Why do fish need to cross the road?

fish passage

requirements for waterway crossings

Written and edited by Sarah Fairfull (NSW DPI (Fisheries))
and Grant Witheridge (Catchments and Creeks Pty Ltd).

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INTRODUCTION

This document aims to minimise impacts on fish passage and general aquatic wildlife by providing practical guidelines to those involved in the planning, design, construction and maintenance of waterway crossings. Considerable effort has been taken to make these guidelines applicable across Australia; however, local knowledge, data and experience should always be used to enhance, modify or even replace the information presented within these guidelines. Your local fisheries department/authority can provide additional information on fish species, design or approval requirements relevant to your area.

WHY IS FISH PASSAGE IMPORTANT?

Fish passage along our waterways is critical to the survival of Australian native fish. Species of both fresh and saltwater fish move within waters at different times to access food and shelter, to avoid predators, and to seek out mates to breed and reproduce.

Examples of the various types and reasons for fish movement include:

Local movement ➔ access food, avoid predators, shelter during daylight.

Daily movement ➔ access habitat, food and shelter, defend territory, avoid predators.

Seasonal movement ➔ breeding cycle in response to rising water levels or temperatures.

Upstream movement ➔ access to new habitats or established spawning areas.

Downstream movement ➔ post-spawning movement, avoid predators.

Lateral movement ➔ access food, breeding cycle and juvenile recruitment to habitat areas.

Of the 83 species of freshwater fish in southeastern Australia, half migrate at least once as part of their life cycle. Four notable long distance swimmers are the Mary River cod (30km), silver perch (570km), Murray cod (1,000 km) and the golden perch which has been recorded swimming a staggering 2,300km.

Approximately 70 per cent of the coastal species in south-eastern Australia also migrate to complete their lifecycles. The sea mullet, a popular commercially caught fish, enters freshwater habitats as a juvenile, then migrates into estuary waters in preparation for annual spawning. Australian bass and barramundi, both prized recreational fish species, migrate from freshwater to estuaries to spawn, and the juveniles then migrate back upstream.

Species such as the climbing galaxias, mangrove jack and flat-tail mullet move up and down rivers or to and from the ocean just to search for food or to avoid predators.

The numbers of fish undertaking movement at any one time can also be staggering. For example, 6000 juvenile fish were recorded in one day moving upstream through a fishway on the Mary River in south-eastern Queensland.

BARRIERS TO FISH PASSAGE

Fish passage barriers may result from the actual physical blockage of the waterway by a dam, weir, floodgate or even debris blocking a culvert. Alternatively the blockage may result from an alteration to the natural flow conditions within the waterway caused by the construction of a waterway crossing. These barriers can exist all the way along a waterway and can include off-stream barriers such as those associated with adjacent wetlands and floodplains.

A recent audit of barriers within the tidal reaches of NSW waterways recorded 4,308 barriers to fish passage, including poorly designed waterway crossings. Similarly, just under 4,000 dams and weirs have been documented throughout NSW waters. In the South Australian River Murray valley, a survey of floodplain wetland complexes identified over 400 potential barriers to flow and fish passage.

The cumulative effect of all of these barriers has been identified as one of the major threats to the continuing survival of native fish in Australia.

IMPACT OF FISH BARRIERS

Barriers to fish passage can effectively stop many fish species from breeding and re-populating waterways by restricting their ability to access breeding partners and spawning grounds. Fish attempting to negotiate barriers are forced to use up precious energy reserves. If this occurs during a breeding event, fish may actually reabsorb their eggs and sperm to replenish their energy reserves, effectively losing a breeding season with possible long-term flow on effects to the size and sustainability of the population.

Local extinction is likely to occur where barriers have stopped fish undertaking migrations. For example, the golden perch has become locally extinct above some waterway structures.

Similarly, barramundi in the Fitzroy River in central Queensland, and freshwater mullet in the Burnett River in south-eastern Queensland are considered locally extinct upstream of the tidal barrages constructed on these rivers. Australian grayling and Australian bass have disappeared completely from some coastal rivers, silver perch has declined by over 90 per cent over the last 50 years, and current levels of native fish populations within the Murray-Darling Basin have declined to about 10 per cent of their original size prior to pre- European settlement. Of all the native fish species within the Basin just under half are listed as threatened under various pieces of State legislation.

Some barriers can also create excellent habitat for pest species to proliferate, such as European carp and mosquito fish. Barriers create still-water pools that are favoured by these species, allowing them to out-compete native fish for food and shelter.

HOW DO FISH SWIM?

To understand fish passage requirements through waterway crossings, it is important to first examine how fish swim. Fish use the following swimming modes to negotiate waterways (Cotterell, 1998):

1. Burst speed - Fish can swim at high speeds for only short periods of time (seconds). This speed is normally used to negotiate high flow conditions. Fish must rest between such bursts of speed. This speed may be used by fish to try and negotiate barriers to move upstream. The majority of native fish do not reach speeds that enable them to "jump" barriers.
2. Sustained speed - Fish can swim at moderately high speeds for longer periods (minutes). This speed can be used to negotiate medium flow conditions associated with flowing streams. However, fish will also need to rest between periods of sustained speed.
3. Cruising speed - Fish can swim at their cruising speed continuously with little effort (days). This speed is used in low flow or no flow conditions, such as in pools in a waterway. Cruising speed is generally the speed used when fish rest.

HOW DO WATERWAY CROSSINGS AFFECT FISH PASSAGE?

Waterway crossings provide access for road vehicles, rail, pedestrians and stock movement. Just as waterways vary in their size and shape, so too do waterway crossings. Not surprisingly, the potential impact of these crossings on fish passage can vary as much as the structures themselves.

BRIDGES AND ARCH STRUCTURES

Bridges and arch structures generally have the least impact on fish passage as they normally involve limited disturbance to the flow or the aquatic habitat of a waterway. Possible impacts include:

- large scale turbulence resulting from bridge piers.
- increased flood flow velocities.
- changes to in-stream and bank vegetation affecting water shading, habitat values and water velocities.
- blockage of fish passage along floodplains caused by elevated approach roads.
- limited light penetration under the bridge deck creating a non-physical barrier for some fish species that may avoid dark areas during daylight hours

CULVERTS

A culvert uses a pipe or box shaped cell to allow water to pass underneath a roadway. Flow conditions can be significantly modified both within and immediately adjacent to these crossings resulting in reduced opportunities for fish passage over a wide range of flow conditions. At worst culverts can cause a complete blockage to fish passage for all flow conditions.

The most common fish passage problems associated with both pipe and box culverts include:

- excessive flow velocities within the culvert.
- inadequate flow depth within the culvert.
- excessive water turbulence.
- debris blockage of the culvert.
- excessive culvert length and a lack of aquatic habitat and "rest" areas within the culvert.
- inadequate lighting within the culvert.
- excessive variation in water level across the culvert outlet (waterfall effect).

WETLAND FLOW CONTROL STRUCTURES

Flow transfer between rivers and adjacent wetlands is often controlled with the use of floodgates or wetland inlet structures.

These structures are generally similar in design to road culverts and can cause fish passage problems. The operation of wetland inlet structures has been investigated by the Australian Landscape Trust on the Lower Murray River.

Research findings and operational recommendations for wetland flow control structures are available through the Australian Landscape Trust. For more information refer to their website at *www.australianlandscapetrust.org.*

CAUSEWAYS

Causeways are usually low cost, near-level waterway crossings, constructed slightly above the natural bed level of the watercourse and designed in a manner that promotes the formation of thin sheet flow passing over the road surface. In some cases a low-flow pipe may be placed under the causeway to keep the crossing dry during periods of low flow.

The most common fish passage problems associated with causeways include:

- excessive flow velocities through the low flow pipe.
- debris blockage of the pipe.
- inadequate lighting within the pipe.
- excessive fall in the water level across the causeway or at the outlet of the low
- flow pipe (waterfall effect).
- inadequate flow depth over the causeway during minor stream flows.
- sediment runoff from the approach roads.

FORDS

Fords differ from causeways in that the road crossing is formed directly on the channel bed resulting in the formation of a "wet" crossing. Flow depths across a ford are likely to be similar to natural stream conditions, unless the crossing is above the natural bed level creating a waterfall effect on the downstream edge. Vehicles travelling across a ford can disturb sediments causing water quality problems which are known to affect fish health and habitat values.

INVESTIGATION AND PLANNING CONSIDERATIONS

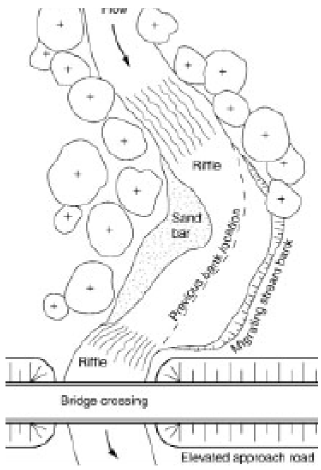
Barriers within a catchment should be assessed and prioritised to focus resources on those that will maximise fish passage. Pethebridge et. al. (1998) provides a useful methodology for such studies.

Recent research conducted by NSW Fisheries on waterway crossings on four streams in northern NSW has found that the numbers and diversity of native fish species were generally greatest below the first culvert or causeway crossing of a stream, at the lower end of a catchment (NSW Fisheries in prep.). The numbers and diversity of native fish were progressively reduced at each consecutive culvert or causeway crossing. This research indicates that rehabilitation efforts should focus on those barriers located at the lowest end of the catchment.

LOCATING CROSSINGS

All waterway crossings, even "fish friendly" crossings, have the potential to impact upon the natural passage of aquatic and terrestrial wildlife. Therefore, a primary objective of strategic planning should be to minimise the total number of crossings - further to this, the following principles should be considered:

- Avoid crossing waterways at or near sharp bends, sections of unstable channel, or major "riffle" systems. Riffles are shallow areas where water flows swiftly over rocks, gravel or timber. They act as channel stabilisers and by altering their stability essential habitat pools may be lost or severe bed erosion can be initiated.
- Avoid locating crossings over "meandering" waterways where such meandering is likely to continue in the future and cause damage to the structure, erosion of the waterway channel, or the future misalignment of the channel with the crossing.
- Avoid works that may change the frequency or spacing of an existing pool – riffle system.
- Avoid disturbances to sections of a waterway channel or its associated bank vegetation, particularly where such areas represent either a unique, endangered or highly valued section of the waterway.
- Avoid the removal of essential shade trees especially on waterways that have already experienced a significant loss of the natural vegetation cover.



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SITE ASSESSMENT

A detailed site assessment should be used to determine whether fish and aquatic habitat are present, the preferred type of watercourse crossing and the presence of existing barriers to fish passage both upstream and downstream of the proposed crossing. If fish are not observed, the presence of fish may need to be confirmed by checking the scientific literature for records of fish species caught either within the site or catchment area and by talking to local residents and fishing clubs. In all cases, the local fisheries department/authority should be consulted to determine whether the crossing design requires consideration of fish passage.

Table 1 provides one way of assessing fish passage needs and waterway crossing preferences.

Table 1 - Matching preferred crossing type to waterway type

Classification	Characteristics of Waterway Type	Minimum [1] Recommended Crossing Type
Class 1 Major fish habitat	Major permanently or intermittently flowing waterway (e.g. river or major creek), habitat of a threatened fish species.	Bridge, arch structure or tunnel.
Class 2 Moderate fish habitat	Named permanent or intermittent stream, creek or waterway with clearly defined bed and banks with semi - permanent to permanent waters in pools or in connected wetland areas. Marine or freshwater aquatic vegetation is present. Known fish habitat and/or fish observed inhabiting the area.	Bridge, arch structure, culvert [2] or ford.
Class 3 Minimal fish habitat	Named or unnamed waterway with intermittent flow and potential refuge, breeding or feeding areas for some aquatic fauna (e.g. fish, yabbies). Semi - permanent pools form within the waterway or adjacent wetlands after a rain event. Otherwise, any minor waterway that interconnects with wetlands or recognised aquatic habitats.	Culvert [3] or ford.
Class 4 Unlikely fish habitat	Named or unnamed waterway with intermittent flow following rain events only, little or no defined drainage channel, little or no flow or free standing water or pools after rain events (e.g. dry gullies or shallow floodplain depressions with no permanent aquatic flora present).	Culvert [4], causeway or ford.

[1] In all cases bridges are preferred to arch structures, culverts, fords and causeways (in that order).

[2] High priority given to the "High Flow Design" procedures presented for the design of these culverts - refer to Design Considerations section of this document, or engineering guidelines (Witheridge, 2002).

[3] Minimum culvert design using the "Low Flow Design" procedures; however, "High Flow Design" and "Medium Flow Design" should be given priority where affordable (refer to Witheridge (2002)).

[4] Fish friendly waterway crossing designs possibly unwarranted. Fish passage requirements should be confirmed with the local fisheries department/authority.

DESIGN CONSIDERATIONS

The following sections provide a brief overview of the design considerations for "fish friendly" waterway crossings within Australia. Detailed engineering guidelines, including terrestrial fauna requirements, are provided in Witheridge (2002).

BRIDGES AND ARCH STRUCTURES

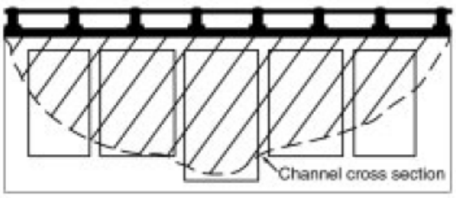
- Avoid locating bridge piers or foundations within the main waterway channel.
- Design and orientate bridge piers, including those located within overbank areas, to avoid the formation of large-scale turbulence or the erosion of the bed and banks of the waterway.

- When sizing the waterway area of the bridge, give appropriate consideration to fish passage requirements along the floodplains, including locating bridge abutments well away from the channel banks and the possible installation of floodplain culverts adjacent to the main crossing.

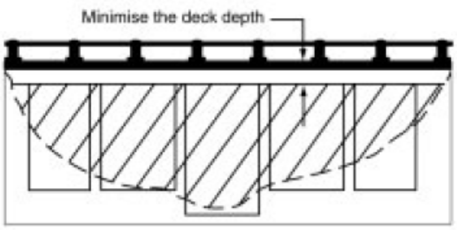
- Maximise light penetration under the bridge or arch to encourage fish passage, possibly by increasing the spacing between divided bridge decks or with the use of skylights or grates in the median strip.
- Minimise the use and extent of those bed and bank erosion control measures that may reduce aquatic habitat values or inhibit the regrowth of natural in-stream and bank vegetation.

CULVERTS

- Give appropriate consideration to fish passage requirements when selecting the type of culvert box or pipe, concrete or corrugated metal, single cell or multi-cell).
- Where practical, align the culvert with the downstream channel to minimise bank erosion.
- In urban areas, a multi-cell culvert usually requires a combination of elevated "dry" cells to encourage terrestrial movement, and recessed "wet" cells to facilitate fish passage.
- Minimise changes to the channel's natural flow, width, roughnes s and base-flow water depth through the culvert's wet cells. Wet cells should have a minimum water depth of 0.2-0.5 metres to encourage fish passage.
- As a first priority, the effective flow area under the waterway crossing should be at least equal to the natural or existing flow area of the channel below the deck/crest level of the crossing ("High Flow Design"). Where this is not feasible, the second priority would be to design the culvert such that the effective flow area is at least equal to the natural or existing channel flow area below the roof of the culvert ("Medium Flow Design"). A Medium Flow Design also requires the depth of the deck slab to be minimised. In all cases, the culvert should be designed to maximise the geometric similarities of the natural channel profile from the bed of the culvert up to a flow depth of 0.5 metres ("Low Flow Design").



Equivalent culvert flow area for a "High Flow Design"



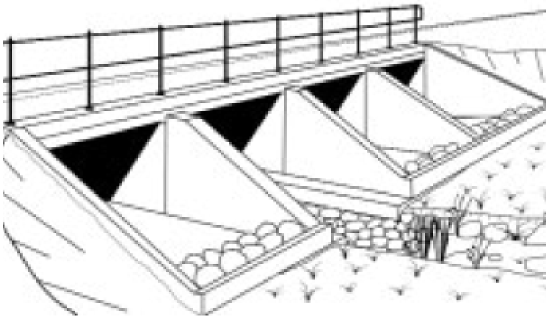
Equivalent culvert flow area for a "Medium Flow Design"

- If a smooth bed culvert must be designed, then flow velocities for water depth up to 0.5 metres ideally should be no more than 0.3 m/s.

- In sand and gravel-based streams, natural bed material should either be placed along the bed of the wet cells, or allowed to deposit in these cells. The hydraulic design of these culverts should allow for this added bed roughness which facilitates upstream fish movement.

  In clay-based streams that do not experience significant movement of bed load sediment, artificial roughness units such as rounded stone, can be grouted across the bed of the wet cells to provide the desirable bed roughness and fish resting areas.

- If fish passage is desirable during bankfull flows, then consideration should be given to the placement of artificial sidewall roughness units along the cell wall immediately adjacent to the channel banks.
- Where conditions allow, construct pools at both the inlet and outlet of the culvert to assist in the dissipation of flow energy and to act as resting areas for migrating fish.



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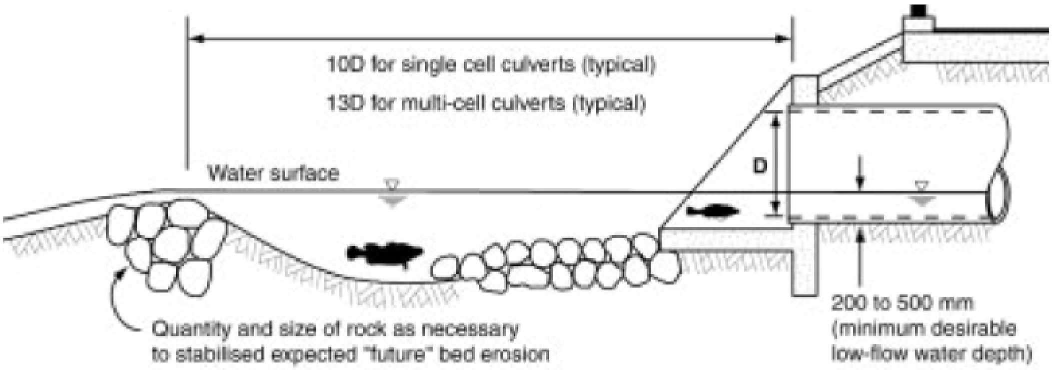
- If a low-flow channel is constructed within the base slab of the culvert, then ensure that the channel extends across the inlet and outlet aprons.
- Debris deflector walls can be used to reduce the impact of debris blockages on fish passage while also reducing maintenance costs.
- Maximise light penetration within the wet cells by maximising the height or diameter of the cells, and possibly by introducing skylights or grated stormwater inlets into the median strip of divided roads. These skylights are only required within the nominated wet cells.
- To avoid the formation of a perched culvert and damage to the stream's bed and banks, erosion at the outlet should be controlled with the use of rock protection and/or the formation of a stabilised energy dissipation pool.



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FORDS

- Where practical, the deck of the ford should follow the natural bed elevation.
- If a concrete surface is used, then consideration should be given to the need for artificial roughness to be placed on the road surface, at least along the lowest section of the crossing. Such roughness may be achieved with the use of grouted rocks (instead of the concrete pad).
- Exposed-aggregate concrete finishing should not be used as its preparation can significantly pollute the stream's waters.

CAUSEWAYS

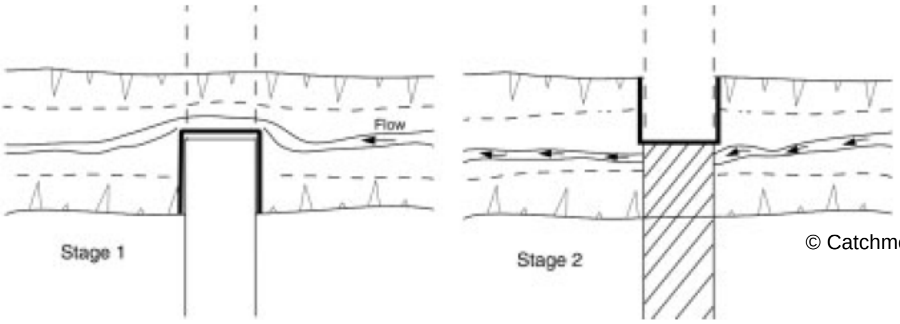
- Minimise the use of causeways where fish passage is required.
- Where practical, construct the deck to follow the stream's natural cross section to achieve variable flow depths over the causeway.
- Install low-flow pipes/boxes to carry the normal dry-weather flow satisfying those conditions specified above for a "low-flow" culvert design.

REHABILITATING EXISTING CROSSINGS

Existing barriers should be programmed for replacement or appropriate rehabilitation. This may include modifications to the approach channels to reduce erosion and increase low-flow water depths, or the incorporation of baffles or added bed and side-wall roughness.

CONSTRUCTION CONSIDERATIONS

- All reasonable and practicable measures should be taken to prevent or minimise environmental harm during the construction phase, including: minimising restrictions of fish passage; minimising the release of sediment into the stream; minimising damage to, or the removal of, bank vegetation, particularly vegetation that shades the low-flow channel.
- Where practical, construction works across the bed of a waterway should be staged to minimise the total disturbance at any given time and to allow the full bypassing of stream flows around the works to maintain fish passage.



- All reasonable efforts should be taken to program construction activities during those periods when flood flows and fish passage is not likely to occur. As a minimum requirement, avoid fish migrations and breeding periods as advised by the local fisheries department/authority.

- The old crossing should be removed in its entirety where it acts as a barrier to fish passage.
- Temporary sidetrack crossings should be constructed from clean fill (free of fines) using pipe or box culvert cells to carry flows, or a temporary bridge structure.
- All temporary works, flow diversion barriers and instream sediment control barriers must be removed as soon as practicable and in a manner that does not promote future channel erosion.
- The construction site should be left in a condition that actively promotes native revegetation and shading of habitat pools.

MONITORING

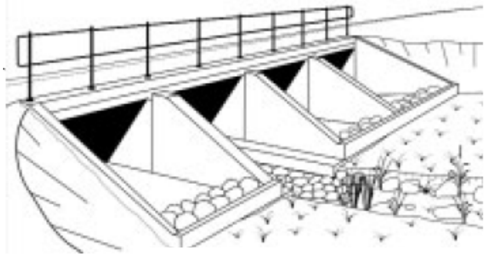
Monitoring is highly recommended during both pre and post construction (especially on Class 1 and 2 streams in Table 1) to ensure that the new waterway crossing design is successful in achieving the desired flow velocities and fish passage outcomes. The monitoring program should be designed in consultation with fisheries scientists and the local fisheries department/authority.

MAINTENANCE CONSIDERATIONS

Culverts and causeways need to be maintained for a variety of purposes, including:

- to maintain the structure's required hydraulic capacity to prevent adverse property flooding and/or to maintain the desired flood immunity of the road way
- to maintain fish passage
- to remove debris
- to remove sediment deposits
- to repair bed or bank erosion resulting from the operation of the structure

Such maintenance activities have the potential to both improve and hinder fish passage. The removal of debris generally improves fish passage. In some cases the removal of sediment can adversely affect the development of desirable fish habitat within the "wet" cells, while in other cases it may be necessary to maintain the designated "wet" cell at a lower elevation to the "dry" cells.



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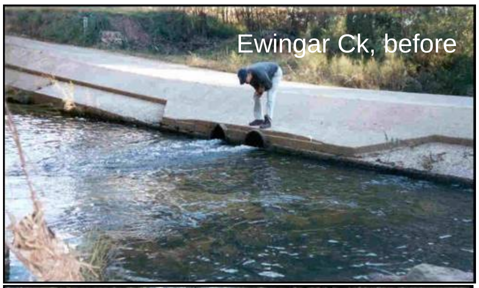
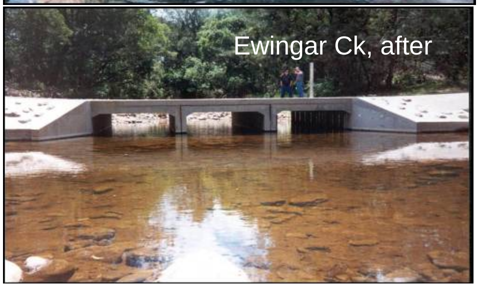
Debris deflector walls and sediment training walls can be used to reduce the impacts of debris blockages and sediment deposits on fish and flood passage. Guidelines on the design of these walls are provided in Witheridge (2002).

Wherever possible, in-stream maintenance activities should be programmed for those times of the year that minimise overall environmental harm, giving appropriate consideration to anticipated critical periods of fish passage and seasonal high flows.

RECENT TESTING OF FISH FRIENDLY WATERWAY CROSSINGS

A recent study has been carried out on three causeways located on northern NSW Class 2 streams. All three structures contained high velocity, low flow pipe(s) that restricted upstream fish passage. The study involved replacing each causeway with a fish friendly multi-cell culvert.





At Ewingar and Tenterfield Creeks, the new box culverts incorporated variations in cell size and bed and side-wall roughness. At Laura Creek, a multi-cell pipe culvert was installed with the cells being partially buried to mimic natural bed conditions within the cells.

Low-flow water depths through the structures were increased at all three sites. The designs also resulted in significant reductions in flow velocities through the crossings. For example, at Laura Creek, typical flow velocities were reduced from 0.52 m/s to 0.38 m/s and minimum flows from 0.45 m/s to 0.03 m/s.

Fish sampling was undertaken to determine differences in fish passage both before and after the crossings were upgraded. Fish passage results for the box culvert designs were positive, but mixed.

The Ewingar Creek culvert recorded an improvement from 0 per cent to 44 per cent with the new design. The Tenterfield Creek site recorded an increase in fish passage from 0 per cent to 14 per cent. The Laura Creek pipe culvert recorded an increase in fish passage from 20 per cent to 69 per cent.

Contact NSW DPI (Fisheries) for further information on this research.

ACKNOWLEDGMENTS

This document has been prepared in consultation with a National Steering Committee incorporating membership from the following organisations from each state and territory in Australia:

- NSW Fisheries
- NSW Roads and Traffic Authority
- NSW Local Government and Shires Associations
- Queensland Department of Primary Industries
- Catchments & Creeks Pty. Ltd. (engineering consultant)
- Department of Primary Industries (Fisheries Section) (Northern Territory)
- The Department of Fisheries, Western Australia
- Primary Industries and Research South Australia
- Department of Sustainability and Environment (Victoria)
- Inland Fisheries Service (Tasmania)
- Australian Landscape Trust
- Murray Darling Basin Commission
- Environment ACT

The member's time and effort in reviewing and providing feedback on the guidelines is gratefully acknowledged.

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NOTES