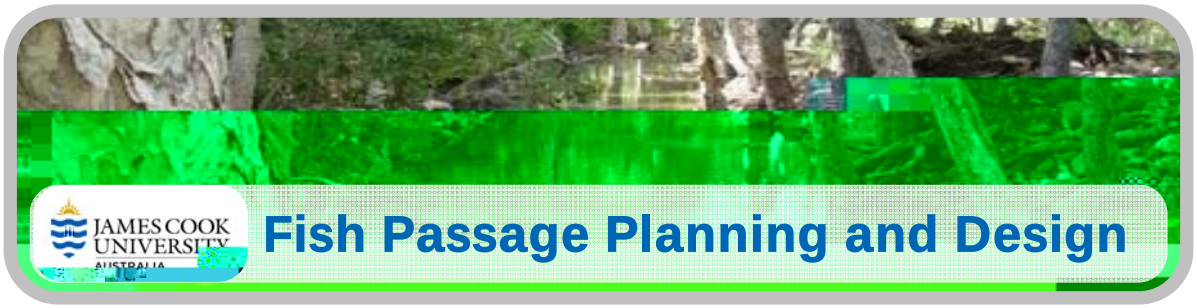
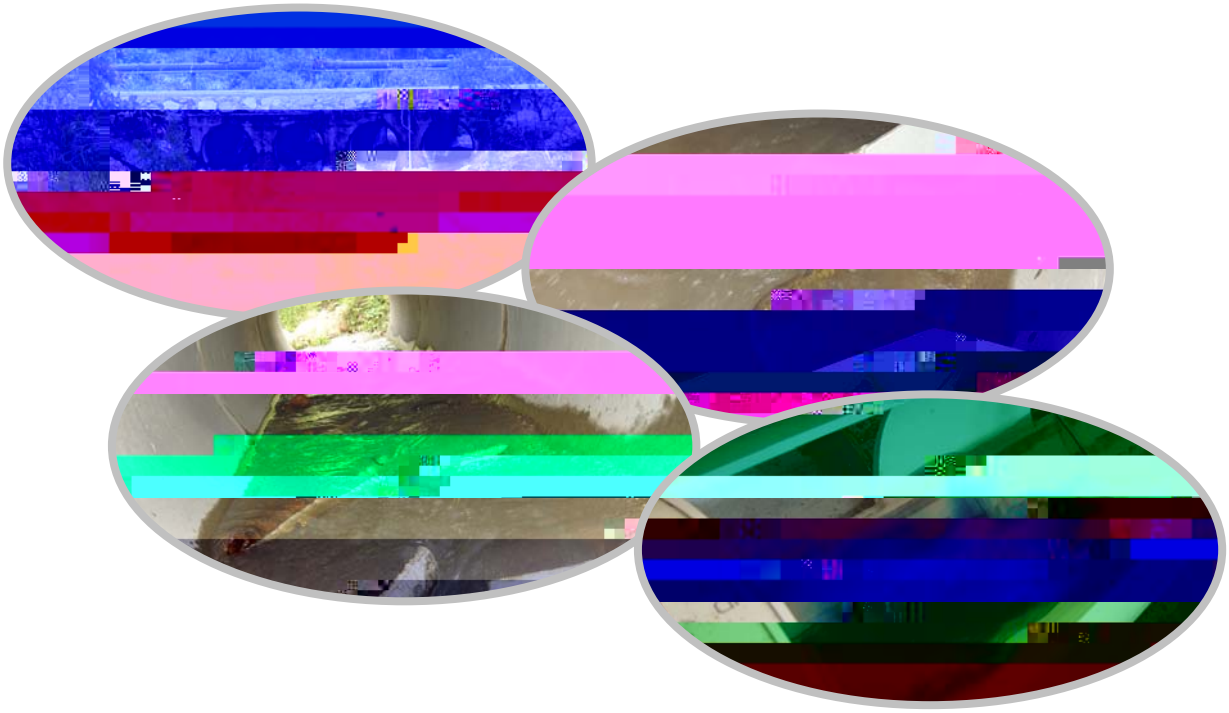


Culvert Fishway Planning and Design Guidelines

Part G – Baffle Fishways for Pipe Culverts



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2 FISH MIGRATION BARRIER PROBLEMS AND BAFFLE FISHWAY DESIGNS

Pipe culverts are used extensively for waterway drainage crossings in Australia, most commonly for small streams. Single or multiple barrel culverts of from 1.2 m to 3 m diameter are often used at roads ranging from narrow tracks with culvert lengths of less than 4 m, to multiple carriageway highways with culvert lengths of up to 60 m. Pipe culverts are sometimes built into causeway structures, which overtop during stream flows in excess of pipe full capacity. Fish migration barrier problems commonly occur at pipe culvert crossings, as they are conventionally designed with a focus on drainage, transport and utility functions, and commonly experience high velocity and other adverse hydraulic conditions that impact on fish movement.

Fish migration barrier problems at pipe culvert crossings can be addressed through use of baffle fishway devices in conjunction with other fishway components to mitigate impacts for new developments or remediate barrier effects through retrofit at existing structures. Many of the principles for use of baffle fishways at pipe culverts are common to the principles applying for baffle fishways in box culverts. In addition specific information on baffle fishway designs for pipe culverts presented in this *Guideline Part G – Baffle Fishways for Pipe Culverts*, general information on design concepts and background, configuration aspects and hydraulic and fish passage performance characteristics of baffle fishways for box culvert and pipe culvert waterway crossings are outlined in *Guidelines Part F – Baffle Fishways for Box Culverts*.

This chapter briefly outlines common fish migration barrier problems at pipe culvert structures and introduces the general aspects of baffle fishway designs to overcome these barriers. Illustrations of fish migration barriers and mitigation / remediation design using baffle fishway devices are provided in this chapter and in subsequent chapters for the Solander Road pipe culvert crossing of University Creek in Townsville (Box G2.1), where the offset baffle and corner "Quad" baffle prototype fishway designs have been implemented as retrofits (Kapitzke 2007c).

Box G2.1: Solander Road pipe culvert crossing of University Creek *(Source: Ross Kapitzke)*

High velocities within the culvert barrel are common features of pipe culvert crossings due to the regular smooth sided nature of the pipe, the relatively steep slopes that are often used for pipe culverts, and the concentrated flow that occurs through the culvert barrel. The setting of the culvert structure at the site and within the stream reach may also contribute to a water surface drop at the culvert outlet, which is another common factor that may present a barrier to fish migration. A perched culvert outlet and associated water surface drop, where the pipe invert or downstream culvert apron is raised above the stream channel bed, are common in pipe culverts installed in relatively steep gradient (upland) stream reaches and at riffle (high point) locations. Although less common than for box culverts, pipe culverts installed at flatter gradient (lowland) sites may have submerged pipe inverts which, as a result of downstream ponding in the waterway, do not produce water surface drops that represent fish migration barriers.

Pipe culvert designs are commonly configured so that the culvert invert initially coincides with the nominal stream bed level at the crossing site, but the pipe outlet and culvert outlet apron may become perched over time as a result of downstream erosion. A pipe invert gradient of up to 3 % is commonly used in Australian culvert crossing structures, and although this may be set to initially coincide with the nominal stream gradient at the site, erosion as a result of the high culvert velocities and erodible stream reaches may lead to a perched outlet with locally steeper gradients at the erosion hole. These erosion processes contribute to adverse hydraulic conditions that are to be overcome to provide fish passage at the waterway structure.

For example, the Solander Road pipe culvert causeway crossing, which is located at a local high point in a relatively steep gradient (1 in 100) reach of University Creek, produces high velocity flows through the culvert and over the causeway that cause severe hydraulic conditions for fish. These high energy flows, in combination with low tailwater levels, have contributed to bed and bank erosion at the culvert outlet, undermining the culvert structure and contributing further to adverse hydraulic conditions for fish passage through the crossing (Box G2.1).

The common types of hydraulic barriers to upstream fish movement within the various parts of a pipe culvert waterway structure are listed below. This is illustrated in Box G2.2, which shows the various hydraulic zones and corresponding fish migration barriers for the Solander Road pipe culvert crossing of University Creek, where the offset baffle and the corner “Quad” baffle fishway designs were incorporated within Culvert Barrels 1 and 2 (Kapitzke 2007c).

Hydraulic zone within culvert	Common barrier effect for fish movement
Downstream channel	x High velocities, excess turbulence, water surface drop
Culvert outlet and downstream apron	x High velocities, shallow water depth, lack of resting place or shelter, excess turbulence, water surface drop
Culvert barrel	x High velocities, shallow water depth, lack of resting place or shelter, excess turbulence
Culvert inlet and upstream channel	x High velocities, shallow water depth, lack of resting place or shelter, excess turbulence, water surface drop

2.2 Baffle fishway designs for pipe culverts

Baffle type fishways are most likely to be used in the culvert barrel or on outlet apron slabs of box or pipe culvert waterway structures to overcome high velocities, shallow water depth, and lack of resting place or shelter that represent barriers to upstream fish movement through the structure. Baffles are used in the hydraulic design approach to culvert fishways, where hydraulic conditions (water depth, velocity, flow patterns) are modified to allow fish to use a burst-rest swim pattern to move upstream through the waterway structure.

Velocity and other hydraulic conditions within the culvert, along with other drainage and utility considerations for the structure, determine the appropriate baffle fishway design for the site (e.g. offset baffle; corner “Quad” baffle). The suitability and effectiveness of baffle type fishways that

may be used in the culvert barrel or on culvert aprons. Floor slabs must be considered within the context of the overall design requirements and the need to provide for fishway components to overcome fish migration barrier problems within each hydraulic zone of the structure (see *Guidelines Part C – Fish Migration Barriers and Fish Passage Options for Road Crossings*). Depending on requirements, other fishway components (e.g. small pools) may be used in addition to baffles within the various structure zones (e.g. culvert outlet and downstream channel).

Design concepts and background, configuration and performance characteristics to assist in the planning and design for the offset baffle and corrugated "Quadrad" baffle fishways for pipe culverts are presented in the following Chapters (3 and 4). The underlying context and general characteristics for the baffle fishway designs for box culverts and pipe culverts are outlined in

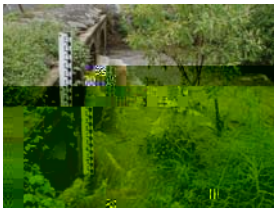
Box G2.2: Hydraulic zones and fish migration barriers within Solander Road pipe culvert crossing *(After: Kapitzke 2007c)*

Zone C: Culvert barrel

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



- x turbulent, high velocity flow at pipe and upstream channel for low flows
- x lack of shelter zones upstream of culvert and constricted flow tending to sweep fish back into pipe at low flows
- x 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*)

baffles that are maintained for a range of flow depths including emerged and submerged baffle conditions. Under shallow flow conditions up to the height of the baffles, the offset baffle fishway functions in a similar manner to the vertical slot fishway for weirs, with highest velocities occurring in the slots between the baffles and flow circulating between the baffles in the horizontal plane on the culvert base. The o

The offset baffle design used in the Solander Road pipe culvert prototype fishway on University Creek in Townsville (Kapitzke 2007c) provides an example of the design configuration for an offset baffle fishway facility (Box G3.2). The So

Box G3.3: Characteristics, configurations and design parameters for offset baffle fishway for pipe culverts	
Design aspect / parameter	Performance characteristic, design consideration, comment and rationale
Materials for construction of offset baffle fishways	
General	

Box G3.4: Hydraulic characteristics of flowfor offset baffle fishway for pipe culverts	
Design aspect / parameter	Performance characteristic, design consideration, comment and rationale
Flow characteristics – emerged baffle condition (flow depth < baffle height)	
Flow patterns – emerged baffle	x for emerged flow conditions with depths less than one baffle height, the water jet passes through the baffle slot as streaming flow with recirculating flow in the horizontal plane of the baffles, and follows a meandering path through the cell / baffle set to the next baffle slot downstream (Rajaratnam et al. 1988; Kapitzke 2007c)
Velocities – Solander Road prototype fishway	x for flows up to the baffle height of 150 mm, the baffle slot and areas adjacent to the oblong baffles have the maximum velocity condition (range 0.5 m/s – 0.6 m/s), whereas areas within the cells between the perpendicular baffles are sheltered (range 0.05 m/s – 0.2 m/s) (Kapitzke 2007c)
Flow characteristics – submerged baffle condition (flow depth > baffle height)	
Flow patterns – submerged baffle	x for submerged conditions with more than one baffle height flow depth, part of the flow goes straight downstream over the perpendicular baffles, another part flows obliquely over the oblong baffles in a spiraling fashion as plunging flow that interacts with recirculating flow in the lower plane below the baffle top, and the slot jet follows a straight path downstream (Rajaratnam et al. 1988; Kapitzke 2007c) x increasing slope produces undesirable flow conditions for fish passage in the pipe culvert offset baffle fishway, involving standing waves with wave lengths equal to baffle spacing, and with crests located at slots and troughs located at the centre of cells (Rajaratnam et al. 1988; Kapitzke 2007c) x depending on channel slope and the type and size of baffles, increased discharge results in progressively supercritical flow conditions and formation of surface waves, which dominate the helical currents / spiraling flow over the oblong baffles and diminish the energy-dissipating role of the baffles (Larinier 2002a)
Velocities – Solander Road prototype fishway	x velocities within the offset baffle fishway were consistently less than velocities in the plain culvert (up to 3.2 m/s for flow depths of 400 mm), and flow depths were correspondingly greater within the fishway (Kapitzke 2007c) x for flows surcharging the baffles, velocities through the baffle slots in the lower flow layer increase to around 0.9 m/s, while surface flow velocities increase to around 1.5 m/s on the perpendicular baffle side and to 0.9 m/s along the oblong baffle side (Kapitzke 2007c)

3.3 Fish passage characteristics of offset baffle fishway

The offset baffle fishway design provides resting pools and local higher velocity conditions between these pools that allow fish to move by burst and rest pattern through the fishway. The configuration of the fishway produces hydraulic characteristics that assist upstream fish movement in a range of flow conditions including shallow flow contained within the baffles and deeper flow that overtops the baffles. This includes the following enabling hydraulic effects for upstream fish passage through the offset baffle fishway and culvert waterway:

- flow retardation when baffles are emerged or submerged
- shelter downstream of the perpendicular ba

Box G4.4: Hydraulic characteristics of flow for corner “Quad” baffle fishway for pipe culverts	
Design aspect / parameter	Performance characteristic, design consideration, comment and rationale
Velocities – Solander Road prototype fishway	x for increased flow depths of up to 2.5 standard baffle heights, velocities at the streamside end of the baffle leg in the lower flow layer are up to 1.6 m/s, compared with velocities of less than 0.3 m/s in the sheltered area within the baffle cells between the baffle elements, and velocities of up to 1.9 m/s in the open channel section in the culvert barrel opposite the baffles

4.3 Fish passage characteristics of corner “Quad” baffle fishway

The corner “Quad” baffle fishway design provides shelter areas and flow recirculation within the baffle field that support the movement of fish in a burst and rest pattern through the fishway. The configuration of the fishway with the baffles extending up the culvert wall produces favourable hydraulic characteristics for fish passage in shallow and deep flows and provides for multiple fishway function that is likely to assist benthic, mid water and surface swimming species. This includes the following enabling hydraulic effects for upstream fish passage through the fishway:

- flow retardation when baffles are emerged or submerged
- shelter downstream of baffles when emerged or submerged
- pooling on the upstream side of baffles when emerged or submerged
- flow circulation in horizontal plane within the baffle field for emerged or submerged baffles
- localised high velocity conditions and flow concentration at baffle ends for emerged or submerged baffles

The general fish passage characteristics for the corner “Quad” baffle fishway for pipe culverts that have been so far established from the literature, from the culvert fishway R & D program, and from conceptual design evaluation are presented in Box G4.5. This information (enabling hydraulic conditions; fish passage effectiveness; design configuration) should be used to guide the design and implementation of a corner “Quad” baffle fishway facility for pipe culverts at a field site. Actual design provisions and configuration requirements for the culvert fishway facility should be established on the basis of the site characteristics (see *Guidelines Part E – Fish Passage Design: Site Scale*). More detailed information on fish passage performance characteristics obtained from field prototype and laboratory model testing of the corner “Quad” baffle fishway for pipe culverts is presented in the attached *Appendix G1 – Solander Road Prototype Offset and Corner Baffle Fishways.*

Box G4.5: Fish passage characteristics for corner “Quad” baffle fishway for pipe culverts	
Design aspect / parameter	Performance characteristic, design consideration, comment and rationale
Enabling hydraulic conditions for fish passage	
Flow patterns	x protrusion of the corner “Quad” baffle fishway from the culvert wall provides favourable hydraulic conditions to assist fish in moving around the end of the baffle when flow is contained within the baffle height
Hydraulic control conditions for fish passage	x barrier velocities at the streamside end of the baffles provide control conditions for fish movement around the baffles in the lower and upper flow layers for a range of flow depths up to the top of the baffles
Resting areas and flow circulation	x sheltered flow conditions and a tendency for flow recirculation within the baffle sets for both the lower and upper flow layers provide enhanced conditions for fish shelter and upstream movement between baffle sets
Attraction flows	x unrestricted flow in the open channel section of the culvert barrel opposite to the corner “Quad” baffle improves attraction flow for fish into the corner “Quad” baffle fishway culvert barrel, and locally accelerated flow around the streamside end of the baffles provides attraction flow for fish to move upstream

Box G4.5: Fish passage characteristics for cover “Quad” baffle fishway for pipe culverts	
Design aspect / parameter	Performance characteristic, design consideration, comment and rationale

5 OVERALL SUITABILITY OF BAFFLE FISHWAY DESIGNS

This chapter summarises overall suitability and performance characteristics for the offset baffle and corner "Quad" baffle fishways for pipe culverts, based on information available from prototype fishway development and testing, hydraulic laboratory modeling, case study culvert fishway projects, and design concepts developed for these fishways. Suggestions for further development and testing of these fishways are also provided.

The major features that apply to the offset baffle fishway for pipe culverts are:

- the offset baffle fishway is suited to shallow high velocity flow in culverts as it provides major reductions in culvert velocities, localised high velocity conditions to the control points between baffles, and increases flow depth to assist fish movement
- this can be applied to steep culverts or culverts with low tailwater conditions, provided other fishway components (e.g. rock ramps / backflood weirs) are provided downstream to raise tailwater levels to the outlet water level through the fishway
- the offset baffle fishway is 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 baffles, and a simpler design (e.g. corner "Quad" baffle) may be adequate to reduce velocities
- the offset baffle fishway is a type of two dimensional vertical slot fishway that provides for fish passage through low velocity zones, shelter areas and flow circulation when flow is contained within the baffles, and low velocity zones and shelter areas within and adjacent to the baffle field when flow surcharges the baffles
- when flow is contained within the baffles at depths up to one baffle height, the offset baffle fishway provides flow circulation and resting areas for fish and reduces maximum velocities through the structure compared with velocities within the adjoining plain culvert barrels
- when flow surcharges the baffles, the offset baffle fishway reduces velocities and provides favourable conditions for fish to move in the low velocity zone adjacent to the perpendicular baffle, but produces adverse hydraulic conditions with standing waves at flows of two or more baffle heights flow depth
- the low profile of the fishway and the flow continuity that is provided through the fishway baffle system minimises flow resistance and the effect on flow conveyance in the culvert
- the offset baffle fishway has inherent self cleaning and through-flow attributes for sediment and debris due to the horizontal flow circulation within the baffle zone when flow is contained within the baffle zone, and the longitudinal spiral flow along the side wall when flow surcharges the baffles
- the offset baffle fishway is less suited to pipe culverts than to box culverts due to less favourable flow conditions to support fish passage within and above the baffles, and coverage of the culvert invert that affects flow conveyance and sediment passage

The major features that apply to the corner "Quad" baffle fishway for pipe culverts are:

- the corner "Quad" baffle fishway provides localised reductions in culvert velocities and is suited to a range of flow depths in culverts, including relatively deep low velocity flow
- this can be applied to culverts with high tailwater conditions, or culverts where other fishway components (e.g. rock ramps / backflood weirs) are provided downstream to raise tailwater levels to the outlet water level through the fishway
- the corner "Quad" baffle fishway is less suited to high gradient culverts and shallow high velocity environments, where other fishway designs (e.g. offset baffle) may be required to provide appropriate reductions in culvert velocities
- the corner "Quad" baffle fishway provides for fish passage through low velocity zones, shelter areas and flow circulation for a range of flow depths in the culvert that will benefit benthic, mid water and surface swimming species

- for flow up to the top of the baffle, the fishway provides flow circulation, resting areas and reduced velocities through the full height of the baffles to assist fish moving throughout the fishway, including at the culvert bed and at the water surface
- the flow continuity that is provided through the unobstructed culvert base minimises flow resistance and the effect on flow conveyance in the culvert
- the corner "Quad" baffle fishway shows good self-cleaning and through-flow attributes for sediment and debris as the culvert invert and each side of the barrel are not obstructed by baffle components
- the corner "Quad" baffle fishway is more readily constructed than the offset baffle fishway because of its simpler configuration

Suggested further development and testing of offset baffle and corner "Quad" baffle fishways for pipe culverts includes the following, which can be undertaken through prototype fishways, hydraulic laboratory modeling, or case study culvert fishway projects:

- hydraulic and biological performance characteristics of the offset baffle and corner "Quad" baffle fishways with variations in culvert slope
- hydraulic and biological performance characteristics of the corner "Quad" baffle fishway with variations in longitudinal spacing of the baffles and baffle dimensions
- adaptations of the corner "Quad" baffle fishway design to examine tilting the baffles from the horizontal plane and angling the baffles to the vertical plane
- adaptations of the corner "Quad" baffle fishway design to examine the merits of providing notches along the truncated edge or on the horizontal and vertical baffle legs
- examination and evaluation of techniques to provide appropriate attraction flows for fish entrance to the fishway components
- examination and evaluation of techniques to provide appropriate hydraulic characteristics for transitions between fishway components
- examination of turbulence characteristics of offset baffle and corner "Quad" baffle fishways and the relationship to fishway flow, culvert slope, and fishway design
- evaluation of biological performance characteristics of the various baffle designs, including fish passage effectiveness and fish movement behaviour for the fishways
- adaptations of the offset baffle and corner "Quad" baffle fishway designs to improve sediment and debris shedding of the baffles (e.g. profiling upstream face)
- comparative evaluation of performance characteristics of the offset baffle, corner "Quad" baffle and other baffle fishway designs for a range of culvert configurations and flows
- examination of materials for fabrication and installation of the baffle fishways and to provide for ready fixing of the baffles to the culvert base and walls

APPENDIX G1 – SOLANDER ROAD PROTOTYPE OFFSET AND CORNER BAFFLE FISHWAYS

James Cook University School of Engineering and Physical Sciences
Culvert Fishway Design Guidelines: Part G – Baffle Fishways for Pipe Culverts
Appendix G1 – Solander Road Prototype Offset and Corner Baffle Fishways

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Culvert Fishway Design Guidelines: Part G – Baffle Fishways for Pipe Culverts
Appendix G1 – Solander Road Prototype Offset and Corner Baffle Fishways

1 SOLANDER ROAD BAFFLE FISHWAYS FOR PIPE CULVERTS

The prototype fishway facility for pipe culverts (Prototype Fishway #3) was developed at the Solander Road culvert / causeway crossing of University Creek in late 2005 (Boxes G1A.1 and G1A.2). This is a full-size facility comprising the offset baffle and corner "Quad" baffle fishways in culvert Barrels 1 and 2, and several other fishway components, including a rock ramp / cascade fishway in the downstream channel and an apron baffle fishway on the culvert outlet apron. Dedicated monitoring facilities are incorporated into the culvert structure to allow hydraulic and biological monitoring of fishway performance during flow events in University Creek. The Solander Road crossing itself consists of a 4-barrel pipe culvert (1200 mm diameter x 7.4 m long) with an invert slope of 1 in 50 or 2.0 % (fall 0.15 m over culvert length). The culvert has an overtopping causeway above the pipe barrels, a concrete apron at the pipe outlets, and (prior to remediation) had a downstream drop of more than 0.5 m to the stream bed level.

The offset baffle is a pool type fishway that is intended to provide suitable conditions for fish passage under relatively high velocity conditions in the culvert. The offset baffle fishway design for the Solander Road pipe culvert is a slightly modified version of the standard offset baffle design for pipe culverts (Engel 1974), in which the geometric configuration of the baffles is defined relative to the width of the top of the fishway for the adopted minimum baffle height of 150 mm. The corner "Quad" baffle fishway is a hybrid roughness and pool type fishway that is intended to provide suitable conditions for fish passage at flow depths up to about half pipe full. A truncated quad shaped baffle is placed perpendicular to the culvert flow on the lower quadrant of the pipe, with the baffle spacing for the Solander Road culvert matching that of the perpendicular baffle for the offset baffle fishway design in Barrel 1 (Boxes G1A.1 and G1A.2).

Box G1A.1: Solander Road fishway for pipe culverts (Prototype #3) established in University Creek (Source: Ross Kapitzke)

Prototype fishway showing rock ramp and apron baffle fishways – looking U/S (09/04/06)	Corner "Quad" baffle fishway in Barrel 2 – looking upstream (10/04/06)

The offset baffle and corner "Quad" baffle fishways were installed in culvert Barrels 1 and 2 with the intention of overcoming fish migration barriers associated with high velocities, excess turbulence, regular cross section and lack of resting place along the culvert barrels. Overall, barriers to fish migration at the Solander Road culvert without the fishway may be produced in various flow conditions as a result of the following:

- excess turbulence downstream of the culvert at high flows
- water surface drop downstream of the apron at low flows
- shallow water depths on the downstream apron at low flows
- high velocities at the culvert outlet and on the downstream apron
- high velocities and excess turbulence within the culvert barrel
- regular cross section and lack of resting place along the culvert barrel

- high velocities, turbulence and constriction at the culvert inlet during low and high flows

Monitoring and evaluation of the hydraulic and biological performance of the offset baffle and corner "Quad" baffle prototype fishways for pipe culverts, as well as for the other fishway components at the crossing, was undertaken over the wet season (2005/06). Hydraulic laboratory modelling of the baffle fishway designs for the pipes was undertaken on a 1:3.3 scale model of the installation to examine hydraulic performance characteristics for a range of flow depths. The following sections describe the findings of field prototype and laboratory model testing, and evaluate the hydraulic and biological performance characteristics of the offset baffle and corner "Quad" baffle fishway design for pipe culverts. The material presented here is taken principally from the report Solander Road pipe culvert fishway (Prototype Fishway # 3): Case study project design and prototype monitoring report to April 2006 (Kapitzke 2007b).

Box G1A.2: Solander Road pipe culvert – offset and corner "Quad" baffle fishway configuration

corner “Quad” baffle fishway barrels, but was generally obtained from the three most downstream baffle sets where the deepest flow conditions in the culverts applied.

Monitoring events established data as part series of flow cases with various headwater values and combinations of flowing or closed conditions for the pipe culverts. Cases were named according to the flow status of the culvert pipe fishway zones and the headwater depth (e.g. CC0X20 = Fishway Zone C – culvert barrel all barrels flowing, headwater 200 mm).

Box G1A.3: Fishway operation and hydraulic monitoring(Source: Ross Kapitzke)	
Manipulating nib wall flow control boards at culvert inlet (11/04/06)	Velocity measurements on apron downstream of culvert fishway barrels (27/01/06)

2.2 Hydraulic monitoring results for 2006

Box G1A.4: Solander Road prototype fishway velocities and flow depths for 2005/06 field monitoring events – Barrel 1 offset baffle fishway

U/S	Baffle Set 1-2	Baffle Set 2-3	Baffle Set	D/S

Box G1A.5: Solander Road prototype fishway velocities and flow depths for 2005/06 field monitoring events – Barrel 2 corner "Quad" baffle fishway

Box G1A.6: Flow characteristics in offset baffle fishway (Source: Ross Kapitzke)	
One standard baffle height flow depth – looking D/S (11/04/06)	One standard baffle height flow depth – looking U/S (11/04/06)
Two and one half standard baffle heights flow depth – looking D/S (11/04/06)	Two and one half standard baffle heights flow depth – looking U/S (11/04/06)

Box G1A.7: Flow characteristics in corner “Quad” baffle fishway (Source: Ross Kapitzke)	
One standard baffle height flow depth – looking D/S (11/04/06)	One standard baffle height flow depth – looking U/S (11/04/06)
Two and one half standard baffle heights flow depth – looking D/S (11/04/06)	Two and one half standard baffle heights flow depth – looking U/S (11/04/06)

Box G1A.12: Major outcomes and findings from biological monitoring – to April 2006
Flow cases, fish monitoring methods and general fish movement conditions
x a series of fish surveys and biological monitoring have been undertaken in University Creek and at the Solander Road prototype fishway over several flow events from January to April 2006
x observation of fish at the Solander Road crossing focused on the movement behaviour and fish passage success of individuals or schools of fish within and through the various fishway components, but included no systematic quantitative surveys of fish movement through the fishway under various flow conditions
Fish movement behaviour and fish passage effectiveness – general findings
x 6 native species were found in University Creek upstream of the Solander Road culvert crossing during the 2006 surveys, demonstrating the success of the fishway in passing 6 species that had migrated upstream to beyond the Discovery Drive crossing
x comparative performance of the fishway over several years prior to fishway development shows that in 2003 – 2005, up to 8 native species migrated upstream to the Solander Road crossing but no species succeeded in passing upstream of the culvert
Fish movement behaviour and fish passage effectiveness – pipe culvert fishway barrels
x successful fish passage through the culvert fishway occurred at flow depths up to about two standard baffle heights within the pipe culvert barrels, with high energy flow conditions at the pipe barrel outlets and on the apron slabs limiting fish passage at higher discharges
x small and large fish species that successfully passed upstream beyond the Solander Road culvert apparently used a burst and rest swim pattern to negotiate through the series of fishway zones associated with Barrels 1 and 2
x no fish were successful in passing upstream through culvert Barrels 3 or 4, or over the corresponding downstream culvert outlet apron slabs, which were not fitted with apron baffle fishway devices
x fish experienced some difficulties in moving through the interfaces between the apron baffle fishways and the fishways within the pipe barrels due to incompatible hydraulic conditions between the fishway components associated with flow patterns, water surface drops, and turbulence
x fish entering the lower end of culvert Barrel 1 with the offset baffle fishway were generally able to negotiate upstream to the culvert inlet, with glass perch observed moving over the perpendicular baffles at low flow conditions, and Plotosid catfish moving through flows up to about two baffle heights flow depth
x although limited information is available on the performance of the corner "Quad" baffle fishway in culvert Barrel 2, a specimen of Plotosid catfish was observed at the downstream end of the fishway, where hydraulic conditions appear conducive to fish moving through this barrel
Suggested further biological monitoring and prototype testing
x fish surveys in University Creek reaches upstream and downstream of the fishway to assess its fish passage effectiveness during flow events in the creek of various magnitudes and seasonal timing
x quantitative surveys of fish species diversity and abundance moving through the various fishway components under a range of flow conditions, including the proportion of fish passing through the facility, and the relative passage effectiveness of the fishway components
x observational data on fish movement behaviour in and around the culvert and fishway zones, including fish swimming ability in various hydraulic conditions, tolerance to turbulence or adverse flow conditions, response to attraction flows, delay time in passing through or adjacent to the various fishway components
x biological monitoring of the facility in conjunction with hydraulic monitoring and adaptation of the fishway designs

4 HYDRAULIC LABORATORY MODELLING

Hydraulic laboratory modelling has been used in conjunction with the Solander Road prototype in the development and testing of the offset baffle and corner "Quad" baffle fishway designs for pipe culverts. The laboratory modelling is used to compare the performance characteristics of the fishway models with those of the Solander Road prototype fishways, and to consider design adaptations that may be suitable for various culvert fishway installations.

This section describes hydraulic laboratory modelling for the offset baffle and corner "Quad" baffle fishways for pipe culverts undertaken at the hydraulic model facility at JCU School of Engineering. The major outcomes and findings for the work until 2006 are summarised,

- velocity variation with flow layers (one, two and three standard baffle heights) at critical points within baffle sets for the maximum flow case (three baffle heights flow depth)
- velocity variation at critical points for particular flow layers and flow depths with varying culvert slopes
- variations in dimensionless discharge and dimensionless velocity at key points in the culvert with dimensionless flow depth
- comparison between hydraulic characteristics of various fishway designs, the plain culvert, and prototype fishway facilities (tested in the field to a maximum flow depth of 500 mm)

The effects of the offset and corner "Quad" baffle fishways on velocities within the fishways, and on flow circulation and shelter / flow retardation within the various flow layers, can be seen from the photographs of flow within the culvert fishways (Boxes G1A.13 – G1A.16). The velocity and flow depth data that is acquired encompasses the flow in layer 1 for the range of flow depths / discharges, and flow layers 1, 2 and 3 for the maximum flow depth / discharge case. The flow pattern interpretations of surface and subsurface flow lines (Boxes G1A.15 and G1A.16) relate to the lower flow layer for flow depths up to one standard baffle height flow depth, and the lower and upper flow layers for flow depths of two or more standard baffle heights flow depth. Comparisons can be made with data for the plain culvert and for the prototype fishways (Boxes G1A.4 and G1A.5), which are available for flow depths of up to 2.5 standard baffle heights.

Box G1A.13: Pipe culvert offset baffle fishway flow patterns – 4.5 % slope (Source: Model testing – Jason Coe; Photo – Ross Kapitzke)

One standard baffle height flow depth: Dye inserted on left showing flow obstruction / shelter within baffle field on left (18/08/06)	One standard baffle height flow depth: Dye inserted on right showing flow obstruction / shelter within baffle field on right (18/08/06)
Three standard baffle height flow depth: Dye inserted on left showing unobstructed surface streamline swinging to centre (18/08/06)	Three standard baffle height flow depth: Dye inserted in middle showing unobstructed central streamline above baffle field (18/08/06)

Box G1A.17: Major outcomes and findings from hydraulic laboratory modeling of offset baffle and corner “Quad” baffle fishway for pipe culverts (model results after Coe 2006; prototype data from field testing – see Section 2.3)
x flow obstruction within the baffle cells and in the invert of the fishway indicates that the fishway may cause some debris obstruction and blockage
Flow characteristics of corner “Quad” baffle fishway
x flow through the corner “Quad” baffle fishway at one and two standard baffle height flow depths retains streamlined flow on the open side of the culvert outside the baffle field, causes flow obstruction / shelter on the baffle side of the culvert, with some flow recirculation within the baffle sets
x flow through the corner “Quad” baffle fishway at three and four baffle height flow depth produces a narrower zone of flow obstruction / shelter in upper flow layers on the baffle side of the culvert, with a wider zone of high velocity flow on the open side
x for the corner baffle fishway at 2% culvert slope, velocities at the outside edge of the corner “Quad” baffle in the lower flow layer are in the range 1.0 m/s to 1.4 m/s for discharge ranging from one baffle height to four baffle heights flow depth, compared with prototype velocities at the baffle edge of about 0.5 m/s for the low discharge
x for the corner “Quad” baffle fishway at 2% culvert slope, surface flow velocities at the outside edge of the corner “Quad” baffle are in the range 1.1 m/s to 1.3 m/s as the discharge increases from one baffle height flow depth to four baffle heights flow depth, compared with surface flow veloc

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