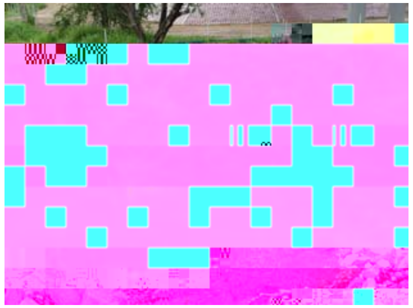
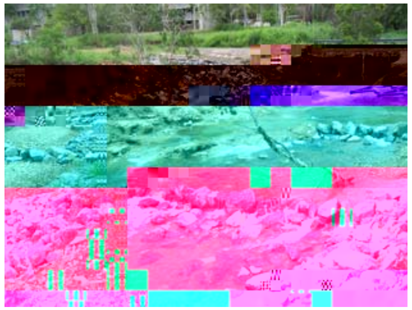
5 APPLICATION AND CHARACTERISTICS OF FISHWAY COMPONENTS

Provisions for fish passage at a waterway structure will commonly include several fishway components incorporated within the various hydraulic zones of the structure to overcome fish migration barrier conditions. This may include, for example, baffle or other fishway devices within the culvert barrel and adjoining aprons, rock ramp type grade control structures in adjacent stream channel sections to provide suitable tailwater conditions for the crossing, and ancillary

Box C5.1: Possible application of fishway component types for particular hydraulic zones of

Box C5.2: Application and characteristics of fishway component types for road-waterway crossings *(Source: Ross Kapitzke)*		
	Configuration and typical application of fishway component	**Performance characteristics of fishway component**
Baffle fishways for box culverts (*Guidelines Part F*)		
Offset baffle fishway (*Photo 15/01/04: Discovery Drive box culvert*)		
	x consists of series of low baffles fixed to the culvert base (short baffles at 90 qto culvert side, and oblong baffles at 30 qto culvert side) x this is a pool type fishway (flow within baffles) transitioning to a roughness type fishway (flow overtopping baffles) suited to relatively shallow high velocity flow in culvert barrels and on inlet and outlet aprons where large velocity reductions are required for fish passage x applies to steep culverts or culverts with low tailwater conditions, where tailwater levels at the culvert may be raised with other fishway components (e.g. rock ramps / backflood weirs) placed downstream x less suited to low gradient culverts and deep slow water environments as the low culvert velocities will provide conditions more prone to sedimentation and blockage of the offset baffle fishway	x type of two dimensional vertical slot fishway that provides for fish passage through low velocity zones, shelter areas and flow circulation for range of flows within and surcharging the baffles x

Box C5.2: Application and characteristics of fishway component types for road-waterway crossings *(Source: Ross Kapitzke)*		
	Configuration and typical application of fishway component	**Performance characteristics of fishway component**
Baffle fishways for pipe culverts (*Guidelines Part G*)		
Offset baffle fishway (*Photo 11/04/06: Solander Road pipe culvert*)		
	x consists of series of low baffles fixed to the culvert base (short baffles at 90 ɖo culvert side, and oblong baffles at 30 ɖo culvert side) x this is a pool type fishway (flow within baffles) transitioning to roughness type fishway (flow overtopping baffles) suited to relatively shallow high velocity flow in culvert barrels where large velocity reductions are required for fish passage x applies to steep culverts or culverts with low tailwater conditions, where tailwater levels at the culvert may be raised with other fishway components (e.g. rock ramps / backflood weirs) placed downstream x less suited to low gradient culverts and deep slow water environments as the low culvert velocities will provide conditions more prone to sedimentation and blockage of the offset baffle fishway x less suited to pipe culverts than to box culverts due to less favourable flow conditions for fish passage within and submerging baffles	x type of two dimensional vertical slot fishway that provides for fish passage through low velocity zones, shelter areas and flow circulation for range of flows within and surcharging the baffles x increases flow depth and provides resting pools and local higher velocity conditions to assist fish movement in a burst and rest pattern through fishway x low fishway profile and flow continuity through baffle system minimises flow resistance and effect on culvert flow conveyance x good self-cleaning and through-flow attributes for sediment and debris due to flow circulation and spiralling flow characteristics
Corner "Quad" baffle fishway (*Photo 11/04/06: Solander Road pipe culvert*)		
	x consists of a series of quad shaped baffles perpendicular to the culvert wall in the lower quadrant of the culvert barrel, extending up the wall to close to half pipe diameter, with pipe invert unobstructed by baffles x this hybrid roughness / pool type fishway is suited for culvert barrels where fish passage is required over a range of flow depths and velocities, including relatively deep low velocity flow x applies to culverts with high tailwater conditions, or culvert6 cs jET.86TD( )Tj/TT4 1 Tf.5933 0 TD.0008 Tc.0025 Tw413.7..0005 Tc.13570.76p6 Tc265.62 re1 Tc.0t	

Box C5.2: Application and characteristics of fishway component types for road-waterway crossings *(Source: Ross Kapitzke)*		
	Configuration and typical application of fishway component	**Performance characteristics of fishway component**
Rock ramp fishways for open channels (*Guidelines Part H*)		
Rock ramp fishway (*Photo 25/01/05: Douglas Arterial Road bridge crossing*)		
	x low gradient structure comprising a series of transverse rock ridges, with short pool sections between the ridges to create a series of miniature pools and riffles to mimic natural stream flow conditions x standard rock ramp fishway comprises a series of ridges at 2 metre intervals, with a localised 100 mm drop (through V-slots between rocks) at ridges and an overall longitudinal slope of 1 in 20 x suited for use as free standing grade control structures in an open channel or as attached structures to the inlet or outlet of road culverts or downstream of weirs or barrier walls x used in open channel applications to overcome water surface drops / steep waterway beds, and in channel sections downstream of road culverts to raise tailwater levels at the culvert x used as attached structures to overcome water surface drops / steep waterway beds either at culvert inlets or outlets or below low-level barriers such as weirs and barrier / grade control structures	x nature-like fishway that provides for fish passage through low velocity zones and shelter areas for range of flows within and surcharging the rock ridges x provides multiple interconnected pathways for fish passage using continuous swimming or a burst and rest swimming pattern x irregular nature of fishway and the diversity of hydraulic conditions (water velocities and depths) provide passage for a variety of fish species and sizes, including juveniles and adults x the open channel fishway configuration provides little obstruction to flow and has little appreciable effect on flow conveyance x tendency for self-cleaning and through-flow attributes for sediment and debris due to the open channel nature-like rock configuration that is submerged at high flows x pool depths in fish resting areas between ridges may be reduced through sediment deposition, and flow hydraulics and fish passage may be affected by debris trapping at rock ridge slots
Rock ramp / cascade fishway (*Photo 29/01/06: Solander Road pipe culvert and causeway*)		
	x low gradient structure in an open channel comprising a series of free standing rock cascade grade control structures with pool sections between them to create a series of pools and riffles to mimic natural stream flow conditions x each rock cascade comprises a single row of transverse ridge rocks and a series of cascade rocks downstream of and abutting the ridge, with a localised longitudinal gradient of about 1 in 9 over the length of the cascade section x rock ramp cascades with a localised drop of 400 mm are spaced along the stream reach to pool water back to adjoining cascade structures and to provide an overall gradient of steeper than 1 in 20 in the reach	x nature-like fishway that provides for fish passage between pools and through cascade structures via low velocity zones and shelter areas for range of flows within and surcharging the rock cascades x provides resting areas for fish in large pools, and local conditions at cascades to assist fish movement in burst and rest swimming pattern, but more severe and lower diversity of hydraulic conditions than conventional rock ramp fishway x the open channel fishway configuration provides little obstruction to flow and has little appreciable effect on flow conveyance x tendency for self-cleaning and through-flow attributes for sediment and debris due to the open channel nature-like rock configuration that is submerged at high flows x fish passage may be affected by debris trapping at rock ridge slots

- adverse conditions in diversion channel constructed at the crossing site (e.g. channelisation)

Drainage provisions that are made at a side track or construction track temporary waterway crossing are typically developed to a lower standard (e.g. smaller culvert waterway area, low embankment subject to overtopping, minimal erosion protection works) than those that would be provided as part of permanent drainage facilities for the site. Whilst some temporary crossings may be in place only during dry season conditions, most temporary crossings will be subject to a range of flow conditions, including periods of flow when fish may be migrating in the waterway. Depending on the duration of the installation and the type and configuration of the crossing structure used (e.g. ford, culvert, bridge), many temporary waterway crossing structures may represent a fish migration barrier problem during critical fish migration flows in the waterway.

Construction pad or bund crossings of a waterway or diversion channel may be provided where a working platform is required for construction activities such as pile driving, foundation preparation, manoeuvre and installation of structural members, formwork and scaffolding support. Drainage provisions at these construction pads or bunds may include low capacity culverts installed through the embankment, drainage inverts to concentrate low flows over the embankment at defined locations, or discontinuous embankment sections with gaps provided to encompass the main waterway channel. Development and use of these embankment structures may be programmed for dry season conditions, but construction of the crossing often extends through periods of substantial stream flow, including flow periods when fish may be migrating.

Where the new road crossing drainage structure

Box C6.2: Common occurrence and description of principal hydraulic barriers to fish passage within various temporary crossing configurations and waterway modifications *(See Chapter 2 for description of barriers; Source: Ross Kapitzke)*

	Ford or level crossing	**Pipe or box culvert**	**Bridge or spanning deck**	**Embank't, pad or bund**	**Channel encroach**	**Diversion channel**
High velocity	9	9	9	9	9	9
Shallow water depth	9	9		9		9
Lack of resting place		9	9			9
Excess turbulence		9		9	9	9
Water surface drop	9	9		9		9

Ford or level crossing (*Photo 17/06/08: Low level gravel and rock causeway Little Stuart Creek, Townsville*)

x a ford or level crossing is a low embankment used to provide for vehicle access across the waterway under very low flow conditions

x this type of crossing may be used off-site in a side track detour or for on-site access track crossings of intermittent waterways during short term projects or where stream flow is unlikely to disrupt work

x fish migration barrier problems are likely to be minimal but may include the following at very low flows and low flows:

- ƒ water surface drop downstream of crossing
- ƒ high velocity and s33 b2e

Box C6.2: Common occurrence and description of principal hydraulic barriers to fish passage within various temporary crossing configurations and waterway modifications *(See Chapter 2 for description of barriers; Source: Ross Kapitzke)*	
Embankment, pad or bund (*Photo 16/01/04: Construction pad Douglas Art Road University Ck, Townsville*)	
	x earth and rockfill embankments are commonly provided at bridge crossing sites as a construction platform for access and machinery x these construction pads or bunds may incorporate through pipes or surface drainage inverts for low flow in smaller waterways, or provide openings between embankment sections in larger streams x fish migration barrier problems may include the following at the embankment and through the pipes at low flows and medium flows: ƒ high velocity and turbulent flow downstream of embankment ƒ water surface drop at downstream edge for overtopping flows ƒ high velocity through embankment opening or through pipes ƒ high velocity and shallow water depth for overtopping flows
Channel encroachment (*Photo 09/11/05: Culvert reconstruction Bruce Highway coastal stream, Innisfail*)	

x 639Tj /T2295 Tf .5933 0 TD .0007 Tc .0026 Tw [(t59h velocity)-12.6(and sha10

6.2.1 Waterway, habitat and fish community assessment

Waterway, habitat and fish community assessment for the temporary crossing is focused on determining if the structure is located within a significant fish movement corridor, and if the fish community within the waterway is likely to be migrating through the site during the period that the temporary crossing is in place. Some information for the temporary road crossing will most likely be available from fish passage assessments undertaken for the permanent road crossing proposed for the site. Site assessment tasks undertaken as part of site scale planning and design for the permanent facility will provide the basis for much of the assessment for the temporary facility, including (see *Guidelines Part E – Fish Passage Design: Site Scale*):

- catchment and waterway characterisation
- waterway and flow characteristics
- stream reach condition and fish habitat characteristics
- road-waterway crossings and fish migration barriers
-

occurrence of the principal hydraulic barriers to fish passage within temporary crossing and waterway modifications are described and illustrated above in Section 6.1.

6.2.3 Fish passage design requirements and multipurpose design objectives

Fish passage goals and other multipurpose requirements for the temporary crossing or waterway modification are used to establish the configuration of fish passage facilities to overcome fish migration barrier problems at the site. The fish passage design requirements are identified in terms of overcoming particular hydraulic barriers within the structure for the design flow condition, and addressing critical drainage and other utility requirements (e.g. flow capacity, sediment, debris) for the site, including the following (see Section 4.1 of this guideline):

- provide suitable hydraulic conditions (e.g. velocity, shelter, turbulence) through the structure to overcome adverse conditions (e.g. high velocities, shallow flow, lack of shelter, excess turbulence, water surface drop) to allow fish to pass upstream during low / medium flows
- provide flow continuity through all zones of the structure and a continuous fish pathway and attraction flow to allow fish to readily locate the downstream entrance to the fish passage facilities and to move upstream through the crossing in response to flow
- provide suitable shelter conditions at the structure inlet and in the upstream channel to allow fish that have passed through to exit the structure and move freely away into the stream during low / medium flows
- minimise obstruction to flow, manage the effects of debris accumulation and sediment deposition, and provide for ready cleaning and maintenance in the waterway structure
- maintain integrity of the temporary waterway crossing structure and provide for transport, drainage and other utility functions at the site

These specific design requirements form a subset of multipurpose requirements for the temporary road crossing relating to transport, drainage, fish passage and amenity (see Section 4.1). Design criteria for fish passage are established according to desired fish passage effectiveness of the crossing, fish passage design flows, and fish movement characteristics of the fish community, in a similar manner to that outlined for permanent structures (see *Guidelines Part B – Fish Migration and Movement Behaviour* and *Guidelines Part E – Fish Passage Design: Site Scale*).

In terms of fish passage effectiveness for temporary crossings, a slightly less conservative approach is likely to be applied compared with that used for a permanent crossing of the waterway. Of the three possible levels of fish passage effectiveness, the more restrictive approaches (Level 2 – Intermediate, and Level 3 - Restrictive) are suggested (Box C6.3).

Box C6.3: Suggested fish passage effectiveness levels and design criteria for provision of fish passage at temporary road crossings *(See Guidelines Part B – Fish Migration and Movement Behaviour)*

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 2 – intermediate	x all native fish species, life stages and maturity	x not mandatory for any native fish species	x not mandatory for any native fish species
Level 3 – restrictive	x all but outlier [1] native fish species (e.g. poor swimmers)	x not mandatory for any native fish species	x not mandatory for any native fish species

Notes 1 0 Tc0 native
fish speciTw(native f274.58 1rblic barri)]TJon TD.0001 2raryish specbasi.7(less c1 Tf.59di)Tj2.4(eci7 .433 0 TDi.52c1 Tf.5

Box C6.4: Key principles and design considerations for mitigation measures to meet fish passage requirements for temporary road-waterway crossings *(see also Box C4.2 for permanent crossings)*

Design aspect / parameter	Design consideration, comment and rationale
Fish passage provisions downstream of embankment and culvert and in downstream channel	x mitigate against water surface drop, shallow water depth and high velocity at the culvert outlet, if needed, by setting the culvert invert below the downstream bed level (suggest countersink up to 25 % of culvert height below channel bed) x mitigate against high velocity and turbulent flow at the culvert outlet and in the downstream channel, if needed, by placing large rocks for energy dissipation and fish shelter at the culvert outlet x mitigate against water surface drop at the culvert outlet, if needed, by providing rock cascade grade control structures in the downstream channel, configured to raise tailwater level to at or above culvert invert level
Fish passage provisions through opening in embankment or bund	x mitigate against high velocity conditions through the embankment opening, if needed, by providing greater flow area through a wider opening x mitigate against high velocity and lack of rest place through the embankment opening, if needed, by providing a roughly formed rock surface with channel complexity and flow diversity along the edges of the opening
Fish passage provisions through pipe or box culvert under embankment	x mitigate against high velocity conditions within the temporary culvert, if needed, by providing greater flow area through more and/or larger culverts x mitigate against high velocity conditions within the temporary culvert, if needed, by setting the culvert invert below the downstream bed level x mitigate against lack of attraction flow for fish to the temporary culvert by placing the culvert adjacent to the stream bank or prominent fish pathway
Fish passage provisions across embankment or bund	x mitigate against high velocity and shallow water depth across the embankment or bund, if needed, by providing a rock lined invert section across the embankment to concentrate flows during overtopping x mitigate against high velocity and shallow water depth across the embankment or bund, if needed, by providing a discontinuous rock sill on the downstream edge of the bund wall, with flow openings at the sill to attract fish x provide rock chute connections from the downstream channel to areas of flow concentration at invert sections or sill openings (preferably adjacent to stream bank) on construction pad for overtopping flows
Provisions for breaching embankment or bund	x although not desirable, consider using an erodible (fuse plug) section through the construction pad that would breach in high flows x allow for monitoring and response to overtopping flood flows on embankment, including contingency plans to rapidly remove the embankment or breach it by excavation if needed to expedite the failure and for clearance of the obstruction
Fish passage provisions for temporary crossings at diversion drain	
Overall suitability for fish passage	x diversion drains are commonly used at temporary crossings and usually require mitigation measures to assist fish passage
Channel form for diversion drain	x mitigate against high velocity and lack of rest place in diversion drain by providing channel complexity and flow diversity along the waterway edges x avoid stream channelisation with hard lining such as concrete, removal of vegetation, or simplification of natural bank structure x ensure that the channel configuration and rock protection in the waterway provides for stability and control of bed erosion, which may otherwise progress further upstream and form a drop in the bed that represents a fish migration

The low level pipe crossing was subsequently installed in February 2004 so that the regular truck movements would not create water disturbance in the shallow flow environment that occurred in University Creek during the spoil haulage operation (Box C6.6). The expectation of the contractor with respect to fish passage was that because the pipe and causeway embankment were contained within the channel, the fish would pass through the pipe at low flows and pass over the embankment fill at higher flows. It was inevitable however, that the pipe crossing would restrict fish passage upstream (at least for part of the time) during any substantial creek flows.

This obstruction occurred in February 2004 when fish were for a time unable to pass through the full-flowing pipe due to the high velocities and lack of shelter and resting areas downstream. During the February flow event, the temporary pipe installation was monitored for velocities at the pipe inlet and outlet. Velocities ranged from 1.6 m/s – 2 m/s at the outlet, and from 1 m/s – 1.4 m/s at the pipe inlet on 12 February 2004, but conditions varied substantially on a daily basis as the stream rose and fell in response to rainfall. Whilst fish were unable to pass through the full-flowing pipe, some fish were apparently able to negotiate their way upstream through the pipe at various other stages of this flow event. The pipe length was considerably less in this installation than in the January installation under the wide road embankment, and although conditions were slightly more favourable for fish passage, the pipe was still clearly too small.

Whilst all flow events during 2003/04 were relatively minor, fish migration to upstream habitat areas and to the Discovery Drive fishway was affected by the temporary road crossings at the Douglas Arterial Road crossing site during the largest events in January and February 2004. Although some fish were able to negotiate the temporary crossings, they were delayed in their upstream movement (possibly for periods of 6 hours or more), thus affecting passage at the Discovery Drive crossing as the hydrograph peak had passed long before they reached this site. The number of fish reaching the upstream fishway site and their motivation to move further upstream or to spawn are expected to have been reduced as a result. Furthermore, those fish that were able to pass through the downstream obstructions may have lost their full capacity to spawn due to the delay and the exertion in overcoming the barrier.

Box C6.6: Fish passage problems associated with flooding at temporary rock invert and pipe access crossing for Douglas Arterial Road project crossing of University Creek – February 2004 *(Source: David Derrick)*

Rock invert crossing in very low flow conditions – looking upstream (02/02/04)

Low flow pipe crossing in very low flow conditions – looking upstream (10/02/04)

6.4.3 Suggested mitigation measures to improve fish passage

Of the series of temporary road crossing configurations installed at the Douglas Arterial Road crossing of University Creek, virtually all drainage structure components represented a barrier to upstream fish migration as a result of some poorly conceived aspect that did not adequately take account of the adverse hydraulic conditions associated with temporary crossing facilities or the swim behaviour of the fish attempting to pass. The initial construction pad and small diameter pipe were intended for dry weather conditions in the creek and were inappropriate for the flood flows experienced as a result of extending the construction phase through the wet season period.

7 BIBLIOGRAPHY

Bates, K., Barnard, R., Heiner, B., Klavas, J.P., and Powers, P.D., 2003, *Design of road culverts for fish passage*, Washington Department of Fish and Wildlife.

Boubee, J. Jowett, I., Nichols, S. Williams, E. 1999, *Fish passage at culverts, a Review with possible solutions for New Zealand indigenous species*