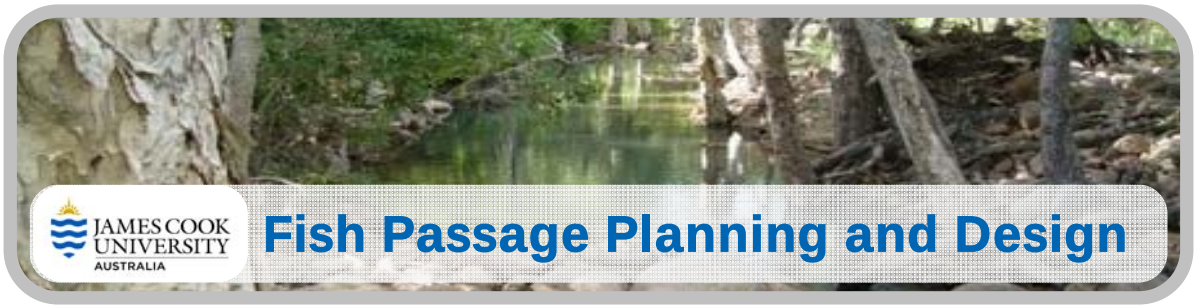

Culvert Fishway Planning and Design Guidelines

Part A – About These Guidelines

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April 2010 – VER2.0

JAMES COOK UNIVERSITY
AUSTRALIA

James Cook University School of Engineering and Physical Sciences
Culvert Fishway Planning and Design Guidelines
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Contents

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1 PURPOSE AND SCOPE

The intention of these *Guidelines* is to:

- introduce road designers, waterway managers, environmental officers and scientists to fish migration barrier problems and fish passage provisions at road crossings and other structures
- assist designers, managers and scientists in the assessment of fish migration barriers, and in the identification of fish passage options at road crossings and other waterway structures
- provide designers, managers and scientists with a framework for the planning, design and implementation of fish passage facilities with the support of specialist advice as required
- provide a basis for users to achieve multipurpose outcomes for road and other structures in relation to fish passage, transport, drainage, and other environmental and amenity needs
- provide preliminary design features of a number of fish passage designs for box culvert, pipe culvert and open channel applications
- provide a reference document on fish passage at small waterway structures for professionals, academics, students and the general community, and a basis for ongoing development and enhancement of fish passage technology in Australia

The *Guidelines* reflect the early stage of development of fish passage technology for road-waterway crossings in Australia. They have been developed from research and development studies involving field prototype, laboratory modelling, and case study projects covering a range of waterway characteristics and road crossing configurations, and from conceptual development and evaluation by the author of new and existing fish passage designs. They do not however cover all situations, and they are not intended for use as a "cookbook" for overcoming fish migration barrier problems and establishing fish passage provisions for any particular site.

The characteristics of some complex projects may require more comprehensive investigation and design approaches than those outlined here. On the other hand, provided conservative approaches are used and no adverse consequences and effects are likely to result, investigation and design methods for simple projects may be abridged in order to keep these costs low in relation to overall project costs. Users should understand the full scope of issues and procedures involved in fish passage projects and should approach the planning and design activities in a manner appropriate to the particular project.

The *Guidelines* are not intended to cover all aspects of road crossing or other waterway structure design, and should be used in conjunction with other standard design procedures and guides for drainage, waterway and environmental management. Users should have a working knowledge of these procedures, and should seek specialist input on fish passage aspects as required.

These *Guidelines* are largely project-based, reflecting the status of the culvert fishway research and development, and the conceptual development and performance evaluation of solutions to fish migration barrier problems. General aspects of fish migration, fish migration barriers and mitigation options are presented; fish passage planning and design protocols and tasks are outlined; and specific assessment methods and fish passage techniques are described. The focus is on the design, development, testing and evaluation of a number of prototype and case study projects, which are used extensively in the *Guidelines* to illustrate the planning and design approaches and particular fish passage provisions and fishway devices.

Enhanced information for fish passage assessment and design with more specific design procedures, design parameters and criteria will be available progressively through ongoing development, monitoring and performance evaluation of fishway facilities.

2 FISH MIGRATION BARRIERS AND PROVISIONS FOR FISH PASSAGE

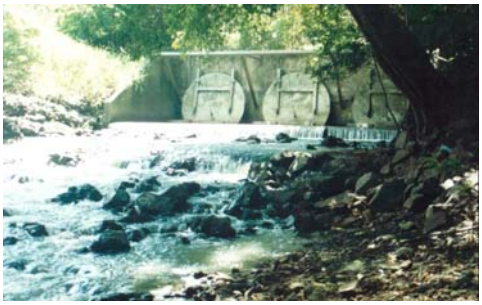
Barriers to fish migration at road crossings and other waterway structures can severely deplete fish populations and alter fish species diversity within a catchment by obstructing migration to critical spawning or growth habitats. Many opportunities are available for practitioners and managers to develop innovative solutions and multipurpose designs for fishway facilities at culverts and other structures in order to provide for fish passage, hydraulic capacity, transport function, operation and amenity values.

Freshwater fish provide significant commercial, recreational and traditional cultural values for humans, play a major role in the physical and biological function of aquatic ecosystems, and represent significant biodiversity and conservation values for streams. Migration is a natural process for most freshwater fish as they fulfil crucial life cycle stages such as adult spawning and juvenile growth dispersal. Whereas large structures such as dams and weirs represent significant fish migration barriers throughout Australia, obstructions to fish movement at road-waterway crossings are also extensive and severe (Harris 2001). Additionally, barriers occur at other structures such as flood gates, tide gates, control structures and drop boards (Box A1.1).

Box A1.1: Fish migration barriers *(Source: Ross Kapitzke)*

Dams, weirs, barrages

Culverts, causeways



Flood gates, tide gates

Control structures, drop boards

Road culverts and other waterway structures commonly present hydraulic barriers to upstream fish passage as a result of high velocities, excess turbulence, shallow water depths, excessive water surface drops, channel simplification and lack of resting places (see *Guidelines Part C – Fish Migration Barriers and Fish Passage Options*). In addition to road culverts, fish migration barriers can also occur at bridge crossings and other constructed waterways where channelisation, grade control or other structures may produce adverse hydraulic conditions due to increased velocities, channel simplification or excessive water surface drops.

Provision of fish passage at road crossings and other structures is a significant natural resource management issue to be addressed in the design of culverts, causeways and other waterway structures. It is also an important research and development topic for engineers, biologists and others. Fish passage design requires a change from conventional road drainage design practice, which has focused on the transport and drainage functions of crossings and primary objectives relating to flood capacity, structure integrity and stream stability. In meeting these conventional requirements, designers have usually maintained high velocities for discharge capacity in culvert

design. This has brought about extensive problems for fish passage, where the objectives are to achieve low velocities, clear fish pathways, and diverse streambed habitat.

Water velocities in culverts and artificial channel sections are usually much higher and more uniform than those in natural channels, where stream meandering, pools and riffles, boulders and other substrate and in-channel form provide diverse patterns of slow or fast velocities suited to fish. Water surface drops at culvert outlets and at grade control structures in constructed waterways are also commonly more severe than in natural channel riffles (Box A1.2). For conditions other than deep slow moving water through the culvert barrel, plain culverts are rarely suited to fish swimming and passage capabilities, particularly for small fish.

Solutions to the ubiquitous problem of fish migration barriers at road crossings have not been firmly established for Australian streams and fish species. Culvert fishway technology from northern hemisphere environments is not directly transferable to local conditions because of vastly different stream hydrology (e.g. fish passage design discharge) and fish movement characteristics (e.g. swimming ability), as well as different culvert structures (e.g. concrete box and pipe culverts compared with corrugated steel pipes).

Very few examples exist in Australia where appropriate provisions for fish passage have been made, either as remediation of existing fish migration barriers or as mitigation of barrier effects at new crossings. Many of the techniques considered lead to expensive designs involving large waterway cross sections in order to achieve low velocities for fish, whilst others are speculative and unproven, commonly failing to meet multipurpose requirements relating to fish passage, drainage, transport, amenity and cost. For many waterways, including some with significant aquatic habitat and fish movement corridor values, conservative design approaches using bridges or arches in lieu of culverts will be unnecessarily expensive and may not be warranted. Furthermore, speculative attempts such as placing rocks as ad hoc roughening elements within the culvert barrels, are often unsubstantiated, and are potentially counter productive.

These issues are addressed in these *Guidelines*, which propose an ecohydraulics design approach that assesses fish passage along with other multipurpose design requirements for the site. A range of solutions are outlined, including incorporation of fish passage facilities into culverts and other waterway structures in order to achieve aquatic fauna connectivity.

Box A1.2: Fish migration barrier and remediation at culvert outlet apron – Solander Road culvert crossing of University Creek in Townsville *(Source: Ross Kapitzke)*

Fish migration barrier prior to construction – Fish accumulating downstream of water surface drop at culvert outlet apron (13/01/04)

Fishway after construction – Raised tailwater level at culvert outlet due to rock ramp fishway allowing fish passage onto outlet apron (10/04/06)

3 OUTLINE OF CULVERT FISHWAY R & D PROGRAM

Fishway research and development requires close coordination and integration between the fish biology and engineering disciplines, and benefits from a combined understanding of fishway hydraulics in the laboratory and volitional swimming ability and behaviour of fish under variable conditions in the field (Katopodis 1999). A purely biological approach (based on field tests and biological performance monitoring) cannot adequately develop criteria and procedures for culvert fishway design. Similarly, a purely hydraulic approach that focuses on hydraulic conditions without knowledge or appropriate consideration of fish movement behaviour and swim characteristics cannot be expected to work.

These *Guidelines* have been developed through extensive research and development over a number of years at James Cook University School of Engineering and Physical Sciences. The culvert fishway R & D program has been supported by the Queensland Department of Transport and Main Roads, and includes a substantial in-kind contribution of expertise and research facilities by JCU Engineering. Third party cash and in-kind funding support for fishway development has been provided by a number of other agencies and organisations.

An ecohydraulics approach is adopted in the research program, using prototype fishways, hydraulic laboratory modelling, case study analyses, and physical and biological monitoring of field sites. Integrated hydraulic and biological studies are adopted in the field to assess hydraulic characteristics (velocities, flow patterns) and biological performance (volitional fish movement behaviour, swimming capabilities) within the natural stream environment.

The intention of the culvert fishway R & D is to develop and test fishway hydraulic design techniques to suit passage for native Australian species through various road-waterway crossing types and other small waterway structures. The aim of the research is to:

- examine the hydraulic and biological performance characteristics of culvert fishway designs
- provide an understanding of fish behaviour in culvert fishway structures
- establish design parameters for fish passage facilities at road culverts in Queensland streams
- incorporate concept design and evaluation of fish passage facilities into the development of successful fishway techniques (e.g. baffle fishway for box and pipe culverts, ramp fishways)

A key feature of the culvert fishway R & D has been the establishment of four operational prototype fishway facilities to develop and test fishway designs on University Creek, which flows through the JCU campus in Townsville (Box A1.3). Development, operation and monitoring of the prototype fishways provides valuable information on design and construction of fishway facilities, flow characteristics of various culvert fishway components, hydraulic and biological performance of culvert fishway techniques in various culvert types and configuration, and swimming characteristics and behaviour of freshwater fish species (see Kapitzke 2006b; Kapitzke 2006c; Kapitzke 2007b; Kapitzke 2007c). The prototypes are also used as demonstration facilities for culvert fishway technology and sustainable development (Box A1.3).

Hydraulic laboratory modelling is used in conjunction with the field prototypes in development and testing of fishway designs for pipe and box culverts (see Kapitzke 2006b; Kapitzke 2007b; Kapitzke 2007c). Geometrically similar scale models of the culverts and fishway designs are used for visualisation and measurement of the flow characteristics and hydraulic performance of various configurations and sizes under a range of flow conditions (Box A1.4).

The other key part to the R & D program is the case study projects relating to the design and development of culvert fishway facilities as part of specific road projects. These projects provide core material in the planning, design, implementation and performance evaluation of a range of fishway and culvert types. In addition to the University Creek prototype fishway projects, the other major case study contributing significantly to these *Guidelines* is the Bruce Highway Corduroy Creek to Tully project (see Kapitzke 2006a; Kapitzke 2007a). Refer Box A1.5.

Box A1.3: Prototype fishways on University Creek in Townsville *(Source: Ross Kapitzke)*

- University Creek is the largest and least altered tributary entering the lower reaches of Ross River in Townsville, and represents a significant corridor for terrestrial and aquatic fauna connecting Ross River with Mount Stuart and adjoining mountain ranges.
- The creek provides natural spawning and growth habitat during wet season conditions for up to 13 native fish species, including Plotosid Catfish, Purple Spotted Gudgeon and Rainbowfish.
- University Creek is a substantial natural asset on the JCU campus, providing an excellent field laboratory for research and teaching, including physical and biological monitoring of fish passage.

University Creek on JCU campus: Intermittent pool habitat for fish in upstream reaches (25/03/06)

- The Discovery Drive prototype offset baffle fishway was developed in 2002 and first substantial testing undertaken in 2004.
- The main hydraulic barriers to be overcome at the crossing are high velocities in the culvert barrel, shallow water depths at low flows, regular culvert cross section and lack of resting place.
- The fishway components installed at the site include the offset baffle fishway for box culverts within the culvert barrel.
- Monitoring facilities at the site include access ladders, platforms, gauge boards, flow control boards, fishway fences and cage.

Prototype Fishway #1: Discovery Drive offset baffle fishway for box culverts (-/01/04)

- Douglas Arterial Project prototype rock ramp fishway was developed in 2004, with the first testing undertaken in 2005.
- The main hydraulic barriers to be overcome as mitigation of the effects of channelisation are high velocities, shallow water depths, regular culvert cross section and lack of resting place.
- The fishway components installed at the site include two rock ramp grade control structures in the open channel, each with a drop of 0.3 m.

Prototype Fishway #2: Douglas Arterial Project rock ramp fishway for open channels (-/01/05)

- The Solander Road prototype pipe culvert fishway was developed in 2005, with the first testing undertaken in 2006.
- The main hydraulic barriers to be overcome at the crossing are water surface drop and turbulence downstream of the culvert, high velocities in the culvert and on the apron, shallow water depths at low flows, regular culvert cross section and lack of resting place.
- The fishway components installed at the site include the rock ramp / cascade fishway, offset baffle and corner "Quad" baffle fishways for pipe culverts, apron baffle fishway.
- Monitoring facilities include gauge boards, flow control boards.

Prototype Fishway #3: Solander Road pipe culvert fishway (-/01/06)

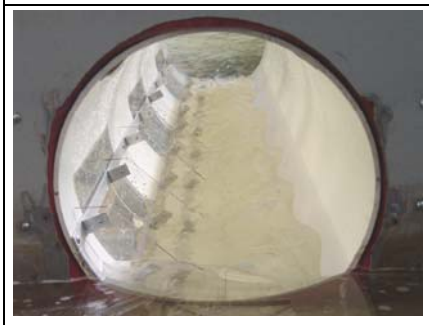
- The Discovery Drive prototype corner baffle fishway was developed in 2005, with the first testing undertaken in 2006.
- The main hydraulic barriers to be overcome at the crossing are high velocities in the culvert barrel and on the culvert inlet and outlet aprons, regular culvert cross section and lack of rest place.
- The fishway components installed at the site include the corner "EL" baffle fishway for box culverts within the culvert barrel.
- Monitoring facilities at the site include access handrails, gauge boards, flow control boards.

Prototype Fishway #4: Discovery Drive corner baffle fishway for box culverts (-/04/06)

Box A1.4: Hydraulic laboratory test facilities and fishway models at JCU *(Source: Ross Kapitzke)*

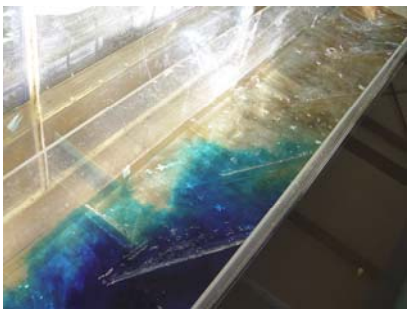
- scale models of the box culvert and pipe culvert prototype fishways on University Creek are established in the hydraulics test flume
- various alternative fishway components at 1:5 scale (box) and 1:3.3 scale (pipe) are tested in the culvert model
- laws of similitude are applied to transfer values between model and prototype, with results applicable to prototypes of various size.
- velocity profiles are measured with a miniature propeller meter for various water depths and discharges, and flow patterns are observed using die tracers and other visualisation techniques

Model set up with pipe culvert model in JCU School of Engineering flume (18/08/06)



- the offset baffle and the corner "Quad" baffle fishways have been tested in the pipe culvert fishway model.
- culvert fishway slopes are varied from 0.5 % to 5 % in the model, and comparison made with hydraulic characteristics of the Solander Road prototype fishways in University Creek (2 %).
- flow pattern, velocity, depth and discharge observations and measurements are compiled for a range of flow depths up to half pipe full

Corner "Quad" baffle fishway for pipe culverts in shallow flow condition (18/08/06)



- the offset baffle and the corner "EL" baffle fishways have been tested in the box culvert fishway model.
- culvert fishway slopes are varied from 0.5 % to 5 % in the model, and comparison made with hydraulic characteristics of the Discovery Drive prototype fishways in University Creek (0.5 %).
- flow pattern, velocity, depth and discharge observations and measurements are compiled for a range of flow depths submerging the fishway baffles

Offset baffle fishway for box culverts using dye to show flow patterns within baffle field (06/06/06)

Box A1.5: Case study project: Bruce Highway Corduroy Creek to Tully *(Source: Ross Kapitzke)*

- the new Bruce Highway crossing of the Tully Murray floodplain incorporates extensive bridge and culvert crossings of major waterways and fish movement corridors.
- road corridor scale assessment of road-waterway crossings identified priority crossings for provision of fish passage.
- site scale assessment established site characteristics, design objectives, and fish passage provisions at priority sites.
- provisions for fish passage have been made at priority box culvert waterway crossings, using the corner "EL" baffle fishway.

Waterway crossing on Tully Murray floodplain where fish passage provisions are to be made (24/03/06)

4 KEY KNOWLEDGE GAPS AND ONGOING R & D PRIORITIES

These *Guidelines* have compiled the findings to date of the culvert fishway R & D program, have synthesised information from existing literature, and have incorporated key concepts developed by the author on development, design and evaluation of culvert fishways. Much is yet required, however, to provide a robust technical guide for provision of fish passage at road crossings and other waterway structures for Queensland Department of Transport and Main Roads, transport agencies, local authorities and other organisations. The key knowledge gaps that could form the basis for ongoing R & D, and conceptual development, design and testing of culvert fishways include the following:

- more extensive design development, testing and hydraulic and biological performance evaluation using field prototype and hydraulic laboratory modelling of existing fishway designs for pipe culverts and box culverts for a range of fishway configurations and design requirements (e.g. culvert slope, baffle spacing, design flow, fish swim speed)
- design development, testing and hydraulic and biological performance evaluation using field prototype and hydraulic laboratory modelling of other fishway designs, including ramp fishways, fishways for culvert inlet and outlet aprons, and bypass fishways for causeways
- culvert fishway configurations and their performance characteristics at transitions between fishway components to provide appropriate flow continuity, hydraulic conveyance, fish passage effectiveness, sediment and debris passage
- culvert fishway configurations to ensure suitable attraction flows and protection of fish at culvert outlet / fishway entrances
- effects of various culvert fishway designs on hydraulic resistance and flow conveyance, and on sediment and debris passage through culverts
- design development and selection of materials for fabrication and construction of various culvert fishway types (e.g. corner “EL” baffle, corner “Quad” baffle, offset baffle)
- fish passage design criteria for Queensland waterways and structures, including design flow and design swim speeds for fish
- fish movement behaviour characteristics of key fish species, including fish swim speeds, ability to ascend water surface drops, and physiological responses to hydraulic conditions
- design configurations and generalised performance characteristics of fishway designs for a range of waterway and culvert applications
- generalised field assessment and evaluation procedures for practitioners’ use in corridor scale and site scale investigations, and fish passage planning and design for road projects
- refined culvert fishway planning and design approaches for mitigation at new road crossings, and remediation through retrofit or upgrade at existing crossings
- evaluation of environmental impact and enhancement effects, and other multipurpose aspects of fish passage facilities incorporated within road-waterway structures
- development of planning and design protocols for agency practitioners, and integration with existing road drainage and infrastructure design manuals and project management guidelines
- feasibility of fishway designs using bridge, arch or other open bottom crossing configurations, feasibility of hybrid fishway designs such as roughened base culvert fishways using rock, and application of other fishway approaches to Queensland streams such as stream simulation design, lowered bed / embedded culvert
- design development, testing and hydraulic and biological performance evaluation using field prototype and hydraulic laboratory modelling of fishways for drop structures, control gates, grade control structures or weirs at culvert inlets or within open channel waterway sections
- field monitoring and hydraulic and biological performance evaluation of culvert fishway designs implemented on road projects and at other waterway structures

5 USING THESE GUIDELINES FOR FISH PASSAGE PLANNING AND DESIGN

These *Guidelines* assist designers, managers and scientists in planning and design for fish passage provisions at road crossings and other small waterway structures. They relate particularly to fish passage facilities at road crossings such as culverts and causeways, and apply to open channel and grade control structures. Although not specifically addressing requirements for weirs, control structures, flood or tide gates, the *Guidelines* provide protocols for assessment and design, and present fish passage techniques that may be used at these other waterway structures.

The approach taken and the fish passage provisions outlined in these *Guidelines* are suited to ***mitigation measures*** to address the potential impact on fish passage at ***new structures***, and ***remediation measures*** to overcome fish migration barriers by retrofit at ***existing structures***. Whereas the examples presented in these *Guidelines* deal with both new and existing crossings, it is anticipated that agencies such as the Department of Transport and Main Roads Queensland will primarily deal with mitigation measures for new road projects.

The material included here encompasses fish passage assessment and planning studies at the ***road corridor scale***, and site investigations and designs for fish passage facilities at the ***site scale***. The *Guidelines* deal primarily with the ***Concept*** and ***Preliminary Design*** phases of planning and design procedures for agencies such as the Department of Transport and Main Roads. Although examples are provided for specific case study projects, the *Guidelines* do not generally encompass detailed design or construction of fish passage facilities for road crossings or other waterway structures.

Part B – Fish Migration and Fish Species Movement Behaviour outlines freshwater fish and fisheries values, fish habitat and stream zones, fish life cycles and fish migration characteristics. Fish species movement behaviour is classified in terms of fish movement groups and movement directions, and fish movement characteristics for design are identified in terms of fish passage design flow and design swim speeds for fish. Fish community data and associated fish movement behaviour is illustrated through the Bruce Highway Corduroy Creek to Tully and the University Creek prototype fishway case study projects.

Part C – Fish Migration Barriers and Fish Passage Options for Road Crossings describes fish migration barriers at road crossings and other waterway structures in terms of adverse conditions within the various hydraulic zones of the structure. Fish passage design approaches and fishway concepts are outlined, with the focus on the hydraulic design approach for culvert fishways using baffles. Culvert fishway options are identified, and the suitability of alternative fishway components to overcome barriers within the various hydraulic zones of the waterway crossing are discussed. Fish migration barrier problems and potential mitigation options to provide for fish passage at temporary road crossings are identified, and are illustrated through the University Creek Douglas Arterial Road and Bruce Highway Corduroy Creek to Tully case study projects.

Part D – Fish Passage Design: Road Corridor Scale outlines waterway character and fish habitat assessment for fish movement corridors, and provides a method of classification of these corridors to assist in determination of fish passage provisions. Assessment of the fish community and fish movement behaviour is described in terms of movement directions, timings and swim capabilities of the various fish species. Methods are presented to identify priority road-waterway crossings for fish passage and the fish passage design requirements for the crossings. Road corridor scale planning for fish passage is illustrated through the Bruce Highway Corduroy Creek to Tully case study project.

Part E – Fish Passage Design: Site Scale presents methods for assessment of waterway characteristics and hydraulic conditions, and for evaluating fish migration barriers at the road-waterway crossing site. Multipurpose design requirements for fish passage are presented, and the objectives, criteria and constraints for fish passage design are outlined. Fishway configuration

options and their suitability for the site are examined in terms of fishway hydraulics, attraction flows, effectiveness and expected performance characteristics of the fishway, and the layout and configuration of the adopted fishway facility is discussed. Site scale design for fish passage is illustrated through the University Creek Solander Road and Bruce Highway Corduroy Creek to Tully case study projects.

Part F – Baffle Fishways for Box Culverts presents baffle fishway design options for box culverts, and describes culvert and fishway configuration and hydraulics. Configurations, design principles and criteria for the offset baffle fishway and the corner "EL" baffle fishway for box culverts are outlined. Baffle fishways for box culverts are illustrated through the University Creek Discovery Drive and Bruce Highway Corduroy Creek to Tully case study projects.

Part G – Baffle Fishways for Pipe Culverts presents baffle fishway design options for pipe culverts, and describes culvert and fishway configuration and hydraulics. Configurations, design principles and criteria for the offset baffle fishway and the corner "Quad" baffle fishway for pipe culverts are outlined. Baffle fishways for pipe culverts are illustrated through the University Creek Solander Road case study project.

Part H – Rock Ramp Fishways for Open Channels describes fishway configuration, hydraulics and fish passage characteristics, and outlines design principles and criteria and construction aspects for rock ramp fishway design. Rock ramp and rock ramp cascade fishways are illustrated through the University Creek Douglas Arterial Road and Solander Road case study projects.

Part I – Design Drawings for Fishway Projects provides example designs for fishway projects undertaken through the University Creek prototype fishways at Discovery Drive, Solander Road and Douglas Arterial Road, and the Bruce Highway Corduroy Creek to Tully case study project.

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