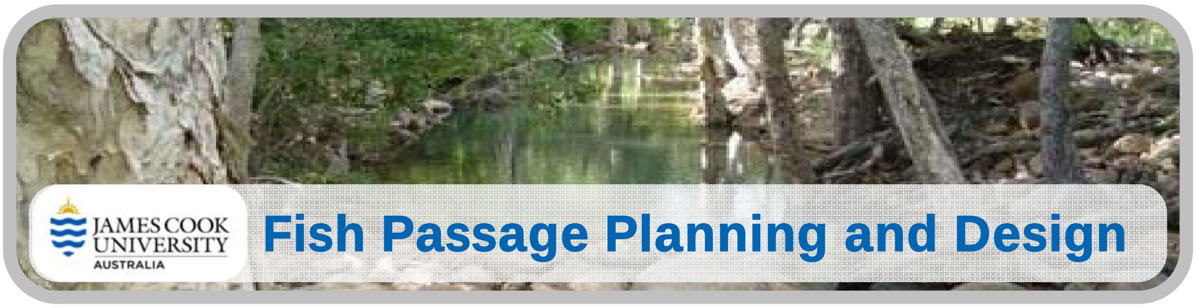

Culvert Fishway Planning and Design Guidelines

Part B – Fish Migration and Fish Species Movement Behaviour

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1 INTRODUCTION

To consider the needs for fish migration within waterways and the provisions that should be made for fish passage at road crossings and other waterway structures, road designers, waterway managers, environmental officers and scientists require general information about the migration, life cycle and movement behaviour of the freshwater fish community. Designers, managers and scientists involved in the planning, design and implementation of fish passage facilities also require information on fish movement design criteria for fish passage provisions at the structure.

These *Guidelines Part B* deal with fish migration and fish movement behaviour, and aim to:

- provide an outline of freshwater fish and fisheries values, fish habitat and stream zones, fish life cycles and fish migration characteristics
- categorise fish movement behaviour in terms of movement groups and movement directions, with illustrations for the Bruce Highway Corduroy Creek to Tully and University Creek prototype fishway case study projects
- identify fish movement characteristics for design in terms of fish passage design flow, design swim speeds and other movement characteristics for fish

The information from *Guidelines Part B* is used in other parts of these *Guidelines* to:

- identify fish migration barriers at road crossings and other waterway structures within the various hydraulic zones of the structure, and identify fish passage options and alternative configurations to overcome particular fish migration barriers (*Guidelines Part C – Fish Migration Barriers and Fish Passage Options for Road Crossings*)
- categorise fish movement corridor crossings and assemble movement characteristics of the fish community for use in road corridor scale assessment (*Guidelines Part D – Fish Passage Design: Road Corridor Scale*) and in site scale assessment (*Guidelines Part E – Fish Passage Design: Site Scale*)

These *Guidelines* deal primarily with the ***Concept*** and ***Preliminary Design*** phases of planning and design procedures for road and other infrastructure projects. Examples of fish movement and barriers to migration at road crossings and other waterway structures are shown in Box B1.1.

Box B1.1: Native freshwater fish within University Creek in Townsville, attempting to migrate upstream at road crossings

Purple spotted gudgeon resting in shallow protected area on culvert apron slab (-/01/06) *(Source: Alan Webb)*

Plotosid catfish struggling through shallow water on culvert apron (-/01/04) *(Source: Ross Kapitzke)*

2 FRESHWATER FISH, FISH HABITAT AND MIGRATION

Information on the freshwater fish community and fish habitat areas within a catchment, and an understanding of the life cycle and migration behaviour of the fish species is vital to the provision of fish passage at road crossings and other waterway structures within the catchment. Information on diversity, abundance and distribution of the fish community for use in fish passage planning and design can generally be obtained from regional fish community data, field surveys, review of previous studies, as well as from anecdotal data for waterways in the area.

The following sections outline freshwater fish, fish habitats and fish migration, and illustrate this through information on the fish communities for the Tully Murray catchment and the University Creek catchment (Townsville) in coastal north Queensland.

2.1 Freshwater fish and fisheries values

Freshwater fish are defined here as those species spending all or part of their life cycle within freshwater environments. This includes species that live wholly within freshwater (e.g. Rainbowfish), species that move between marine and freshwater systems as an essential part of their spawning and growth life cycle (e.g. Barramundi), and species that live primarily in marine environments and may migrate into freshwater systems (e.g. Sea mullet).

Freshwater fish provide a range of commercial, recreational and traditional cultural values for humans, and represent significant biodiversity and conservation values for streams (Box B2.1). Species such as Sea Mullet *Mugil cephalus* are important for commercial and recreational fisheries. Jungle Perch *Kuhlia rupestris*, for example, represent important freshwater recreational fishing values, and together with other wholly-freshwater species such as Purple Spotted Gudgeon *Mogurnda adspersa*, contribute significantly to biodiversity and aquatic ecosystem functions. Many species, including Barramundi *Lates calcarifer* are important for traditional and cultural values, as well as being highly sought after for commercial and recreational purposes.

Box B2.1: Fisheries values and significance of freshwater fish	
 *Sea mullet* **Commercial fisheries**	 *Jungle Perch* **Recreational fishing**
 *Purple spotted gudgeon* **Conservation & biodiversity**	 *Barramundi* **Traditional/cultural values**

2.2 Fish habitats, fish life cycles and fish migration

Freshwater fish inhabit various habitat types ranging from riffle and runs in upland fast running systems (lotic environments), to pools and backwaters in slower lowland streams and wetlands (lentic environments). This includes perennial pools and wetlands providing permanent habitat for fish, and intermittent streams where pool habitats are available temporarily during wet season flows. Marine environments such as coastal waters and tidal wetlands also form essential habitat for freshwater species that have obligate marine life cycle stages (diadromous species). Freshwater fish require good stream habitat quality and suitable aquatic fauna connectivity between these habitat areas to successfully complete their life cycle functions.

University Creek in Townsville is an example of an intermittent stream that provides spawning and growth habitat for fish moving upstream from permanent water bodies in Ross River.

University Creek typically flows for several months each year during periods of sustained rainfall, and the intermittent pooled water sources along the creek channel provide major ecosystem support functions in the landscape. The upper reaches of the creek comprise coarse boulder and cobble substrate that provides ideal spawning and growth habitat for a number of fish species that depend on access to these habitats for recruitment success (Box B2.2).

As another example, the Tully Murray floodplain and associated wetlands provide important breeding and nursery areas for fish and other aquatic fauna and represent substantial coastal (freshwater and marine) ecosystems adjoining the Great Barrier Reef. Natural wetlands are located in a range of freshwater and marine landscapes, and some artificial wetlands that have been constructed and revegetated in agricultural areas for flood mitigation and sediment retention also provide enhanced aquatic habitat (Box B2.2).

Box B2.2: Fish habitats in small intermittent tributary stream (University Creek) and large permanent stream and wetland system (Tully Murray floodplain) *(Source: Ross Kapitzke)*

Upper reaches of University Creek providing temporary spawning habitat during wet season flows (-/01/06)

Downstream reaches of University Creek adjacent to Ross River providing permanent growth habitat (-/08/04)

Freshwater habitat in constructed wetland and rehabilitated farm drain on Tully Murray floodplain (-/11/05)

Tidal saline wetland habitat in Bedford Creek in the coastal zone of the Tully Murray floodplain (-/11/05)

Migration between discrete habitats is a natural process for most freshwater fish. Fish migrate upstream (or downstream) for a variety of reasons, which may include: fulfilling crucial life cycle stages such as adult spawning migrations and juvenile growth dispersal; recolonising habitats in response to condition fluctuations during flood or drought; or compensating for downstream drift of pelagic eggs or larvae (Harris 2001). Fish migration also facilitates gene flow through evolutionary-scale movement within and between catchments. In addition to broad scale movements associated with spawning and dispersal migrations, all species display localised movement to take advantage of changing conditions and habitat availability. Fish commonly move upstream after flood flows to re-occupy habitats lost through downstream drift. Fish migratory stages may be adult and/or juveniles of both large and small species.

Altered stream flow through floods, and other stimuli such as water temperature change and altered photoperiod, provide cues for many freshwater fish species to migrate downstream or upstream for reproduction or habitat colonisation. The life cycle characteristics of the various fish species govern their migration behaviour, including the time of the year (season), the direction of movement (upstream or downstream), and the size of the migrating fish (adult or juvenile). Depending on the species and the life stage, migrations between habitat areas may occur at various temporal and spatial scales, ranging from river-basin scale movements of hundreds of kilometres over period of years, to local, tens-of-metres scale over days. Different fish species possess differing movement capabilities and capacities to negotiate various barriers to fish passage along the route such as adverse flow velocities and water depths at road crossings and other waterway structures.

Fish are categorised into various life cycle groups, depending on their movement between and within freshwater and marine habitats for spawning or growth (Box B2.3). This includes the ***potamodromous*** life cycle, involving movement wholly within freshwater (e.g. Rainbowfish) and the ***diadromous*** life cycle, where migration occurs between marine and freshwater habitats. The diadromous group includes ***catadromous*** – migrating downstream to spawn at sea, while growing in fresh water (e.g. Barramundi); and ***anadromous*** – migrating upstream to freshwater spawning grounds, growing mostly in saline waters (e.g. Salmon). Another group (***amphidromous*** life cycle) includes species migrating between marine and freshwater environments (or vice versa) at some stage in their life cycle but not for the purpose of reproduction (e.g. Mullet).

Fish life cycles can be shown graphically (Box B2.3) in terms of migrations between spawning and growth habitat zones situated within the various stream zones (upland / headwater; intermediate / transfer; lowland / floodplain / freshwater wetland; estuary / coastal / tidal wetland). Anadromous species (e.g. Salmon) have downstream growth habitats in marine waters, and move upstream as adults to spawning habitats in freshwater stream zones. Juveniles disperse downstream to marine growth habitats, and adults too disperse downstream after spawning. The catadromous species (e.g. Barramundi) follow opposite movement patterns, with downstream spawning migrations by adults to marine waters, and upstream juvenile dispersal migrations to freshwater growth habitats. Potamodromous species (e.g. Sooty grunter), which move completely within freshwater systems, will follow either an upstream or a downstream migration pattern as adults to spawning habitats, with juveniles dispersing either downstream or upstream to growth habitats, depending on the particular species.

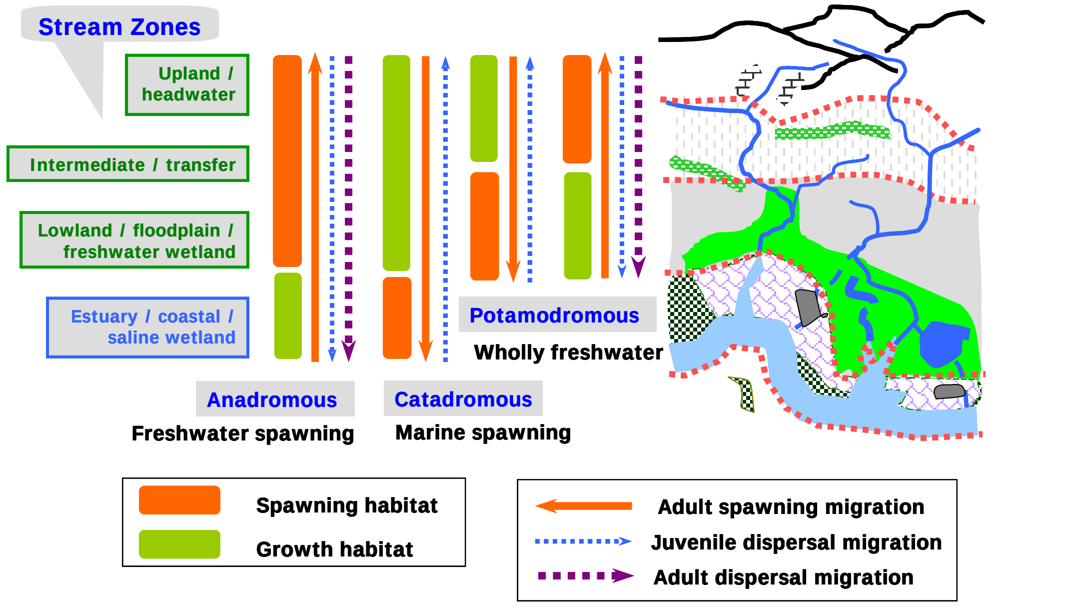
Catadromous life cycles are common in fish communities in Australia's coastal fringe river systems, where adult fish of moderate body size pass downstream to spawn and juveniles travel upstream for growth (Harris 2001). Weakly swimming early life stage catadromous fish are less able to negotiate barriers to upstream movement than adult stage anadromous species, which predominate in the Northern Hemisphere. Many headwater spawning (potamodromous and anadromous) species in Australia (e.g. Plotosid Catfish), although having the advantage of upstream migration as adults rather than as juveniles, also lack the swimming capabilities of Northern Hemisphere species (e.g. Salmon). Furthermore, some of these species rely on intermittent rather than perennial streams for spawning, and are therefore very susceptible to barriers because suitable flow conditions exist for only a short period of time.

Alteration to natural fish migration behaviour at road crossings or other waterway structures may affect the fish community in the waterway in many ways, including:

- risk of injury and mortality during passage
- increased metabolic cost of passage under conditions of severe physical demand
- excessive delays in migration leading to loss of stored energy necessary for successful migration, maturation and spawning
- delay in access to or isolation of fish from spawning or growth habitats, with inability to fulfil critical life cycle requirements

- concentration of fish downstream of obstruction leading to starvation, disease, and increased predation by other fish or animal prey, particularly for juveniles
- reduced species diversity and abundance
- impact on genetic diversity through isolation

Box B2.3: Fish lifecycles, waterway habitat zones and fish migration



Diadromous	Fishes that regularly migrate between fresh and salt water during a definite period of their life cycle. This includes catadromous and diadromous species.
Catadromous	Fishes that spend most of their life cycle in freshwater and which migrate to the marine environment to reproduce. The opposite is anadromous.
Anadromous	Fishes that spend much of their life in a marine environment and which migrate to freshwater as adults to reproduce. The opposite is catadromous.
Potamodromous	Fishes that make true migrations wholly in freshwater.
Amphidromous	Fishes that migrate between marine and freshwater environments (or vice versa) at some definite stage in their life cycle but not for the purpose of reproduction.

2.3 Fish species diversity, abundance and distribution

General information on the diversity, abundance and distribution of the fish community for the catchment under consideration can typically be obtained from broader scale studies of the catchment and surrounding region, and from related fish species surveys of the waterway or adjoining catchments. Fish community data compiled from these sources gives substantial information on the range of species that can be expected to inhabit waterways within the catchment, but information on the distribution of species along particular waterways is commonly far less detailed. Data from previous catchment studies and other general information on the fish community will commonly be adequate for fish passage assessment, but dedicated fish surveys of the waterway may be required in some instances where more specific information is required in relation to habitat and fauna connectivity issues for particular species or locations.

Information on freshwater fish fauna within Australia and for particular regions can be obtained from several primary references, including:

- *Australian freshwater fish: Biology and management* (Merrick and Schmida 1984)
- *Freshwater fishes of Australia* (Allen 1989)
- *Field guide to the freshwater fishes of Australia* (Allen et al. 2003)
- *Freshwater fishes of North-eastern Australia* (Pusey et al. 2004)
- *Distribution and conservation status of Queensland freshwater fishes* (Wager 1993)

- *Freshwater fishes of Far North Queensland* (Herbert and Peeters 1995)

The Pusey et al. (2004) publication provides a comprehensive record of fish species, their life cycle characteristics, and their movement behaviour for catchments in north eastern Australia. This book sources published material and previously unpublished documents and provides reference material in a standard format. It also provides regional and catchment scale information on the distribution of fish species within these catchments.

2.3.1 Fish species diversity within catchments in north eastern Australia

To illustrate, species diversity of native freshwater fishes is summarised here for the catchments of north eastern Australia. This area encompasses the North-east Coast Drainage Division (Drainage Division 1 identified under the Australian Water Resources Council system), and includes the easterly flowing catchments within several sub-regions in the relatively narrow coastal strip of Queensland bounded by the Great Dividing Range and the Coral Sea, and extending from Cape York Peninsular to the southern state border with New South Wales.

North-eastern Australia contains the most diverse freshwater fish fauna in Australia, with over 130 native species in about 30 families, which is approximately half of the fauna of the entire continent (Pusey et al. 2004). The Australian freshwater fish fauna is strongly endemic, with approximately 70% of freshwater dependent species found exclusively in Australia (Allen et al. 2002). Unlike other parts of the world, Australia has few primary freshwater fishes (entire evolutionary history restricted to freshwater), and Australia's freshwater fishes include mostly secondary freshwater species (freshwater forms secondarily derived from marine stocks). This contributes to many diadromous species (moving between freshwater and marine environments) in Australia, with the catadromous reproductive strategy (migration out of freshwaters to breed) particularly common in northern Australian fishes (Pusey et al. 2004).

In addition to native species, Australia has at least 43 introduced fish species, 15 of which occur in Queensland waters. Common among these are Gambusia (often referred to as mosquitofish) and Tilapia. Many of the exotic or alien species were originally imported into Queensland for aquarium display purposes, and some for disease / vector control. They now threaten native fish by readily establishing as dominant fish species within certain wetland communities.

In terms of the subregions of the North-east Coast Drainage Division, waterways of the Wet Tropics bioregion have greater species diversity than waterways in Eastern Cape York Peninsular, Central Queensland or South-eastern Queensland subregions (Pusey et al. 2004). Within-river habitat heterogeneity accounts for patterns of fish diversity, and accordingly, Wet Tropics waterways contain a more diverse array of habitat types and fish species than waterways of the other regions. The spatial variation in species richness between river basins in Drainage Division 1 is best explained by the variation in magnitude of the mean annual discharge and seasonality / perenniality of the flow regime (Pusey et al. 2004). More species occur in waterways with large mean annual discharge (e.g. Wet Tropics), and less species occur in waterways with highly seasonal flow regime (e.g. Eastern Cape York Peninsular).

The Wet Tropics region, in particular, is an area of outstanding biological diversity, which supports a community of freshwater fishes that is among the most diverse and rich in Australia (Herbert and Peeters 1995; Pusey et al. 1999). The region has more than 80 recognised species, representing over 40 % of Australia’s freshwater fish species (Pusey and Kennard 1996).

2.3.2 Fish community for road project catchment or waterway

The fish community for a particular catchment or waterway under consideration in a road corridor assessment of fish passage requirements, or for fish passage design at a waterway structure, will be a subset of the sub-regional fish community data for that area. Fish species composition, distribution and abundance will vary across the catchment, within the waterway, and over time. Considerable variation will occur within each main ecosystem, depending on natural and human-induced factors such as aquatic habitat quality, terrestrial vegetation, streamflow characteristics, and human pressures on the system. Whereas any particular freshwater site may be populated by relatively few species (e.g. 5 to 15 species), the overall waterway and subcatchment of interest may have a species diversity in excess of 50 species.

As an illustration, the Tully Murray catchment, which is within the Wet Tropics region in coastal north Queensland, has in total 56 native freshwater species within 20 families identified in local and regional surveys (including 49 species from Pusey et al. 2004, and a further 7 species from Hogan and Graham 1994). In contrast, University Creek in Townsville, which is an intermittent stream with a much smaller catchment than Tully Murray, has 13 native fish species within 9 families. The 56 native species and 20 families within the Tully Murray fish community are shown in Box B2.4, where they are grouped by family names and listed alphabetically by common name, with genus and species included. The listing identifies the 13 native species and 9 families, forming a subset of this group, that are also present in University Creek.

Box B2.4: Fish species of the Tully Murray catchment [1] *(Source: Kapitzke 2006a)*

Common name	Family	Common name	Genus, species
Biddies	**Gerreidae**	Short finned silver biddy	*Gerres ovatus*
		Spotted silver-biddy	*Gerres filamentosus*
Blue eyes	**Pseudomugilidae**	Pacific blue-eye	*Pseudomugil signifer*
		Spotted blue-eye	*Pseudomugil gertrudae*
Cardinalfishes	**Apogonidae**	Mouth almighty **	*Glossamia aprion*
Eels	**Anguillidae**	Long finned eel **	*Anguilla reinhardti*
		Pacific short finned eel	*Anguilla obscura*
Eel-tailed catfish	**Plotosidae**	Black catfish **	*Neosilurus ater*
		Freshwater catfish	*Tandanus tandanus*
		Hyrtl's tandan **	*Neosilurus hyrtlii*
		Rendahl's tandan	*Porochilus rendahli*
Flagtails	**Kuhliidae**	Jungle perch	*Kuhlia rupestris*
Giant herring	**Elopidae**	Tarpon, ox-eye herring	*Megalops cyprinoides*
Glass perchlets	**Chandidae**	Agassiz's glass perch **	*Ambassis agassizii*
		Flag-tailed glassfish	*Ambassi miops*
		Glass perch	*Ambassis vachelli*
		Long-spined glass perchlet	*Ambassis interuptus*
		Northwest glassfish	*Ambassis sp.(cf mulleri)*
		Sailfin perchlet / Glass perch	*Ambassis agrammus*
		Pennyfish	*Denariusa bandata*
Gobies	**Gobiidae: Gobiinae**	False celebes goby	*Glossogobius sp.1*
		Pacific mangrove goby	*Mugilogobius notospilus*
		Roman nosed goby	*Awaous acritosus*
		Speckled goby	*Rediogobius bikolanus*
		Tully River goby	*Stenogobius psilosinionus*
Grunters	**Terapontidae**	Banded grunter **	*Amniataba percoides*
		Khaki grunter / Tully grunter	*Hephaestus tulliniensis*
		Sooty Grunter / Black bream	*Hephaestus fuliginosus*
		Spangled perch **	*Leiopotherapon unicolor*
Gudgeons	**Gobiidae:**	Aru gudgeon	*Oxyeleotris aruensis*

Box B2.4: Fish species of the Tully Murray catchment [1] *(Source: Kapitzke 2006a)*

Common name	Family	Common name	Genus, species
	Eleotrididae	Brown gudgeon	*Eleotris fusca*
		Ebony gudgeon	*Eleotris melanosoma*
		Empire gudgeon **	*Hypseleotris compressa*
		Fire tailed gudgeon **	*Hypseleotris galii*
		Greenback gauvina	*Bunaka gyrinoides*
		Midgley's carp gudgeon	*Hypseleotris sp. 1*
		Northern trout gudgeon	*Mogurnda mogurnda*
		Poreless gudgeon	*Oxyeleotris nullipora*
		Purple spotted gudgeon **	*Mogurnda adspersa*
		Sleepy cod	*Oxyeleotris lineolatus*
		Snakehead gudgeon	*Giurus margaritacea*
Hardyheads	**Atherinidae**	Fly specked hardyhead **	*Craterocephalus stercusmuscarum*
		Hardyhead	*Craterocephalus sp.?*
Herring	**Clupeidae**	Bony bream **	*Nematolosa erebi*
Jacks	**Lutjanidae**	Mangrove jack	*Lutjanus argentimaculatus*
Mullets	**Mugilidae**	Sea mullet	*Mugil cephalus*
Rainbow fishes	**Melanotaeniidae**	Eastern Qld rainbowfish **	*Melanotaenia splendida*
		Lake Eacham rainbow	*Melanotaenia eachamensis*
		McCulloch's rainbowfish	*Melanotaenia maccullochi*
Sea bass	**Centropomidae**	Barramundi	*Lates calcarifer*
Swamp eel	**Synbranchidae**	Swamp eel	*Ophistemon gutturale*
		Unidentified swamp eel	*Synbranchidae spp.?*
	Scorpaenidae	Bullrout / Freshwater stonefish	*Notesthes robusta*
	Soleidae	Selhiem's sole	*Brachirus selheimi*
Other			
		Mud cod	*Ophieleotris aporos*
		Giant trevally	*Caranx sexfasciatus*
Alien (exotic) species			
Top minnows	**Poeciliidae**	Guppy	*Poecilia reticulata*
		Platy	*Xiphophorus maculatus*
No of Families	**20 natives 1 exotic**	**No of Species**	**56 natives 2 exotic**

Notes	1	Species list for Tully Murray catchment developed from Pusey et al. (2004); Hogan and Graham (1994)
	**	Species within University Creek at Townsville (Total 9 families; 13 species) – list developed by Webb (2003)

3 FISH SPECIES MOVEMENT BEHAVIOUR

In order to provide for fish passage at road crossings and other waterway structures where hydraulic barriers prevent upstream fish movement through the structure, an understanding is required of the movement behaviour of the various species within the fish community present at the site. This includes information on the movement characteristics of these fish both spatially (upstream, downstream) and temporally (season, flood stage), and the swimming capabilities of the fish to negotiate the flow conditions at the waterway crossings. Information on the movement behaviour of the fish community (movement between habitats, life cycle stage and maturity, movement capability through the waterways) is most commonly established from general data in the literature, supplemented in some cases by local data where available.

Classification of fish movement groups assists with establishing fish movement characteristics for the fish community. Categorisation assists with evaluation of the range of fish species that are likely to be migrating through any particular reach of a waterway, the life stage and maturity of the fish at the time of movement, the direction of movement, the time of movement in relation to seasonal flow and flood stage in the stream, and the fish species size and swimming ability. To assist with rationalisation, correlation within and between groups is sought for migration timing, migration movements and zones, and fish species size and swimming ability.

The following sections (derived from Kapitzke 2006a) outline a classification framework for fish movement group and fish movement direction, and describe fish swimming modes and swim behaviour characteristics for use in fish passage design (see Chapter 4). Examples of fish movement group classification and fish movement behaviour characteristics for the Tully Murray catchment in coastal north Queensland are presented. These data are included for illustration only, and the applicability of this information to other fish communities in other regions or catchments should be checked before use elsewhere.

3.1 Fish movement group classification

The fish movement group classification presented here provides a further subdivision of the conventional life cycle and spawning movement categorisation (anadromous, catadromous, potamodromous, amphidromous) outlined above. For species commonly found in Queensland, seven movement groupings are defined in terms of migrations between spawning and growth habitat zones within various stream zones (upland / headwater; intermediate / transfer; lowland / floodplain / freshwater wetland; estuary / coastal / tidal wetland). This grouping on the basis of life cycle, migration movements and stream migration zones is shown in Box B3.1.

Catadromous species are subdivided into two groups – those moving between marine and upland freshwater habitats (Group C1) and those moving between marine and lowland freshwater habitats (Group C2). Potamodromous species, which complete their life cycle in freshwater, are subdivided into four groups – upland spawning fish (Group P1), lowland spawning fish (Group P2), those that spawn locally in lowland to upland habitats (Group P3), and those that spawn locally in lowland habitats (Group P4). The other life cycle group – amphidromous (freshwater vagrant) species, which migrate to and from estuary and lowland freshwater habitats on an occasional basis, retain a single fish movement grouping (Group M1). No anadromous life cycle grouping is included as these species are not common in Queensland.

The fish community for a particular waterway or catchment under consideration can usually be categorised into these groups by examining information on the movement characteristics of the fish species available from the general literature. This will typically show some correlation within and between fish movement groups in terms of migration timing, migration movements and zones, which will allow generalised movement directions and timings to be identified for these fish groups at various locations within the catchment. Categorisation according to fish species size and swimming ability will also help define general swim characteristics for design.

Generalised interpretation of fish migration zones and fish migration calendars for the various fish movement groupings assists with identifying fish spawning or dispersal movement as adults or juveniles between the various marine and freshwater zones, and their movement during the various seasonal periods. Delineating fish migration zones (spawning / growth habitat) and movement in relation to stream zones (headwater / intermediate / lowland / estuary) allows spatial movement patterns of particular species to be mapped against the location of waterway structures or other features on the stream course in order to assist with fish passage considerations for that location. Similarly, delineation of the fish migration calendar (spawning / growth movement) in relation to seasonal periods (spring / summer / autumn / winter) allows temporal movement patterns of particular species to be mapped against seasonal hydrologic conditions in the stream, including wet season flood flows and low flow conditions.

Box B3.1: Fish movement groups: Life-cycle stage, movement direction, fish maturity and size, waterway habitat zones	
Group C1 - Catadromous species, marine to upland habitats	Fishes migrating downstream as adults from freshwater habitats to spawn in estuarine / marine waters, and migrating upstream as juveniles for growth in *lowland to upland* freshwater habitats.
Group C2 – Catadromous species, marine to lowland habitats	Fishes migrating downstream as adults from lowland freshwater habitats to spawn in estuarine / marine waters, and migrating upstream as juveniles for growth in *lowland* freshwater habitats.
Group P1 – Potamodromous species, upland spawning	Fishes migrating upstream as adults from lowland waters to spawn in *upland* waters, and migrating downstream as juveniles for growth in *lowland* freshwater habitats.
Group P2 – Potamodromous species, lowland spawning	Fishes migrating downstream as adults from upland waters to spawn in *lowland* waters, and migrating upstream as juveniles for growth in *upland* habitats.
Group P3 – Potamodromous species, local spawning, lowland to upland habitats	Fishes spawning and growing in local stream and wetland habitats, with no substantial broad scale spawning migration, but migrating upstream and downstream to other habitats as adults and juveniles.
Group P4 – Potamodromous species, local spawning, lowland habitats	Fishes spawning and growing in local *lowland* stream and wetland habitats, with no substantial broad scale spawning migration, but migrating to adjacent *lowland* habitats as adults and juveniles.
Group M1 – Amphidromous (freshwater vagrant) species	Marine fishes spawning and growing in estuarine / marine waters, and migrating to and from estuary and lowland freshwater habitats on an occasional basis, other than for the purpose of reproduction.

The movement group classification and spatial and temporal movement characterisation are illustrated below for the fish community of the Tully Murray catchment. Fish species lists, movement grouping, and generalised species size and swimming ability data for these fish are presented here and are referred to in *Guidelines Part D – Fish Passage Design: Road Corridor Scale*. Generalised movement information for the Tully Murray fish community has been synthesised and adapted form various key references on fish community and behaviour characteristics for these species, including Allen et al. (2003), Cotterell (1998), Herbert and Peeters (1995), and Pusey et al. (2004). The applicability of this information to other fish communities in other regions or catchments should be checked before use elsewhere.

Fish species within *Group C1 – Catadromous species, marine to upland habitats* spawn in estuarine / marine waters and typically grow in lowland to upland freshwater habitats (Box B3.1). Spawning adults migrate downstream from freshwater to marine waters, whilst juveniles and adults disperse upstream from estuary to freshwater habitats after spawning. Generalised temporal information on movement for the fish community of the Tully Murray catchment indicates that adult downstream spawning migration typically occurs in spring to autumn (Nov – May), in association with increased stream flows, temperature and photoperiod. Juvenile upstream dispersal migration typically occurs during summer (Dec – April), particularly during wet season stream flow, whilst adult upstream dispersal migration after spawning typically occurs in association with floods.

In contrast, fish species within *Group C2 – Catadromous species, marine to lowland habitats* spawn in estuarine / marine waters but typically grow in lowland rather than upland freshwater habitats (Box B3.1). Adult downstream spawning migration, and upstream dispersal migration of juveniles and adults occurs between freshwater and marine waters, but the freshwater range is typically confined to lowland habitats compared with lowland and upland habitats for *Group C1*. Life stages, migration timing, and cues for movement for the Tully Murray fish community remain much the same in the generalised migration calendars for *Group C2* and *Group C1*, the differences confined to the reduced spatial extent of movement to and from freshwater habitats for *Group C2* compared with *Group C1*.

Potamodromous species *Group P1 – Potamodromous species, upland spawning* and *Group P2 – Potamodromous species, lowland spawning* are complementary opposites in terms of upland and lowland locations of spawning and growth zones, and upstream and downstream spawning and dispersal migration directions for adults and juveniles between freshwater habitats (Box B3.1). *Group P1* species migrate upstream from lowland waters to spawn, whilst juveniles and adults disperse downstream from upland to lowland freshwater habitats after spawning. For the Tully Murray catchment, adult upstream spawning migration typically occurs during wet season stream flow (Nov – Mar), whilst juvenile and adult downstream dispersal migration after spawning also occur during the wet season stream flow periods (Dec – April). *Group P2* species migrate downstream from upland to lowland waters to spawn, whilst juveniles and adults disperse upstream from lowland to upland freshwater habitats after spawning. Adult downstream spawning migration typically occurs in spring and summer (Aug – Mar), associated with increased stream flows, temperature and photoperiod, whilst juvenile and adult upstream dispersal migration after spawning occurs during summer and autumn (Mar – May), often associated with low stream flows.

Potamodromous species *Group P3 – Potamodromous species, local spawning, lowland to upland habitats* and *Group P4 – Potamodromous species, local spawning, lowland habitats* are wholly freshwater fish that display no substantial broad scale spawning migration (Box B3.1). *Group P3* species typically spawn and grow locally in streams and wetlands from lowland to upland waters, whilst juveniles and adults of some species in this group disperse upstream or downstream to other habitats after spawning. For the Tully Murray catchment, spawning typically occurs in stable low flow conditions in winter, spring and early summer (July – Dec), associated with increased temperature and photoperiod, whilst localized juvenile and adult dispersal movement after spawning is often associated with increased stream flows (Mar – May). *Group P4* species differ from *Group P3* in that spawning and growth is typically restricted to lowland waters only, and juveniles and adults disperse locally within adjacent lowland habitats after spawning. As for *Group P4*, spawning typically occurs in stable low flow conditions in winter, spring and early summer (July – Dec), associated with increased temperature and photoperiod, and localised dispersal movement after spawning is often associated with increased stream flows (Mar – May).

Group M1 – Amphidromous (freshwater vagrant) species are marine fishes spawning and growing in estuarine / marine waters, and migrating to and from estuary and lowland freshwater habitats on an occasional basis, other than for the purpose of reproduction (Box B3.1). No adult spawning migration to freshwater habitats takes place, whilst juveniles disperse upstream from estuary to lowland waters and adults disperse between estuary and lowland waters in a facultative manner (not obligatory for life cycle of the species). Juvenile and adult dispersal movement between estuary and lowland waters is often associated with increased stream flow.

3.2 Fish movement direction classification

The ability of a fish to move through a stream reach or past a migration barrier such as a road culvert depends on the movement characteristics of the fish and the hydraulic characteristics of the stream or barrier (e.g. flow direction, velocity, water surface drop, turbulence, flow pattern). Fish movement characteristics that govern the movement capability and success of the fish in negotiating the stream or migration barrier without undue delay or physical distress include:

- direction of movement – upstream migration, downstream migration, localised movement
- nature of the migration – obligatory (essential) or facultative (non-essential)
- life cycle stage of the fish – spawning, dispersal / growth
- fish maturity and size – adult, juvenile
- migration timing and flow – wet season flood flows, low flow events
- stimulus to movement – stream flow, temperature, photoperiod (light), refuge / colonisation
- fish swimming capability – swim speed, jumping ability, tolerance to turbulence

Categorising movement direction information for the fish community assists with determining the critical fish species and movement characteristics for negotiating movement through the particular stream reach or past the migration barrier. The movement classification system presented here defines 10 fish movement direction categories (AUS, JUD, AUD….) according to nature of the migration, direction of movement, fish maturity and size, and life cycle stage of the fish (Box B3.2). The success of fish passage also depends on the timing of fish movement with respect to seasonal flow and flood conditions in the stream, which can be considered in terms of flood flow (wet season), low flow, and tidal flow conditions.

Upstream movement against the stream flow is more difficult and typically more critical to achieve than downstream movement with the flow, or localised movement to adjacent and readily accessible habitats. Obligatory migration that completes an essential life stage for the fish (spawning, dispersal / growth) is more critical than facultative (non-essential) movement such as freshwater excursions for amphidromous species. Spawning migration is typically more critical than dispersal migration as delays and physical distress to spawning fish may affect their reproduction capacity, whilst similar delays and distress to dispersing fish may not be so critical provided migration through the obstruction is still possible. Juvenile fish are more susceptible than adult fish to obstruction due to their smaller size and swimming capabilities, and therefore providing for juvenile fish passage is typically more difficult than for adult movement.

Box B3.2: Fish movement direction categories: Migration nature, movement direction, fish maturity and size, life-cycle stage	
Obligatory movement – essential migration for fish life cycle stages	
AUS – Adult upstream spawning migration	Crucial upstream movement for adult potamodromous species en route to spawning habitats in upland or lowland freshwater reaches.
JUD – Juvenile upstream dispersal migration	Crucial upstream movement for juvenile catadromous or potamodromous species en route to growth habitats in upland or lowland freshwater reaches.
AUD – Adult upstream dispersal migration	Upstream movement for adult catadromous or potamodromous species following spawning in estuarine / marine or lowland freshwater reaches.
ADS – Adult downstream spawning migration	Downstream movement for adult catadromous or potamodromous species en route to spawning habitats in estuarine / marine or lowland freshwater reaches.
JDD – Juvenile downstream dispersal migration	Downstream movement for juvenile potamodromous species en route to growth habitats in lowland freshwater reaches.
ADD – Adult downstream dispersal migration	Downstream movement for adult potamodromous species following spawning in upland freshwater reaches.
Facultative movement – not essential for fish life cycle stages	
ALS – Adult localised spawning movement	Localised movement for adult potamodromous species en route to spawning habitats in local stream and wetland habitats.

Box B3.2: Fish movement direction categories: Migration nature, movement direction, fish maturity and size, life-cycle stage	
JLD – Juvenile localised dispersal movement	Localised movement for juvenile potamodromous species en route to growth habitats in local stream and wetland habitats.
ALD – Adult localised dispersal movement	Localised movement for adult potamodromous species following spawning in local stream and wetland habitats.
LFM – Localised facultative movement	Localised movement for adult or juvenile amphidromous species migrating to and from estuary and lowland freshwater habitats on an occasional basis.

In order to identify the critical movement directions, fish life cycle stage and maturity for each of the seven fish movement groups (C1, C2, P1….) identified above, the generalised fish movement categories (AUS, JUD, AUD….) can be applied to each group. Box B3.3 shows the generalised relationship between movement directions and fish movement groups, and includes information on the generalised migration timing in relation to flow for the fish community of the Tully Murray catchment. The applicability of this information to other fish communities in other regions or catchments should be checked before use elsewhere.

Box B3.3 shows that Potamodromous *Group P1* is the only group clearly displaying adult upstream spawning migration (AUS). This is the critical movement event for adult fish, and for the Tully Murray fish community, occurs in low flow and flood flow conditions. Juvenile upstream dispersal migration (JUD), which is the critical movement event for juvenile fish, occurs for Catadromous *Group C1* and *Group C2*, and for Potamodromous *Group P2*, *Group P3* and *Group P4*. Flood flow conditions apply to several of these groups for the Tully Murray catchment, whilst movement conditions for Potamodromous *Group P3* and *Group P4* are not clearly defined. Adult upstream dispersal migration (AUD) applies to the same five groups as for juvenile upstream dispersal, but this movement event is typically less critical than juvenile movement. The same critical flood flow conditions do not apply to adult upstream dispersal migration that apply to juvenile upstream dispersal for the Tully Murray catchment species.

The critical movement events are therefore typically considered to be adult upstream spawning migration (AUS) and juvenile upstream dispersal migration (JUD), each under flood and low flow conditions. These features and the fish movement direction and movement timing characteristics for individual species in the fish community (see below) are used to develop the fish movement characteristics for design of the road crossing or other waterway structure.

Box B3.3: Generalised fish movement direction for fish movement groups: Migration nature, movement direction, fish maturity and size, life-cycle stage, and including migration timing and flow for fish species of the Tully Murray catchment *(Source: Kapitzke 2006a)*

Fish movement group	Upstream movement - obligatory			Downstream movement - obligatory			Localised movement ALS / JLD / ALD / LFM
	Adult spawning AUS	Juvenile dispersal JUD	Adult dispersal AUD	Adult spawning ADS	Juvenile dispersal JDD	Adult dispersal ADD	
Group C1 - Catadromous species, marine to upland habitats		✓^{F}	✓	✓^{F}			
Group C2 – Catadromous species, marine to lowland habitats		✓^{F}	✓	✓$^{L/F}$			
Group P1 – Potamodromous species, upland spawning	✓$^{L/F}$				✓^{F}	✓^{F}	
Group P2 – Potamodromous species, lowland spawning		✓$^{L/F}$	✓*	✓$^{L/F}$			
Group P3 – Potamodromous species, local spawn., lowland to upland habit.	(✓^{L})	✓*	✓*				ALS / JLD / ALD $^{L/F}$
Group P4 – Potamodromous species, local spawning, lowland habitats		(✓)	(✓)		(✓)	(✓)	ALS / JLD / ALD
Group M1 – Amphidromous (freshwater vagrant) species							LFM $^{T/L}$

Legend	F	Predominantly flood flow (wet season) conditions	*	Substantial movement for some species
	L	Predominantly low streamflow conditions	( )	Tentative categorisation
	T	Tidal flow conditions	?	Unknown

3.3 Fish movement groups and migration characteristics

The fish community within any particular waterway catchment exhibits a range of migratory characteristics associated with movement between habitats for spawning, growth or refuge. Categorisation of these fish into movement groups and collation of information on habitat, migration, swimming characteristics, fish movement direction and timing assists in determining fish movement characteristics of these groupings for use in design.

For the Bruce Highway Corduroy Creek to Tully road project, the 56 native freshwater species of the Tully Murray fish community were categorised into the seven fish movement groups, and generalised interpretation of migration zones, migration calendars, and movement characteristics was undertaken for these groupings (see Kapitzke 2006a). An extract from fish movement summary characteristics (habitat preferences, migration characteristics, spawning cues and timing, life stage, size and swimming characteristics) for catadromous Group C1 is shown in Box B3.4. This generalised movement information for the Tully Murray fish community was synthesised and adapted from various key references on fish community and behaviour characteristics for these species, including Allen et al. (2003), Cotterell (1998), Herbert and Peeters (1995), and Pusey et al. (2004). The applicability of this information to other fish communities in other regions or catchments should be checked before use elsewhere.

In terms of fish movement direction and timing, information collated on upstream, downstream or localised movement of the fish community under various flow conditions allows provisions to be made for particular species if required at individual waterway structures within the catchment or at road corridor crossings of the stream. As an illustration for the Bruce Highway Corduroy Creek to Tully road project (see Kapitzke 2006a), an extract from the characteristics for the Tully Murray fish community is presented in Box B3.5.

Box B3.4: Extract from Tully Murray fish movement characteristics: Group C1 - Catadromous species, marine to upland habitats *(Source: Kapitzke 2006a)*

Common name	Family, genus, species	Habitat, migration, spawning cues and timing [1]	Life stage, size and swimming characteristics [1]
Eels	**Anguillidae**		
Long finned eel	*Anguilla reinhardti*	• widespread through freshwater streams and lakes, with preference for flowing water • adults spawn in marine waters, juveniles inhabit estuaries and lowland waters • adult downstream spawning migration to marine waters in high flow (Dec – May) • juvenile upstream dispersal migration to upland and lowland waters in high flow (Sep - Mar) • widespread adult dispersal movement and recolonisation	• maximum adult size 300 cm, commonly to 100 cm • commonly moves in contact with stream bed • maximum swimming speed for juveniles (50 mm length), prolonged speed = 0.3 m/s; burst speed = 0.75 m/s [(2)] • can climb natural and artificial obstacles (waterfalls, weirs) • will move over damp ground to bypass obstacles
Pacific short finned eel	*Anguilla obscura*	• freshwater streams and lakes, with preference for coastal lagoons and lowland waters • adults spawn in marine waters, juveniles inhabit estuaries and lowland waters • adult downstream spawning migration to marine waters • juvenile upstream dispersal migration to upland and lowland waters	• maximum adult size 110 cm, commonly to 60 cm • commonly moves in contact with stream bed • can climb natural and artificial obstacles (waterfalls, weirs) • will move over damp ground to bypass obstacles
Flagtails	**Kuhliidae**		
Jungle perch	*Kuhlia rupestris*	• fast flowing streams and pools (commonly in rainforests), as well as f'plain lagoons • adult downstream spawning migration to marine waters during floods (Nov – May) • juvenile upstream dispersal migration to upland and lowland waters during wet season stream flow (Jan – April) • upstream adult dispersal migration after spawning is unknown	• maximum adult size 45 cm, commonly to 25 cm • commonly moves in the upper water column • prolonged speed of TL[A] 70 mm juvenile = 1 m/s for 15 min [3]
Giant herring	**Elopidae**		
Tarpon, ox-eye herring	*Megalops cyprinoides*	• widespread freshwater stream, lake and floodplain wetland habitats • adult downstream spawning migration to marine waters during floods (Dec – Mar) • juvenile upstream dispersal migration to wetland, lowland and upland habitats during wet season stream flow (Jan – May)	• maximum adult size 130 cm, commonly to 50 cm • commonly moves in the upper water column
Sea bass	**Centropomidae**		
Barramundi	*Lates calcarifer*	• widespread habitats, including freshwater streams, floodplain wetlands, brackish estuaries and coastal embayments, lakes and reservoirs (dams and weirs) • adult downstream spawning migration to marine waters in spring and early summer pre-wet season (Oct – Feb), in response to increased temperature and photoperiod • juvenile and adult upstream dispersal migration to wetland, lowland and upland habitats during summer (Sep – Mar), and particularly during wet season stream flows	• maximum adult size 180 cm, commonly to 120 cm • commonly moves in the upper water column • NV95[B] = 0.66 m/s burst speed for juveniles (43 mm length) [4] • juvenile fish (200 mm length) burst speed = 1.4 m/s [5] • juvenile fish (200 - 300 mm) prolonged speed = 0.4m/s for 15 min [3] • juvenile fish (150 - 500 mm length) unable to negotiate 3 m/s [6]

Notes	1 Synthesised and adapted from key references incl Allen et al. (2003); Cotterell (1998); Herbert & Peters (1995); Pusey et al. (2004)			2 Langdon and Collins (2000) in Pusey et al. (2004)
	3 Hajkowicz and Kerby (1992)	4 Mallen-Cooper (1992)	5 Kowarsky and Ross (1981)	6 Griffin (1987)

[A] TL = total length of fish
[B] NV95 = maximum velocity of water that 95% of fish of one size class can negotiate – approximates burst swim speed for this experiment

Box B3.5: Extract from fish movement direction for Tully-Murray fish species: Migration nature, movement direction, fish maturity and size, life-cycle stage, migration timing and flow *(Source: Kapitzke 2006a)*

Common name	Family, genus, species	Life-cycle, spawning and migration (Fish movement group)	Upstream movement - obligatory			Downstream movement - obligatory			Localised movement (facultative) ALS / JLD / ALD / LFM	Comment
			Adult spawning AUS	Juvenile dispersal JUD	Adult dispersal AUD	Adult spawning ADS	Juvenile dispersal JDD	Adult dispersal ADD		
Blue eyes	**Pseudomugilidae**									
Pacific blue-eye	*Pseudomugil signifer*	Potamodromous – local spawning, lowland to upland habitats (P3)							**JLD / ALD**	no known spawning migration; localised dispersal movement; no substantial broad scale dispersal migration
Spotted blue-eye	*Pseudomugil gertrudae*	Potamodromous – local spawning, lowland habitats (P4)							**JLD / ALD**	no known spawning migration; localised dispersal movement; no substantial broad scale dispersal migration
Eels	**Anguillidae**									
Long finned eel	*Anguilla reinhardti*	Catadromous – marine to upland habitats (C1)		✓^{H}	✓	✓^{H}				adult downstream spawning migration and juvenile upstream dispersal migration – high flows; adult upstream dispersal migration – unknown timing
Pacific short finned eel	*Anguilla obscura*	Catadromous – marine to upland habitats (C1)		✓	?	✓				adult downstream spawning migration and juvenile upstream dispersal migration – unknown timing
Eel-tailed catfish	**Plotosidae**									
Black catfish	*Neosilurus ater*	Potamodromous – upland spawning (P1)	✓^{H}				✓^{H}	✓^{H}		highly synchronised adult upstream spawning migration, juvenile and adult downstream dispersal – high flow
Freshwater catfish	*Tandanus tandanus*	Potamodromous – local spawning, lowland to upland habitats (P3)							**JLD / ALD**	no known spawning migration; localised dispersal movement; no substantial broad scale dispersal migration
Flagtails	**Kuhliidae**									
Jungle perch	*Kuhlia rupestris*	Catadromous – marine to upland habitats (C1)		✓^{H}	?	✓^{H}				adult downstream spawning migration and juvenile upstream dispersal migration – high flow conditions

Legend	ALS	Adult localised spawning movement	LFM	Localised facultative movement	^{T}	Tidal flow conditions
	JLD	Juvenile localised dispersal movement	^{H}	High streamflow (wet season) conditions	( )	Tentative categorisation
	ALD	Adult localised dispersal movement	^{L}	Low streamflow conditions	?	Unknown

3.4 Swim characteristics of fish movement capability groups

Swim characteristics and capabilities of fish attempting to negotiate a barrier at a waterway structure depend on the fish species, fish maturity and size (adult / juvenile), and the swim mode adopted (burst / prolonged / sustained). Only limited information is available about the swim capabilities of particular species of Australian fish to negotiate various hydraulic conditions (velocity, water surface drop, turbulence). Fish swim capabilities can be established from:

- information that may be available in the literature for the particular species
- generalised capabilities related to fish groupings of similar body type, size and maturity
- default relationships between swim speed and body length (or some other surrogate)

A combination of these approaches is outlined here, and estimates of fish swim speeds are presented for illustration using data for the Tully Murray fish community compiled in Section 3.3. The fish swim speed data presented here is based on limited quantitative information, and is a conservatively low estimate of likely fish swim capability for many of the species. The applicability of this information to fish communities in regions or catchments other than for the Tully Murray should be checked before use elsewhere.

The method for establishing generalised swim capabilities for groups of fish uses the fish movement directions and timings for the fish community identified above, and establishes fish movement capability groupings for species within critical movement direction categories. The compilation of fish movement direction and timing data for the fish community (Box B3.5) shows upstream, downstream or localised movement under various flow conditions, and is used in conjunction with the listing of fish movement groups for the fish community (see Box B3.1) to determine those species facing the most adverse upstream movement conditions. In terms of fish movement in a waterway and fish passage past a potential waterway barrier, the most critical fish movement directions identified in Section 3.2 are upstream against the stream flow – adult upstream spawning migration (AUS) and juvenile upstream dispersal migration (JUD).

Information on fish movement capabilities for species moving in these critical directions is extracted from fish movement data available for these species or other species within the fish movement capability group for the fish community. As an illustration for the Tully Murray catchment, the critical information on fish movement capabilities for these movement directions has been extracted from fish movement group lists for the Tully Murray fish community, and categorisation of fish movement directions and timings for the fish (see Section 3.3). Swimming ability and other aspects of movement capabilities for this fish community are presented below in terms of flow conditions, migration timing and common length of the fish (Box B3.6).

To assist with categorisation of fish swim speeds to be used for road crossing or other waterway structure design, several fish movement capability groupings can be adopted within the critical fish movement direction categories AUS and JUD. The Tully Murray fish community data (based on Kapitzke 2006a) includes available quantitative and qualitative information on fish movement capabilities for each of the groups (Box B3.6). Movement capability groupings (AUS1, AUS2, JUD1…) are based on families and common length range for the fish species, and may comprise species from several fish movement groups (C1, C2, P1…). For example, Group AUS1 comprises Eel tailed catfish of 15 – 25 cm common adult length, Group JUD6 comprises a number of similar species (Cardinalfishes / Glass perchlets / Gobies / Gudgeon) less than 10 cm common adult length, and Group JUD3 comprises Flagtails / Herring of 20 - 25 cm common adult length.

Box B3.6: Fish movement capability groupings for Tully-Murray fish community – upstream movement *(Source: Kapitzke 2006a)*

Common name (fish movement group)	Family, genus, species	Common length of fish	Flow condition / migration timing	Fish movement capability [1]
AUS – Adult upstream spawning migration (fish movement groups P1, P3)				
Medium size fish species – adults				
Group AUS1 – Eel-tailed Catfish, 15 – 25 cm common adult length				
Black catfish (P1)	*Neosilurus ater*	adults 25 cm	flood flow	• Black catfish, Hyrtl's tandan: inhabits still to slow flowing habitats but capable of negotiating substantial flow velocities • Rendahl's tandan: prefers still to slow flowing habitats
Hyrtl's tandan (P1)	*Neosilurus hyrtlii*	adults 20 cm	flood flow	
Rendahl's tandan (P1)	*Porochilus rendahli*	adults 15 cm	low flow / flood flow	
Group AUS2 – Grunters, 15 – 25 cm common adult length				
Khaki grunter / Khaki bream / Tully grunter (P1)	*Hephaestus tulliniensis*	adults 20 cm	low flow / flood flow	• Sooty grunter: burst speed of TL 20 mm juveniles = 30 BL/s [2]; prolonged speed of TL 20 mm juveniles = 0.28 m/s for 15 min [2]; juvenile fish capable of 7 km / day (average 0.08 m/s) [3] • Spangled perch: fast moving fish capable of 9 km / day (average 0.10 m/s) [3]; juvenile fish traveling average 2.7 km / hr over 6 hr period, (sustained speed = 0.75 m/s) [4]
Sooty grunter / Black bream (P1)	*Hephaestus fuliginosus*	adults 25 cm	low flow / flood flow	
Spangled perch (P1)	*Leiopotherapon unicolor*	adults 15 cm	low flow / flood flow	
Small size fish species – adults				
Group AUS3 – Rainbowfish, < 10 cm common adult length				
Eastern Qld rainbowfish (P3)	*Melanotaenia splendida*	adults 8 cm	low flow	• Eastern Qld rainbowfish: prefers low velocity habitats
JUD – Juvenile upstream dispersal migration (fish movement groups C1, C2, P2, P3, P4)				
Medium - large size fish species – juveniles				
Group JUD1 – Eels, 60 - 100 cm common adult length				
Long finned eel (C1)	*Anguilla reinhardti*	adults 100 cm	flood flow	• Long finned eel: maximum swimming speed for juveniles (50 mm length), prolonged speed = 0.3 m/s; burst speed = 0.75 m/s [5]; can climb natural and artificial obstacles (waterfalls, weirs); will move over damp ground to bypass obstacles
Pacific short finned Eel (C1)	*Anguilla obscura*	adults 60 cm	?	
Group JUD2 – Giant Herring / Sea bass, 50 - 120 cm common adult length				
Tarpon, ox-eye herring (C1)	*Megalops cyprinoids*	adults 50 cm	flood flow	• Barramundi: NV95 = 0.66 m/s burst speed for juveniles (43 mm length) [6]; juvenile fish (200 mm length) burst speed = 1.4 m/s [7]; juvenile fish (200 - 300 mm length) prolonged speed = 0.4m/s for 15 min [2]; juvenile fish (150 - 500 mm length) unable to negotiate 3 m/s [8]
Barramundi (C1)	*Lates calcarifer*	adults 120 cm	flood flow; movement occurs day and night	
Group JUD3 – Flagtails / Herring, 20 - 25 cm common adult length				
Jungle perch (C1)	*Kuhlia rupestris*	adults 25 cm	flood flow	• Jungle perch: prolonged speed of TL 70 mm juvenile = 1 m/s for 15 min [2] • Bony bream: may be found in low velocity or fast flowing habitats
Bony bream (P3)	*Nematolosa erebi*	adults 20 cm	low flow / flood flow; movement at day, limited at night	
Small size fish species – juveniles				
Group JUD4 – Hardyheads / miscellaneous species, < 20 cm common adult length				
Fly specked hardyhead (P4)	*Craterocephalus stercusmuscarum*	adults 6 cm	low flow	• Fly specked hardyhead: prefers low velocity • Bullrout: capable of short bursts of speed when alarmed, but typically moves slowly
Bullrout / Freshwater stonefish (C1)	*Notesthes robusta*	adults 20 cm	low flow; apparently prefers to migrate at night	
Group JUD5 – Gobies / Grunters / Gudgeons, 10 – 20 cm common adult length				
False celebes goby (C2)	*Glossogobius sp.1*	adults 10 cm	?	• False celebes goby: prefers moderately flowing waters • Roman nosed goby: prefers moderately flowing waters; powerful swimming ability of limited duration
Roman nosed goby (P2)	*Awaous acritosus*	adults 10 cm	?	
Banded grunter (P2)	*Amniataba percoides*	adults 12 cm	low flow	
Greenback gauvina (C2)	*Bunaka gyrinoides*	adults 15 cm	?	

Box B3.6: Fish movement capability groupings for Tully-Murray fish community – upstream movement *(Source: Kapitzke 2006a)*

Common name (fish movement group)	Family, genus, species	Common length of fish	Flow condition / migration timing	Fish movement capability [1]
Northern trout gudgeon (P3)	*Mogurnda mogurnda*	adults 10 cm	?	• Banded grunter: juvenile fish capable of 7 km / day (average 0.08 m/s), with adults moving at 9 km / day (average 0.10 m/s) [3] • Greenback gauvina, Snakehead gudgeon: prefers low velocity habitats • Northern trout gudgeon: prefers low velocity habitats; capable of negotiating cascades and waterfalls
Snakehead gudgeon (C2)	*Giurus margaritacea*	adults 17 cm	flood flow	
Group JUD6 – Cardinalfishes / Glass perchlets / Gobies / Gudgeon, < 10 cm common adult length				
Mouth almighty (P3)	*Glossamia aprion*	adults 8 cm	low flow / flood flow	• Mouth almighty: prefers low velocity habitats • Agassiz's glass perch: difficulty negotiating high velocities and turbulent flow conditions • Sailfin perchlet / Glass perch: slow moving fish capable of 5 km / day (average 0.06 m/s) [3] • Pacific mangrove goby, Speckled goby: prefers still to slow flowing waters • Brown gudgeon, Ebony gudgeon, Fire tailed gudgeon, Midgley's carp gudgeon: prefers low velocity habitats • Empire gudgeon: limited swimming capacity, particularly for prolonged speed; capable of moving about 30 km in 3 days (average 0.12 m/s); prolonged speed limited to about 0.3 m/s [9] • Purple spotted gudgeon: prefers low velocity habitats; capable of negotiating cascades and waterfalls
Agassiz's glass perch (P3)	*Ambassis agassizii*	adults 5 cm	low flow / flood flow	
Flag-tailed glassfish (C2)	*Ambassi miops*	adults 6 cm	?	
Northwest glassfish (P3)	*Ambassis sp.(cf mulleri)*	adults 5 cm	low flow / flood flow	
Sailfin perchlet / Glass perch (P2)	*Ambassis agrammus*	adults 5 cm	low flow / flood flow; mass upstream migrations in dusk and dawn hours	
Pacific mangrove goby (C2)	*Mugilogobius notospilus*	adults 3 cm	?	
Speckled goby (P3)	*Rediogobius bikolanus*	adults 3 cm	?	
Tully River goby (P?)	*Stenogobius psilosinionus*	?	?	
Brown gudgeon (C2)	*Eleotris fusca*	adults 7 cm	?	
Ebony gudgeon (C2)	*Eleotris melanosoma*	adults 7 cm	?	
Empire gudgeon (C2)	*Hypseleotris compressa*	adults 7 cm	flood flow	
Fire tailed gudgeon (P3)	*Hypseleotris galii*	adults 5 cm	flood flow	
Midgley's carp gudgeon (P3)	*Hypseleotris sp. 1*	adults 5 cm	flood flow	
Poreless gudgeon (P3)	*Oxyeleotris nullipora*	adults 3 cm	flood flow	
Purple spotted gudgeon (P3)	*Mogurnda adspersa*	adults 8 cm	?	
Purple spotted gudgeon (P3)	*Mogurnda adspersa*	adults 8 cm	?	

Legend	TL = total length of fish		NV95 = maximum velocity of water that 95% of fish of one size class can negotiate – approximates burst swim speed for this experiment	
Notes	1	Synthesised and adapted from various key references including Allen et al. (2003); Cotterell (1998); Herbert and Peeters (1995); Pusey et al. (2004): and others as noted		
	2	Hajkowicz and Kerby (1992)	3	Bishop et al. (1995) in Pusey et al. (2004)
	4	Shipway (1947)	5	Langdon and Collins (2000) in Pusey et al. (2004)
	6	Mallen-Cooper (1992)	7	Kowarsky and Ross (1981)
	8	Griffin (1987)	9	Alf Hogan (pers. comm. 11/07/05)

3.5 Fish swimming characteristics for use in design

The swimming characteristics of fish within the various swimming modes are used to evaluate the significance of fish migration barriers, and for design of fishway devices to overcome adverse hydraulic conditions at road crossings or other waterway structures. Fish use several alternative swim modes (as follows) that are considered in design:

- ***Burst speed*** – highest speeds attainable by fish and maintained for short periods of usually 5 to 20 seconds before ending in fatigue
- ***Prolonged speed*** – speed maintained by fish for 20 seconds to 200 minutes before ending in fatigue [commonly estimated at 3 body lengths per second – BL/s (Bates 1999 in Mallen-Cooper 2001; Martin Mallen-Cooper, pers. comm. 19/07/05)]
- ***Sustained speed*** – speed maintained for greater than 200 minutes, usually without fatigue

Two sets of muscles are used for swimming. For sustained or prolonged swimming, a high supply of blood is available to low-power red muscles, allowing fish to swim almost continuously without oxygen deficit or lactic acid build up. For darting or burst swimming, low volumes of blood flow to white muscles provide high power for a short time, but energy is quickly depleted or too much lactic acid is accumulated.

Fish mainly use sustained and prolonged speeds for routine activities such as foraging and schooling, and when migrating upstream in natural waterways. They occasionally use burst speeds to overcome high velocity areas such as rapids or waterway obstructions, or to avoid predators or capture prey. Flow conditions in culvert crossings are usually more severe than those in natural channels, and velocities in plain culverts generally exceed sustained swim speeds for fish. Fish cannot normally maintain burst swim mode long enough to navigate the entire length of most culverts, but where culvert flow velocities are within an acceptable range, they may use prolonged mode for continuous passage through the culvert, even when no resting areas are available. The fish may use a burst and rest pattern to take advantage of low water velocities and rest points created by placement of baffles and other elements within the culvert.

As an illustration for the Tully Murray catchment, the nominal swim speeds for groups of fish undertaking adult upstream spawning migration (AUS) or juvenile upstream dispersal migration (JUD) are compiled in Box B3.7. This uses swim speed data for fish movement capability groups from Box B3.6, and generic swim speed relationships where no other data are available. The applicability of this information to other fish communities in other regions or catchments should be checked before use elsewhere.

For the Tully Murray fish community listed in Box B3.6, there are 7 species (from potamodromous fish movement Groups P1 and P3) for which AUS – adult upstream spawning migration is to be provided. These are considered in 3 fish movement capability groupings (AUS1 – Eel-tailed Catfish; AUS2 – Grunters; AUS3 – Rainbowfish). With the exception of the rainbowfish in Group AUS3 (< 10 cm common adult length), each of these species are medium size fish (15 – 25 cm common adult length).

The only swim speed data available for these groups relates to juvenile Sooty Grunter and Spangled Perch within group AUS2 (Box B3.6). In lieu of other data for adult fish, the default value of 3 body lengths / second is used for prolonged swim speed for the 7 species within these groups. This equates to a range for prolonged speed of 0.45 m/s to 0.75 m/s for the medium size fish (15 cm – 25 cm common adult length) within groups AUS1 and AUS2 (Box B3.7). Prolonged speed for the rainbowfish in Group AUS3 (8 cm common adult length) would be about 0.25 m/s. No data are available for burst speed for these species, and notional values of twice prolonged speed (0.5 m/s to 1.5 m/s) are used to give some indication of burst speed.

In terms of JUD – juvenile upstream dispersal migration for the Tully Murray fish community, there are a total of 28 species (from catadromous fish movement groups C1 and C2, and potamodromous fish movement Groups P2, P3 and P4) for which provisions for migration are to be made. These species are considered in 6 fish movement capability groupings in Box B3.6 (JUD1 – Eels; JUD2 – Giant Herring / Sea bass; JUD3 – Flagtails / Herring; JUD4 – Hardyheads / miscellaneous species; JUD5 – Gobies / Grunters / Gudgeons; JUD6 – Cardinalfishes / Glass perchlets / Gobies / Gudgeon).

Whilst the size range for adult fish is extensive (< 10 cm to 120 cm common adult length), the smallest size of juvenile fish attempting to migrate upstream can be expected to range from about 3 cm to 30 cm for the various species within these groups. Swim speed data for the large and medium size species in groups JUD1, JUD2, and JUD3 (Box B3.6) shows that juvenile eels, barramundi and jungle perch of from 5 cm to 30 cm length, display prolonged speed ranges of from 0.3 m/s to 1.0 m/s, and a burst speed range up to 1.4 m/s (Box B3.7).

Little quantitative data is available for the smaller species in groups JUD4, JUD5, and JUD6, apart from what apparently relates to the sustained swim mode for several species (Banded grunter, Agassiz's glass perch, and Empire gudgeon), with average speeds of from 0.06 m/s to 0.12 m/s over a period of 1 day or more (Box B3.6). Assuming juveniles range from 3 cm to 10 cm in length for these species, prolonged speed would range from 0.1 m/s to 0.3 m/s, based on the default value of 3 body lengths / second (Box B3.7). Notional burst speed values of 0.2 m/s to 0.6 m/s (twice prolonged speed) could be assumed, to give some indication of magnitude.

Apart from the adult upstream spawning group (AUS) and the juvenile upstream dispersal group (JUD), fish moving upstream as adults for dispersal (AUD) should also be catered for in provisions for fish passage at waterway structures. With the exception of several of the gobies, gudgeon and other species, the group of species of upstream dispersing adults is mostly incorporated within those species in the juvenile upstream dispersal group. If provision for upstream movement is made for the juvenile fish, conditions should be adequate for adult fish.

A number of species display localised facultative movement within the waterways, either for spawning or dispersal within and between local habitats, or for movement between marine and freshwater lowland reaches (for amphidromous species). Although substantial migration between habitat areas is generally not undertaken as an obligatory part of the life cycle of these species, it is also desirable to provide for fish passage for these localised movements.

For the Tully Murray fish community, the majority of the wholly freshwater fish in this category (from potamodromous fish movement Groups P3 and P4) are small size species such as blue eyes and gudgeon, which would display low prolonged speed and burst speed values of similar magnitude to those for small size fish in the juvenile upstream dispersal group (JUD). Many of the amphidromous fish (Group M1) are medium to large size species (e.g. mullet and mangrove jack) with higher swim capabilities. The only data available is for mullet, which have displayed prolonged speeds of greater than 0.3 m/s, and burst speeds of up to 2.0 m/s for juveniles of up to 10 cm length.

Box B3.7: Nominal fish swim speeds for Tully-Murray fish community – upstream movement [1]
(Source: Kapitzke 2006a)

Fish movement capability group	Common length of fish	Prolonged speed – nominal (20 sec to 200 min duration)	Burst speed – nominal (5 sec to 20 sec duration)	Comment
AUS – Adult upstream spawning migration (fish movement groups P1, P3)				
Medium size fish species – adults				
Group AUS1 – Eel-tailed Catfish	adults 15 cm - 25 cm	0.45 m/s to 0.75 m/s	0.9 m/s to 1.5 m/s	3 BL/s used for prolonged swim speed (default value) 2 x prolonged speed used for burst swim speed (notional value)
Group AUS2 – Grunters	adults 15 cm - 25 cm			
Small size fish species – adults				
Group AUS3 – Rainbowfish	adults < 10 cm	0.25 m/s	0.5 m/s	3 BL/s used for prolonged swim speed (default value) 2 x prolonged speed used for burst swim speed (notional value)
JUD – Juvenile upstream dispersal migration (fish movement groups C1, C2, P2, P3, P4)				
Medium - large size fish species – juveniles				
Group JUD1 – Eels	adults 60 cm - 100 cm (juveniles to 30 cm)	0.3 m/s to 1.0 m/s	up to 1.4 m/s	prolonged and burst swim speeds based on data for juvenile eels, barramundi and jungle perch (see Box 3.6)
Group JUD2 – Giant Herring / Sea bass	adults 50 cm - 120 cm (juveniles to 30 cm)			
Group JUD3 – Flagtails / Herring	adults 20 cm - 25 cm (juveniles to 10 cm)			
Small size fish species – juveniles				
Group JUD4 – Hardyheads / misc. species	adults < 20 cm (juveniles to 10 cm)	0.1 m/s to 0.3 m/s	0.2 m/s to 0.6 m/s	3 BL/s used for prolonged swim speed (default value) 2 x prolonged speed used for burst swim speed (notional value)
Group JUD5 – Gobies / Grunters / Gudgeons	adults 10 cm - 20 cm (juveniles to 10 cm)			
Group JUD6 – Cardinalfishes / Glass perchlets / Gobies / Gudgeon	adults < 10 cm (juveniles to 5 cm)			
Notes	1 The fish swim speed data presented here is based on limited quantitative information, and is a conservatively low estimate of likely fish swim capability for many of the species			

4 DESIGN CRITERIA FOR PROVISION OF FISH PASSAGE

A diverse range of fish species of various sizes, maturity and swimming abilities may attempt to move past a road crossing or other waterway structure to complete essential life cycle phases within the waterway. The characteristics of the fish community, their need to migrate under various hydrological conditions, and their capacity to negotiate the stream and fish migration barrier, are all relevant to determining the requirements for provision of fish passage. Different fish display different movement behaviours and possess differing capacities to negotiate various barriers to fish migration such as flow velocities, water depths, turbulence, and light conditions. The life stage of the fish and timing of movement with respect to stream flow are also important.

Design for fish passage at a road-waterway crossing or other fish migration barrier relies on providing suitable flow conditions to encompass desired swimming capabilities for relevant species passing upstream or downstream at the site. This involves producing the desired hydraulic conditions (velocities, depths, turbulence levels, flow patterns) at the appropriate design flow rates in the waterway during fish migration. The adopted design flow range is important because the associated hydraulic conditions affect the duration of fish passage, the species and life stage of the fish able to pass, the number of fish able to pass, and as a result, how far the fish community can move upstream to new habitats during the migration event.

In order to establish design criteria for provision of fish passage at road-waterway crossings or other barriers, specific fish passage requirements should be defined for each of the relevant hydrological and hydraulic conditions at the structure. Broad envelopes are usually applied to encompass design flow rates and hydraulic requirements at the barrier, and to provide for the recognised minimum swimming capabilities for the fish community at the site. Conservative design provisions should be made where no other substantial information is available. Adopted fish passage design standards for the waterway crossing will be governed by the value assigned to fish habitat in the fish movement corridor / waterway under consideration, the classification of the fish movement corridor at the crossing, and the importance of providing substantial fish passage at that location (refer *Guidelines Part D – Fish Passage Design: Road Corridor Scale* and *Guidelines Part E – Fish Passage Design: Site Scale*).

The following sections introduce the concept of fish passage effectiveness for the structure, identify fish passage design flow and fish swim speed parameters, and discuss other fish movement characteristics for design.

4.1 Fish passage effectiveness at waterway structure

The concept of fish passage effectiveness at the waterway structure is used to establish the appropriate fish movement characteristics for design. Fish passage effectiveness relates to the degree of fish passage available at the structure compared with the unaltered natural fish passage capabilities in the waterway. This is a qualitative measure of the breadth of the fish community able to pass and the range of flow conditions during which passage is provided. Fish passage effectiveness is comparable to and is the converse of the fish migration barrier classification at waterway structures defined by Dane (1978) to include total, partial and temporal barriers (refer *Guidelines Part C – Fish Migration Barriers and Fish Passage Options for Road Crossings*):

Classification of fish migration barriers at waterway structures *(After: Dane 1978)*	
Total barrier	Impassable to all fish at all flows - all of the time
Partial barrier	Impassable to some fish at all flows - all of the time
Temporal barrier	Impassable to all fish at some flows - some of the time

The effectiveness of fish passage provisions that are made at a road crossing or other waterway structure to overcome temporal, partial, or total fish migration barriers depends on the aquatic fauna connectivity / fish passage goals adopted for the project. At the conservative end of the scale, fish passage facilities would aim to provide for 100 % effectiveness in passage for the complete native fish community over the full range of flow conditions for which fish passage is available in the natural waterway condition. A more restrictive approach with reduced fish passage effectiveness would aim to provide passage for a reduced diversity of fish species, life stage and maturity, and / or a reduced range of flow conditions. This would overcome a total fish migration barrier at the crossing, but would retain partial or temporal barrier status.

The adopted fish passage effectiveness and design criteria for particular waterway structures depends on the value of the fish movement corridor / waterway / fish habitat at the structure, and the aquatic fauna connectivity / fish passage goals for the waterway. No prescriptive basis for identifying aquatic fauna connectivity goals or for establishing fish passage design flow or fish swim speed criteria have been established for Queensland waterways and fish communities. Several levels of fish passage effectiveness are proposed here, with associated flow band conditions and target fish community, which will allow desired fish passage provisions at the road crossing or other waterway structure to be chosen (Box B4.1). Delineation of flow bands (low flow / medium flow / high flow) and fish swim speed parameters (burst speed / prolonged speed) are discussed in sections below.

Box B4.1: Fish passage effectiveness levels and design criteria for provision of fish passage at road crossings and other waterway structures

Fish passage effectiveness	**Fish passage provisions for design flow conditions – upstream migration**		
	Low flow (flow up to approx. 0.5 m deep)	**Medium flow (flow from appr. 0.5 m to approx 1.5 m deep)**	**High flow (flow in excess of approx. 1.5 m deep)**
Level 1 – conservative	• all native fish species, life stages and maturity	• all but outlier [(1)] native fish species (e.g. poor swimmers)	• not mandatory for any native fish species
Level 2 – intermediate	• all native fish species, life stages and maturity	• not mandatory for any native fish species	• not mandatory for any native fish species
Level 3 – restrictive	• all but outlier [(1)] native fish species (e.g. poor swimmers)	• not mandatory for any native fish species	• not mandatory for any native fish species
Notes	1 Restricted fish community may be identified on the basis of fish species diversity (e.g. icon species, weak swimming species), or on fish life stage and maturity (adult spawning / juvenile dispersal / adult dispersal / facultative movement for adults and juveniles)		

The Level 1 (conservative) criterion for fish passage effectiveness provides for fish passage for all native fish species, life stages and maturity at the low flow condition, and for all but outlier species (e.g. poor swimming adult species, small juvenile species, or other less valued species) at the medium flow condition. No mandatory requirement for fish passage is defined at the high flow condition, because fish are less likely to be migrating during peak stream flows, and these flow conditions will be maintained for relatively short periods. The Level 1 fish passage effectiveness criteria would normally apply for the most valuable fish movement corridor class / waterway / fish habitat (refer *Guidelines Part D – Fish Passage Design: Road Corridor Scale* and *Guidelines Part E – Fish Passage Design: Site Scale*), for situations where aquatic fauna connectivity / fish passage goals are high, for road crossings and other waterway structures where hydraulic conditions constituting the fish migration barriers are not severely adverse, and where it is readily feasible to overcome the barrier.

The Level 2 (intermediate) criterion for fish passage effectiveness provides passage for all fish species, life stages and maturity at the low flow condition, with no mandatory requirement for passage at medium flow or high flow conditions. This criterion would apply for high value or medium value fish movement corridors / waterway / fish habitat, for situations where aquatic fauna connectivity / fish passage goals are medium to high, for road crossings and other waterway structures where the hydraulic conditions that constitute the fish migration barriers are not severely adverse, and where it is feasible to overcome the fish migration barrier.

The Level 3 (restrictive) criterion would further restrict provisions for fish movement at the low flow condition, allowing passage for all but outlier species and during smaller windows of time during these lower flows. No mandatory requirement for fish passage is defined at the medium or high flow conditions for the Level 3 criterion. This would apply for low value fish movement corridors / waterway / fish habitat, for situations where aquatic fauna connectivity goals are low to medium, for waterway structures where the hydraulic conditions that constitute fish migration barriers are not severely adverse, and where it is feasible to overcome the fish migration barrier.

The fish passage effectiveness band for the waterway structure, and associated fish passage design flows and swim speeds for the target fish community, is chosen by the designer on a discretionary basis, taking into account the following [more guidance is provided in *Guidelines Part D – Fish Passage Design: Road Corridor Scale*]:

- fish movement corridor class (Class A – Class C)
- aquatic fauna connectivity / fish passage goals (high – low)
- fish migration barrier hydraulic conditions for waterway structure
- feasibility of overcoming the fish migration barrier at the structure

4.2 Fish passage design flow

In their natural movement behaviour, fish migrate at various stages of stream flow and rely on passage through a particular section of waterway with acceptable delay times. The timing of the movement, the range of stream flows, and the acceptable delays at fish migration barriers depends on the fish life cycle (catadromous, potamodromous, amphidromous); life stage (spawning, growth, dispersal); and maturity (adult, juvenile). Fish migration commonly occurs through triggers related to stream flow, season, temperature, and photo-period, and successful fish passage is closely associated with movement at particular stream flows and water depths.

The fish passage design flow at the waterway structure defines the range of flow conditions in the waterway for which provisions for fish passage are to be made. Different fish species may move within the waterway under different seasonal flow conditions such as wet season flood flows or more regular flows, and at different stages of the flow event such as peak flow or the tail end of the flow hydrograph. Design flow conditions are chosen to provide acceptable fish passage effectiveness, which relates to the degree of interference with the natural fish movement behaviour at the fish migration flows of the target fish community within the waterway.

Design flow magnitudes for fish passage are much less than the drainage design flows commonly used for trafficability, inundation or erosion protection for the road-waterway crossing, which are typically in the range of 5 year to 100 year ARI (Average Recurrence Interval) flows. Waterways in Queensland commonly display a large range in flow magnitude from no flow to flood flow, and whilst upstream fish migrations typically take place at flows above very low flow dry-weather conditions and well below peak discharges in the waterway, these migrations often occur over a very short period of time. Downstream migrations are not likely to be a constraining factor in fish passage design for road-waterway structures.

A flow range with a maximum and minimum flow condition is used for fish passage design, providing a window of time within a flow event where conditions are intended to be suitable. The maximum design flow condition relates to the required period for passibility and permissible delay time for the fish community within a flow event (which are a function of the peak discharge and the hydrograph shape), and the required period for passibility within a fish migration season to allow life cycle function. The maximum flow also relates to the limiting flow providing high flow connectivity for fish within the waterway channels (constrained by adverse hydraulic conditions – e.g. velocity, turbulence, water surface drop). The minimum design flow condition relates to the limiting flow stimulating fish movement between habitat areas, and providing low flow connectivity within waterway channels. Maximum and minimum design flow conditions are also constrained by practical limitations in configuration of fishways to effectively provide fish passage at the structure.

A variety of methods are used internationally and within Australia for defining the range of fish passage design flows for waterway structures, but these are generally not directly transferable to fish passage design for road crossings or other waterway structures in Queensland. In northern America, where fish passage requirements have historically been focussed on providing for migration of strong-swimming salmon to upstream spawning habitats, relationships between biological and hydrological variables were examined to establish the characteristic stream discharge that would produce an acceptable delay time in migration for particular species. In Canada, the three-day 10-year ARI discharge is used, which corresponds to the stream discharge that is exceeded for no more than 3 days in the 10 year ARI flood.

The technique for defining fish passage design flow for weirs in southern Australian streams provides for fishway operation for 95% of flows until drown-out of the weir (Mallen-Cooper 2000). Although meaningful for large rivers with slowly rising and falling flow conditions, this approach is not applicable to Queensland waterways where highly variable streamflow characteristics may mean that fishways operating for 5% of time may miss a substantial period of flow in some waterways, and are unlikely to encompass short duration flow events or intermittent stream flow conditions that represent a limited window of time for fish passage.

Whilst the importance of fish migration across a range of flow magnitudes (including low flows) has been recognised in Australia, information on fish movement behaviour for Australian fish species does not provide prescriptive data on critical timing, stream flows and water depths for fish migration. In the absence of more specific data, the desired approach is to provide for fish passage within nominal flow ranges that encompass anticipated movement for the target fish species. Rather than specify flow range in terms of stream flow discharge with a particular recurrence interval or probability of exceedance, the approach adopted here is to use depth of flow in the waterway to define broad bands of stream flow magnitude. Three bands of flow (low, medium, high) are adopted according to nominal flow depth in relation to channel form in a natural waterway.

A large amount of fish migration occurs in *low flow* conditions at the tail end of flood hydrographs in the wet season, or during moderate non-wet season flow periods. The low flow condition is defined as flow up to about 0.5 m deep, inundating the channel bed for a defined waterway. Fish migration can also be expected to occur during the *medium flow* condition, which is defined as flow from about 0.5 m to about 1.5 m deep, and below the low flow channel bench for a defined waterway. Migration is least likely to occur under natural conditions for *high flow*, which is defined as flow in excess of about 1.5 m deep, contained within the upper channel or flowing overbank for a defined waterway.

Flow bands for fish passage design at waterway structures	
Low flow condition	Flow up to approx 0.5 m deep
	Inundating channel bed for defined waterway
Medium flow condition	Flow from approx 0.5 m to approx 1.5 m deep
	Below low flow channel bench for defined waterway
High flow condition	Flow in excess of approx 1.5 m deep
	Upper channel or overbank flow for defined waterway

4.3 Design swim speeds and other fish movement characteristics

Swimming performance and movement behaviour in response to flow are key elements governing fish passage. Swimming capabilities vary with fish species and swimming mode, and with body morphology, fish length, water temperature and other variables. Australian freshwater fish species migrate mostly in response to flow stimulation, and they are relatively poor swimmers compared with northern hemisphere species. They have poor jumping abilities to overcome water surface drops and they are readily obstructed by rapids and small waterfalls. Many Australian fish move upstream as juveniles, thereby making passage through waterway barriers more difficult as they attempt to combat difficult flow conditions.

Fish swim speed data are commonly established from eco-hydraulics flumes where fish move in a non-volitional manner under controlled flow conditions. This often underestimates swim behaviour in a stream or through a waterway structure in the field, where fish move in a volitional manner in response to flow or other triggers. Most published data on swimming ability of fish relates to species from the northern hemisphere, and data on swim speed, jumping ability, minimum water depth requirements, and tolerance to turbulence are lacking for most Australian native fish species. With the exception of barramundi, golden perch, Australian bass, silver perch, sooty grunter and sea mullet, the available swim speed data often relates to sustained speeds with little known about burst speeds and endurance levels (Hajkowicz and Kerby 1992).

The design swim speed for the waterway structure should be based on the swim capabilities of the target fish species under the relevant swim mode (burst or prolonged swimming). Fish swim speed information such as that presented for the Tully Murray fish community (Box B3.7), or other more specific data for particular species, life cycle stage and maturity can be used where available. An envelope is usually applied to the fish swimming capabilities for the various groups of fish species, life stages and maturity and for the particular swimming modes. Closer examination of design criteria and selection of priority species for passage may be warranted at particular structures and for particular situations.

For a conservative approach where no other swim speed data are available, the criteria suggested by Cotterell (1998) is to use a prolonged swim speed of 0.3 m/s or less to allow for migration of all native species. Mallen-Cooper (2001) advocates a default prolonged swimming speed value of 3 body lengths (length of fish) per second (BL/s), with design swim speeds of 0.15 m/s for fish less than 80 mm in length, and 0.75 m/s for fish greater than 250 mm in length.

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