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Manual

Fauna Sensitive Transport Infrastructure Delivery
Chapter 19: Species profile – Fish

June 2024

Queensland Government

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1 Introduction

Australia has approximately 300 species of native freshwater fish. Despite being a large continent, the diversity of freshwater fish in Australia is relatively low compared to other countries because of Australia's vast extent of arid and semi-arid environments. Within Australia, the greatest number of freshwater fish species are found in tropical and subtropical regions. Many of Australia's freshwater fishes evolved from marine ancestors and most are related to groups found in the tropical Indo-Pacific, including the catfishes (*Ariidae and Plotosidae*), hardyheads (*Atherinidae*), rainbowfishes (*Melanotaeniidae*), blue-eyes (*Pseudomugilidae*), grunters (*Terapontidae*), gobies (*Gobiidae*), and gudgeons (*Eleotridae*)[1].

Approximately 215 species of native fish have been recorded in Queensland's freshwater systems. Of these 215 species, 65 species predominantly inhabit estuarine waters, 137 are predominantly freshwater and 13 predominantly inhabit marine waters. Whilst some native freshwater fish have very specific and limited habitats, several species, particularly gudgeons, are extremely widespread with broad habitat requirements and are therefore likely to be encountered on many transport infrastructure projects.

Twenty-five non-native species from six families have also been recorded in Queensland freshwaters[2]. Invasive species that have a major impact on native fishes in Queensland include gambusia (*Gambusia holbrooki*), common carp (*Cyprinus carpio*) and Mozambique tilapia (*Oreochromis mossambicus*)[3].

In Queensland the conservation and enhancement of the community's fisheries resources and fish habitats is managed by the *Planning Act* 2016 and *Fisheries Act* 1994. Development involving constructing or raising waterway barrier works is assessable under the *Planning Act* 2016 unless it is an 'accepted development'. Waterways in Queensland are mapped on a spatial data layer called the 'Queensland waterways for waterway barrier works'. The waterways are mapped into colours reflecting their stream order and location in the catchment. The colours are used to determine design elements for waterway crossings such as culverts and bed level crossings so that they can be constructed in accordance with specific criteria without the need to obtain a development approval. For more information see Chapter 5.

1.1 Commonly encountered freshwater fish species

Table 1.1 lists threatened species of freshwater fish found in Queensland which are likely to be impacted by transport infrastructure. Note that this is not intended to be an exhaustive list and does not replace site-specific investigations.

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[1] (Bray 2018)
[2] (Queensland Museum 2022)
[3] (DAF 2020)

Table 1.1 – Threatened freshwater fish species in Queensland that are likely to be encountered on transport infrastructure projects

SCIENTIFIC NAME	COMMON NAME	DISTRIBUTION	HABITAT
Bidyanus bidyanus	Silver perch	Murray Darling system	Prefer faster-flowing water, including rapids and races, and more open sections of river, throughout the Murray-Darling Basin.
Hemitrygon fluviorum	Estuary stingray	Coastal Queensland	Most commonly inhabits shallow inshore waters, specifically mangrove-lined rivers and estuaries where it occurs on seagrass beds and amongst mangrove roots. Can also occur offshore in depths to at least 28 metres.
Maccullochella mariensis	Mary River cod	Mary River in South East Queensland. Historically more widespread. However, currently present in these locations: • Tinana-Coondoo Creek upstream from Tinana Barrage • Six Mile Creek downstream from Lake Macdonald • Obi Obi Creek (upper section) • Widgee Creek • Glastonbury Creek • Amamoor Creek • Yabba Creek	Occurs in high gradient, rocky, upland streams through to large, slow-flowing pools in lowland areas. Ideal habitat includes deep, shaded, slow flowing pools with plenty of snags and log-piles.
Maccullochella peelii	Murray cod	• Border Rivers • Condamine River (upland reaches) • Warrego River (Charleville to Cunnamulla) • McIntyre River – downstream of Texas	Murry Cod are frequently found in the main channels of rivers and large tributaries. Preferred microhabitat consists of complex structural in-stream features (i.e. large rocks, large pieces of submerged woody debris) and overhanging waterway banks and vegetation which reduce flows and provide shelter from fast-flowing water.
Nannoperca oxleyana	Oxleyan pygmy perch	Confined to low oxygen, acidic freshwater in wallum heaths in South East Queensland.	Specific habitat requirements for this fish include slow-flowing, fresh, acidic waters with abundant aquatic vegetation.

SCIENTIFIC NAME	COMMON NAME	DISTRIBUTION	HABITAT
Neoceratodus forsteri	Australian lungfish	Core populations are naturally restricted to two main river systems: • Burnett River • Mary River Translocated populations occur in: • North Pine River • Brisbane River • Albert River • Coomera River	Species utilises still or slow-flowing, shallow, vegetated pools with clear or turbid water and emergent or submerged vegetation.
Pristis clavata	Dwarf sawfish	Coastal and estuarine waters between Cairns and Cape York Peninsula.	Usually inhabits shallow coastal waters and estuarine habitats and appear to preference silt / sand flats in areas almost completely devoid of instream structure.
Pristis pristis	Freshwater sawfish	Coastal regions within Cape York Peninsula and rivers including: • Gilbert • Mitchell • Normanby • Wenlock • Mission • Embley • Leichhardt	Occur in fresh or weakly saline water, preferring turbid channels of large rivers and mud bottoms of river embayments and estuaries.
Pseudomugil mellis	Honey blue-eye	Located between Brisbane and Bundaberg and is relatively abundant in the Noosa River and on Fraser Island.	Inhabit acidic, tannin-stained lakes and streams in wallum areas of South East Queensland, usually occurring where there is little, or no flow and shelter afforded by emergent and submerged sedges along the margins.

2 Ecology

2.1 Biology

Fish move among waterways to feed, spawn, seek refuge, escape unfavourable conditions (e.g. hypoxic events), and disperse. These movements can be metres to hundreds of kilometres in length, usually in response to water temperature and variations in water flow. Australian native fish have evolved to cope with generally unpredictable rainfall patterns that in many circumstances result in a boom-and-bust ecology with complex relationships to aquatic habitats.

Migration is an essential part of the life cycle of fish and the majority of the 14,000 species of freshwater fish globally need to move to complete their lifecycles[4]. Migration can be obligatory and seasonal such as some well-known spawning migrations, or facultative, short-term, and opportunistic[5]. In some cases, fish make intergenerational movements where they disperse laterally into or from wetlands or refugia – after completing multiple generations – to repopulate a river system following a population contraction after drought. Although intergenerational, these are obligate movements that sustain the distribution and abundance of the population over time. Migratory movements of fish are described by two broad classifications; potamodromy and diadromy, with diadromy further classified into catadromous, amphidromous, and anadromous species (Table 2.1).

Table 2.1 – Description of the migration patterns of freshwater fish with example species from Queensland

CLASSIFICATION	DESCRIPTION	EXAMPLE SPECIES IN QUEENSLAND
Potamodromous	Species that migrate solely within the freshwaters of a river system.	Mary River cod, Murray cod, oxleyan pygmy perch, golden perch (*Macquaria ambigua*), various species of eel-tailed catfish, gudgeon, rainbowfish, hardyhead and glassfish.
Diadromous	Species that migrate between fresh water and sea water. Further classified into catadromous, amphidromous, and anadromous species.	See below for specific examples of each type.
Catadromous	Species migrate to the sea for breeding and back to freshwater to feed and grow.	Barramundi (*Lates calcarifer*), sea mullet (*Mugil cephalus*), pink eye mullet (*Trachystoma petardi*), Australian bass (*Macquaria novemaculeata*), and freshwater eel species (*Anguilla spp*.).
Amphidromous	Species that migrate between freshwater and the sea but not for the purpose of breeding.	Fork-tailed catfish (*Neoarius graeffei*), various species of gudgeons, gobies, and glassfish.
Anadromous	Species that migrate into freshwater to spawn, with adults generally being resident in marine waters.	Lampreys

Migration and movement of fish within waterways is also essential to maintain gene flow within populations. The major interaction between fish and waterway crossings is during migration and movement among habitats in both upstream and downstream directions. Barriers to fish passage, such as transport infrastructure crossings, dams, and weirs, can impede genetic mixing between sub-populations, which decreases genetic diversity and increases the risk of inbreeding depression and species extinctions (Case Study 19.1). Maintaining a diverse and healthy gene pool is important to enable fish to adapt to changing conditions, such as water temperature, chemistry, and flows. Globally, freshwater migratory fish have declined by 96% over the last 50 years, the greatest decline of any vertebrate group. Barriers to movement and migration are a major contributor to this decline[6],

[4] (Ottburg and Blank 2015)
[5] (Ottburg and Blank 2015)
[6] (Consuegra et al. 2021)

including from transport infrastructure[7]. Climate change is expected to represent an additional impact on freshwater fishes globally[8].

Case Study 19.1 – Impacts of barriers on genetic connectivity in the Australian Smelt

The Australian smelt (*Retropinna semoni*) is a widespread, abundant small bodied (~75 millimetres in length) potamodromous species. The species genetic connectivity within and amongst rivers of the northern reaches of their habitat was recently investigated[9]. The study found relatively low levels of connectivity within river systems because of wateway barriers to movement. Dispersal barriers led to genetic isolation of individuals within rivers, and dispersal among river systems to the north and south of South East Queensland was low. Hydrological connectivity and the modification or removal of fish passage barriers within a river is imperative to the genetic health of potamodromous fish populations like the Australian smelt.

2.2 Behaviour

Understanding fish swimming behaviour and ability is an important factor in determining the impacts of transport infrastructure projects. Fish employ different swimming strategies according to their geographic location, body shape, size, and habitat preferences[10]. It is the combined result of prolonged swim speed, sprint speed, and swim duration that need to be considered when assessing impacts and designing fish crossings.

All fish have a maximum prolonged swimming speed, with pelagic species generally having a higher maximum speed and greater endurance than benthopelagic and benthic fish (Section 2.3). Another important swimming mode for fish attempting to move upstream against water flow using burst and rest behaviour is termed sprint mode. An important aspect in this behavioural mode is the provision of suitable resting areas between sprints that suit each species. Both prolonged and sprint swimming modes are highly relevant to native fish migration within Queensland waterways.

Unfortunately, there is a paucity of data on the swimming ability of most Australian native fish, with a few exceptions[11]. Subsequently, criteria for fish passage have predominantly been derived from the evaluation of fishways such as those constructed in the Sea to Hume program on the Murray River[12].

2.3 Habitat

Freshwater fish can be separated into three broad habitat categories; pelagic (open water specialists, such as lakes and deep water in large rivers); benthopelagic (mid-water and waterway bed generalists) and benthic (waterway bed specialists).

While freshwater fishes are commonly present in rivers, creeks, and wetlands, they can also occur in a variety of anthropogenic habitats including artificial irrigation and drainage channels. Highly adaptable species such as long-finned eel (*Anguilla reinhardtii*) and short-finned eel (*Anguilla australis*) can

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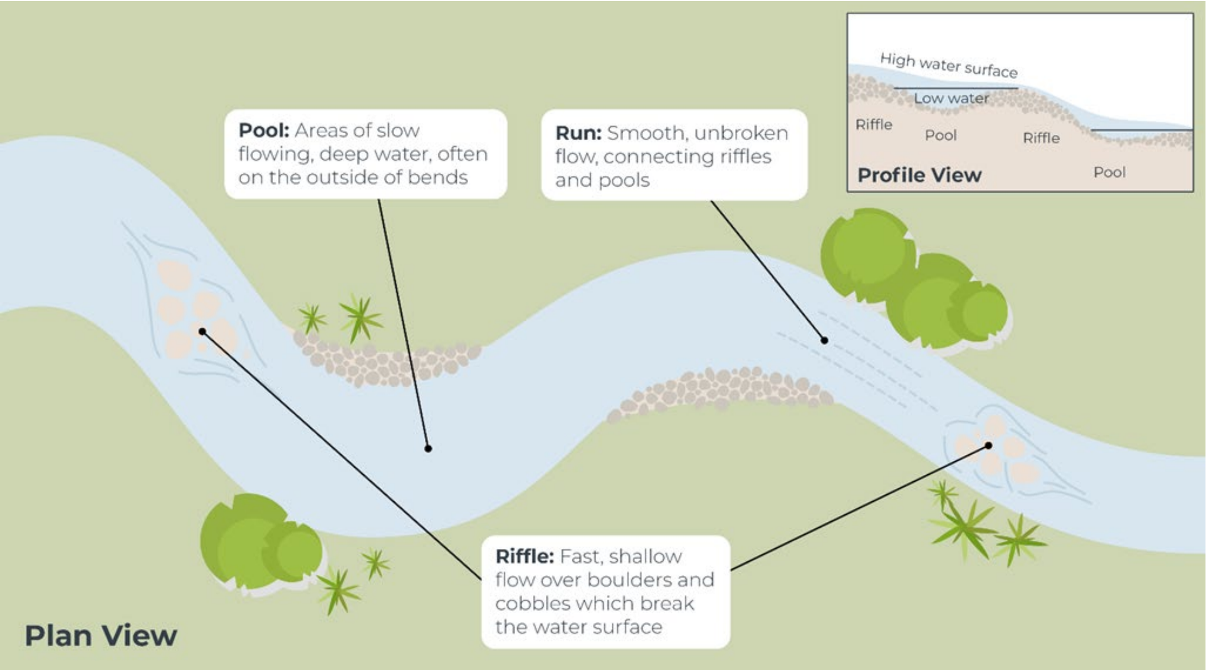
[7] (Brink et al. 2018)
[8] (Barbarossa et al. 2021)
[9] (Islam et al. 2019)
[10] (Ottburg and Blank 2015)
[11] (O'Connor et al. 2017, Watson et al. 2019)
[12] (Barrett and Mallen-Cooper 2006)

travel overland and occupy water storages a substantial distance from major waterway networks. Any location that contains permanent or semi-permanent water that has some connectivity to streams (even if only during extreme flood events) has the potential to contain fish. Hence, freshwater fish habitats can include small streams and major rivers, freshwater lakes (natural and created), swamps, billabongs, and floodplains.

Riverine fish habitat varies by geography and particularly gradient, with the headwaters of many coastal-draining rivers and streams generally occurring at higher elevations and draining to low gradient plains and coastal floodplains. Inland-flowing rivers and streams are often low gradient and long in length, terminating in a landlocked floodplain. Flows are often seasonal and unpredictable, in some areas occurring for a large part of the year and others only after heavy rainfall and floods. These variations should be considered when assessing the potential impacts of transport infrastructure projects.

Various fish habitat zones such as pools, riffles, snags, wetlands, and riparian vegetation occur throughout the length of rivers and streams, as well as a range of microhabitats within these zones (Figure 2.3). Pools and riffles provide important feeding and breeding habitat. As flows recede, the permanent and semi-permanent pools provide refuge areas for fish to retreat to until flows return. Other channel habitats such as undercut banks, rock ledges, boulders, snags, weed beds, and velocity refuges all offer critical habitats for fish. If works associated with road and rail projects result in the modification of any of these habitats, the works should include post construction rehabilitation to ensure no net loss of fish habitat.

Figure 2.3 – Fish habitat in a river system



Wetlands and river floodplains provide feeding, spawning, and nursery areas for many species of freshwater fish, supporting diverse plant communities including trees, rushes, reeds, or floating and submerged aquatic plants. Aquatic macrophytes (including submerged and emergent species) act as sources and sinks of nutrients, stabilise sediments, and provide habitat for fish and other aquatic organisms.

Snags are trees, branches, and root masses that occur in the waterway and are one of the most important habitat components for fish. Snags and other natural elements provide resting refuge areas and breeding areas as well as protect the waterway bed and banks from erosion[13].

Riparian vegetation stabilises riverbanks and contributes food, such as organic matter and falling insects, into the waterway, while overhanging trees provide shade, which buffers water temperature. A suitable riparian zone also assists in filtering out pollutants, limiting the concentration of sediments, pesticides, and fertilisers entering the waterway.

3 Direct impacts

3.1 Common barriers to fish movement at waterway crossings

Any structure, including natural barriers (e.g. waterfalls and logjams) and anthropogenic structures (see above), within a waterway can alter natural flow regimes and physically obstruct passage of aquatic fauna. The installation of a waterway barrier can prevent or limit access to key habitats needed for the life cycles of aquatic species. Barriers therefore can impact connectivity, reduce access to breeding grounds, increase predation (by causing downstream aggregations of fish), and limit access to drought refugia and feeding areas. Barriers close to estuarine waters can have impacts on the life cycle of fish species that require access to estuarine and saline waters for migration and breeding. Barriers can also change the hydrology of a waterway (e.g. weir pools) and reduce the diversity of aquatic habitats.

There are numerous anthropogenic structures in waterways that are associated with transport networks that can directly affect fish passage[14]. Importantly, the impacts of these structures are cumulative because many waterways are crossed repeatedly by transport infrastructure. The potential barriers to fish movement include:

- Pipe, arch, and box culverts.
- Bed level crossings and causeways.
- Tidal or flood gates.
- Partial bunds such as those used for temporary instream construction.
- Silt curtains.
- Netting and screens, either temporary or permanent.
- Litter booms.
- Trash racks in waterways.

Maintenance of existing structures has the potential to impact on fish movement by creating new barriers or exacerbating existing conditions. Some of these works include:

- Scour protection.
- Retrofitting culvert inverts and culvert lining or relining.

[13] (Wagner 2015)
[14] (Ottburg and Blank 2015, Wagner 2015)

- Apron repair and installation.
- End wall and wing wall replacement.

3.1.1 Physical barriers

One of the impacts to fish passage is where the base of the waterway crossing is above the level of the waterway bed and fish are prevented from moving upstream by a physical barrier. Native Australian fish cannot jump over physical barriers and therefore their upstream migration is prevented under these conditions under water levels are such that the physical drop is drowned out (Figure 3.4).

The depth of cover, or amount fill between the culvert obvert and road surface will directly impact the duration for the structure to drown out under elevated flow conditions. Minimising the depth of cover is particularly important for structures with a low flood immunity, and in western waterways where fish movement is seasonally limited and where minimal low flows and significant flood conditions are typically characteristic of these waterways.

3.1.2 Hydraulic conditions

Hydraulic conditions that create excessive velocities or turbulence within culverts can also cause a structure to become a barrier to upstream movements. Design of waterway crossings should span a sufficient aperture of the main channel width of the waterway. Increasing the culvert aperture decreases water velocity, which will assist in providing fish passage. Design elements such as baffles on sidewalls and roughening of culvert inverts can help to reduce velocities within a culvert cell. Low flows should also be provided for so that water is directed through a low flow culvert and not spread thinly throughout the base of all culvert cells.

3.1.3 Behavioural barriers

The design of waterway crossings can sometimes result in behavioural barriers to fish passage. For example, long, dark pipes can be a behavioural deterrent for fish movement[15]. Design features could incorporate light wells or gaps between culverts where possible.

3.2 Habitat loss and modification

Modifications to key elements of aquatic habitats may result in the loss of some fish species with specialised habitat requirements and an increase in generalist species, in particular invasive non-native species. Habitat quality in waterways can be impacted through:

- The straightening and simplification of waterways.
- Removal of instream habitat features.
- Removal of riparian vegetation.

For instance, the construction of transportation infrastructure over a waterway can result in the loss of habitat in the waterway bed and on the banks to enable machinery to move freely around the site. Consequently, the loss and modification of waterways due to transportation infrastructure is a major contributor to reductions in water quality and the decline of freshwater fish populations internationally

[15] (e.g. Jones et al. 2017, Keep et al. 2021)

and within Australia[16]. These impacts can potentially occur directly because of new transport projects and maintenance of existing infrastructure or indirectly from secondary impacts long after construction.

3.3 Noise and vibration

Noise and vibration generated by rail and road infrastructure can have significant impacts on aquatic species. Vibrations in water travel faster and attenuate slower than vibrations in air. Their propagation is difficult to model due to microhabitat changes such as water depth and interactions with surfaces and substrates[17]. A study in the United States estimates that road traffic impacted the aquatic soundscape as far as 1.2 km from the road[18]. Another study conducted over 46,000 km² of five major river systems in North America estimated that anthropogenic noises accounted for 92% of the aquatic soundscape by relative percent time[19].

Fish can sense vibrations in water through several appendages which can include highly sensitive Weberian ossicles and swim bladders. Species with more sensitive structures are likely to be more impacted by disturbances[20]. The hearing ranges and sensitivities of fish are highly diverse, but nearly all fish respond to and can be negatively impacted by sound.

The documented impacts of noise and vibration pollution on fish include[21]:

- Masking of communication, including attraction of mates, alarm calls, and territory defence.
- Disturbance of predator and prey interactions, including reduced foraging efficiency and increased predation risk[22].
- Increased stress, including higher susceptibility to disease and larval deformations[23].
- Avoidance of noisy areas.
- Physical injury, including of internal organs and hearing structures.

High intensity activities such as pile driving during construction can produce high levels of impulsive vibration that can injure fish[24].

3.4 Erosion and sedimentation

Any transport infrastructure located within or near a waterway has the potential to impact the hydraulic performance of the waterway. The installation of culverts that reduce the cross-sectional area of the waterway results in a localised area of elevated velocity downstream of the structure during high flows[25]. The impact of these high velocity areas is often a limited area of erosion that scours the waterway bed and sometimes one or both banks. Typically scour of the banks only occurs where the culverts are not aligned with the direction of water flow or where the culverts are placed on a bend, rather than a straight section of waterway. If uncontrolled, this loss of the bed can travel downstream

16 (Wagner 2015, Harris et al. 2016)
17 (Akyildiz et al. 2005)
18 (Holt and Johnston 2015)
19 (Rountree et al. 2020)
20 (Proulx et al. 2019, Pieniazek et al. 2020)
21 (Cox et al. 2016, Mickle and Higgs 2018, Popper and Hawkins 2019)
22 (Hanache et al. 2020, Fernandez-Declerck et al. 2023)
23 (Vandenberg et al. 2012, Masud et al. 2020)
24 (Parris 2015)
25 (Wagner 2015)

leading to head cut erosion which then raises the base of the culverts above the downstream bed (Figure 3.4). A well-designed culvert array will include the hydraulic requirements to minimise very high velocity flows that cause downstream erosion and incorporate suitable scour protection works.

Sedimentation within culverts and under bridges can cause a physical barrier to fish movement by raising the waterway bed at the site. Generally, sedimentation issues are greatest within culvert crossings, particularly when the low flow channel is eliminated, but can also occur upstream of / or under bridge sites with instream structures. Common causes of sedimentation are due to a slowing of flow at the location, either because of the design of the structure itself or a build-up of debris on the structure that traps sediment and causes blockages.

Figure 3.4 – Examples of perched culverts that have developed because the downstream waterway bed has eroded and flowed downstream. All examples act as barriers to upstream movement of fish

Source: © Andrew Berghuis, Aquatic Biopassage Services

4 Indirect impacts

4.1 Habitat degradation due to weed invasion

The construction and operation of transport infrastructure over a waterway can create opportunities for aquatic weeds that are present in a catchment by disturbing existing aquatic and riparian habitat. Over time and if left unattended, weeds can displace native vegetation and alter other important habitat features. Such changes can result in increased water temperature, overabundance of instream organic matter (i.e. willows), destabilisation of banks, and increased turbidity and sedimentation loads.

5 Avoidance and minimisation

Planning the location of new transport infrastructure should always avoid key fish habitats such as rivers, creeks, and wetlands wherever possible[26]. Where waterways are unable to be fully avoided, the design of the waterway crossing should completely span the width of the waterway where possible so that natural bed and banks remain intact. The number of waterway crossings should be minimised to the greatest extent possible. Where multiple crossings can't be avoided, they should be spaced as far apart as practical.

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[26] (Ottburg and Blank 2015)

6 Mitigation

Where transport infrastructure crosses a waterway, it is important to mitigate the barrier impacts as much as feasible. The overarching goal should always be to allow the unhindered movement of all native species of fish.

The hierarchy of design selection for crossing structures should consider the most suitable transport solution combined with the importance of the waterway to fish communities and aquatic habitat. The following list identifies the design mitigation options in decreasing order of impact avoidance:

1. Single span bridge (including slab deck culverts) extending from each high bank.
2. Multi-span bridge extending from each high bank with supports outside of the low flow channel.
3. Multi-cell box culvert (including arches and slab-deck culvert) arrays spanning the low flow channel and at least 75% of main channel.
4. Multi-cell pipe culvert array spanning all of the low flow channel and at least 75% of main channel open.

It is important to not rule out enhancing waterway crossings when crossings upstream or downstream also present barriers. Over time, all culverts and bridges will require repair or replacement and enhancements should be considered wherever possible.

6.1 Bridges

Under Department of Agriculture and Fisheries (DAF) guidelines, new single span bridges that have no components within the waterway (option 1 above) are not considered to be waterway barrier works. Similarly, new multi-span bridges (option 2 above) may not be classified as waterway barrier works provided they comply with the requirements specified by DAF in *What is not a waterway barrier work?*.

It is common that some components of the bridge works, such as piers and piles, are required to be located within the waterway and these may be classified as waterway barrier works where they limit fish access and movement along the waterway. The design of the bridge should seek to maximise fish passage potential by keeping instream structures out of the low flow channel and minimising other instream components (i.e. option 3 above). In most cases, this type of bridge design will have less impact on fish passage than a well-designed culvert array.

Bridges with structures that are fully outside the waterway will also benefit the movement of terrestrial fauna where they have been appropriately designed (Chapter 6).

6.2 Culverts

As detailed in Section 3.1, the installation of culverts in a waterway has the potential to impact fish passage by creating physical, hydraulic, and behavioural barriers to fish movement.

An understanding of the hydrology of the waterway is also critical when designing fish passage culvert crossings. Options for hydrological assessment are dependent on the scale of the project, the size and flow of the waterway, and the availability of suitable data. Modelling options include basic rainfall and runoff models through to the Hydrologic Engineering Centre's River Analysis System (HEC-RAS) to perform one and two-dimensional unsteady flow calculations. Three dimensional models such as Computational Fluid Dynamics (CFD) or physical models are typically only required on large projects on major waterways as these models are highly complex and costly. Transport and Main Roads has also been experimenting with simple one and two-dimensional hydraulic models to support Development Applications to support fish passage requirements[27].

Some preliminary laboratory trials have been performed on the passage of Australian native fish through culverts[28]. The trials quantified how water velocity, depth, and fish body size interact to affect fish swimming performance and the ability to traverse a 12-metre culvert-scale swimming channel. The results demonstrated the importance of considering size-class of fish and species-specific swimming capabilities in culvert design criteria. However, comprehensive field trials should also be undertaken to test the recommendations[29] before they are widely adopted in the field[30].

It should be noted that when providing hydraulic modelling for the purposes of demonstrating adequate fish passage, modelling should be provided for frequent flow events, for example, 1 and 2 Exceedances per Year (EY), 2 and 5 Average Recurrence Interval (ARI).

The following criteria apply to the use of single cell culverts[31]:

- Choose a culvert width as close as possible to the width of the waterway and depth in the culvert matches typical depths upstream and downstream of the culvert.
- Install the culverts with a slope close to that of the waterway.
- Avoid oblique (>10°) waterway-to-culvert angles by aligning the culvert with the channel direction.

Key design considerations for multi-cell culverts include:

- Maximise the cross-sectional area of the culvert openings in relation to the main channel width of the waterway, which reduces the velocity through the culverts as flow volumes increase.
- Consider lowering the invert of one or more culverts below waterway bed level with the remainder at waterway bed level, which ensures a low flow channel that will become lined with natural sediment.
- Roughen culvert walls and floors with baffles to provide different water velocities, enabling fish to swim at varying speeds through the culvert (e.g. Figure 6.2). Roughening options other than baffles include rock armouring, and baffle blocks.

The retention of ambient light through the culverts is also beneficial for the passage of some fish species. The most suitable solution to increase light levels is to oversize the height of the culverts above the commence to flow water level and to minimise the length of the culvert in an upstream downstream direction.

The technical report *Guidelines for fish passage at small structures*[32] provides the headloss (vertical drop between inlet and outlet of a culvert) and maximum water velocity specific to fish sizes to inform culvert design (Table 6.2).

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[27] (Johannessen et al. 2022)
[28] (Shiau et al. 2020, Cramp et al. 2021)
[29] (Shiau et al. 2020)
[30] (Johannessen et al. 2020)
[31] (Cafferata et al. 2004)
[32] (O’Connor et al. 2017)

Table 6.2 – Headloss, water velocity, and minimum fish sizes that might negotiate a culvert

HEADLOSS (MM)	MAX. WATER VELOCITY (M/S)	FISH LENGTH (MM)
2	0.15	< 80
10	0.3	> 100
20	0.45	> 150
50	0.75	> 250
80	0.93	(> 400)
100	**1.05**	**(> 500)**

Source: O'Connor et al. (2017)

Figure 6.2 – Example of aluminium right-angle baffles installed on bankside culvert viewed from upstream

Source: © Andrew Berghuis, Aquatic Biopassage Services

Box culverts provide better passage opportunities for fish than pipe culverts and should always be a preference when fish passage through culverts is required as:

- Box culverts can provide a more uniform cross-sectional area and therefore more consistent hydraulics over the range of flows and can be set at or below waterway bed level to follow the natural bed profile.
- The cross-sectional area of pipe culverts is narrower at the obvert which increases depth and flow velocity at low flows.
- The installation of floor baffles in pipe culverts can assist in reducing the velocity however they can be prone to clogging and sedimentation.

A better alternative for pipe culverts is to partially bury one or more of the pipes below bed level to create a flat floor in the low flow channel and set the other pipes at or above bed level to follow the waterway bed. Other options for pipe culvert designs that may provide suitable fish passage conditions are oversized pipe culverts that span the main channel or large arches. However, large arches are typically more expensive to install than pipe or box culverts and so are more likely to have been selected for other reasons.

6.3 Habitat enhancement

Habitat enhancement is the process of reinstating natural elements and processes within impacted waterways to provide the diversity of habitats required for a healthy waterway ecosystem. Works involving transport infrastructure on waterways sometimes necessitate the removal of riparian vegetation or the alteration of the waterway profile.

Historically, waterway alterations have been aligned to be as straight and hydraulically efficient as possible. However, a straightened waterway lacks habitat and flow diversity and can increase the risk of flooding downstream. The introduction of waterway meanders provides a more natural course and river profile with the aim of improving habitat diversity and biodiversity. Introducing some form of in-channel roughness, such as woody material, riffle zones, or berms will create flow diversity, new habitats, and areas of refuge.

Re-establishment of the impacted vegetation in the riparian zone is also an important aspect of habitat enhancement. Healthy riparian ecosystems improve water quality throughout the entire catchment area, provide shelter, reduce erosion, regulate flows, and provide critical habitat for wildlife.

Projects that require habitat enhancement should be integrated at a catchment scale to ensure maximum benefit of Transport and Main Roads projects and other works across the catchment. Co-ordination among projects undertaken by Transport and Main Roads, catchment management groups, and other managers will help to minimise conflict among projects and achieve maximum conservation gain. For example, trees and root balls from transport projects can be used away from the immediately impacted area by other managers to provide wider catchment-scale benefits.

7 Construction

The construction stage of transport projects on waterways can be high-risk if poorly planned and implemented. Well-informed planning and design, especially during the construction phase of projects, can prevent or minimise short-term and long-term impacts[33]. Some of the key steps include:

- Only clear vegetation where necessary.
- Only disturb banks and waterway beds when necessary, and to the smallest extent possible.
- Ensure erosion and sediment controls are installed as described in the accepted plans and maintained in working order.
- Time construction works to take place during periods of where no or low-flow conditions are most likely to occur and fish are absent or in low numbers.
- Use construction techniques that minimise noise and vibration. Where this is not possible, gradually increase noise and vibration intensity from low to high, and include regular breaks to allow fish and other aquatic species to move around[34].

[33] (Ottburg and Blank 2015, Wagner 2015)
[34] (Parris 2015)

- Consider entrapment of fish in sedimentation basins and during dewatering to enable construction.
- All temporary instream components are designed to be durable, reliable, and adequately protected from damage during high-flow and flood events.
- Following the completion of works, all waterway profiles are restored back to the original grade and profile and:
  - Instream habitat enhancement features are installed.
  - The riparian zone is restored and adequately protected from weed infestation and floods until re-established.

8 Maintenance and operation

A key component of all successful waterway infrastructure works is an effective maintenance program that maintains the design hydraulic efficiency and fish passage aspects to the greatest extent practical (Chapter 6 and Chapter 8). However, access for routine inspection and maintenance activities of bridges, culverts, and other infrastructure, including by vehicles and other machinery, is often required and may result in periodic vegetation clearing. As such, ongoing and periodic maintenance works may reduce the availability of suitable fish habitat.

Maintenance and operation activities should identify and assess all opportunities to retrofit existing waterway crossings with enhancements to improve fish passage. These can include the fitting of baffles to existing culverts, restoration of aquatic and riparian fish habitat and remediation works to restore perched culverts.

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