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Greater Brisbane Fish Barrier Prioritisation

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Cover Figure: From top, left to right (fish barriers): Luscombe Weir located on the lower Albert River, DNRM V- notch gauging weir located on the lower Warrill Creek upstream from the Cunningham Highway, Pipe culverts located on the Pimpama River downstream from the Pacific Highway, Enoggera Creek tidal interface weir located adjacent to Hulme St, Berrys Weir partial width rock-ramp fishway located in the lower reaches of the Bremer River in Yamanto. Fish images; juvenile freshwater mullet (captured from Leitchs Crossing fishway– South Pine River), juvenile and adult bullrout, (top to bottom) Sea mullet, Duboulay's rainbowfish, unspecked hardyhead, firetail gudgeon Australian smelt, empire gudgeon, and forked- tailed catfish and yellowfin bream all captured successfully ascending Berrys weir rock-ramp fishway on the lower Bremer River.

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Glossary of Terms

Diadromous: Diadromous fishes are migratory species whose distinctive characteristics include that they (i) migrate between freshwater and saltwater; (ii) their movement is obligate to maintain species distribution and ecosystem health; and (iii) migration takes place at fixed seasons or life stages. There are three distinctions within the diadromous category, including: catadromy, amphidromy and anadromy.

- **Catadromous** - Diadromous fishes which spend most of their lives in freshwater and migrate to saltwater to breed.
- **Amphidromous** - Diadromous fishes in which migration between the saltwater and freshwater (or vice versa) is not for the purpose of breeding, however occurs at some other stage of the life cycle.
- **Anadromous** - Diadromous fishes which spend most of their lives at sea and migrate to freshwater to breed.

Potamodromous - Fish species whose migrations occur wholly within freshwater for breeding and other purposes.

Ontogenetic Migration – Different life stages migrate into different habitats.

Potential Barrier – A barrier identified within a stream through the use of GIS, however has not been ground- truthed to assess the true impacts and extent of the barrier.

Head loss – The difference (or 'loss') of water surface height between an upstream and downstream water body bisected by a barrier

Declared Downstream Limit – The lower-most freshwater reach of a stream, as determined by Queensland Department of Natural Resources and Mines.

Acronyms

CS -	Catchment Solutions
NRM -	Natural Resource Management Group
RCL -	Reef Catchments Limited
GBFBP -	Greater Brisbane Fish Barrier Prioritisation
GB -	Greater Brisbane
FBPP -	Fish Barrier Prioritisation Process
GIS -	Geographic Information Systems
GEP -	Google Earth Pro
DDL -	Declared Downstream Limit
DAF -	Department of Agriculture and Fisheries
DNRM -	Department of Natural Resources and Mines
GPS -	Global Positioning System
EPBC -	Environment Protection and Biodiversity Conservation
RRF -	Rock-ramp fishway

Preamble

Fish passage barriers such as dams, weirs, causeways, culverts, earthen bunds and floodgates represent significant threats to the health of river systems through altering natural flow regimes and causing impassable barriers to aquatic fauna. Anthropogenic obstructions are widespread in the highly urbanised coastal catchments throughout Australia and have been implicated in the decline of many iconic native fish species, in particular, migratory diadromous species.

Diadromous species which require unimpeded access between freshwater and saltwater habitats are often of the highest socio-economic importance, being of key commercial and recreational value, as well as being key ecological assets within the trophic ecology of their associated waterways. Species such as Australian bass, barramundi, jungle perch, long- finned eel, mangrove jack, freshwater mullet and sea mullet have all been found to adhere to strict migratory life-cycle strategies which require unimpeded access between inland freshwater habitats and the estuary. The decline of many of these species throughout their natural range can be largely attributed to the proliferation of movement barriers, and further compounded by the resultant diminished available habitat and poor water quality.

Through modern insight and a greater understanding of various life-cycle requirements, fish passage restoration works have seen the remediation of many barriers, with fishways or fish ladders identified as the key method to offset the impacts of barriers on ecological integrity. Various fishway designs are becoming increasingly factored in to waterway developments, with many identified historical barriers having retrofitted fishways constructed, often to the immediate benefit of the aquatic assemblages of the waterways they impede.

Executive Summary

This report forms part of the overarching project ‘Re-Connecting Aquatic Habitats Across the Greater Brisbane Urban Area’, which was commissioned by the Federal Government under the ‘Targeted Area Grants’ program via Reef Catchments Limited (RCL) Natural Resource Management (NRM) group. The objective of the Greater Brisbane Fish Barrier Prioritisation (GBFBP) was to identify and assess the large number of anthropogenic barriers that prevent, delay or obstruct fish migration in the Greater Brisbane (GB) region. Fish barriers identified through this process were ranked in order of priority, accounting for the cumulative impacts barriers have on the environment, fisheries resources, economy and local community.

Fish migration is an essential life history adaptation utilised by many freshwater fish species in the GB region. Migration strategies between key habitats have evolved for a variety of reasons, including feeding and reproduction purposes, predator avoidance, nursery habitat utilisation and maintaining genetic diversity. Barriers preventing connectivity in the GB region impact fisheries’ productivity and create environmental conditions favourable for invasive pest fish species. Significantly, almost half of the GB freshwater fish species undertake ontogenetic shifts in habitat use between estuarine and freshwater environments. Remediating barriers and maintaining connectivity between saltwater and freshwater is therefore critical to ensuring freshwater fish community condition and improving overall aquatic ecosystem health. This project aimed to address such issues, through identifying, ranking and remediating fish passage barriers throughout the GB region.

Explicitly, the overall aims of the project were to;

1. Systematically identify all potential barriers to fish passage in the GB region.
2. Undertake catchment-scale GIS analysis of biological, geographic and environmental characteristics associated with each potential barrier to produce a prioritised list for ground-truthing, i.e. visit the most important potential barriers first.
3. Perform fine-scale, site specific barrier assessment to validate, score and rank priority barriers based on passability, configuration, in-stream habitat availability and flow conditions.
4. Further refine and prioritise barriers based on economic, social and fisheries productivity criteria.
5. Produce a list of the top 50 priority ranked fish barriers in the GB region showing remediation options and indicative costs
6. Facilitate the adoption of fish barrier remediation by Local Governments and Natural Resource Managers
    a. Construction of appropriately designed fishways at several high priority sites in partnership with respective Councils
    b. Evaluation monitoring to assess remediation success
    c. Field day – South-East Queensland fish passage field trip

The fish barrier prioritisation process involved identifying potential barriers using high resolution aerial imagery across the GB region. In total, 13,629 potential barriers were identified in the project area (3,582 km^2) at a rate of 3.8 potential barriers per km^2. Geographic Information System (GIS) software was then applied to rapidly assess and prioritise the high number of potential barriers using a collective optimisation rank-and-score approach. Importantly, key socio-economic flow-on benefits of improving aquatic ecosystem connectivity were considered i.e. the degree to which barrier remediation may increase fisheries productivity and/or conserve vulnerable fish species, e.g. jungle perch.

In many parts of the world, remediation of man-made barriers with appropriately designed fishways is one of the most successful management tools utilised by government agencies and natural resource management groups to help restore populations of fish impacted by barriers. Objectively choosing the 'right' barriers to remediate in order to obtain the greatest benefits requires a holistic prioritisation process. In this prioritisation assessment, the process guided the authors to groundtruthing the top priority potential barriers in order of importance. The resultant GBFBP report and associated priority ranked fish barrier list will assist natural resource managers and decision makers in determining where best to allocate funding opportunities to ensure the greatest environmental and socio-economic outcomes for the GB region.

The GBFBP was also used to guide the remediation of several priority fish barrier sites as part of the overarching project. Fish barrier sites were chosen based on priority ranking and available resources. Five fishways were designed, constructed and monitored by Catchment Solutions (CS) between 2016 and 2017, and delivery of individual fishway projects were undertaken in partnership with each respective Local Government (LG) (Table A). Rock-ramp fishways (RRF) were chosen as the preferred design option at all sites due to their ability to pass weaker swimming juvenile and small bodied species, their natural appearance, pool roughness (creating micro-eddies) and minimal cost outlay when compared to highly engineered, smooth-sided fishways such as vertical-slot fishways. Rock-ramp fishways were constructed on the:

- Bremer River (Berrys Weir - ranked 7th),
- South Pine River (Leitchs Crossing - ranked 11th),
- Hilliards Creek (Hilliards Weir - ranked equal 36th) and
- Slacks Creek (Paradise Road overpass - ranked equal 36th). Due to site constraints, a horizontal culvert baffle fishway was constructed in addition to the rock-ramp fishway at Paradise Road on Slacks Creek.

Fishway monitoring was undertaken to evaluate the success of each fishway at facilitating fish passage for the entire fish community. Results showed that all expected juvenile diadromous and small bodied species were able to ascend the fishways. The 2.4 m high, 90 m long, 33 ridge Bremer River partial width rock-ramp fishway recorded the highest numbers and diversity of fish, with over 16,000 individuals recorded in just over four days of monitoring at a catch rate of 4,075 fish per day. The median size of all fish captured was just 34 mm, highlighting the success of the fishway at passing weaker swimming juveniles and small bodied species. Notable captures included the migration of key juvenile diadromous species, such as sea mullet, freshwater mullet and bullrout, which represented catch rates of 316, 266, and 27 individuals per day respectively. The success of each fishway project can be directly attributed to the strong working partnerships developed between CS and each LG to remediate priority fish barriers and deliver significant aquatic connectivity remediation outcomes for the benefit of the environment and local communities.

Table A. Showing information relating to the remediation of fish barriers as part of this project.

Waterway	Barrier	Local Gov.	Rank	Barrier Height	Fishway Type/s
Bremer River	Berrys Weir	ICC	7th	2.4 m	33 ridge partial width rock-ramp
South Pine River	Leitchs Crossing	MBRC	11th	0.45 m	7 ridge full width rock-ramp
Hilliards Creek	Relict Weir (Sturgeon St.)	RCC	36th	0.7 m	9 ridge full width rock-ramp
Slacks Creek (x2)	Paradise Road Culverts	LCC	36th	1.8 m	16 ridge full width rock-ramp and 10 ridge horizontal concrete baffle f/way

Introduction

The majority of freshwater fish species of the Greater Brisbane (GB) region migrate at some stage during their life history. Some of these migrations are short and confined wholly within freshwater habitats, while some migrations occur across vast distances and between varying habitats, including between estuarine and freshwater environments. Of the 50 native freshwater fish species found to occur in the GB region (See 'Greater Brisbane Freshwater Fish Communities Overview', pp. 31- 35), almost half (44%) require unimpeded access between freshwater and estuarine habitats to complete their life cycle and/or maintain species distribution.

Migration strategies between key habitats have evolved for a variety of reasons, including;

- Feeding and reproduction purposes,
- Avoidance of predators,
- Utilisation of nursery areas,
- Dispersal – to avoid being trapped in drying waterholes,
- Maintain genetic diversity, and
- Removing parasites.

The following Greater Brisbane Fish Barrier Prioritisation (GBFBP) has been developed to assess and rank fish passage barriers having the greatest impacts on freshwater fish communities of the GB region. Low passability barriers located within close proximity to the tidal interface on high ordered waterways have the greatest impact on freshwater fish community condition in coastal Queensland catchments. This is largely due to the ability of these barriers to prevent or impede juvenile diadromous species from undertaking longitudinal life-cycle dependant migrations upstream into important nursery habitats. A single low passability barrier located on the tidal interface has the potential to exclude almost half (44%) of the 50 native freshwater fish species recorded in GB freshwater environments (Rolls et al. 2013; 2014).

As fish barriers located close to the estuarine interface have significant impacts on aquatic ecosystem health and fish population distribution, the GBFBP scoring system has been designed to ensure these types of barriers are prioritised. Barriers located in headwater reaches remain important to remediate, particularly if vulnerable fish species occur in these locations and this is accounted for in the prioritisation process. These headwater barriers have the greatest impact on movements of potamodromous fish species, which are able to complete their life-cycle wholly within freshwater, thus reducing the overall impact of such barriers.

The consequences of tidal interface barriers on diadromous fish species are well understood, but their impacts on displaced potamodromous species can also be significant. Tidal interface barriers eliminate the salinity gradient which occurs in natural waterways, and therefore removes important physiological stressors (increasing salinity) that may prevent potamodromous species from moving into downstream reaches of waterways. Depending on the size of the waterway, the removal of the salinity gradient potentially results in tens of thousands of individuals being displaced over barriers during flow events into saltwater environments, where they potentially perish without access to freshwater.

Many Greater Brisbane diadromous fish species sit on top of the aquatic food web as top order predators within freshwater environments and therefore play important roles in maintaining the balance of aquatic biodiversity. In coastal QLD waterways with unimpeded connectivity, two diadromous species; long-finned eel (*Anguilla reinhardtii*) and jungle perch (*Kuhlia rupestris*) generally inhabit the entire river continuum, including lower, middle and headwater river reaches. Their position at the top of the trophic food web, combined with their wide-ranging distribution within waterways along the QLD coastline suggests they would also play important roles influencing predator-prey relationships. Therefore, it's plausible to suggest that well connected waterways with healthy native freshwater fish communities comprising top order diadromous predator species would be more resilient to threats posed by pest fish and that barriers preventing key migratory species potentially contribute towards conditions that favour the establishment and proliferation of pest fish populations (Stoffels 2013).

The impact of coastal barriers on freshwater fish communities is confounded in situations where barriers create lentic environments i.e. weir pools. Coastal freshwater fish species prefer lotic environments exhibiting a diversity of in-stream habitats typified by pools, runs and riffles. Weir pools created by barriers mediate and diminish lotic habitats, creating impounded lentic environments favoured by invasive pest fish species such as tilapia (*Oreochromis mossambicus*) and carp (*Cyprinus carpio*) (Koehn and Kennard 2013). Therefore, fish barriers not only directly impact upstream freshwater fish community composition through exclusion of diadromous fish species, but also impact indirectly through the establishment of inferior habitat conditions (e.g. lentic habitats) that favour pest fish species and reduce native potamodromous fish abundance and diversity.

In addition to their ecosystem service value, diadromous species are also recognised as contributing significant societal values, comprising high value commercial, recreational and Indigenous fisheries. Historically, sea mullet (*Mugil cephalus*) (Figure 1) and long-finned eels (*Anguilla reinhardtii*) have been established as important food sources for indigenous people (Barnett and Ceccarelli, 2007). Today, both sea mullet and long-finned eels form important commercial fisheries, with sea mullet forming the most important commercial inshore net fishery in South-East Queensland (Williams, 2002). Diadromous species are also important recreationally, in particular Australian bass (*Percalates novemaculeata*), jungle perch (Figure 1), mangrove jack (*Lutjanus argentimaculatus*), tarpon (*Megalops cyprinoides*) sea mullet and freshwater mullet (*Trachystoma petardi*) (Figure 1). Healthy, sustainable populations of these species have the ability to attract fisherman to local coastal communities, providing valuable social and economic benefits. Ensuring connectivity between habitats is therefore a critical component in managing aquatic environments, and crucial to securing the long-term sustainability of important fisheries that underpin the social fabric of many coastal Queensland communities.

Figure 1. Diadromous fish species impacted by barriers: sea mullet (*M. cephalus*) (top left), freshwater mullet (*T. petardi*) (bottom left) and jungle perch (*K. rupestris*) (right). Sea and freshwater mullet (sampled from the Bremer River) form important recreational, commercial and indigenous fisheries, while jungle perch are a highly prized recreational fishing species.

Objectives

Due to the large project area and high number of barriers encountered within the project boundaries, it was important to accurately prioritise potential barriers so funding resources could be utilised in the most appropriate manner. A desktop GIS analysis approach was established as the most efficient way to conduct a comprehensive fish barrier analysis. The initial utilisation of GIS enabled the prioritisation process to assess thousands of potential barriers and systematically rank them in order of importance.

The initial GIS process allowed managers undertaking the prioritisation to set an achievable target of potential barriers to be ground-truthed in stage two of the process, i.e. top 500 potential barriers. The availability of resources typically determines the size of the inventory, if resources are unlimited then all potential barriers could be ground-truthed. Due to the large geographic area, high numbers of barriers and restricted funding streams for fisheries based riverine restoration projects, this level of ground-truthing is rarely achievable. Therefore, the ability of GIS to rapidly assess large amounts of geo-spatial vector data for each potential barrier and produce a list of the top ranked barriers after stage one is critical to the prioritisation's success, as it allows resources to be directed towards evaluating the most important potential barriers first.

The GBFBP involves a three-stage rapid assessment process that ensures available financial resources are efficiently utilised to identify and prioritise barriers having the greatest impact on fish migration. The rapid assessment process comprehensively evaluates fishery, economic, social and eco-system benefits of barrier remediation. This is achieved by applying a multi-faceted approach, initially utilising the efficiency and unique decision-making capabilities of an automated GIS process. The advantage of GIS during the first stage of the prioritisation revolves around its capacity to assess wide-ranging temporal and spatial habitat characteristics associated with thousands of potential barriers over a large geographic area. Following the validation of high ranking potential barriers, further assessment and prioritisation of actual barriers is undertaken using scoring and ranking methods in stage two and three. Important geospatial characteristics fundamental to a potential barrier scoring high in the first stage (GIS) of the prioritisation include:

- Potential barriers located on large, low gradient, high ordered waterways,
- Potential barriers located in close proximity to the sea,
- 1st barrier located longitudinally along the waterway,
- Large amount of connected habitat upstream of the potential barrier,
- Low proportion of intensive land use within the sub-catchment.

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3. Perform fine-scale site specific barrier assessment to validate, score and rank priority barriers based on passability, configuration, in-stream habitat availability and flow conditions.
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5. Produce a list of the top 50 priority ranked fish barriers in the GB region showing remediation options and indicative estimated costs
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a. Construction of appropriately designed fishways at several high priority sites in partnership with respective Councils
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Barriers to Fish Migration

Barriers to fish passage include any anthropogenic or environmental obstruction that prevents, delays or impedes the free movement of fish. For the purpose of this prioritisation process, environmental barriers such as weed chokes, waterfalls, low dissolved oxygen slugs and water temperature barriers have not been included, even though anthropogenic factors may have contributed to their occurrence. Anthropogenic barriers identified in this prioritisation process include structures such as box culverts, pipes, road crossings, weirs, dams, stream flow gauging structures, floodgates, barrages and bunds (or ponded pastures) (Figure 2). These structures have been built for a variety of purposes such as irrigation supply, flow gauging and regulation, stock watering, urban and industrial supply, flood mitigation, prevention of tidal incursion, road crossings or simply for urban beautification and recreation facilities (Marsden et al. 2003).

Figure 2. Barrier structures: a) Road causeway & concrete apron (Elimbah Ck), b) tidal floodgates (Behm Ck), c) V-notch stream gauging weir (Warrill Ck), d) Sheet pile and gabion basket weir (Warrill Ck), e) pipe culvert causeway (Albert River) and f) Tidal barrage (Caboolture River).

Barriers impact fish communities in many ways, with some barriers such as significant head loss dams forming complete blockages, whereas other structures such as culverts present partial or temporary barriers, restricting passage during particular flow events (e.g. small, medium or high flows). Even small vertical drops downstream of road crossings and culvert aprons (≥200 mm) are sufficient to form barriers for many fish, particularly juvenile and small bodied species. Often single structures possess multiple barrier types. It is common for culvert crossings to possess physical water surface drop barriers due to stream bed erosion on the downstream extent of culvert aprons, while hydraulic velocity barriers are often created when stream flows pass through their smooth internal surfaces. Perched culverts or those without low flow channels installed below bed level can result in insufficient water depth barriers (low flows are spread out across multiple culvert barrels).

The swimming abilities of fish play a critical part in understanding the effects of barriers (Wang, 2008). Physiology, size, developmental stage and morphology all influence the ability of fish to ascend past barriers (Koehn and Crook 2013). Generally, juvenile (Rodgers et al. 2014) and small bodied fish (Domenici, 2001) possess weaker swimming abilities than larger adult fish. This is because larger fish have more muscle to propel them through the water (Tillinger and Stein, 1996). Significantly, the vast majority of migrating native fish in coastal Queensland catchments comprise juvenile diadromous and small bodied species (McCann and Power 2017; Power 2016; Moore 2016; Moore and Marsden 2008). The small size of migrating fish is further highlighted by fishway evaluation monitoring studies undertaken as part of this project. The median size of native fish recorded successfully ascending Slacks Creek, Bremer and South Pine River rock-ramp fishways during low flow conditions equated to just 25 mm (n= 6,548 fish at a catch rate of 1,385 per day), 34 mm (n= 16,401 fish at a catch rate of 4,075.5 fish per day) and 30 mm (n= 5,070 at a catch rate of 1,406.7 fish per day) respectively (See 'Case Studies' in the Appendices of report for detailed breakdown of fishway monitoring results).

The potential impact of small head loss barriers on coastal fish communities is further exacerbated when these results are categorised by migration class, i.e. proportion of individual diadromous fish undertaking life-cycle dependant migrations. Of the 6,548 individual fish recorded successfully ascending the Slacks Creek rock-ramp fishway, 97% of individuals were diadromous fish undertaking life-cycle dependant migrations, while correspondingly, 96% of the individuals monitored ascending the Bremer River rock-ramp were diadromous fishes.

Swimming abilities of different fish species play a critical role in their ability to ascend fishways. Mallen-Cooper (1989) tested the swimming abilities of two iconic and recreationally important diadromous fish species, barramundi (*Lates calcarifer*) and Australian bass through a vertical-slot fishway, and found that juvenile barramundi (43 mm) were only able to negotiate velocities of around 0.66 m/sec, while Australian bass (40 mm) are able to negotiate slightly faster velocities of around 1.04 m/sec. Rodgers et al. (2014) tested the prolonged swimming performance of empire gudgeon (*H. compressa*), a small-bodied diadromous species (32 - 77 mm) and found that they were only able to sustain swimming speeds of ≤0.10 m/sec.

It must be noted that the swimming performance data mentioned above was collected under laboratory conditions. Fishway monitoring data collected in the field suggests that the majority of fish species are able to negotiate greater velocities than has been recorded under controlled conditions. For example, sampling of a rock-ramp fishway on the Bremer River in South-East Queensland as part of this project showed that juvenile empire gudgeon (*H. compressa)* (34 mm), striped gudgeon (*Gobiomorphus australis)* (44 mm) and sea mullet *(M. cephalus)* (55 mm) were recorded negotiating ridge slot velocities of 2.1 m/sec and pool velocities of 0.4 m/sec. Similarly, a fishway monitoring study undertaken by Power et al*.,* (2016) on a rock-ramp fishway on the Condamine River in South-West Queensland recorded small gudgeon (*Hypseleotris* sp.), rainbowfish (*Melanotaenia* sp.), bony bream (*Nematalosa erebi*) and spangled perch (*Leiopotherapon unicolor*) negotiating ridge slot velocities of 2.0 m/sec and pool velocities up to 1.5 m/sec. The ability of fish to negotiate faster velocities through rock-ramp fishways compared to smooth sided vertical-slot fishways can be explained by the high geometrical diversity of rock-ramps as a result of their irregular forms (rocks) used in their construction, which create interstitial spaces and micro eddies (Wang 2008).

The stream velocities Australian fish species are able to negotiate are lower in comparison with their northern-hemisphere counterparts such as adult Atlantic salmon, which are able to negotiate velocities of at least 2.4 m/sec (Mallen-Cooper, 1989). Unfortunately, many early Australian fishway designs were based on northern hemisphere designs and the swimming abilities of salmonids (Mallen-Cooper, 1996), which have the added capability of 'leaping' past small barriers (Thorncraft and Harris, 2000).

These fishways have drops between pools, velocities and turbulence far in excess of what coastal Queensland fish communities are capable of ascending on a regular basis and have themselves become fish barriers e.g. Luscombe Weir (Albert River), Mt Crosby Weir (Brisbane River) and Berrys Weir (Bremer River) (Figure 3). McCann and Moore (2017) measured the velocity of a pool and weir fishway constructed in the 1960's on the Bremer River (Berrys Weir) and recorded a velocity of 3.3 m/sec at the fishway exit (Figure 3. white circle), which is substantially faster than what native fish are able to negotiate, and potentially even faster than the velocities adult Atlantic salmon can withstand.

Figure 3. Showing northern hemisphere 'salmonid' style fishway designs exhibiting hydraulic conditions in excess of the swimming abilities of most native freshwater fish species. a) Denil fishway located on Luscombe Weir (Albert River, QLD) showing steep gradient and excessive velocities (note baffles removed). b) Showing the bottom section of the Mt Crosby weir pool and weir fishway (Brisbane River). Note the inadequate fishway entrance with excessive turbulence associated with the large water surface drop and shallow entrance pool and c) Pool and weir fishway located on the Bremer River (Berrys Weir). The exit of this style of fishway has a 600 mm high drop and velocities during base flows of 3.3 m/sec.

Ecophysiology & Barrier Type

Ecophysiology determines the ability of fish to successfully ascend past various types of barriers. What comprises a barrier for one species or age class may not necessarily apply to others. For instance, a 200 mm vertical drop on the downstream side of a damp, but not flowing culvert apron, will more than likely prevent passage of juvenile sea mullet. However, the unique climbing abilities of juvenile long-finned eels enables them to ascend up and over ≥200 mm damp vertical surfaces (Jellman, 1977). Other barrier characteristics such as velocity and turbulence affect fish swimming ability in different ways. To counteract the natural variability in flow conditions, fish exhibit different swimming modes. Generally, these modes fall within three widely recognised categories (adapted from Domenici and Blake 1997):

- Sustained – swimming more than >200 minutes
- Prolonged – 15 seconds -200 minutes, and
- Burst - <15 seconds

Burst speed is used by fish to negotiate fast velocities (Webb 1984; Ch. 6) and one that fish species would most commonly use when attempting to migrate over small head loss barriers (<120 mm) and through box culverts during medium and high flow conditions. Burst speed is an energetically expensive and aerobic form of swimming, and as such cannot be sustained for long periods. This is why less obvious barriers such as culverts and pipes become problematic for juvenile and small bodied fish when stream flow conditions through smooth-surfaced structures exceed 0.1 m/sec (Rodgers et al. 2014). Generally, barriers can be defined into 6 types:

- Water surface drop – Vertical drop off road crossings, weirs and culvert aprons that are greater than 200 mm in waterways close to the freshwater/estuarine interface and 300 mm in headwater/high gradient streams (Figure 4).
- Turbulence – The motion of water having local velocities and pressures that fluctuate randomly. This is often observed downstream of culvert aprons, weirs, pipes and poorly designed fishways

(Figure 3), without proper provision of pool depth. Turbulence is most often encountered during medium and high flow conditions.

- Velocity – When the speed of water is in excess of the swimming capabilities of fish attempting to pass the obstruction. High velocities often occur through pipes and culverts and downstream of weirs and regulators during medium and high flow events (Figure 4).
- Water Depth – Shallow water depth of 5 mm - 100 mm depending on species, size and morphology. Larger bodied demersal species are affected greater. Shallow water is often experienced during low flow conditions across road crossings, through culverts and across culvert aprons (Figure 4).
- Behavioural – Darkness, shadows and reduced light conditions inside culverts/pipes, and under low bridges (Figure 4).
- Chemical – Low dissolved oxygen slugs, often experienced during the first flow events in the lead up to summer (Oct. - Dec.) in waterways and wetlands, particularly in catchments with high proportions of intensive land use. Other chemical impacts include acid sulphate soil discharge and high temperatures associated with channel modification i.e. channel straightening and widening works combined with the removal of riparian vegetation.

Figure 4. Left to right: Culvert causeway displaying a water surface drop, shallow water surface (through culvert and on apron) and velocity barrier (during medium- high flow conditions) exacerbated due to a culvert diameter <60% of stream width; Pipe causeway displaying velocity and behavioural barriers (dark shadows/insufficient lighting in pipe) and water surface drop barrier.

Barrier Passability

Barrier passability, sometimes referred to as barrier transparency, describes the extent to which in-stream barriers impede fish passage (Kemp an O'Hanley, 2010), and forms an integral part of the current GBFBP scoring criteria when assessing barriers in the field. Barrier passability can be extremely complicated, with many dynamic temporal and spatial eco-physical characteristics influencing the extent and magnitude of barriers at different scales (Bourne et al. 2011). The four underlying characteristics of barrier passability include:

- Fish physiology – biology, species, size, swimming ability
- Waterway – stream size, stream slope, stream reach, temperature, dissolved oxygen
- Rainfall – precipitation duration and volume
- Barrier type – culverts, pipes, weirs, dams, road crossings, bund walls, sand dams, etc.

For the purpose of the current GBFBP, barrier passability was simplified into three categories.[1]

Low Passability (Figure 5)

- Rarely drowns out (e.g. average 1 or less flow event/yr),
- Dams and weirs >2 m head loss,
- Causeway >2 m high with pipe/culvert configuration <10 %, bankfull stream width & head loss >1m.

Medium Passability (Figure 5)

- Occasionally drowns out (e.g. average 2-5 times/yr)
- Velocities through culverts/pipes exceed swimming ability of fish during medium and high flow events
- Shallow water surface barrier during low flows (culverts)
- Weir, causeway, bund wall, sand dam: 0.3 - 2 m head loss
- Culverts/pipes that span <60 % of bankfull stream width.

High Passability (Figure 5)

- Frequently drowns out (most flow events)
- Culverts/pipes that span >60 % of bankfull stream width
- Causeway <0.3 m
- Barrier only for small proportion of flow events, i.e. high flows (full-width culverts) and very low flows (shallow water surface)

Figure 5. Left to right: Low passability barrier, Medium passability barrier, High passability barrier.

[1] It is imperative that experienced fisheries biologists have an understanding of local waterways, barrier types, fish biology and species expected to occur at a site scale within the study region when assessing these criteria.

Fish Passage Remediation Options

Complete barrier removal is generally the first remediation option. However, this is generally only a viable option if the structure is redundant. In most circumstances, the barrier structure (legal or illegal) exists for a reason (e.g. irrigation, water supply, transportation, etc.), and retrofitting a fishway is the only fish passage solution. There have been numerous fishway designs implemented in Australian waters over the years. Many of the original designs were based on northern hemisphere fish species such as Atlantic salmon, which are able to negotiate faster velocities and higher water turbulence than Australian native fish species, with the added advantage of a leaping ability. Atlantic salmon migrate as larger bodied adults, whereas many coastal QLD species migrate as juveniles which makes ascending these early fishway designs virtually impossible. Unfortunately, this was not immediately recognised, resulting in a high proportion of fishways constructed between the 1960-80's that were inadequate for Australian fish passage rehabilitation; a legacy which today is still blocking fish migration in a number of systems on a daily basis.

Fortunately, fishways constructed today generally take into consideration the swimming abilities of Australian native fish, with a growing recognition that all fish species and size classes are catered for. Fishways can be broken into two main groups; highly engineered, expensive fishways for high barriers >4 m such as dams and high weirs located on large rivers e.g. Murray River. These fishways generally entail fish lifts (elevator- style fish ladders) and large vertical-slot type fishways. Often costing millions of dollars, these fishways are usually out of the feasible realm of local government and community groups rehabilitation efforts. The second and most common fishway types are generally designed for barriers <4 m in height. These include nature like rock-ramps, bypass channels, concrete cone ramps, vertical-slot, denil and vertical and horizontal culvert baffle fishways.

Rock-ramp fishways

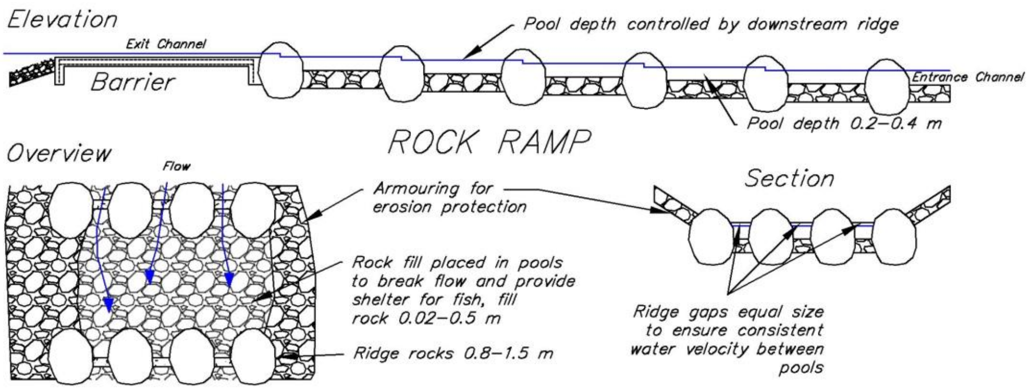
Rock-ramp fishways, or nature-like fishways, are the most common fishway type constructed in Queensland. Over the past decade, rock-ramps have been refined to suit the swimming abilities of native fish species and represent a low cost option to more formal fishway designs (Gebler 1988; Pasche et al 1995; Steiner 1995; Baumgartner and Lay 2002). They have proven to be effective fishways for the whole fish community, particualry weaker swimming juvenile diadromous and small bodied species (Table 1). The success of rock-ramps in passing small bodied species is largely due to the surface rougness, micro-eddies and flow complexity imparted by natural rock materials used to construct rock-ramps when compared to more structural, smooth-sided fishways (e.g vertical-slot, denil, etc.).

Figure 6. Nature like rock-ramp fishways: a) Full width (Gooseponds Ck, Mackay), b) Dog-leg (Lake Callemondah, Gladstone) c) Partial width (Tedlands Ck, Koumala)

In Australia, rock-ramps (Figure 6) are generally constructed on barriers up to 2.5 m in height, but could essentially be constructed on barriers much higher. Rock-ramp fishways are designed to mimic natural rock riffle stream conditions, with the added advantage of deep resting pools between ridges. Rock-ramps are generally constructed on a gradient of approximately <1:20 and designed to create a series of deep pools interspersed by rock ridges, with the falls between ridges usually set at between 60-90 mm, with smaller falls in lower river reaches and higher falls in headwater streams. Native fish utilise the deep pools between rock ridges to rest and regain their energy, before using their burst speed to negotiate the small falls between rocks to enter the next upstream pool. The natural materials (rock) used to construct rock-ramps provide interstitial spaces and surface irregularities which assist weaker swimming fish as they migrate upstream. Rock-ramps are aesthetically pleasing and their natural appearance means they blend into the surrounds of the natural stream environment. See table 1 below for a full list of advantages and disadvantages of rock-ramp fishways.

Table 1. Showing advantages, disadvantages and conceptual design of nature-like rock-ramp fishways

TYPE	DESCRIPTION	ADVANTAGES	DISADVANTAGES
Nature like Rock-ramp: Full width Partial width. Dog-leg Bypass Channel	Minimum Requirements: 1:20 - 1:30 grade Ridge rock height 1.2 m -1.8m Wall rock height 1.5 m -2.0 m wall 300 mm pool depth at cease to flow High flow & low flow slots Well graded rock mix to secure ridge and wall rocks Fibre-reinforced concrete to seal pools (small waterways/partial width designs)	Effective for the whole fish community, particularly juvenile diadromous and small bodied species Cost Effective Natural appearance High flows and low flows Reasonably high degree of redundancy (i.e. if partly blocked by debris, etc., will still function in rest of fishway) Good for downstream passage Simple construction	Entrance location needs to be considered or fish won't use the fishway. It needs to be suitable for different discharge flows / conditions. Require rock supply relatively close to site – cost consideration Construction needs to be well supervised by fish biologist experienced in fishway construction May requires maintenance– removal of debris (e.g. sticks) from the ridge slots



Cone Fishways

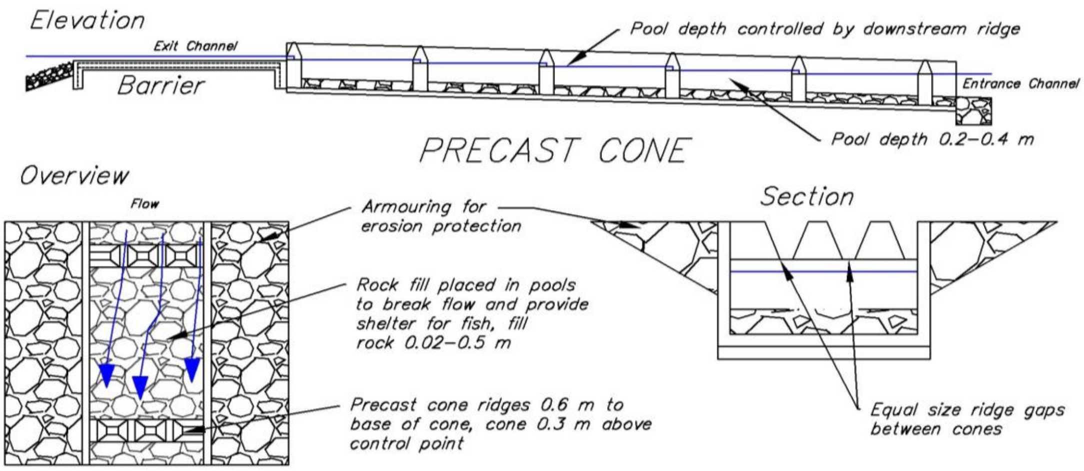
In an operational sense cone fishways are similar to rock-ramps, comprising of a series of pools interspersed at regular intervals by ridges within a channel on a minimum gradient of approximately 1:20. The main differences between the two fishway types, centers around the prefabrication of materials and unnatural appearance for cone fishways in comparison to the natural appearance of materials used for rock-ramps. Cone fishways have the added advantage of requiring less space than for rock-ramps and can be extremely useful when rock is in short supply e.g. Southern Gulf in northern Australia, as the side walls and cone ridge components can be prefabricated off site (Table 2). The highly engineered structural nature of cone fishways (Figure 7) ensures flow characteristics are also more consistent between ridges when compared to rock-ramps. Conversely, the smooth sided internal walls of cone fishways lack the surface roughness and micro-eddies associated with rock-ramps, which assist the migration of weaker swimming species.

The ridge components of cone fishways can be prefabricated using concrete or HDPE plastic. The pre-cast concrete or plastic cone ridges are inserted into a concrete channel creating a pool upstream and a small drop downstream. Generally, this type of fishway is more expensive to construct due to the cost of the pre-cast components and increased installation time when compared to rock-ramps.

Figure 7. Concrete cone fishway on Boundary Creek, Koumala; showing fish successful at ascending, top to bottom; juvenile barramundi and empire gudgeon, giant herring & over one thousand juvenile banded scats & threadfin - silver biddy.

Table 2. Showing advantages, disadvantages and conceptual design cone fishways

TYPE	DESCRIPTION	ADVANTAGES	DISADVANTAGES
Concrete cone Full width Partial width. Dog-leg –	Consists of a channel with steps to form a hydraulic gradient of approximately 1:20 Steps have fabricated cones installed as ridges to create a pool upstream and a small drop downstream. Gaps between the ridge rocks afford passage for smaller fish at low flows. 300 mm pool depth at cease to flow High flow & low flow slots	Geometric design means that this can accurately control flow rate down fishway. Has been used elsewhere throughout Queensland with excellent results. Has a reasonably high degree of redundancy (i.e. if partly blocked by debris, etc., will still function in rest of fishway. All reinforced concrete components make this design less susceptible to damage during high flows	Entrance location needs to be considered or fish won't use the fishway. It needs to be suitable for different discharge flows / conditions. Precast components can be costly, however may be comparable to rock that has to be imported from long distance. Highly engineered appearance may not fit with the natural character of the waterway



Vertical-slot Fishways

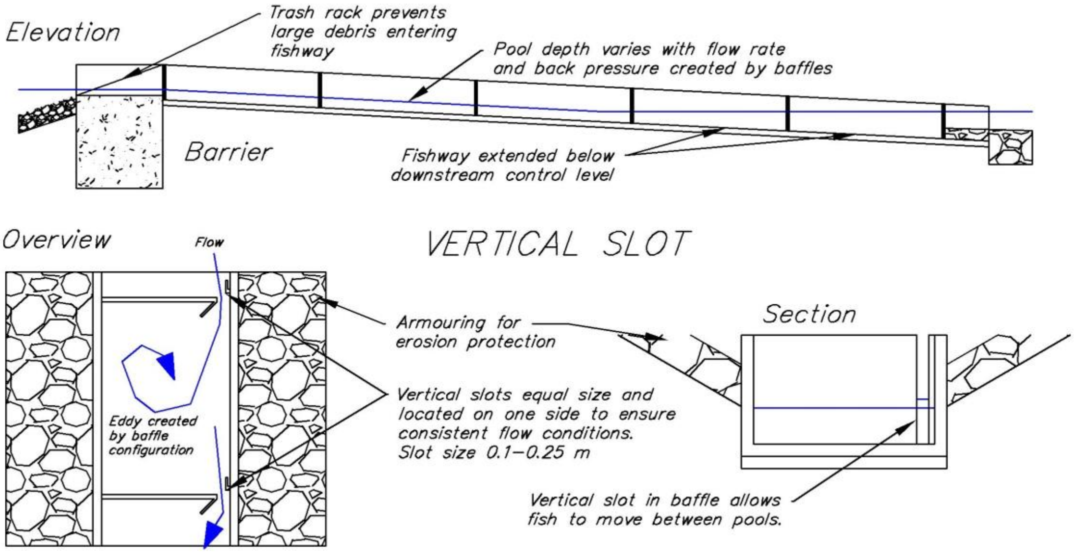
Vertical-slot fishways have been widely used throughout Australia and proven successful at passing a variety of species. Vertical-slot fishways operate by creating a series of pools separated by baffles that have a narrow vertical-slot on one side (Table 3). The baffles are installed into a concrete channel constructed on a minimum gradient of 1:20. As water travels through the fishway eddies are created by the baffles which form resting areas for the fish. As with the other fishway styles, the number of baffles needed is determined by the height of the barrier and the desired pool size. Typical pool size of vertical-slot fishways is 1- 2 m by the width of the concrete channel (1-2 m). As the vertical-slot extends the height of the baffle pool depth varies with flow rate, i.e. the more water travelling through the fishway, the greater the depth of the pools. As with the other fishways the entrance of a vertical-slot fishway is usually set below the level of the downstream control point to account for potential stream bed erosion.

Figure 8. Showing a vertical-slot fishway on Waterpark Creek, Byfield. Note: The partial width nature and small entrance of vertical-slot fishways means it may be difficult for fish to locate the entrance.

Vertical-slot fishways (Figure 8) are limited to partial width in all but very small streams. As with all partial width designs, entrance positioning and provisions for low flow conditions is important and 'dog-legs' are often incorporated into vertical-slot designs to ensure fish are able to locate the entrance. Vertical-slot fishways are more prone to clogging by debris. As this style relies on a single slot in each baffle, a build-up of debris can reduce the efficacy of the fishway and in some instances prevent fish from moving past the obstruction. Vertical-slot fishways are generally fitted with trash racks to prevent large debris from entering the fishway but are ineffective at preventing finer sediments e.g. sand.

Table 3. Showing advantages, disadvantages & design characteristics of Vertical-slot fishways.

TYPE	DESCRIPTION	ADVANTAGES	DISADVANTAGES
Vertical-slot	Consists of a series of constructed cells with internal baffles that create pools and small head drops between each.	Good for large fish species. Good precedence examples of effective fishways. Can provide downstream passage. Can control hydraulic conditions reasonably well.	Small entrance aperture and limited attraction flows can make it difficult for fish to locate the entrance Single slot. Debris lodged in slot has the ability to impede fishway operation Sedimentation / debris issues following a flood or high flow event. Expensive to fabricate baffles and cast concrete Smooth sided walls and baffles may preclude smaller bodied fish species



Culvert Baffles

Vertical Baffles

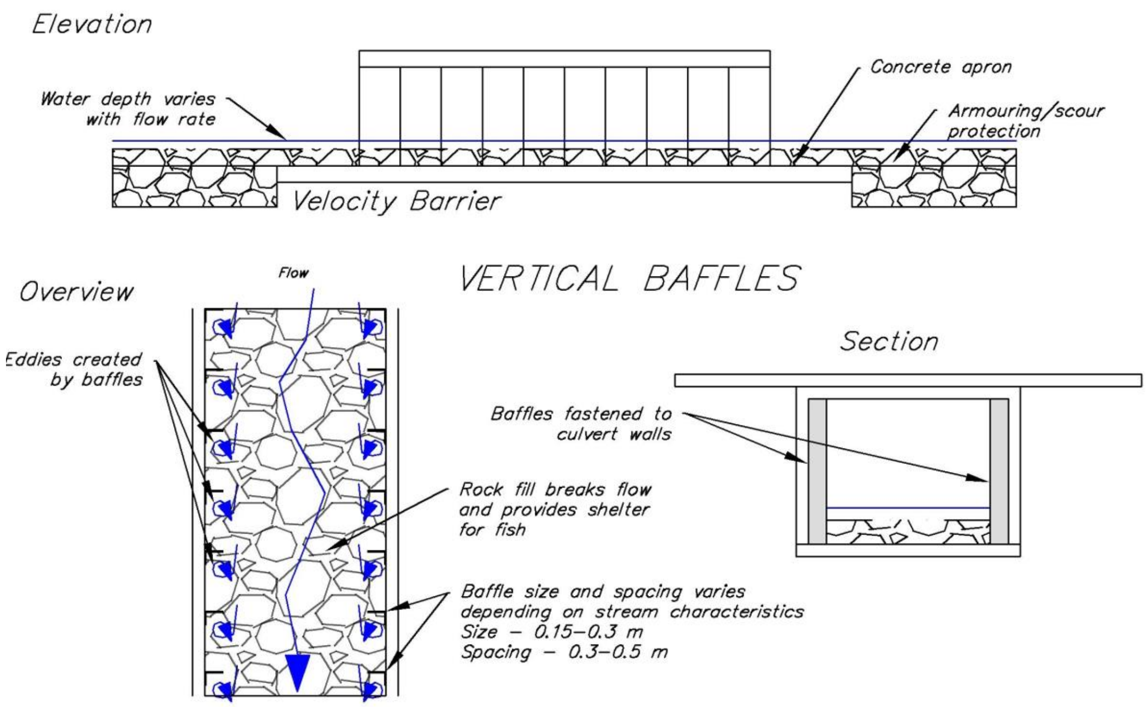
Vertical culvert baffles are an option for improving fish passage through box culverts. The relatively low cost and ability to easily retrofit to existing structures has seen the installation of baffles at many culvert structures throughout Queensland (Table 4). However, unlike horizontal baffles, they do not provide resting pools, which may potentially impact small-bodied, weaker swimming species, particularly over the long distances often experienced through culverts located under road transportation networks. Other potential deficiencies of vertical baffles include their ability to ameliorate shallow water surface barriers through culverts under low flow conditions, which can impact upstream passage of larger bodied species.

Baffle fishways consist of 'L' shaped panels that are fixed to the outer walls of the bank side culvert barrels (Figure 9). The baffles are designed to break flow and reduce water velocity through the barrels. As water passes the baffles, eddies are created on the downstream side and form small resting areas for the fish. The size of the baffles and spacing within the culvert vary depending on the position of the culverts within the system, stream characteristics and culvert configuration. Generally, baffles between 150-300 mm that extend from the base to the culvert roof and are spaced at 300-500 mm for the length of the barrel. Construction material also varies from low cost galvanised 'C' section purlins to fabricated stainless steel baffles that provide extra corrosion resistance. Regular maintenance checks are required for vertical baffles, particularly after flooding, as the baffles occasionally become dislodged, and new baffles retrofitted. Vertical baffles have also been known to corrode, requiring replacement. Advantages and disadvantages of vertical baffles including a conceptual diagram of a single barrel box culvert fitted with baffles is provided in Table 4.

Figure 9. a) Vertical culvert baffles with scour protection (Aims Rd, Townsville) b) Close up view of vertical baffles retrofitted to a culvert c) Vertical baffles in conjunction with a rock-ramp fishway (Sheepstation Creek, Ayr).

Table 4. Showing advantages, disadvantages and conceptual design of vertical culvert baffles

TYPE	DESCRIPTION	ADVANTAGES	DISADVANTAGES
Vertical baffles – culvert barrel/apron	Metal baffles fixed to the outer barrel walls and apron wing walls. Baffle protrusion into culvert barrel – 0.15-0.30 m Spacing between baffles – 0.3-0.6 m	Reduced laminar flow in high flow conditions. Minimises' sediment build-up. Good for downstream passage.	No resting pools. Reduced water conveyance capacity of culverts. Prone to damage from large debris. Corrosion may impact baffles over time No remediation of water surface barrier during low flow conditions



Horizontal Culvert Baffles

Horizontal culvert baffles (Figure 10) are a recent, innovative option for improving fish passage through box culverts. Monitoring has demonstrated that they are highly effective at passing fish, particularly juvenile species, with the fishway in Figure 10 recording a catch rate of 1,371 individual fish per day. Unlike vertical baffles, they provide resting pools for migrating fish (Table 5). Resting pools are important for native fish attempting to ascend past velocity barriers, particularly when these barriers occur for extended distances, such as through culverts located under road transportation networks. Resting areas are even more imperative for small-bodied species which don't possess the swimming abilities of larger bodied species (Rodgers et al., 2014; Domenici, 2001). This is because larger fish have more muscle to propel them through the water (Tillinger and Stein, 1996). Small bodied fish comprise the most common component of fish communities migrating upstream through coastal waterways in Queensland.

Conversely, larger bodied species are more susceptible to shallow water depth barriers often experienced through culverts during low flow conditions, whereby flows can be spread out across multiple culvert barrels. Retrofitting vertical baffles under these conditions would only minimally increase the depth of water through the culverts, and remediation of the water surface barrier would not be achieved. However, the ability of horizontal baffles to incorporate low and high flow slots in-conjunction with resting pools increases the depth of water through culverts, remediating the water surface drop barrier and providing increased fish passage for larger bodied species. The capital cost associated with horizontal baffles may be higher than for vertical baffles, however, this may be offset by the greater design life, improved fish passage and reduced likelihood of damage from flood flows i.e. vertical baffles are prone to dislodging after floods and are often impacted by corrosion over time, requiring replacement.

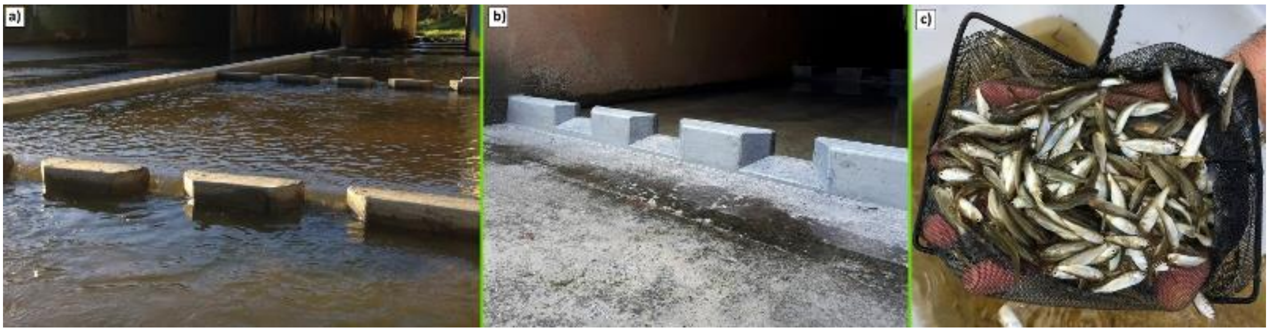
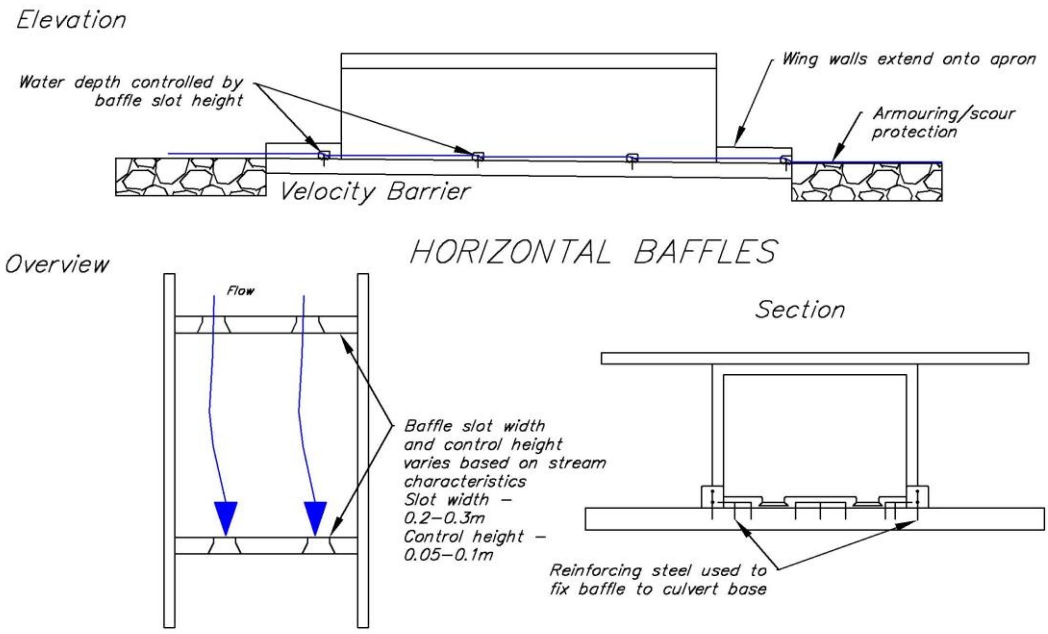


Figure 10. a) Retrofitted horizontal culvert baffles in operation under Paradise Road on Slacks Creek. Note: Nib wall to divert all base attraction flows down the fishway. Prior to remediating this barrier, the flow was spread out across four 2.4 m wide culvert barrels creating a shallow water surface barrier under base flow conditions. b) Horizontal baffles with the boxing recently removed c) Predominantly showing Juvenile sea mullet and striped gudgeon captured successfully ascending through the horizontal culvert baffle fishway at catch rates of 256 and 793 individuals per day respectively.

In addition to the baffles, rock fill is commonly added to the floor of the culvert barrels. This creates a more natural bed and helps improve fish passage by further breaking up flow and providing shelter for fish as they move through the culverts. Culvert structures that consist of multiple barrels and are located on larger streams often incorporate a low flow channel. Low flow channels are formed by setting one or more barrel(s) at a lower level. All water is directed through this channel during periods of low flow and helps maintain an adequate depth for fish to swim past the structure.

Table 5. Showing advantages, disadvantages and conceptual design of horizontal culvert baffles

TYPE	DESCRIPTION	ADVANTAGES	DISADVANTAGES
Horizontal baffles – culvert barrel/apron	Formed/precast concrete baffle fixed to culvert floor. Baffle protrusion into culvert barrel – 0.2 - 0.5 m Spacing between baffles – 2.0 - 5.0 m	Resting pools provided. Minimal reduction in water conveyance capacity of culverts. All reinforced concrete components make this design less susceptible to damage during high flow. Remediates water surface barriers during low flows	Reduced functionality during high flow conditions. Potential for sediment build-up – maintenance consideration.



Greater Brisbane Regional Overview

The South-East Queensland region covers an area of approximately 23,000 km^2 incorporating a total of 14 catchments (SEQ Catchments 2018). The region extends from the Noosa, Maroochy and Mooloolah catchments in the north, out to the upper Brisbane and Lockyer catchments in the west, down through to the regions southern boundaries of the Logan-Albert and Gold Coast catchments in the south. For most of the region, headwaters of major rivers originate in the coastal hinterlands, including the Sunshine and Gold Coast hinterlands as well as the Great Dividing Range, and drain east towards the greater Moreton Bay region.

Figure 11 below displays a regional map of South-East Queensland, with the LGA boundaries outlined in bold (MBRC, BCC, ICC, LCC, RCC and GCCC). This map also shows the defined project boundaries, as coloured waterways identified on the map. The spatial stream layer depicted on the map is the Queensland Waterways for Waterway Barrier Works layer.

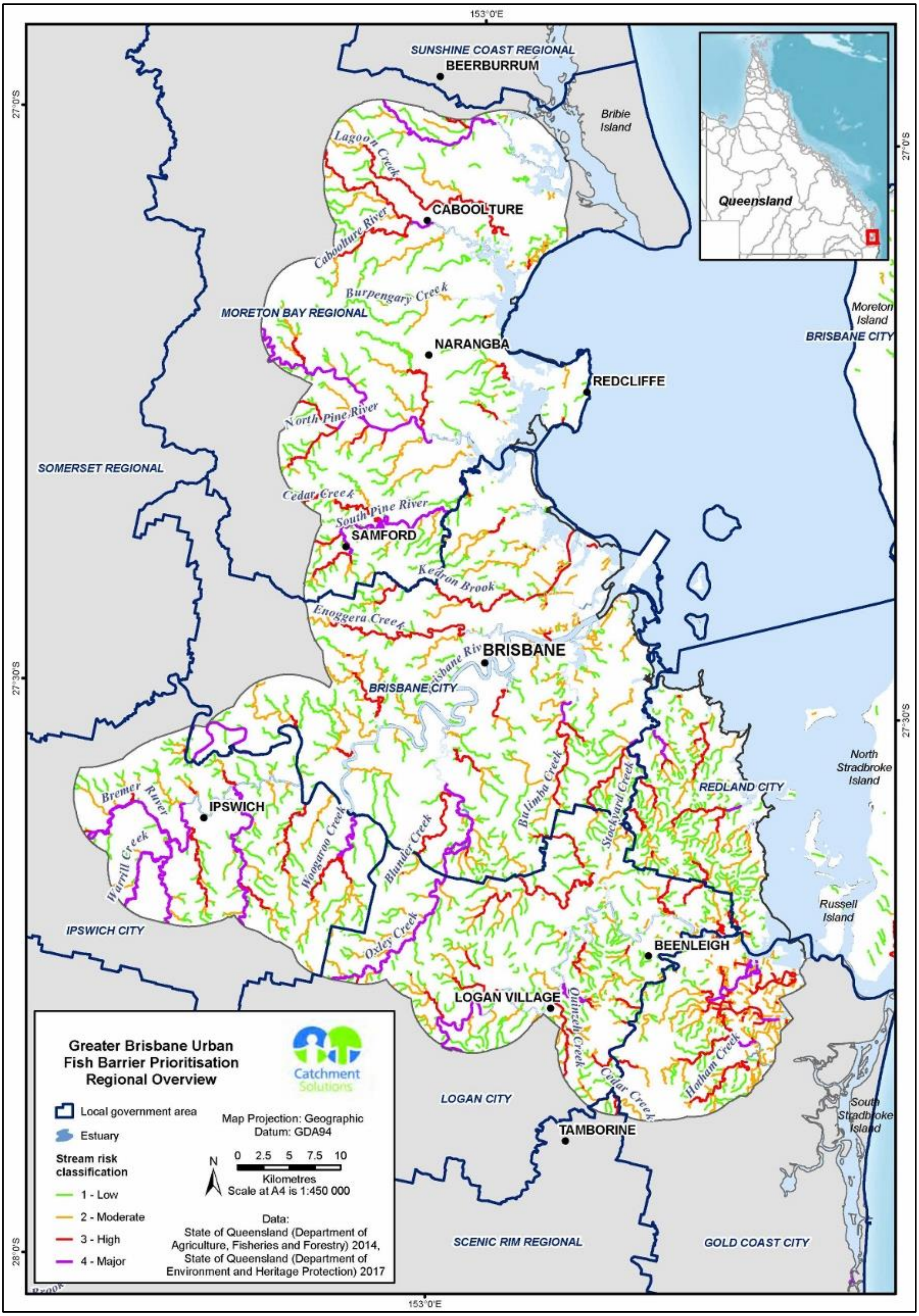


Figure 11. South-East Queensland regional overview, with local government area boundaries shown

South-East Queensland is one of the most highly urbanised and populated regions in Australia, accommodating 3.3 million of Queensland's 4.7 million residents (Queensland Government Statisticians Office 2018). Despite the many areas of exceptional biodiversity in the upper reaches and associated national parks of the regions catchments, the majority of the lower reaches have been cleared or heavily modified due to urbanisation and the pressures associated with population growth (Queensland Government 2017). Generally, current land usage in South-East Queensland is dominated by residential, industrial and commercial development, whilst in the regional districts agricultural land and transport corridors further fragment native wildlife habitats. Infestations of the region by introduced species is also recognised to place further pressure on native flora and fauna, with many localised population decreases of native species observed.

Due to the intensive land use, the overall water quality of most of the regions systems has declined. Clearing of native forests and riparian vegetation has contributed to the decline in water quality and has also had detrimental impacts on instream habitat such as woody debris and vegetation overhangs. De-stabilisation of the river banks and surrounding plains has resulted in extensive erosion and regular sediment run-off following heavy precipitation throughout the region, with high nutrient and pollutant loading causing eutrophication throughout many systems. Run-off has also been dramatically intensified through the extent of impenetrable surfaces such as rooves and roads, deflecting water as opposed to absorbing it. Figure 12 maps the intensity of land usage in South-East Queensland, in which catchment condition was used as important criteria throughout the barrier scoring process. The image clearly illustrates the intensity of land usage in South-East Queensland, with over half of the total project area ranking as the most intensive land use.

Water storage infrastructure throughout the region for domestic, industrial and agricultural supply usage is extensive, with Seqwater owning and operating 26 major dams and 51 weirs which supply up to 90% of the regions drinking water (Seqwater 2016). Whilst undoubtedly serving a purpose for societal welfare, these large, significant head loss barriers cause many issues for the aquatic communities of the catchments they impede (Poff et al. 1997). Not only do they form impassable barriers and fracture longitudinal connectivity, but barriers also impact the natural flow regimes of waterways (Kennard and Balcombe 2014). Changes such as reduced stream flow frequency, diminished flow magnitudes and changes in seasonal flow timings all have confounding impacts on native aquatic assemblages (Lytle and Poff 2004).

Seqwater's total list of 77 owned and operated water storage facilities are only a snapshot of the total number of fish passage barriers in South-East Queensland, with many other gauging stations, weirs, causeways and culvert crossings known to significantly obstruct fish passage within the region (Kennard and Balcombe 2014).

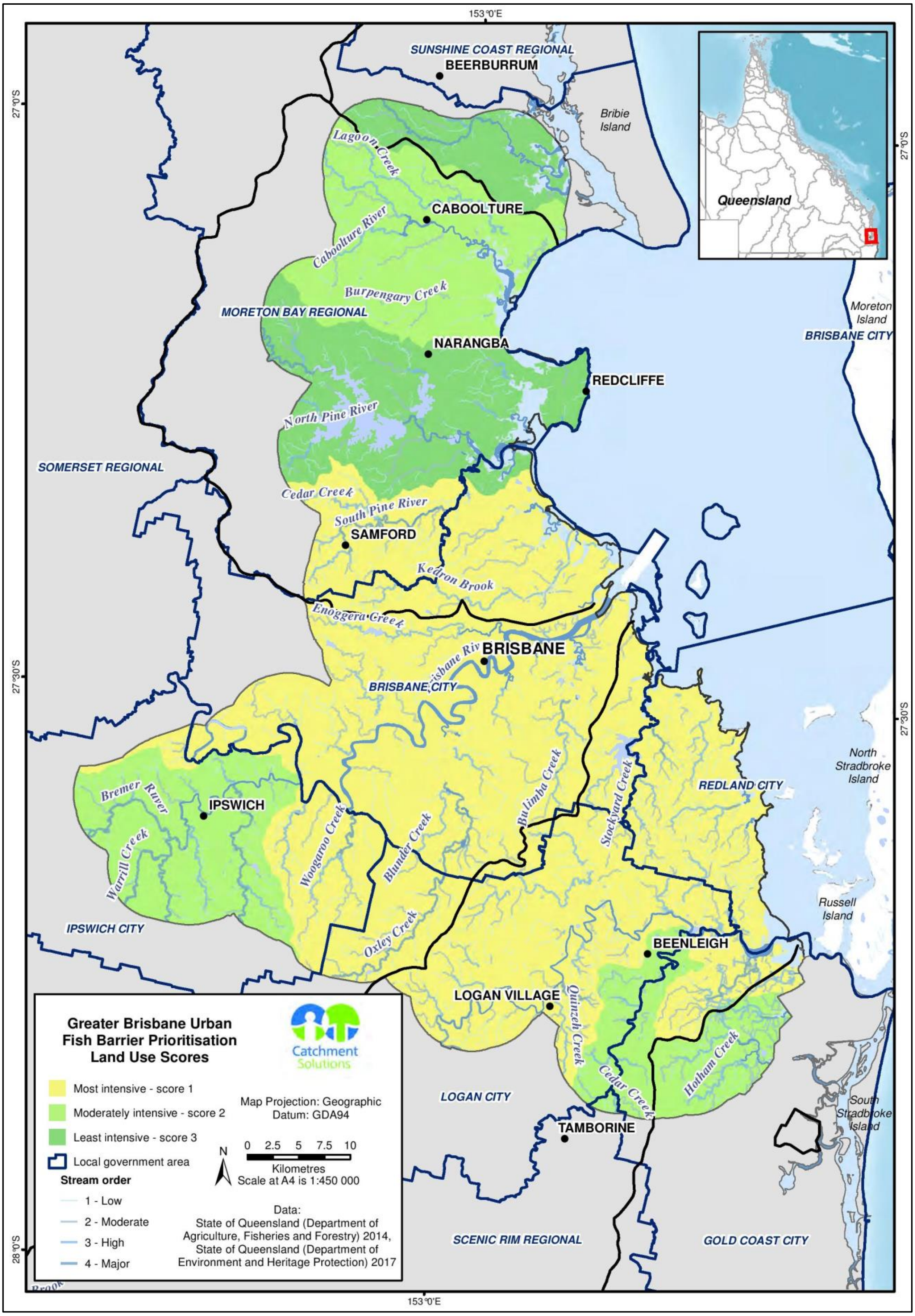


Figure 12. Map of South-East Queensland with regional land usage highlighted

Fish Migration

For the current study, the definition of diadromy has included fish species that migrate between estuarine and freshwater environments, and that this migration is important to maintain population distribution and aquatic ecosystem health. Fish which undertake migrations between these two contrasting environments have to overcome significant physiological challenges, including overcoming the osmotic barrier between saltwater and freshwater. Migration can also impact the fitness and survival of fish, requiring energy allocation for swimming and increasing the risk of mortality during migration (Miles, 2007). Fish which migrate between saltwater and freshwater environments do so at great cost, and therefore these migrations must be important.

For the purpose of this report, the term 'diadromous' is used for fish in which migration between estuarine and freshwater environments is obligate in order to (adapted from Mallen- Cooper 1999):

- Contribute to its abundance,
- Maintain its natural distribution,
- Maintain aquatic ecosystem health, and
- For those species of fisheries importance; maintain sustainable fisheries

Greater Brisbane Freshwater Fish Communities Overview

In undertaking a fish passage barrier prioritisation in the Greater Brisbane region, it was fundamental to the overall project outcomes to have a sound understanding of the fish species present within the region. Having this understanding is critical when evaluating potential fish passage barriers, as knowledge on the biological processes and different life-cycle approaches which drive the species that inhabit these waterways, can potentially intensify the impacts of certain barrier types. This is particularly significant when it comes to understanding the diadromous fish present within waterways, as these migratory species require unimpeded passage from saltwater riverine reaches of the system right up to the upstream freshwater stream reaches (Harris 1988; Rolls et al. 2014).

When undertaking a review of the freshwater fish species present within the project area, it was decided that an approach would be taken to make the species list as current as possible. To do this, Queensland Government Ecosystem Health Monitoring Program (EHMP) data was obtained, which includes all fish survey data from 110 surveyed waterways within the 14 catchments of South-East Queensland. These fish community surveys have been undertaken annually since 2003 and are used as grading criteria in the annual *'Ecosystem Health Report Cards'* produced by the program. To this dataset, all of Catchment Solutions own recorded fish surveys over the last five years within freshwaters of South-East Queensland were added, which provided several additional species to the overall species list.

The finalised list comprised of a total of 59 fish species being identified within freshwaters of South-East Queensland since 2003. This can be broken down into five species categories based on migration classifications (Table 6);

- 4 Marine vagrant species - Species which occasionally, through natural dispersal, will enter freshwater habitats for periods of time, however biologically are not obliged to do so.
- 18 Diadromous species - True migratory species which at some point, and often at regular intervals, require unimpeded access between fresh and saltwater to complete their life-cycle and maintain species distribution.
- 27 Potamodromous species - Species which migrate wholly within freshwater habitats, and can complete their entire life-cycle within these environments.
- 1 Insufficient knowledge species - The snub-nosed garfish (*A. sclerolepis*) was unable to be categorised into a distinguished migration classification, as this species is known to complete its entire life-cycle in freshwater habitats, and in riverine saltwater habitats.
- 9 Pest fish species - These species are all potamodromous fish and exist wholly within freshwater environments, however were kept separate from native fish in their own classification.

This dataset displays the diverse range of species that exist within South-East Queensland streams, with almost half (44%) of the native fish population found within freshwaters of the region requiring unimpeded access to estuarine habitats to maintain sustainable populations. The number and type of barriers within aquatic ecosystems and the distance to the first low-passability barrier in each high ordered stream can often be the limiting factor in determining the health of a particular waterway's fish assemblage. High ordered and connected lowland aquatic ecosystems in the region generally contain diverse and abundant fish communities, with a high proportion of diadromous species. The cumulative impact of barriers along high ordered steams has the ability to reduce upstream fish diversity, particularly diadromous species, and in some instances may cause localised extinctions upstream of the barrier (Bunn and Arthington, 2002). Therefore, the amount of connected in-stream habitat longitudinally from the tidal interface to the first barrier is extremely important. In summary, the greater the amount of connected in-stream habitat, the greater the diversity and abundance of diadromous species, ultimately resulting in better condition and more resilient fish communities.

The number of in-stream barriers located within streams significantly reduce the ability of diadromous species to reach upstream nursery areas. On occasions, diadromous species may be able to use intermittent high flow conditions that 'drown out' barriers, enabling them to ascend upstream, but only if they are present at the barrier when the barrier experiences these conditions, and possess swimming abilities sufficient to ascend past the barrier. The likelihood of the 'right' conditions prevailing at the next upstream barrier, and the next after that, is reduced each time. Additionally, juvenile life stages of some diadromous fish species appear to favour the tail end of high flow conditions through to low flow conditions when undertaking their upstream migration. This may be due to juvenile species not possessing the same swimming abilities as adults, as they don't have the same muscle mass to propel them through the water. Therefore, 'drown out' conditions may predominantly favour stronger swimming returning adults. The cumulative impact of barriers and amount of connected in-stream habitat between barriers, are extremely important spatial attributes influencing the composition of Greater Brisbane fish communities.

It was determined that 66% of the native species found in the regions streams are deemed to be of socio-economic importance through conservation status, commercial, recreational, indigenous and aquarium trade fisheries. Species including Australian bass (*P. novemaculeata*), jungle perch (*K. rupestris*), sea mullet (*M. cephalus*) and freshwater mullet (*T. petardi*) are all key diadromous species with significant economic value. Further to this, four species present in the region are listed as threatened species on the EPBC Act (1999), including the endangered Mary River cod (*M. mariensis*) and Oxleyan pygmy perch (*N. oxleyana*), the vulnerable Queensland lungfish (*N. forsteri*) and Honey blue-eye (*P. mellis*). In-addition to these four species, the status of freshwater mullet (*T. petardi*) and the potential listing of this species under the EPBC Act (1999) is currently under review. This is due to significant declines in population abundance across its known range.

Note, this species list is an overall species list for South-East Queensland and all of these species were considered in the barrier prioritisation process. Some of these species have been surveyed within the defined project catchments, however not within defined project boundaries. For example, headwaters of the Brisbane River catchment were outside the defined project boundary, whereas the lower reaches of the Brisbane River catchment were within the project boundary, however, all fish species recorded in the Brisbane River catchment have been included. Additionally, some of these species in the table have been surveyed within South-East Queensland, however not within the defined project catchments, for example, catchments between and including Burpengary and Doonan Creeks were outside project boundary, yet fish species recorded in these catchments have been included. These species have been identified throughout the species list table.

Figure 13. Showing fish species occurring in SEQ waterways. See Table 6 for common and species name.

Table 6. Freshwater fish species recorded in SEQ waterways, including migration class, common name, species name and importance to commercial, recreational, indigenous or aquarium trade fisheries. Note: Letter e.g. (A) after common name refers to species with a fish image in Figure 13 above.

Migration Classification	Common name	Species	Importance
Marine Vagrant (n= 4)	Bull shark	*Carcharhinus leucas*	C, R
	Dusky flathead	*Platycephalus fuscus*	C, R, I
	Estuary glassfish (R)	*Ambassis marianus*	-
	Yellowfin bream (S)	*Acanthopagrus australis*	C, R, I
Diadromous (n= 18)	Australian bass (N)	*Percalates novemaculeata*	R, I, A
	Bullrout (W)	*Notesthes robusta*	A
	Common silverbiddy	*Gerres subfasciatus*	-
	Cox's gudgeon	*Gobiomorphus coxii*	-
	Empire gudgeon (D)	*Hypseleotris compressa*	A
	Freshwater mullet (V)	*Trachystoma petardi*	R, I
	Fork- tailed catfish (M)	*Arius graeffei*	I, A
	Jungle perch (H)	*Kuhlia rupestris*	R, I, A
	Lamprey species[2]	*Mordacia sp.*	-
	Large- mouth goby	*Redigobius macrostoma*	-
	Long- finned eel (B)	*Anguilla reinhardtii*	C, R, I
	Pacific shortfin eel	*Anguilla australis*	C, R, I
	Roman- nosed goby	*Awaous acritosus*	-
	Sea mullet (Q)	*Mugil cephalus*	C, R, I
	Speckled goby (F)	*Redigobius bikolanus*	-
	Striped gudgeon (G)	*Gobiomorphus australis*	A
	Tamar goby[2]	*Afurcagobius tamarensis*	-
	Tarpon (X)	*Megalops cyprinoides*	R, A
Potamodromous (n= 27)	Agassizi's glassfish (A)	*Ambassis agassizii*	A
	Australian smelt (J)	*Retropinna semoni*	A
	Banded grunter (K)	*Amniataba percoides*	A
	Bony bream (O)	*Nematalosa erebi*	-
	Common galaxias[2]	*Galaxias maculatus*	-
	Crimson- spotted rainbowfish (L)	*Melanotaenia duboulayi*	A
	Dwarf flathead gudgeon (T,b)	*Philypnodon macrostomus*	-
	Eel- tailed catfish	*Tandanus tandanus*	R, I, A
	Firetail gudgeon (E)	*Hypseleotris galii*	A
	Flathead gudgeon (T,a)	*Philypnodon grandiceps*	I
	Unspecked hardyhead	*Craterocephalus fulvus (I)*	A
	Honey blue- eye[2]	*Pseudomugil mellis*	S, A
	Marjorie's hardyhead	*Craterocephalus marjoriae*	-

	Mary River cod (P)	*Maccullochella mariensis*	S
	Mouth almighty	*Glossamia aprion*	A
	Ornate rainbowfish	*Rhadinocentrus ornatus*	A
	Oxleyan pygmy perch[2]	*Nannoperca oxleyana*	S, A
	Pacific blue- eye (C)	*Pseudomugil signifer*	A
	Purple- spotted gudgeon	*Mogurnda adspersa*	A
	Queensland lungfish	*Neoceratodus forsteri*	S
	Rendahl's catfish[1]	*Porochilus rendahli*	I
	Sleepy cod[1]	*Oxyeleotris lineolatus*	A
	Spangled perch (U)	*Leiopotherapon unicolor*	I
	Swamp eel	*Ophisternon sp.*	-
	Unspecked hardyhead	*Craterocephalus fulvus*	A
	Western carp gudgeon	*Hypseleotris klunzingeri*	-
	Yellowbelly	*Macquaria ambigua*	R, I, A
Insufficient Knowledge (n= 1)	Snub- nosed garfish	*Arrhamphus sclerolepis*	R, I
Pest Fish (n= 9)	Carp	*Cyprinus carpio*	-
	Goldfish	*Carassius auratus*	-
	Guppy	*Poecilia reticulata*	-
	Mosquitofish	*Gambusia holbrooki*	-
	Oriental weatherloach	*Misgurnus anguillicaudatus*	-
	Pearl cichlid	*Geophagus brasiliensis*	-
	Platy	*Xiphophorus maculatus*	-
	Swordtail	*Xiphophorus helleri*	-
	Tilapia	*Oreochromis mossambicus*	-

[1] **Species surveyed within project catchments, however not within project boundaries**

[2] **Species surveyed within South-East Queensland, however not within project catchments**

Importance: S= Status, C= Commercial, R= Recreational, I= Indigenous and A= Aquarium

Methods

Greater Brisbane Region

The GB region boundary used for the current study was determined by the Federal Government to align with the Targeted Area funding theme 'Restoring and Maintaining Urban Waterways and Coastal Environments'. The project boundary encompasses all urban and peri-urban catchments surrounding the Brisbane region, from Pimpama River catchment in the south, northwards along the coast to and including Elimbah Creek catchment and west to Ipswich. Headwater reaches of the Brisbane, Caboolture, Bremer and Logan-Albert River systems were outside the project boundary, with the vast majority of the lower and middle reaches of these systems within the project boundary. Smaller coastal rivers and creeks wholly within the project boundary include; South Pine River, Kedron Brook, Oxley, Enoggera, Bulimba, Cedar, Norman, Moggill, Burpengary and King John Creeks to name a few.

Fish Barrier Prioritisation Process

In order to best achieve the defined objectives of the project, a three-stage selection criteria process used and developed by Moore and Marsden (2008) and Moore (2015) was refined and enhanced with the latest innovative river network analysis technology by Hornby (2015). The three stages involved evaluating the biological, social and economic benefits of providing free fish passage past barriers for the environment and local community. Note: All barriers are defined as 'potential' barriers until they have been validated in the field as 'actual' barriers in stage two of the process.

Stage 1. Catchment Scale GIS Analysis – Spatial & Temporal Habitat Characteristics

Stage 1 of the barrier prioritisation involved identifying all 'potential' barriers within the study area using high resolution aerial imagery (Google Earth Pro (GEP) and Queensland Globe (QG)). Barrier information was also acquired from Local Government structure inventories and local community knowledge. A desktop GIS process was then undertaken to efficiently investigate spatial and temporal habitat characteristics associated with each potential barrier on a whole of catchment basis.

Stage 1 of the prioritisation process used a desktop computer running ArcMap 10.2 GIS software. Potential barrier waypoints (kml files) identified using high resolution aerial imagery were imported into ArcMap. Waypoints were assigned to obvious barriers such as weirs and likely potential barriers such as culverts and road crossings. Potential barriers were also assigned to bridges that extend over waterways. Although bridges usually extend over waterways and have no impact on fish passage, on occasions, actual barriers exist underneath the bridge. Waypoints were also assigned along waterways that indicated a barrier may be in place but a structure was not clearly visible. Key barrier traits to look out for in these scenarios include dead trees, which have potentially drowned and died due to the ponding of water caused by a downstream barrier, and 'lake like' large bodies of water that are out of character with the rest of the waterway. On occasions when river reaches comprised dense canopy cover, potential barrier waypoints were assigned when well used vehicle tracks appeared to enter one side of a waterway and exit on the other side on a similar trajectory. This is often a telltale sign indicating a causeway of some description.

Each potential barrier waypoint created in GEP and imported into ArcMap was assigned a unique geo-referenced identification number that remained with the potential barrier throughout the three-stage process. Each identification number contains its own geo-spatial dataset that stores location and geometry data for each individual potential barrier. Identified potential barriers were then assessed against five geo-spatial questions relating to the barrier's position in the catchment, type and amount of available upstream habitat, stream hierarchy (Strahler stream order and gradient), proportion of intensive land use (e.g. sugar cane) and number of barriers downstream.

The 100K Queensland east-coast ordered drainage stream network was utilised as the 'base' waterway data layer while identifying potential barriers. All potential barriers on this stream network were assigned a unique waypoint. Fisheries QLD spatial waterway data layer 'Queensland waterways for waterway barrier works' was utilised as the 'base' waterway data layer during GIS analysis in stage 1. This data layer is derived from the 100K Queensland east-coast ordered drainage stream network, however it includes additional data such as stream slope, flow regime, number of fish present, and fish swimming ability. This additional data was used to produce a stream network layer that categorises waterways based on the level of risk any waterway barrier would pose to fisheries resources on each particular stream. Four categories were created, with some categories having more than one stream order within each, i.e. the highest category 'Major' includes coastal stream orders 4-7, as barriers on these ordered waterways were equally determined to be a major risk to fisheries. At the other end of the scale the 'Low' risk category only included first ordered waterways that discharge directly into the estuary. First ordered waterways that did not intersect the estuary were deemed to have low fish habitat values and were removed from the classification.

The specialised river network GIS processing tool 'RivEX' (Hornby 2015) was used to analyse the 100K Queensland Waterway Barrier ordered drainage stream network, apply attributes, perform quality control, calculate distance between barriers and calculate the number of downstream barriers along the stream network. Each potential barrier was then assigned a score (i.e. 1 - 10) depending on how well the criteria was answered for each question. Scores for all questions were combined and totaled and the final rank after stage 1 determined, i.e. highest total score becoming the highest ranking barrier after stage 1. The following attributes were fundamental for a potential in-stream barrier to be given a high score in stage one of the selection criteria process:

- Located on a high ordered stream,
- Minimal to no barriers downstream,
- Good catchment condition, i.e. minimal intensive land use practices,
- Large area of *available* upstream habitat (distance to the next barrier or top of catchment),
- Barrier located in lower reaches, i.e. close to the sea

Question 1. Stream Hierarchy

Waterways within the Greater Brisbane region were classified into five separate classes based on Fisheries QLD 'Waterway Barrier Works Stream Layer'. Scores were assigned to potential barriers based on the stream risk class they were situated on (Table 7). Potential barriers on major risk waterways score highest. Potential barriers located on first ordered waterways that did not discharge directly into estuarine environments were deemed low priority and were removed.

Table 7: The five stream classes and associated scoring system for Question 1.

Option	Stream classification (represented by colour code)	Stream characteristics	Score
a.	Purple (Major risk)	Strahler stream orders 4-7	10
b.	Red (High risk)	Strahler stream orders 2-3 with low gradient Strahler stream order 3 with medium gradient	5
c.	Amber (Moderate risk	Strahler stream order 3 with high gradient Strahler stream order 2 low/medium gradient	3
d.	Green (low risk)	Strahler stream order 2 with high gradient Strahler stream order 1 within tidal waters	1
e.	*Removed*	Strahler stream order 1 outside tidal waters	0 -removed

Question 2. Catchment Condition

Proportion (%) of intensive land use in each sub-catchment the potential barrier is located in. *Example* 'intensive' land use included; Irrigated cropping, manufacturing and industrial, intensive animal husbandry and residential. *Example* 'non-intensive' land use categories include; conservation and natural environment areas, plantation forestry, wetlands, estuaries and grazing native vegetation (Table 8).

Table 8. Showing proportion (%) of intensive land use and associated scores for each category.

Option	Proportion (%) Intensive land use within the sub-catchment	Score
a.	0%	5
b.	0.1 - 5%	4
c.	5.1 - 15%	3
d.	15.1 - 30%	2
e.	30.1 - 50%	1
f.	>50.1%	0

Question 3. Number of Potential Barriers Downstream

Number of potential barriers downstream along the stream network until the declared downstream limit (DDL) e.g. estuary. *Example:* The first potential barrier upstream from the DDL receives a score of 7. The next barrier upstream receives a score of 5. The 25th barrier receives a score of 0 (Table 9)

Table 9. Number of potentials barriers downstream and associated score.

Option	Number of barriers downstream	Score
a.	0	7
b.	1	5
c.	2 – 4	3
d.	5 – 9	2
e.	≥10	0

Question 4. Distance to Next Barrier Upstream

The total upstream length to the next potential barrier or top of catchment (if there are no barriers) i.e. amount of available upstream habitat if the barrier is remediated. *Example:* 15 km's of stream length (habitat) from barrier 1 to barrier 2, then barrier 1 receives a scores of 4 (Table 10).

Table 10. Stream length (km) to the next barrier or top of catchment categories and associated score.

Option	Stream length (km) to the next barrier/or top of catchment	Score
a.	≥25	5
b.	10 - 24.99	4
c.	5 - 9.99	3
d.	2 - 4.99	2
e.	0.5 - 1.99	1
f.	0 - 0.499	0

Question 5. Barrier's Geographical Position within the Sub-catchment

Question 5 determines the potential barrier's geographic position in the catchment and the amount of stream network inaccessible due to the barrier as a proportion of the total sub-catchment stream network (potential available habitat). This is derived by determining the stream length from the DDL to the potential barrier in question as a proportion (%) of the total stream length in the whole sub-catchment (Table 11). Barriers close to the tidal interface that prevent connectivity to the rest of the catchment score high.

Table 11. Distance (km) of sub-catchment upstream of barrier as a proportion (%) of total sub-catchment

Option	Distance (km) of sub-catchment upstream of barrier as a proportion (%) of total sub-catchment.	Score
a.	80 -100%	5
b.	50 -79.99%	4
c.	20 - 49.99%	3
d.	5 - 19.99%	2
e.	1 - 4.99%	1
f.	0 - 0.99%	0

Stage 2 – Fine Scale, Site- Specific Ecological Assessment

Stage 2 of the prioritisation involves field validation of the top ranked potential barriers (~500) after stage 1 of the process. To achieve this a GPS (Garmin GPSmap76) tracking system was set up in conjunction with a laptop computer using OziExplorer mapping software. This was used to systematically locate the geographic position of each barrier in relation to uniquely identifiable locations (towns, roads, streams), allowing for efficient validation of potential barriers. Once a potential barrier was located and confirmed to be a barrier to fish passage, important information regarding the barrier's physical characteristics were collected. Important barrier parameters collated included: barrier type, number of culverts/pipes, head loss, length, height and width of structure and apron dimensions. Additional information such as photos and site constraint information was also acquired i.e. access for heavy machinery and structure owner.

Detailed ecological information on the stream (Table 13) and flow condition (Table 14), in-stream habitat condition for migratory fish upstream of the barrier (Table 15) and distance from the tidal interface (Table 16) were assessed. Barriers were assigned a score of 1- 5 for each of the ecological criteria. Scores were collated and added to stage 1 scores to obtain an overall score and rank after stage 2. The ecological questions and associated scoring system used to prioritise barriers in the second stage are as follows:

Question 6. Barrier Type

Assessment criteria for question 6 (barrier type) is displayed below in Table 12. Note: Dam or weir refers to all barriers with a water surface drop. The height of the barrier refers to the head loss over the entire structure. Tidal barrage refers to a barrier located on the tidal interface and/or the tide reaches the barrier.

Table 12. Barrier type assessment criteria and associated score.

Option	Barrier Type	Score
a.	Tidal barrage or bund.	5
b.	Dam, weir or culvert apron drop >1.5 m high	4
c.	Dam, weir or culvert apron drop 0.8 m – 1.5 m high.	3
d.	Dam, weir or culvert apron drop <0.8 m high or culvert aperture <60% of bankfull stream width.	2
e.	Culvert aperture that spans >60% of bankfull stream width.	1
f.	No barrier – DO NOT SCORE REMAINING CRITERIA	

Question 7. Stream/Riparian Condition

Riparian corridor condition within 250 m upstream and downstream of the barrier were assessed on-site. High quality, undisturbed sites are characterised by no apparent clearing of riparian vegetation or bed and bank degradation, invasive weeds, or visible pollution. Assessment criteria for this question is displayed below in Table 13.

Table 13. Stream/riparian condition assessment criteria and associated score

Option	Stream/Riparian Condition	Score
a.	High quality-undisturbed.	5
b.	Low disturbance (<25% of upstream habitats degraded as above).	4
c.	Moderate disturbance (25-50% of upstream habitats degraded as above).	3
d.	High disturbance (51-75% of upstream degraded).	2
e.	Very high disturbance (>75% of upstream degraded).	1

Question 8. Stream Flow Classification

Stream flow characteristics used to assess and score question 8 are displayed below in Table 14.

Table 14. Stream flow classification assessment criteria and associated score.

Option	Water Supply/Quantity	Score
a.	High stream permanence with perennial base flow.	5
b.	High stream permanent via supplemented flow.	4
c.	Stream very occasionally dries up with refuge pools.	3
d.	Stream dries seasonally with refuge pools.	2
e.	Stream dries seasonally with no refuge pools.	1

Question 9. In-stream Habitat Condition – For Migratory Species

In-stream habitat condition within 250 m upstream and downstream of the site were assessed on-site. Assessment criteria options and scores are displayed below in Table 15.

Table 15. Upstream fish habitat condition for migratory species assessment criteria and associated score.

Option	Upstream Fish Habitat Condition	Score
a.	Excellent. Diverse and abundant fish habitat (i.e. large woody debris, pool-run-riffle habitats, macrophytes, undercut banks, deep pool refuge)	5
b.	Good. Reasonable amount of suitable fish habitat.	4
c.	Moderate amount of suitable fish habitat.	3
d.	Poor. Little suitable fish habitat.	2
e.	Very poor. Little or no suitable fish habitat.	1

Question 10. Proximity to Estuary

Proximity to estuary assessment criteria and scores (question 10) are displayed below in Table 16.

Table 16. Proximity to estuary assessment criteria and associated score.

Option	Proximity to Estuarine Habitats	Score
a.	In the estuary or on the tidal interface	5
b.	< 500 m from the tidal interface	4
c.	500 m – 2 kms from the tidal interface	3
d.	>2 kms - <5 kms from the tidal interface	2
e.	>5 kms from the tidal interface	1

Stage 3 – Social, Economic and Fisheries Productivity Prioritisation

The third stage of the prioritisation process involved investigating the social, economic and fisheries productivity benefits of barrier remediation. Importantly, this stage considered the net benefits of improving connectivity versus the economic cost of remediation. This was achieved by assessing all ranked barriers after stage 2. Barriers that can be remediated with low cost fishways while increasing fisheries productivity or restoring vulnerable fish species score high, whereas barriers requiring technical and expensive fishways score lower. Similar to the previous stages of the prioritisation, each criterion contained a question with a range of answers. A separate score (1-5) was assigned for each answer. After all barriers had been analysed, scores were collated, with the highest scoring barrier becoming the top ranked barrier in the GB region. The end result of the third stage is a priority ranked list of the top 50 barriers to fish migration in the GB region. See Appendix 1 for priority ranked list (top 50), including remediation cost and fishway type required.

The following attributes were fundamental for in-stream barriers to score well in this stage three:

- Low cost to remediate,
- Suitable site access for heavy machinery e.g. excavators & concrete pumping trucks,
- Landholder permission to remediate barrier,
- Fishway to benefit listed or restricted species,
- Fishway to benefit commercial and/or recreational and/or indigenous fisheries productivity

The social, economic and fisheries productivity questions and associated scoring system used to prioritise barriers in the third stage included:

Question 11. – Estimated Cost

Estimated cost to undertake fishway design, organisation, construction, supervision and approvals can be seen below in Table 17. Fishway monitoring *not* included in cost estimates.

Table 17. Estimated remediation cost assessment criteria and associated score.

Option	Estimated Remediation Cost	Score
a.	Low cost: <$40 k i.e. Removal, small rock-ramp (RR) or short culvert baffle (CB) fishway	5
b.	Low- moderate cost: $40 - $80 k i.e. Removal, medium RR, long CB or small cone (C) fishway	4
c.	Moderate cost: $81 - $120 k i.e. Removal, high RR/small-medium size C or VS fishway	3
d.	Moderate- high cost: $121 - $500 k i.e. Removal, by-pass RR, medium size C or VS fishway	2
e.	High cost: > $500 k i.e. Removal, large size technical fishway i.e. fish lift or VS fishway	1

Question 12. – Community & In-kind Support

What local community, financial or in-kind support is available? Community support may refer to local government/community, landcare or NRM group undertaking and/or prioritised to undertake rehabilitation projects along the waterway. Location of project must be in close proximity to barrier site or within sub-catchment. Access refers to the ability of heavy machinery to reach the site and/or landholder/asset owner permission to remediate barrier. Assessment criteria and scores for question 13 are displayed below in Table 18.

Table 18. Community and in-kind support assessment criteria and associated score.

Option	Community & In-kind Support	Score
a.	Easy access, good community, financial or in-kind support available	5
b.	Easy access, some community, financial or in-kind support available	3
c.	Easy access, no community, financial or in-kind support available	1
d.	No access or no community, financial or in-kind support available	0

Question 13. – Conservation Significance

Will improved connectivity have a positive impact on the conservation of listed species? Assessment criteria and scores for question 13 are displayed below in Table 19.

Table 19. Conservation significance assessment criteria and associated score.

Option	Conservation Significance	Score
a.	Listed species present.	5
b.	Species that are rare or restricted within the region (but not rare or restricted outside the region, i.e. jungle perch).	3
c.	Only common or abundant species within the region present.	1

Question 14. – Fisheries Productivity and Economic Benefits

Will the species benefited improve commercial harvest, recreational or indigenous fishing opportunities? Assessment criteria and scores for question 14 are shown below in Table 20.

Table 20. Fisheries Productivity and economic benefit assessment criteria and associated score.

Option	Fisheries Productivity & Economic Benefits	Score
a.	High benefit to commercial and/or recreational and/or indigenous fishery species.	5
b.	Moderate benefit to commercial and/or recreational and/or indigenous fishery species	3
c.	Small benefit to commercial and/or recreational and/or indigenous fishery species	1
d.	No benefit to commercial and/or recreational and/or indigenous fishery species	0

Question 15. – Barrier Passability

Barrier passability (barrier transparency) – How often are fish potentially able to ascend past the barrier?

Table 21. Barrier Passability assessment criteria and associated score.

Option	Barrier Passability	Score
a.	**Low Passability** - Rarely drowns out (e.g. average 1 or less flow event per/yr), - Dams and weirs >1.5 m head loss, - Causeway >2 m high with culvert aperture <20% bank full stream width & head loss >1 m, i.e. raised culvert and/or raised culvert with apron drop	5
b.	**Medium Passability** - Occasionally drowns out (e.g. average 2-5 times per/yr), - Weir, causeway, raised culvert or culvert apron drop with head loss = 0.25 – 2 m, - Velocity through culverts may exceed swimming ability of fish during medium & high flows, - Culverts/pipes that span <40 % of bank full stream width	3
c.	**High Passability** - Frequently drowns out (most flow events), - Weir, causeway, raised culvert or culvert apron drop with head loss 0.12 - 0.25 m, - Culverts/pipes that span >40 % of bank full stream width, - Culverts - Barrier only for small proportion of flows i.e. velocity barrier during high flows only or shallow water surface barrier only during low base flows	1

Results

Stage 1 - Catchment Scale GIS Analysis

A total of 13,629 potential in-stream barriers were identified (Figure 16). Ipswich City Council (ICC) recorded the highest rate of potential barriers per km² at a rate of 4.84 potential barriers per km², followed by Logan City Council (LCC), Redland City Council (RCC), Moreton Bay Regional Council (MBRC), Gold Coast Council (GCCC) and Brisbane City Council (BCC) with 4.38, 4.20, 4.18, 3.76 and 2.48 PB's per km² respectively. Following the identification of potential barriers, those that were not located on Fisheries QLD fish passage stream risk classification waterway layer were removed from further assessment, leaving 4,916 potential barriers that were assessed against stage 1 criteria. Three potential barriers received the equal highest stage 1 score of 29 out of a possible 32 points; Elimbah Creek Tidal Causeway, Mt Crosby Weir on the Brisbane River and Kerkin Road Tidal Floodgates on the Pimpama River. The Caboolture River Barrage and Behm Creek Tidal Floodgates each recorded the second highest score in stage 1 with 28 points.

Stage 2 - Fine Scale Site Specific Ecological Assessment

A total of 522 potential barriers were assessed in the field during the second stage of the prioritisation. Actual barriers to fish passage accounted for 264 (51%) of the field validated potential barriers (Figure 17), the remaining 258 non-barriers predominantly consisted of bridges, logs (Figure 14), bed control structures and full-width culvert configurations constructed within the stream bed and/ or with a low flow channel and roughening. A further 217 potentials barriers were removed via desktop that were identified on local government structure inventories and confirmed by respective council officers as total span bridges. The 264 fish barriers were assessed against site specific ecological criteria set out for stage 2, before advancing to stage 3 of the prioritisation process. The tidal causeway barrier on Elimbah Creek (barrier ID 3728) was the highest scoring barrier in stage 2, scoring 23 out of a maximum 25 points, to bring its combined stage 1 and 2 score to 52 points and an overall rank of 1. Four fish barriers recorded the equal second highest score (22) in stage 2; Luscombe Weir on the Albert River (ID 10352), Caboolture River Barrage (ID 13941), and Pimpama River (ID 13801) and Behm Creek (ID 13800) Tidal Floodgates.

Figure 14. Showing example potential barriers identified via aerial imagery & assessed in the field as not affecting fish passage

Stage 3 – Social, Economic and Fisheries Productivity Prioritisation

The third and final stage involved assessing the top 264 ranked barriers after stage 2. The end product was a priority ranked list of the top 50 barriers to fish passage in the Greater Brisbane (GB) region. The top-ranking barrier in stage 3 was the DNRM gauging weir on Warrill Creek (ID 8231) with a score of 20 out of a possible 25 points. Scores for the three stages were totalled to acquire the final priority rank. The Caboolture River Barrage acquired the highest score after 3 stages (70 points) becoming the number one ranked priority fish barrier in the GB region, followed by Elimbah Creek Tidal Causeway with 69 points and an overall rank of two (Table 22). Luscombe Weir on the Albert River and Mt Crosby Weir (ID 12850) on the Brisbane River each scored 68 points and an overall rank of three, followed by the Pimpama River Tidal Floodgates and Stanmore Road Causeway on the Albert River equal with a score of 67 points and a rank of five. The location and priority rank of the top 50 barriers is shown in Figure 18. Details of the top 50 priority ranked barriers including remediation options and indicative estimated costs are provided in Appendix 1.

Remediated Barriers

Four high priority ranked barriers were remediated as part of this project: Berrys Weir on the Bremer River (overall rank 7th), Leitchs Crossing on the South Pine River (11th), Paradise Road Causeway on Slacks Creek (36th)(Figure 15) and Hilliards Creek Weir (36th). These remediated barriers have been removed from the three-stage scoring assessment found within this report. The location of these remediated barriers and their associated fishways can be seen in Figure 16. Case studies with information regarding fishway type and monitoring results can be found in Appendix 2.

Figure 15. Showing one of the four priority ranked barriers remediated as part of this project; Slacks Creek, (Paradise Road) 17 ridge rock-ramp and horizontal culvert baffle fishway (photo courtesy of Leo Lee).

Table 22. Top 36 priority ranked fish barriers, including: total score after each assessment stage, overall final rank, barrier ID, barrier name and configuration and name of waterway each barrier is located on.

Barrier ID	Waterway	Barrier Configuration/Name	Stage 1 Score	Stage 2 Score	Stage 3 Score	Final Rank
13941	Caboolture River	Tidal Weir- ~3 m head loss (Redundant structure)	28	22	20	**1**
3728	Elimbah Creek	Tidal Causeway- ~1 m head loss and small pipe culvert	29	23	17	**2**
10352	Albert River	Weir– Luscombe weir (Redundant structure)	27	22	19	**3**
12850	Brisbane River	Weir- Mt Crosby Weir	29	20	19	**3**
13801	Pimpama River	Tidal Flood Gates- Kerkin Rd	29	22	13	**5**
10351	Albert River	Tidal Pipe Causeway- Stanmore Rd	27	21	16	**5**
4374	Tingalpa Creek	Dam- Leslie Harrison Dam	27	21	15	**7**
13800	Behm Creek	Tidal Gates- Jacobs Well Rd	28	22	13	**7**
218	South Pine River	Culvert Causeway & Apron Drop- Bunya Crossing	27	16	19	**9**
12199	Enoggera Creek	Tidal Weir- Hulme St, 1.2 m head loss	25	21	15	**10**
2279	North Pine River	Dam- North Pine Dam	26	18	15	**11**
2252	North Pine River	Culvert Causeway & Apron Drop- Young's Crossing	26	18	14	**12**
8231	Warrill Creek	DNRM V-Notch Gauging Weir- ~800 mm head loss	22	15	21	**12**
8933	Bremer River	DNRM V- Notch Gauging Weir- ~300 mm head loss	25	14	19	**12**
4876	Hilliards Creek	Causeway & Buried Pipe- Fellmonger Pk	20	19	18	**15**
4170	Scrubby Creek	Causeway & Apron Drop– Queens Rd	20	19	18	**15**
13807	Warrill Creek	Gabion Basket and Sheet Pile Weir- ~ 1 m head loss	23	15	19	**15**
13911	Hotham Creek	Tidal Bund – Private Property	24	18	14	**18**
10719	King John Creek	1 x Small pipe + 300 mm drop - Private Property	26	17	13	**18**
5810	Sandy Creek	Tidal Floodgates - Loves Rd - Main West Arm	23	17	15	**20**
11864	Norman Creek	Apron Drop- ~300 mm drop into Estuary – Hanlon Pk	23	16	16	**20**
2107	Freshwater Creek	Tidal Bund - Further investigation required during flow	26	18	10	**22**
5807	Sandy Creek Trib.	Tidal Gates (East)- School Rd	23	16	15	**22**
2278	North Pine River	Weir - 3 m high @ Petrie Town- Seqwater	22	16	16	**22**
13992	King John Creek	1 x small pipe + 500 mm drop into Estuary	26	15	13	**22**
12433	Moggill Creek	Old pipes & concrete - 750 mm head loss - Moggill Rd	19	19	15	**26**
2277	North Pine River	Causeway + 2 small pipes - next to sporting fields	23	16	14	**26**
4890	Hilliards Creek	1.5 m high Weir + culverts @ DPI Research St.	17	17	19	**26**
7083	Quinzeh Creek	1.5 m large rock weir on estuarine interface	19	20	14	**26**
13942	Waraba Creek	Weir- Waraba Weir ~1.5 m head loss	17	16	20	**26**
13996	Cabbage Tree Creek	Weir- ~500 mm rock weir- Est interface @ AFL oval	20	20	13	**26**
2106	Freshwater Creek	Bund - Further investigation during flow	24	18	10	**32**
9649	Bundamba Creek	Weir- Rock/Bed Control	26	12	14	**32**
12435	Moggill Creek	2 x Small pipes + 300 mm apron drop @ Kilkivan Ave	18	18	16	**32**
6388	Scrubby Creek	Relic Causeway/weir - 0.8 m high - D/S Logan Motorway	17	17	18	**32**
6387	Scrubby Creek	Weir, Small Pipe & Apron Drop- ~1.5 m, Gilmore Rd	17	17	18	**32**

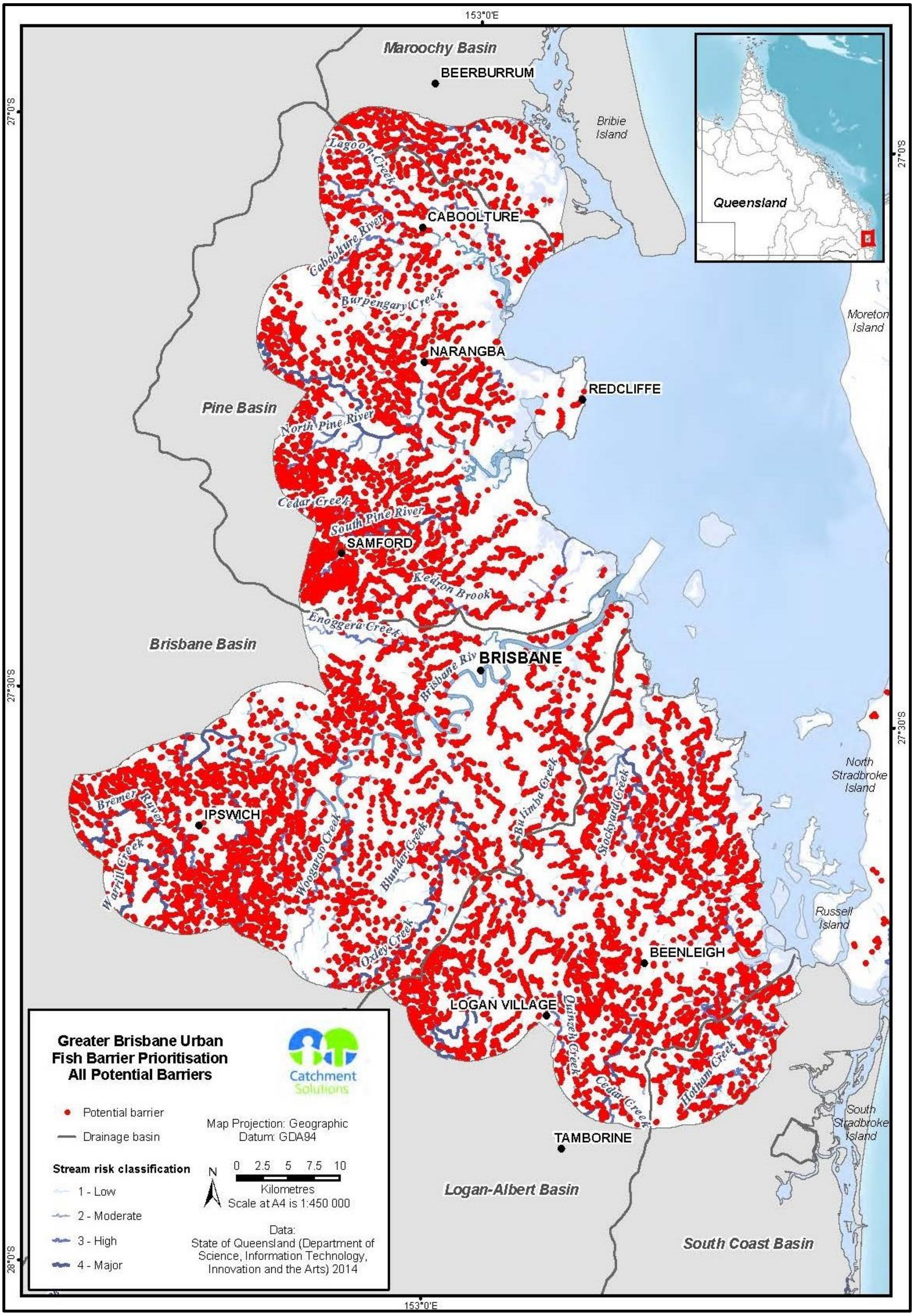


Figure 16. Locations of 13,629 potential barriers identified in the current study.

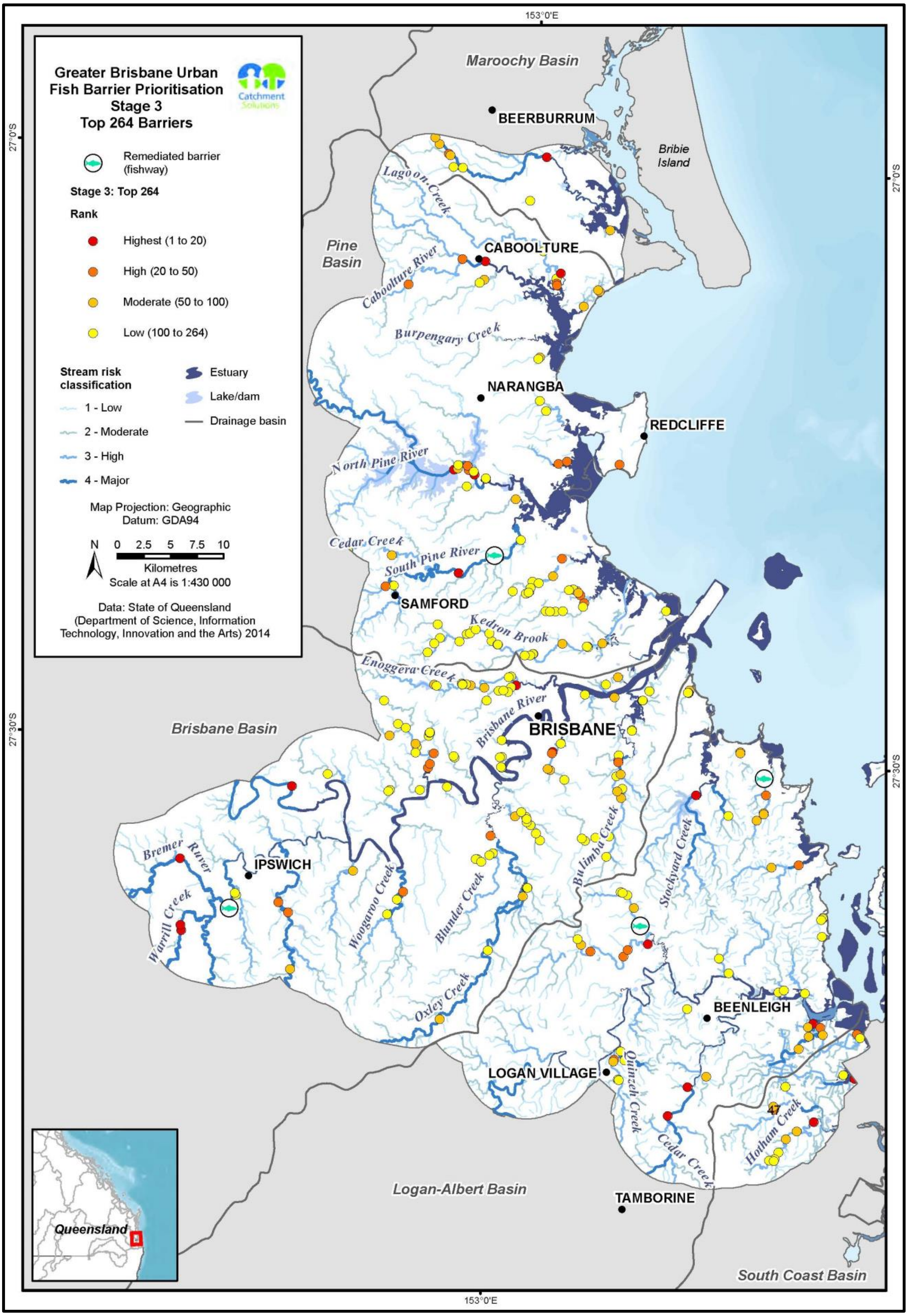


Figure 17. Showing the location of the top 264 barriers after stage 2 of the prioritisation

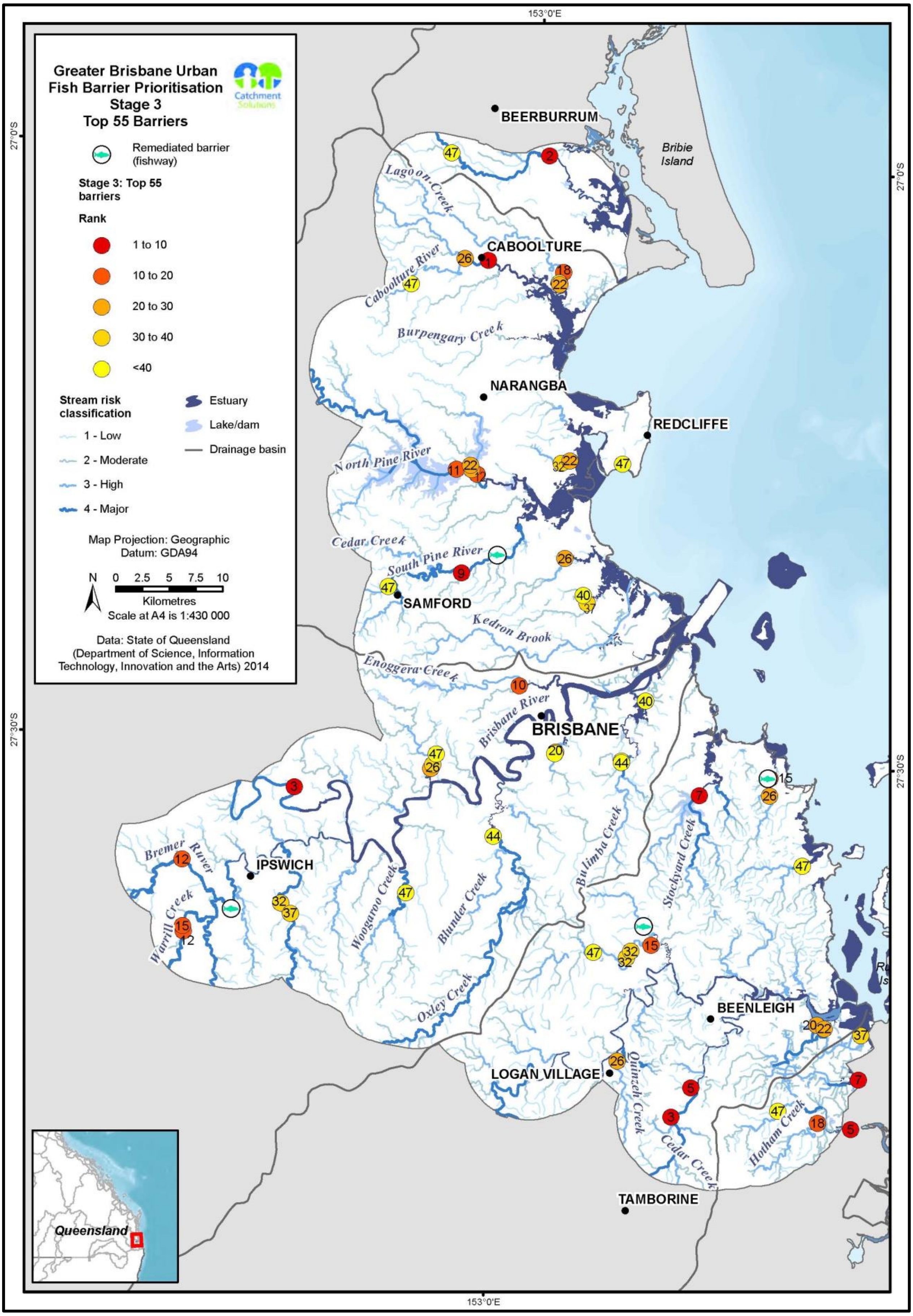


Figure 18. Location and overall priority rank of the top 50 barriers to fish passage in the GB region.

Discussion

The desktop study of the Greater Brisbane region identified a total 13,629 potential barriers at a density of 3.8 potential barriers per km² (total catchment area). Potential barriers located on first ordered waterways that didn't discharge directly into estuarine environments were removed from further assessment in stage 1. These waterways are generally typified as ephemeral headwater streams and are deemed to be low risk in terms of fish passage requirements (Fisheries QLD, 2013). Although some fish may intermittently utilise these habitats during periods of elevated stream flow, the expected species possess good swimming and/or unique climbing abilities (eel sp., cox's and striped gudgeon). Some upper catchment specialists have evolved an ability to climb wet surfaces and negotiate faster velocities to enable them to ascend natural barriers such as waterfalls and steep rock riffles which are commonly encountered in upper catchment headwater streams (Pusey, Kennard and Arthington 2004; Allen, Midgley and Allen 2002). Therefore, the small size and ephemeral nature of these waterways combined with the climbing abilities of the fish that commonly occur in these habitats meant that potential barriers in these locations were a low priority. Although these potential barriers were removed prior to stage 1 scoring and assessment, they remain on file for any potential future assessment.

Following the removal of all potential barriers which occurred on first order waterways (and did not discharge directly into estuarine waters), a total of 4,916 potential barriers remained. These barriers were assessed and ranked in accordance with the spatial and temporal habitat characteristic criteria set out in stage 1. This was achieved using the analytical GIS stream network processing tool; RivEX. 522 high ranking potential barriers were visited in the field in line with the prioritisation list. Of the 522 ground-truthed potential barriers, 264 were determined to be barriers that prevent, delay or obstruct fish migration. The remaining 258 potential barriers were assessed as not affecting fish passage (Figure 16). These generally consisted of bridges, logs and full width culverts installed below bed level and/or with a low flow channel and wall baffles (Figure 19). All waterway barrier works (culverts, pipes, weirs, causeways) in QLD are regulated under the Fisheries Act 1994. Minor works or those deemed low risk due to the waterway type (stream classification), can be completed via self-assessment (Accepted Development). In this situation, works can be completed by adhering to the standards and requirements of Fisheries QLD *Accepted Development requirements for operational work that is construction or raising waterway barrier work* without having to gain Development Approval. A high number of potential barriers visited in the field comprised culvert crossings which appeared to conform to the Accepted Development requirements and therefore deemed not to be barriers (Figure 19).

Figure 19. Culvert crossing conforming to Accepted Development requirements. Note: Low flow channel and wall roughening.

Through the prioritisation process, barriers were ranked according to the impact they have on Greater Brisbane fish communities and the cost and technical feasibility of rehabilitation of fish passage at the site. From this process a list of top priority barriers has been developed. This list (See Appendix 1) provides a prioritised guide to the most important places that targeted rehabilitation of fish passage will have the greatest benefit to fish communities of the region. The list also contains a number of structures that have fishways installed on them, however it should be recognised that some of these are older 'salmon' fishways, and due to their poor design, block fish passage.

Overall, the top three highest priority ranked barriers in the GB region were (1) Caboolture River Barrage, (2) Elimbah Creek Tidal Causeway, and equal third, Luscombe Weir on the Albert River and Mt. Crosby Weir on the Brisbane River. The reason these barriers scored so highly in the prioritisation process, along with many other barriers ranked in the top 50, was due to a combination of critical criteria these barriers met in terms of potential for fish community impacts. Generally these barriers were on high ordered streams, situated on, or in close proximity to the estuary, had minimal to no barriers downstream and blocked access to large areas of available habitat upstream. This combination of factors meant that these barriers, and barriers with similar traits, present the biggest overall impacts to fish community condition and overall aquatic ecosystem health, and thus, ranked highest in priority for remediation works.

With the prioritisation now completed and a list of potential sites for rehabilitation of fish passage recommended, investment and funding is required to remediate the various options outlined for each structure in the priority list (Appendix 1). It should be recognised that the list is a guide only and some unforeseeable scenarios may make some sites more or less practical. In all cases, rehabilitation of a site should be further investigated to ensure circumstances have not changed and investment expenditure is being spent at the most beneficial site.

Conclusion

13,629 potential barriers within the GB region were identified and refined to a list of the highest priority sites within the region. The priority ranked sites represent the greatest return in terms of ecological restoration with the least financial expenditure. By remediating fish passage at these sites, extensive areas of fish habitat will become accessible to many socio-economically important migratory fish species. This will ensure the sustainability of fish populations and improve aquatic ecosystem health in many of the region's waterways, while investing rehabilitation funds in the most efficient manner.

"Access to habitat is just as important as habitat itself"

Recommendations

- Development of individual council and relevant state government agency investment strategies for a fish migration barrier remediation program targeting the top 5-10 barriers identified in each LGA area within this report. This program would include:
  - Preparation of an investment strategy for the highest priority sites based on information in this report
  - Undertake Fish Passage Options Assessment to determine most appropriate remediation option at each site
  - Detailed survey of the sites and production of design documents for suitable fishways
  - Construction of agreed fishway designs
  - Monitoring of the rehabilitated sites to ensure proper operation of the fishway
  - Pre and post barrier remediation fishway and fish community sampling to determine the effectiveness of providing fish passage past the barrier.
- A SEQ wide fish barrier remediation project targeting the top 5-10 barriers identified in this report.
- Fish monitoring of potential and/or actual barriers to determine the degree of impact the structure is having on fish communities i.e. if you're unsure if it's a barrier to fish passage, then quantify through barrier monitoring the number, type and size of species able to ascend past (See Slacks Creek Case Study 1 in Appendix 2).
- Further fishway monitoring to better understand fish communities and their migration requirements.

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Appendix 1- Top 50 Barriers and Associated Information

Overall Priority	1	
LGA/LGA Priority	MBRC	1
Barrier ID	13941	
Stream Name	Caboolture River	
Location	-27.086745°	152.957708°
Barrier Type	Redundant Tidal Barrage	
Barrier Name	Caboolture Weir	
Fishway Type Needed	Bypass R.Ramp/Retrofit Cone	
Approx. Cost of Fishway	$180 - $250k	

Overall Priority	2	
LGA/LGA Priority	MBRC	2
Barrier ID	3728	
Stream Name	Elimbah Creek	
Location	-26.996403°	153.010241°
Barrier Type	Tidal Causeway	
Barrier Name/Info	Within Forestry Area	
Fishway Type Needed	Removal/Bed Lvl Xing/R.Ramp	
Approx. Cost of Fishway	$60 -$100k	

Overall Priority	3	
LGA/LGA Priority	GCCC & LCC	1* & 1*
Barrier ID	10352	
Stream Name	Albert River	
Location	-27.800196°	153.169262°
Barrier Type	Redundant Weir	
Barrier Name	Luscombe Weir	
Fishway Type Needed	Removal	
Approx. Cost of Fishway	$1.3 million	

Overall Priority	**3**	
LGA/LGA Priority	BCC	1
Barrier ID	12850	
Stream Name	Brisbane River	
Location	-27.537293°	152.797935°
Barrier Type	Weir	
Barrier Name	Mt Crosby Weir	
Fishway Type Needed	Concrete Cone	
Approx. Cost of Fishway	$800 k - $1 .1 million	

Overall Priority	**5**	
LGA/LGA Priority	GCCC	2
Barrier ID	13801	
Stream Name	Pimpama River	
Location	-27.802888°	153.339623°
Barrier Type	Tidal Floodgate	
Barrier Name	Kerkin Road North	
Fishway Type Needed	Fish Friendly Auto-tidal Gates	
Approx. Cost of Fishway	*$25 - $150k	

Overall Priority	**5**	
LGA/LGA Priority	GCCC & LCC	3 & 2
Barrier ID	10351	
Stream Name	Albert River	
Location	-27.775037°	153.186256°
Barrier Type	Tidal Pipe Causeway	
Barrier Name	Stanmore Road	
Fishway Type Needed	Bridge/Culverts	R.Ramp/Cone
Approx. Cost of Fishway	$100-$300 k	$50-$90 k

Overall Priority	**7**	
LGA/LGA Priority	RCC	1
Barrier ID	4374	
Stream Name	Tingalpa Creek	
Location	-27.528354°	153.180559°
Barrier Type	Dam	
Barrier Name	Leslie Harrison Dam	
Fishway Type Needed	Fish Lift/Cone	
Approx. Cost of Fishway	$1-2 million	

Overall Priority	**7**	
LGA/LGA Priority	GCCC	4
Barrier ID	13800	
Stream Name	Behm Creek	
Location	-27.760848°	153.344678°
Barrier Type	Tidal Floodgate	
Barrier Name	Stapylton-Jacobs Well Rd	
Fishway Type Needed	Fish Friendly Auto Tidal Gate	
Approx. Cost of Fishway	*$25 - $75 k	

Overall Priority	**9**	
LGA/LGA Priority	MBRC	3
Barrier ID	218	
Stream Name	South Pine River	
Location	-27.350244°	152.946384°
Barrier Type	Culvert Causeway	
Barrier Name	Bunya Crossing	
Fishway Type Needed	Rock Ramp	
Approx. Cost of Fishway	$25 -$40 k	

Overall Priority	10	
LGA/LGA Priority	BCC	2
Barrier ID	12199	
Stream Name	Enoggera Creek	
Location	-27.443336°	153.005675°
Barrier Type	Tidal Weir	
Barrier Name	Bancroft Park (Hulme St)	
Fishway Type Needed	Full-width or partial Rock Ramp	
Approx. Cost of Fishway	$80 -$100 k	

Overall Priority	11	
LGA/LGA Priority	MBRC	4
Barrier ID	2279	
Stream Name	North Pine River	
Location	-27.263543°	152.937002°
Barrier Type	Dam	
Barrier Name	North Pine Dam	
Fishway Type Needed	Fish Lift	
Approx. Cost of Fishway	$1 - 2 million	

Overall Priority	12	
LGA/LGA Priority	ICC	1
Barrier ID	8231	
Stream Name	Warrill Creek	
Location	-27.659011°	152.698957°
Barrier Type	DNRM V-notch Gauging Weir	
Barrier Name	DNRM Weir	
Fishway Type Needed	Cone (1st ridge) &/or R.Ramp	
Approx. Cost of Fishway	$70 - $100 k	

Overall Priority	**12**	
LGA/LGA Priority	ICC	1
Barrier ID	8933	
Stream Name	Bremer River	
Location	-27.602753°	152.695117°
Barrier Type	DNRM V-notch Gauging Weir	
Barrier Name	DNRM Weir	
Fishway Type Needed	Cone (1st ridge) &/or R.Ramp	
Approx. Cost of Fishway	$50 - $80 k	

Overall Priority	**12**	
LGA/LGA Priority	MBRC	5
Barrier ID	2252	
Stream Name	North Pine River	
Location	-27.266964°	152.956523°
Barrier Type	Culvert Causeway	
Barrier Name	Youngs Crossing	
Fishway Type Needed	Rock Ramp + Vertical Baffles	
Approx. Cost of Fishway	$25 - $40 k	

Overall Priority	**15**	
LGA/LGA Priority	RCC	2
Barrier ID	4876	
Stream Name	Hilliards Creek	
Location	-27.511266°	153.246640°
Barrier Type	Causeway (pedestrian)	
Barrier Name	Fellmonger Park	
Fishway Type Needed	New Culverts + Rock Ramp	
Approx. Cost of Fishway	$60 - $100 k	

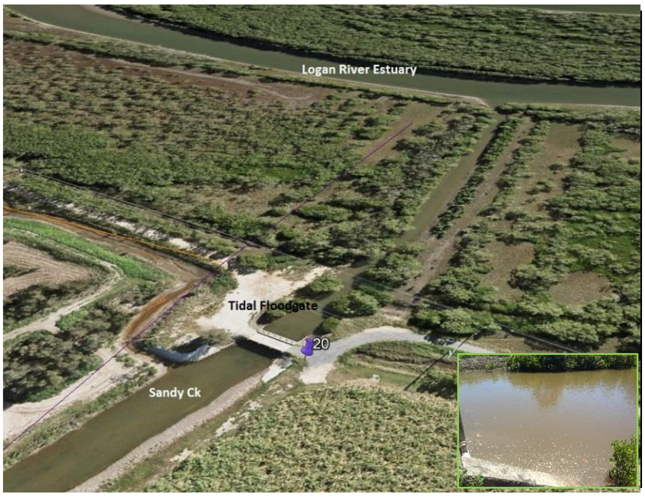
Overall Priority	**15**	
LGA/LGA Priority	ICC	3
Barrier ID	13807	
Stream Name	Warrill Creek	
Location	-27.602485°	152.695277°
Barrier Type	Weir - Sheet Pile & Gab. Bask.	
Barrier Name	200 m U/S Cunningham Hwy	
Fishway Type Needed	Removal/Full-width R.Ramp	
Approx. Cost of Fishway	$50 - $80 k	

Overall Priority	**15**	
LGA/LGA Priority	LCC	3
Barrier ID	4170	
Stream Name	Scrubby Creek	
Location	-27.656718°	153.142060°
Barrier Type	Culvert Causeway + Ap. Drop	
Barrier Name	Queens Rd	
Fishway Type Needed	Removal + Bridge	
Approx. Cost of Fishway	$70 - $90 k	

Overall Priority	**18**	
LGA/LGA Priority	GCCC	5
Barrier ID	13911	
Stream Name	Hotham Creek	
Location	-27.799051°	153.307883°
Barrier Type	Tidal Causeway	
Barrier Name	Sugar Cane Crossing	
Fishway Type Needed	Removal/Rock Ramp	
Approx. Cost of Fishway	$30 - $40 k	

Overall Priority	18	
LGA/LGA Priority	MBRC	6
Barrier ID	10719	
Stream Name	King John Creek	
Location	-27.093888°	153.028851°
Barrier Type	Pipe Causeway	
Barrier Name	Estuary diverted	
Fishway Type Needed	Bed Level Xing &/or R.Ramp	
Approx. Cost of Fishway	$15 - $25 k	

Overall Priority	20	
LGA/LGA Priority	GCCC	6
Barrier ID	5810	
Stream Name	Sandy Creek	
Location	-27.716465°	153.302614°
Barrier Type	New Tidal Floodgate	
Barrier Name	Loves Rd (main west arm)	
Fishway Type Needed	Fish Friendly Auto Tidal Gate	
Approx. Cost of Fishway	*$25 - $75 k	



Overall Priority	20	
LGA/LGA Priority	BCC	3
Barrier ID	11864	
Stream Name	Norman Creek	
Location	-27.497907°	153.043011°
Barrier Type	Tidal Culvert Apron Drop ~300mm	
Barrier Name	Logan Road - Hanlon Park	
Fishway Type Needed	R.Ramp/Cone + horizontal baffles	
Approx. Cost of Fishway	$20 - $40 k	

Overall Priority	**22**	
LGA/LGA Priority	MBRC	7
Barrier ID	2107	
Stream Name	Freshwater Creek	
Location	-27.252072°	153.043054°
Barrier Type	Tidal Bund	
Barrier Name	Hays Inlet FHA	
Fishway Type Needed	Removal/Rock Ramp	
Approx. Cost of Fishway	$5 - $30 k	

Overall Priority	**22**	
LGA/LGA Priority	MBRC	7
Barrier ID	13992	
Stream Name	King John Creek	
Location	-27.104366°	153.025763°
Barrier Type	Tidal Pipe Causeway	
Barrier Name	Tidal causeway adj FHA	
Fishway Type Needed	Removal/Bed level Crossing	
Approx. Cost of Fishway	$5 - $25 k	

Overall Priority	**22**	
LGA/LGA Priority	MBRC	7
Barrier ID	2278	
Stream Name	North Pine River	
Location	-27.259740°	152.950767°
Barrier Type	Weir ~2.5 m high	
Barrier Name	Seqwater @ Petrie Town	
Fishway Type Needed	Rock Ramp	
Approx. Cost of Fishway	$60 - $90 k	

Overall Priority	22	
LGA/LGA Priority	GCCC	7
Barrier ID	5807	
Stream Name	Sandy Creek East	
Location	-27.719208°	153.309700°
Barrier Type	Tidal Floodgate	
Barrier Name	School Rd	
Fishway Type Needed	Fish Friendly Auto Tidal Gate	
Approx. Cost of Fishway	*$25 -$75 k	

Overall Priority	26	
LGA/LGA Priority	BCC	4
Barrier ID	12433	
Stream Name	Moggill Creek	
Location	-27.516509°	152.925948°
Barrier Type	Concrete & Pipe Weir ~1m high	
Barrier Name	Under Moggill Rd	
Fishway Type Needed	Removal and/or Rock Ramp	
Approx. Cost of Fishway	$40 - $70 k	

Overall Priority	26	
LGA/LGA Priority	RCC	3
Barrier ID	4890	
Stream Name	Hilliards Creek	
Location	-27.525889°	153.246758°
Barrier Type	Box Culvert Causeway	
Barrier Name	QLD Gov.(DAF) Research Stn.	
Fishway Type Needed	Rock Ramp + Culverts	
Approx. Cost of Fishway	$60 - $90 k	

Overall Priority	**26**	
LGA/LGA Priority	BCC	4
Barrier ID	13996	
Stream Name	Cabbage Tree Creek	
Location	-27.334655°	153.043116°
Barrier Type	Rock Weir	
Barrier Name	Lemke Rd - adj AFL Club	
Fishway Type Needed	Removal/Rock Ramp	
Approx. Cost of Fishway	$5 - $10 k	

Overall Priority	**26**	
LGA/LGA Priority	LCC	4
Barrier ID	7083	
Stream Name	Quinzeh Creek	
Location	-27.755147°	153.115479°
Barrier Type	Causeway	
Barrier Name	D/S Waterford-Tamborine Rd	
Fishway Type Needed	Removal + Bd Level Xing/R.Ramp	
Approx. Cost of Fishway	$25 - $60 k	

Overall Priority	**26**	
LGA/LGA Priority	MBRC	10
Barrier ID	13992	
Stream Name	North Pine River	
Location	-27.263190°	152.951383°
Barrier Type	Pipe Culvert Causeway	
Barrier Name	Opposite Old Petrie Town	
Fishway Type Needed	Bed Level Xing/New Culverts	
Approx. Cost of Fishway	$20 - $50 k	

Overall Priority	**26**	
LGA/LGA Priority	MBRC	10
Barrier ID	13942	
Stream Name	Waraba Creek	
Location	-27.086080°	152.935456°
Barrier Type	Weir	
Barrier Name	Waraba Weir - Caboolture	
Fishway Type Needed	Cone/V-Slot/Bypass R.Ramp	
Approx. Cost of Fishway	$80 - $200 k	

Overall Priority	**32**	
LGA/LGA Priority	BCC	6
Barrier ID	12435	
Stream Name	Moggill Creek	
Location	-27.513516°	152.927873°
Barrier Type	Pipe Culvert Causeway	
Barrier Name	Kilkivan Avenue	
Fishway Type Needed	Low Flow & High Flow Rock Ramp	
Approx. Cost of Fishway	$20 - $80 k	

Overall Priority	**32**	
LGA/LGA Priority	LCC	5
Barrier ID	6387	
Stream Name	Scrubby Creek	
Location	-27.662613°	153.123738°
Barrier Type	Pipe Culvert Causeway	
Barrier Name	Gould Adams Prk - Kingston Rd	
Fishway Type Needed	Full-width Rock Ramp	
Approx. Cost of Fishway	$60- $100 k	

Overall Priority	**32**	
LGA/LGA Priority	MBRC	12
Barrier ID	2106	
Stream Name	Freshwater Creek	
Location	-27.668090°	153.119794°
Barrier Type	Earthern Bund	
Barrier Name	Upstream Hays Inlet FHA	
Fishway Type Needed	Removal/Rock Ramp	
Approx. Cost of Fishway	$5 - $30 k	

Image courtesy MBRC

Overall Priority	**32**	
LGA/LGA Priority	LCC	5
Barrier ID	6388	
Stream Name	Scrubby Creek	
Location	-27.668090°	153.119794°
Barrier Type	Pipe Culvert Causeway	
Barrier Name	D/S Logan Motorway	
Fishway Type Needed	Removal/Bed Level Xing + R.Ramp	
Approx. Cost of Fishway	$30 k - $60 k	

Overall Priority	**32**	
LGA/LGA Priority	ICC	4
Barrier ID	9649	
Stream Name	Bundamba Creek	
Location	-27.635605°	152.790513°
Barrier Type	Rock Weir	
Barrier Name	Worley Park	
Fishway Type Needed	Rock Ramp	
Approx. Cost of Fishway	$5 - $8 k	

Overall Priority	**37**	
LGA/LGA Priority	BCC	7
Barrier ID	665	
Stream Name	Downfall Creek	
Location	-27.371446°	153.065862°
Barrier Type	Weir	
Barrier Name	Virginia Golf Course	
Fishway Type Needed	Removal & or RRamp/Cone	
Approx. Cost of Fishway	$30 k - $80 k	


Image courtesy BCC

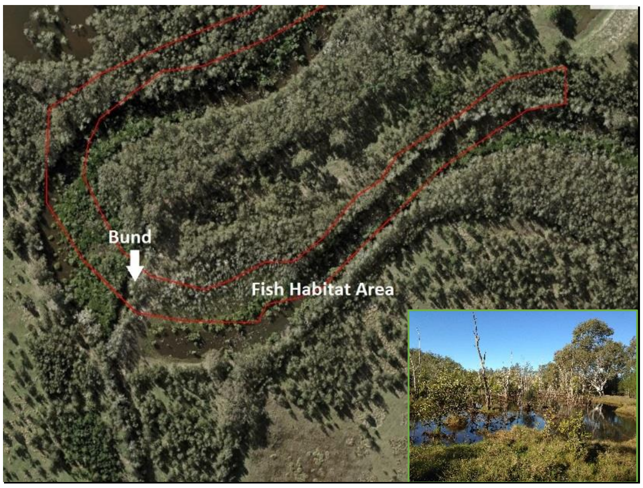
Overall Priority	**37**	
LGA/LGA Priority	ICC	8
Barrier ID	9748	
Stream Name	Bundamba Creek	
Location	-27.644044°	152.800083°
Barrier Type	Pipe Causeway	
Barrier Name	East Owen Street	
Fishway Type Needed	New Box Culverts &/or Rock Ramp	
Approx. Cost of Fishway	$20 - $90 k	

Overall Priority	**37**	
LGA/LGA Priority	GCCC	8
Barrier ID	5525	
Stream Name	Cabbage Tree Point Creek	
Location	-27.722999°	153.344490°
Barrier Type	Tidal Floodgate - Pipe	
Barrier Name	Cabbage Tree Point	
Fishway Type Needed	Fish Friendly Auto-tidal Gates	
Approx. Cost of Fishway	$10 - $15 k	

Overall Priority	**40**	
LGA/LGA Priority	BCC	8
Barrier ID	343	
Stream Name	Zillmere Waterholes	
Location	-27.364832°	153.061926°
Barrier Type	Culvert Causeway	
Barrier Name	Sandgate Road	
Fishway Type Needed	Rock Ramp + Nib wall & Baffles	
Approx. Cost of Fishway	$30 - $50 k	

Overall Priority	**40**	
LGA/LGA Priority	BCC	8
Barrier ID	13828	
Stream Name	Hemmant Creek	
Location	-27.451713°	153.125205°
Barrier Type	Tidal Floodgate	
Barrier Name	Hemmant Tingalpa Rd	
Fishway Type Needed	Fish Friendly Auto-tidal Gates	
Approx. Cost of Fishway	$25 - $35	

Overall Priority	**40**	
LGA/LGA Priority	MBRC	13
Barrier ID	13940	
Stream Name	King John Creek	
Location	-27.102760°	153.025381°
Barrier Type	Earthern Bund	
Barrier Name	Deception Bay FHA	
Fishway Type Needed	Removal/Bed Level Crossing	
Approx. Cost of Fishway	$5 - $15 k	



Overall Priority	**40**	
LGA/LGA Priority	BCC	8
Barrier ID	11865	
Stream Name	Norman Creek	
Location	-27.499142°	153.042516°
Barrier Type	Concrete lined drain	
Barrier Name	Hanlon Park	
Fishway Type Needed	Horizontal Culvert Baffles	
Approx. Cost of Fishway	$40 - $90 k	

Overall Priority	**44**	
LGA/LGA Priority	BCC	11
Barrier ID	11647	
Stream Name	Bulimba Creek	
Location	-27.502643°	153.105451°
Barrier Type	Culvert Causeway	
Barrier Name	Opposite Carindale Shop. Cntr	
Fishway Type Needed	Rock Ramp	
Approx. Cost of Fishway	$15 - $25	

Overall Priority	**44**	
LGA/LGA Priority	BCC	11
Barrier ID	13943	
Stream Name	Blunder Creek	
Location	-27.571258°	152.987956°
Barrier Type	Causeway	
Barrier Name	Oxley Creek Junction	
Fishway Type Needed	Removal/Bed Level Xing	
Approx. Cost of Fishway	$3 -$5 k	

Overall Priority	**44**	
LGA/LGA Priority	BCC	11
Barrier ID	11648	
Stream Name	Bulimba Creek	
Location	-27.504079°	153.105604°
Barrier Type	Culvert Causeway	
Barrier Name	Opposite Carindale Shop. Cntr	
Fishway Type Needed	Removal	
Approx. Cost of Fishway	$3 - $5 k	

Overall Priority	**47**	
LGA/LGA Priority	ICC	9
Barrier ID	12970	
Stream Name	Woogaroo Creek	
Location	-27.622268°	152.908130°
Barrier Type	Rock Weir	
Barrier Name	Newman St Easement	
Fishway Type Needed	Rock Ramp	
Approx. Cost of Fishway	$30 - $50 k	

Overall Priority	**47**	
LGA/LGA Priority	MBRC	14
Barrier ID	1523	
Stream Name	South Pine River	
Location	-27.365176°	152.877745°
Barrier Type	Culvert Causeway	
Barrier Name	Cannington Crt - Samford	
Fishway Type Needed	Rock Ramp + Baffles/Culverts	
Approx. Cost of Fishway	$40 k - $80 k	

Overall Priority	47	
LGA/LGA Priority	BCC	14
Barrier ID	12461	
Stream Name	Moggill Creek	
Location	-27.504555°	152.930528°
Barrier Type	Pipe Causeway	
Barrier Name	Branton Street	
Fishway Type Needed	Removal/Rock Ramp	
Approx. Cost of Fishway	$20 k - $80 k	

Overall Priority	47	
LGA/LGA Priority	MBRC	15
Barrier ID	11071	
Stream Name	Caboolture River	
Location	-27.109714°	152.885927°
Barrier Type	Culvert Causeway	
Barrier Name	Litherland Road	
Fishway Type Needed	Rock Ramp + Baffles	
Approx. Cost of Fishway	$30 - $50 k	

Overall Priority	47	
LGA/LGA Priority	LCC	14
Barrier ID	13407	
Stream Name	Scrubby Creek	
Location	-27.664953°	153.087981°
Barrier Type	Weir	
Barrier Name	Demeio Park	
Fishway Type Needed	Full-width Rock Ramp	
Approx. Cost of Fishway	$50 k - $80 k	

Overall Priority	**47**	
LGA/LGA Priority	MBRC	14
Barrier ID	3953	
Stream Name	Six Mile (Elimbah) Creek	
Location	-26.997845°	152.918202°
Barrier Type	Relic Causeway	
Barrier Name	Beerburrum West State Forest	
Fishway Type Needed	Removal	
Approx. Cost of Fishway	$4 - 8 k	

Overall Priority	**47**	
LGA/LGA Priority	GCCC	9
Barrier ID	7749	
Stream Name	Pimpama River	
Location	-27.790614°	153.269688°
Barrier Type	Pipe Causeway	
Barrier Name	Relic barrier in GC train corridor	
Fishway Type Needed	Removal	
Approx. Cost of Fishway	$5 - $15 k	

Overall Priority	**47**	
LGA/LGA Priority	MBRC	14
Barrier ID	2417	
Stream Name	Bells Creek	
Location	-27.252733°	153.092914°
Barrier Type	Culverts + Concrete lined drain	
Barrier Name	Bells Paddock Reserve	
Fishway Type Needed	Horizontal & Vertical Baffles	
Approx. Cost of Fishway	$15 - $50 k	


Image courtesy MBRC

Overall Priority	**47**	
LGA/LGA Priority	RCC	4
Barrier ID	5071	
Stream Name	Eprapah Creek	
Location	-27.583315°	153.281349°
Barrier Type	Culvert Causeway	
Barrier Name	Redland Bay Road	
Fishway Type Needed	Culvert Baffles	
Approx. Cost of Fishway	$15 - $40 k	


Image courtesy RCC

Overall Priority	**56**	
LGA/LGA Priority	ICC	10
Barrier ID	3953	
Stream Name	Six Mile Creek	
Location	-27.606753°	152.859900°
Barrier Type	Rock Weir	
Barrier Name	Urban Utilities Pipeline barrier	
Fishway Type Needed	Removal/Rock Ramp	
Approx. Cost of Fishway	$10 - $40 k	

Overall Priority	**56**	
LGA/LGA Priority	MBRC	18
Barrier ID	1264	
Stream Name	Cedar Creek	
Location	-27.338880°	152.882218°
Barrier Type	Perched Culvert Causeway	
Barrier Name	Hanson Road	
Fishway Type Needed	New culverts/ Rock Ramp	
Approx. Cost of Fishway	$40 - $80 k	

Overall Priority	56	
LGA/LGA Priority	LCC	15
Barrier ID	10540	
Stream Name	Oxley Creek	
Location	-27.728289°	152.948461°
Barrier Type	Perched Culvert Causeway	
Barrier Name	Roberts Road	
Fishway Type Needed	New culverts/Rock Ramp	
Approx. Cost of Fishway	$40 - $80 k	

Overall Priority	56	
LGA/LGA Priority	RCC	5
Barrier ID	4850	
Stream Name	Tarradarrapin Creek	
Location	-27.490879°	153.220676°
Barrier Type	Culvert Apron Drop	
Barrier Name	Dorsal Drive	
Fishway Type Needed	Retro-fit Cone/Rock Ramp	
Approx. Cost of Fishway	$50 - $80 k	

Overall Priority	56	
LGA/LGA Priority	BCC	15
Barrier ID	4256	
Stream Name	Wynnum Creek	
Location	-27.440850°	153.169327°
Barrier Type	Tidal Weir	
Barrier Name	Adjacent Tingal Rd	
Fishway Type Needed	Removal/Rock Ramp	
Approx. Cost of Fishway	$4 - $30 k	

Overall Priority	56	
LGA/LGA Priority	BCC	15
Barrier ID	13995	
Stream Name	Bulimba Creek	
Location	-27.514289°	153.108399°
Barrier Type	Rock Weir	
Barrier Name	Pacific Golf Course	
Fishway Type Needed	Removal	
Approx. Cost of Fishway	$2 - $5 k	

Overall Priority	56	
LGA/LGA Priority	GCCC	10
Barrier ID	7811	
Stream Name	Pimpama River	
Location	-27.787995°	153.268460°
Barrier Type	Culvert Causeway	
Barrier Name	Stewarts Road	
Fishway Type Needed	Rock Ramp + Baffles/Box Culverts	
Approx. Cost of Fishway	$30 - $70 k	

Appendix 2 - Greater Brisbane Fish Barrier Remediation Case Studies

Case Study 1 - Paradise Road Overpass, Slacks Creek

Introduction

The remediation of the Paradise Road overpass barrier in Slacks Creek was undertaken in partnership between Logan City Council and Catchment Solutions. The Paradise Road overpass was ranked the 36th highest priority barrier in the GB region. A fish passage options assessment was undertaken to determine the most appropriate fish passage solution at this site. The investigation determined that a combination of two fishway designs would provide suitable fish passage; rock-ramp fishway to assist fish ascending the concrete culvert apron drop, and a series of horizontal concrete baffles retrofitted to the base of the culverts to assist fish passage through the 50 m long culverts (500 mm head loss).

Barrier Ranking	36th in the Greater Brisbane region
Barrier Type(s)	Surface drop, water depth and flow velocity
Total Surface Drop (head loss)	1.8 m, consisting of 0.5 m through culverts and 1.3 m off culvert apron
Best Remediation Method	Combination of nature-like partial-width rock-ramp and horizontal culvert baffle fishways
Length of Fishway	91 m
Number of Ridges	17 ridges in rock-ramp, 10 horizontal culvert baffle ridges
Drops Between Pools	80 mm for rock-ramp & 50 mm for the horizontal baffles
Slots (number & type)	4 slots, consisting 2 x high flow and 2 x low flow
Total Construction Time	3 weeks
Total Rock Used	783 t – predominantly consisting of large rock: 1.2 - 3 m (up to 11 t)
Total Overall Cost	$ 124 000

Figure 20. Left; showing the 1.3 m surface drop barrier off the downstream face of the culvert apron. Right; showing stream flow spread out across all four box culverts creating a shallow water surface barrier along the entire 50 m length of the structure. During stream flow events the culverts also created a flow velocity barrier.

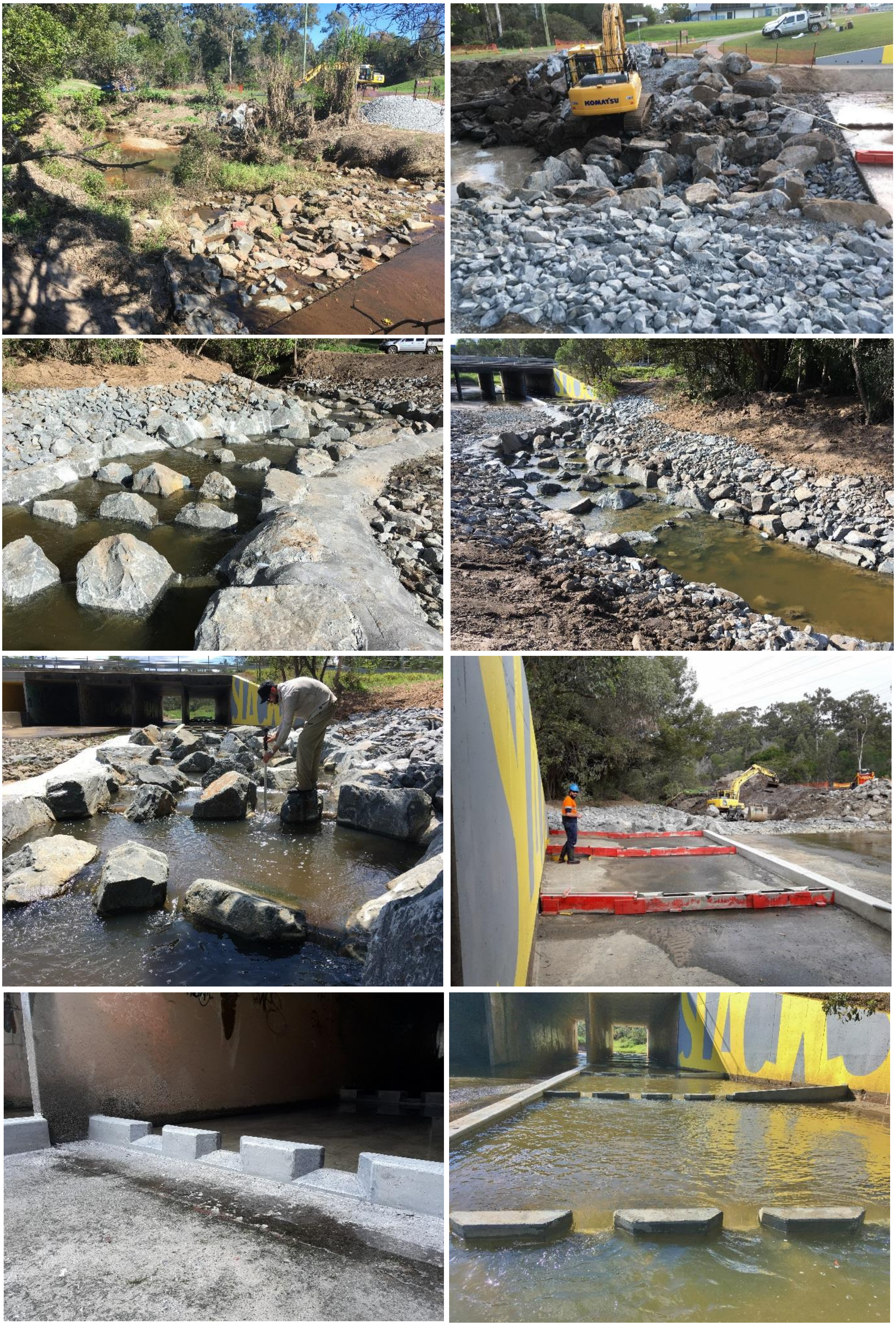


Figure 21. Showing during and post construction of the rock-ramp and horizontal culvert baffle fishways

Pre Fishway Construction Monitoring

Prior to fishway construction works, the barrier was monitored for one week to evaluate the overall impacts to the fish communities of Slacks Creek and determine how many, and what species, were making it past the barrier. Over almost five days of monitoring, six species were surveyed ascending the barrier, at an overall catch rate of 4.12 individual fish per day. Two of the fish species recorded in the trap; striped gudgeon and long-finned eel, possess an ability to climb vertical wet surfaces (barriers).

Migration Classification	Common Name	Species Name	Size Range (mm)	CPUE (Fish/day)
Diadromous	Empire gudgeon	*Hypseleotris compressa*	21- 64	0.62
	Long-finned eel	*Anguilla reinhardtii*	19- 56	0.82
	Striped gudgeon	*Gobiomorphus australis*	19- 69	0.82
Potamodromous	Hypseleotris sp.	*Hypseleotris species*	17	0.21
	Firetail gudgeon	*Hypseleotris galii*	31- 46	0.62
	Western carp gudgeon	*Hypseleotris klunzingeri*	16- 20	1.03
		Total Species and Overall CPUE	**6**	**4.12**

Post Remediation Works

Following the construction of the rock-ramp and horizontal baffle fishway, monitoring was again carried out to assess the success of the fishways at passing the full suite of fish species and size classes expected to occur within Slacks Creek. Over almost five days of monitoring, 6,546 fish representing 11 species were surveyed successfully ascending the fishways, at an overall catch rate of 1,384.18 fish per day. This is a substantial increase from pre-construction monitoring results of only 4.12 fish per day able to ascend the barrier, and highlights the numbers of fish which were previously trying to move past the Paradise Road overpass barrier, however were unable to do so. Significantly, juvenile diadromous fish species were recorded at the highest catch rates, with striped gudgeon captured at a rate of 812 fish per day, followed by empire gudgeon and sea mullet with 272 and 258 fish per day respectively. Native fish comprised 98.9% of the total catch (individuals), which again emphasises the importance of this remediated fish barrier.

Migration Classification	Common Name	Species Name	Size Range (mm)	CPUE (Fish/day)
Diadromous	Empire gudgeon	*Hypseleotris compressa*	16- 72	272.14
	Long-finned eel	*Anguilla reinhardtii*	40- 300	4.65
	Sea mullet	*Mugil cephalus*	24- 51	257.76
	Striped gudgeon	*Gobiomorphus australis*	14- 112	812.62
Potamodromous	Firetail gudgeon	*Hypseleotris galii*	31- 36	0.85
	Flathead gudgeon	*Philypnodon grandiceps*	19- 62	12.69
	Western carp gudgeon	*Hypseleotris klunzingeri*	18- 34	8.88
Pest Fish	Mosquito fish	*Gambusia holbrooki*	12- 44	12.26
	Platy	*Xiphophorus maculatus*	31- 33	0.85
	Swordtail	*Xiphophorus helleri*	38	0.42
	Tilapia	*Oreochromis mossambicus*	125- 390	1.06
		Total Species and Overall CPUE	**11**	**1384.18**

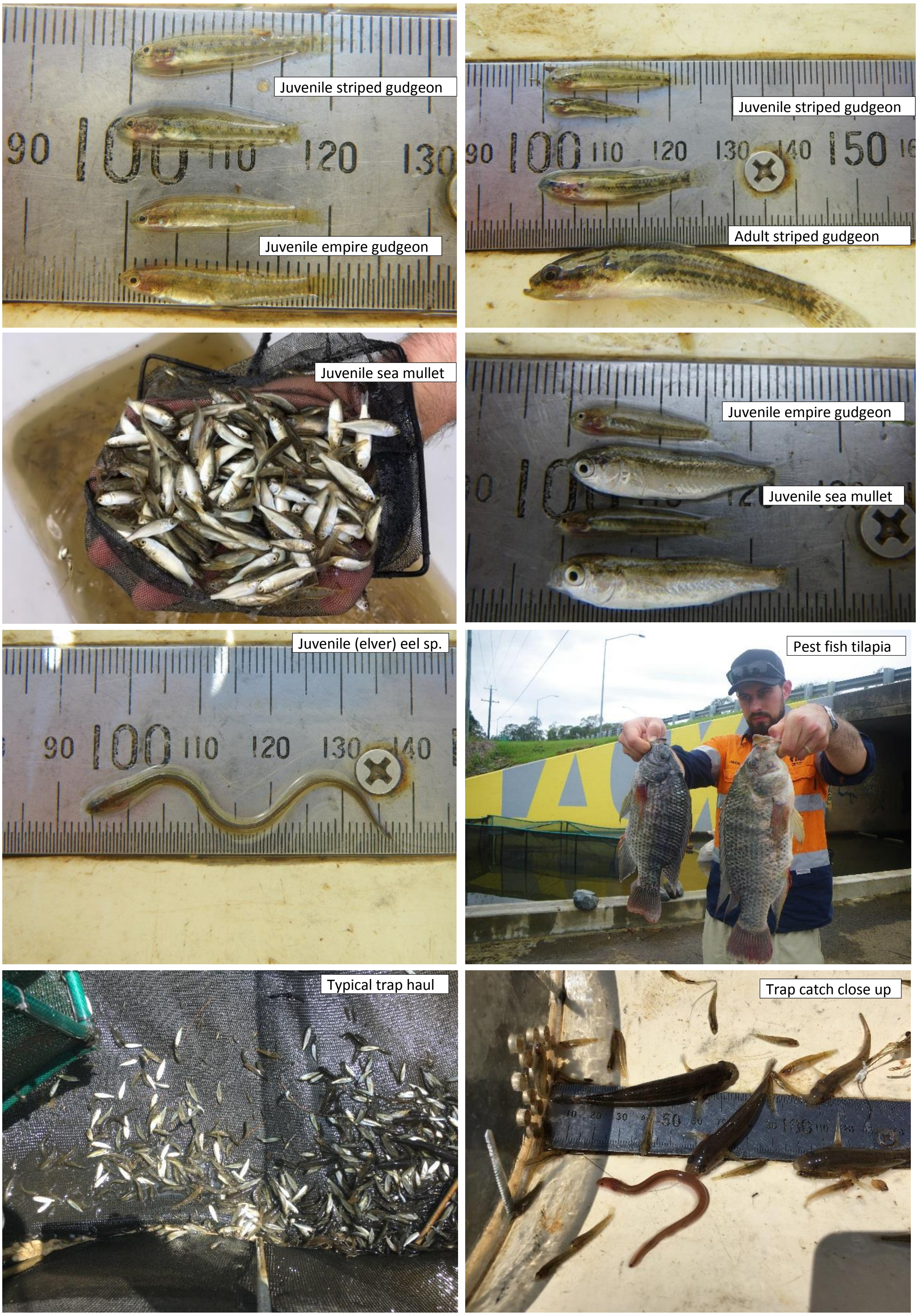


Figure 22. Fish captured successfully ascending the Slacks Creek fishways during assessment monitoring

Case Study 2- Berrys Weir, Bremer River

Introduction

The remediation of Berrys Weir with rock-ramp fishway on the Bremer River was undertaken in partnership between Ipswich City Council and Catchment Solutions in 2016. Berrys Weir was the 7th highest priority ranked fish barrier in the Greater Brisbane region. The 2.4 m high weir was constructed in the 1960's to impound water for power generation (Stanwell). A fish passage options assessment determined that a partial width rock-ramp fishway would be the best remediation option at this site.

Barrier Ranking	7th in Greater Brisbane region
Barrier Type(s)	Surface drop
Total Surface Drop	2.4 m
Best Remediation Method	1:33 Partial- width rock-ramp fishway + 1:15 full width
Length of Fishway	90 m
Number of Ridges	33
Drops Between Pools	75 mm
Total Construction Time	3 weeks
Total Rock Used	480 t
Total Overall Cost	$ 96 000

Figure 23. Berrys Weir fish barrier before remediation works, with relict north- American style fish ladder visible down left side of weir

Fishway Construction Works

Figure 24. Berrys Weir fishway construction images

Fishway Monitoring

Following fishway construction, two separate rounds of monitoring were carried out in December 2016 and December 2017 to assess the capabilities of the fishway at passing the full suite of fish species and size classes expected to occur within Bremer River. On both occasions, the fishway trap was set at the exit of the fishway on the upstream side of the weir, to show the numbers and species of fish that were able to ascend the rock-ramp fishway. In 2016, a total of 19 different species were captured at a rate of 690.4 fish per trapping day, whilst in 2017, 16 species were captured at a rate of 4,075.5 fish per day. Significantly, four 'new' native species were captured successfully ascending the fishway that had not been recorded in over 14 years of EHMP fish surveys within the Bremer River, including freshwater mullet, speckled goby, yellowfin bream and fork-tailed catfish. These results highlight the impact that barriers close to the estuarine interface have on the health of freshwater fish communities. Other notable fishway monitoring results (2017) include the capture of 1,073 juvenile freshwater mullet at a catch rate of 267 fish per day, and 1,273 sea mullet at a catch rate of 316 fish per day.

Migration Classification	Common Name	Species Name	Size Range (mm)		CPUE (Fish/day)	
			2016	2017	2016	2017
Marine Vagrant	Yellowfin bream	*Acanthopagrus australis*	254	-	0.2	-
Diadromous	Empire gudgeon	*Hypseleotris compressa*	19- 52	21- 64	114.1	2020.5
	Long-finned eel	*Anguilla reinhardtii*	70- 550	400- 1200	2.8	1.5
	Bullrout	*Notesthes robusta*	35- 58	28- 165	1.6	27.8
	Eel sp.	*Anguilla species*	-	50- 65	-	1
	Freshwater mullet	*Trachystoma petardi*	-	51- 79	-	266.6
	Sea mullet	*Mugil cephalus*	38 72	34- 234	38.9	316.3
	Striped gudgeon	*Gobiomorphus australis*	21- 52	21- 83	80	1283.7
Potamodromous	Firetail gudgeon	*Hypseleotris galii*	31- 33	28- 42	1	12.7
	Flathead gudgeon	*Philypnodon grandiceps*	20- 51	19- 25	10.2	0.5
	Crimson-spotted rainbowfish	*Melanotaenia duboulayi*	18- 74	36- 41	177.4	0.5
	Hypseleotris sp.	*Hypseleotris species*	15- 41	-	248.1	-
	Bony bream	*Nematalosa erebi*	110- 254	39- 204	1.2	21.1
	Speckled goby	*Redigobius bikolanus*	25- 33	-	2.4	-
	Australian smelt	*Retropinna semoni*	24- 40	22- 54	2	121
	Fork-tailed catfish	*Arius graeffei*	230- 350	-	1.2	-
	Pacific blue-eye	*Pseudomugil signifer*	32	-	0.2	-
	Eel-tailed catfish	*Tandanus tandanus*	34	-	0.2	-
	Agassiz's glassfish	*Ambassis agassizii*	40- 53	-	0.4	-
	Banded grunter	*Amniataba percoides*	-	110	-	0.2
	Spangled perch	*Leiopotherapon unicolor*	-	165- 195	-	0.5
	Unspecked hardyhead	*Craterocephalus fulvus*	-	35- 56	-	1.2
Pest Fish	Platy	*Xiphophorus maculatus*	25	-	0.2	-
	Tilapia	*Oreochromis mossambicus*	72	385	0.2	0.2
Total Species and Overall CPUE			**19**	**16**	**690.4**	**4075.5**

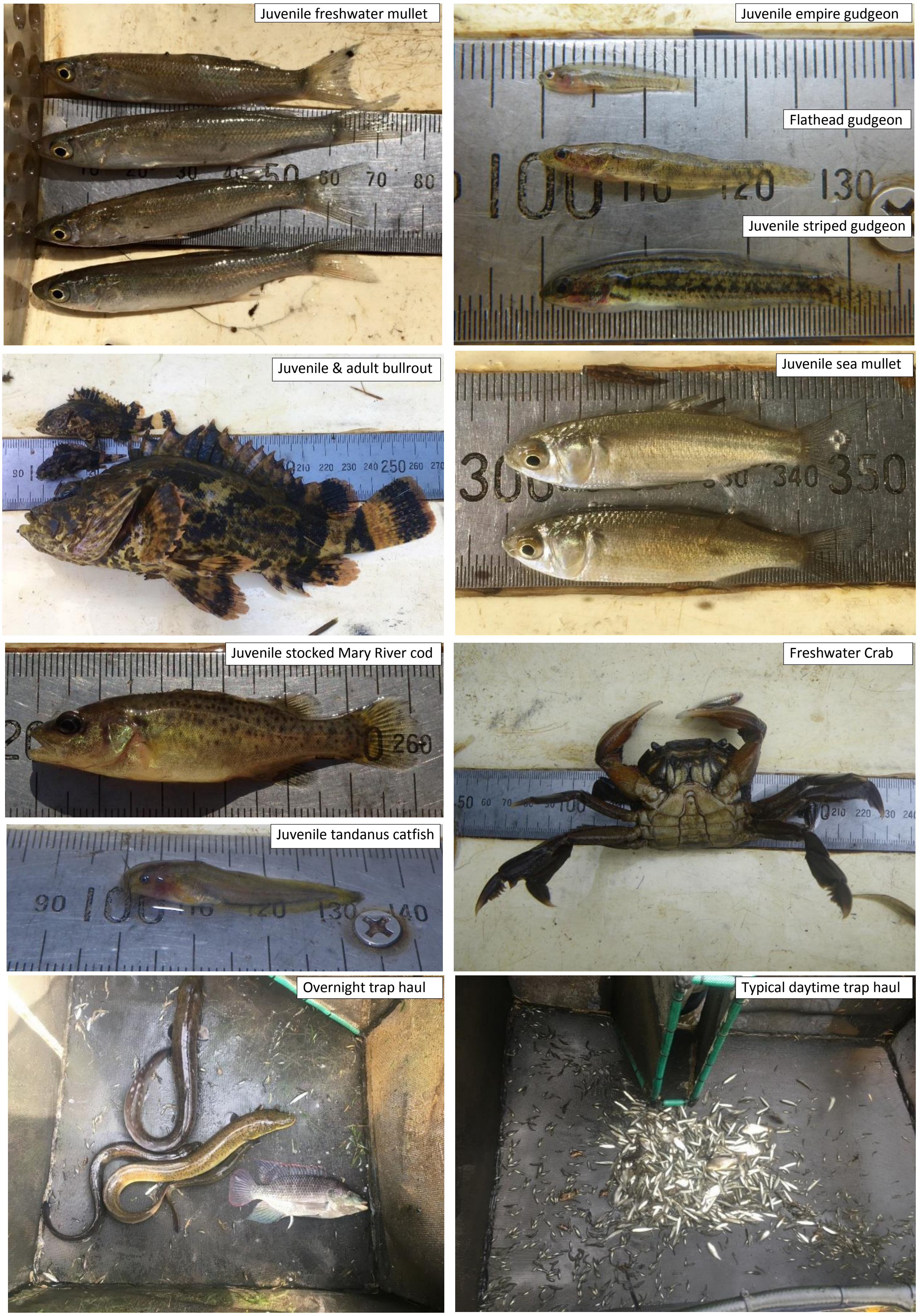


Figure 25. Fish captured ascending Berrys Weir fishway during monitoring

Case Study 3 - Leitchs Crossing, South Pine River

Introduction

The remediation of Leitchs Crossing with a nature-like rock-ramp fishway was undertaken in partnership between Moreton Bay Regional Council and Catchment Solutions. Leitchs Crossing is located in the lower reaches of the South Pine River and was ranked the 11th highest priority fish barrier in the Greater Brisbane region. A fish passage options assessment determined that a full width rock-ramp fishway was the best fish passage remediation option for this barrier type in assisting fish to ascend past the barrier.

Barrier Ranking	11th in Greater Brisbane region
Barrier Type(s)	Surface drop barrier, water depth barrier and flow velocity barrier
Total Surface Drop (head loss)	0.5 m
Best Remediation Method	Full width rock-ramp fishway
Length of Fishway	15
Number of Ridges	7
Drops Between Pools	75 mm
Total Construction Time	4 days
Total Rock Used	192 t
Total Overall Cost	$60 000

Figure 26. Showing Leitchs Crossing fish barrier prior to fishway construction

Fishway Construction Works

Figure 27. Showing during and post construction of Leitchs Crossing fishway

Post Remediation Works

Following the construction of the rock-ramp fishway at Leitchs Crossing, fishway monitoring was carried out in October 2017 to assess the capabilities of the fishway at passing the full suite of fish species and size classes expected to occur in South Pine River. The fishway trap was set at the exit of the fishway on the upstream side of the crossing, to show the numbers and species of fish that were able to ascend the rock-ramp fishway. Across five days of monitoring, a total of 19 species were surveyed ascending the fishway, at an overall rate of 1,195.9 fish per day. Notable captures include juvenile freshwater mullet and speckled goby, both diadromous fish species that had not previously been recorded during annual EHMP fish surveys in the South Pine River (survey site located upstream of the barrier/fishway site). It's anticipated that improved connectivity as result of the fishway will assist in the recovery of freshwater mullet and speckled goby populations in the South Pine River. Also significant was the high numbers of juvenile sea mullet; SEQ most important inshore net commercial species, recorded at a catch rate of 209 fish per day. Similar to all fishway monitoring sites, no wild Australian bass were recorded, potentially suggesting poor and/or failed recruitment of this species. Australian bass populations in SEQ waterways appear to be masked by escaped stocked fish from impoundments during overtopping events.

Migration Classification	Common Name	Species Name	Size Range (mm)	CPUE (Fish/day)
Diadromous	Empire gudgeon	*Hypseleotris compressa*	19- 72	19.87
	Long-finned eel	*Anguilla reinhardtii*	70- 800	1.42
	Sea mullet	*Mugil cephalus*	23- 308	209.36
	Striped gudgeon	*Gobiomorphus australis*	19- 41	17.74
	Bullrout	*Notesthes robusta*	45- 150	2.60
	Freshwater mullet	*Trachystoma petardi*	50- 65	6.86
Potamodromous	Firetail gudgeon	*Hypseleotris galii*	19- 38	812.62
	Flathead gudgeon	*Philypnodon grandiceps*	19- 56	62.69
	Western carp gudgeon	*Hypseleotris klunzingeri*	19- 34	0.95
	Agassiz's glassfish	*Ambassis agassizii*	25- 54	15.38
	Unspecked hardyhead	*Craterocephalus fulvus*	25- 63	15.61
	Crimson-spotted rainbowfish	*Melanotaenia duboulayi*	54	0.24
	Dwarf flathead gudgeon	*Philypnodon maculatus*	16- 28	15.38
	Philypnodon sp.	*Philypnodon species*	21- 45	1.42
	Speckled goby	Redigobius bikolanus	21- 26	0.95
	Australian smelt	Retropinna semoni	21- 42	8.75
Pest Fish	Mosquito fish	*Gambusia holbrooki*	19- 29	1.18
	Platy	*Xiphophorus maculatus*	28- 32	0.95
	Tilapia	*Oreochromis mossambicus*	15- 330	1.89
		Total Species and Overall CPUE	**19**	**1195.86**

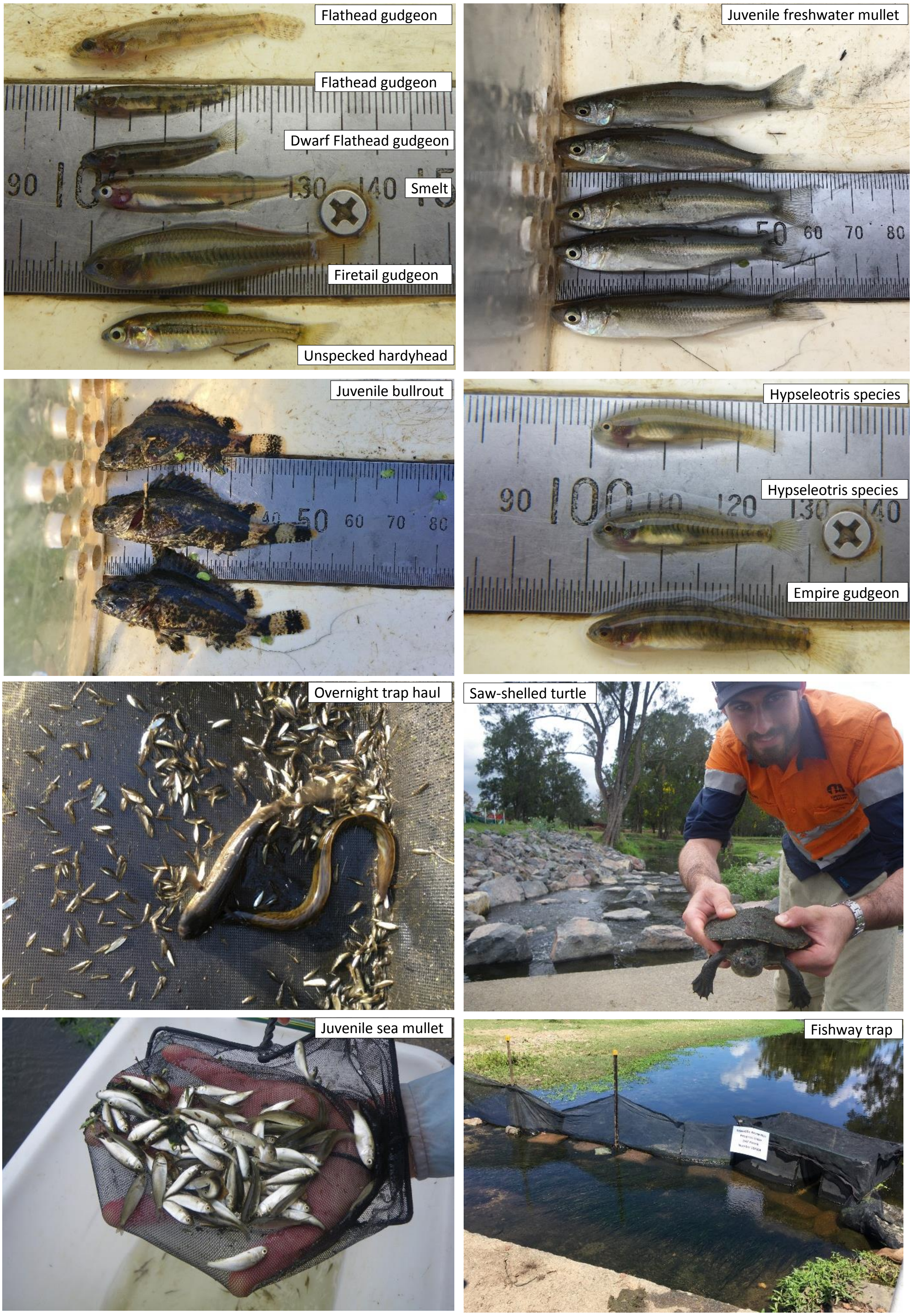


Figure 28. Fish captured successfully ascending Leitchs Crossing fishway during monitoring

Case Study 4 - Hilliards Weir, Hilliards Creek

The remediation of Hilliards Creek Weir with a rock-ramp fishway was undertaken in partnership between Redland City Council and Catchment Solutions. The relic weir on Hilliards Creek was ranked the 36th highest priority fish barrier in Greater Brisbane region. A fish passage options assessment determined that a full width rock-ramp fishway was the best fish passage remediation option for this barrier type in assisting fish to ascend past the barrier.

Barrier Ranking	36th in Greater Brisbane region
Barrier Type(s)	Surface drop barrier
Total Surface Drop	0.75 m
Best Remediation Method	Full width rock-ramp fishway
Length of Fishway	18 m
Number of Ridges	9
Drops Between Pools	80 mm
Total Construction Time	4 days
Total Rock Used	205 t
Total Overall Cost	$ 42 000

Figure 29. Showing the Hilliards Creek weir prior to fishway construction.

Fishway Construction Works

Figure 30. Showing construction images of Hilliards Creek fishway

Post Remediation Works

Following the construction of the rock-ramp fishway, monitoring was carried out in December 2016 to assess the capabilities of the fishway at passing the full suite of fish species and size classes expected to occur in Hilliards Creek. The fishway trap was set at the exit of the fishway on the upstream side of the crossing, to show the numbers and species of fish that were able to ascend the rock-ramp fishway. Across five days of monitoring, a total of 9 species were surveyed ascending the fishway, at an overall catch rate of 177.66 fish per day. The small size of fish (≥15 mm) that were successful at ascending the fishway indicates the fishway is operating as intended (small size fish are generally weaker swimmers than adults, as they don't possess the same muscle to propel them through the water). However, due to a low passability fish barrier located downstream in Fellmonger Park (Figure 31), the numbers of fish migrating through the fishway were reduced when compared to other fishways constructed as part of this project.

The Fellmonger Park barrier consists of a raised pedestrian causeway with two small partially blocked pipe culverts buried underneath. This causeway is a major barrier to fish passage during all base, low and medium flow events. Only during very in-frequent 'drown out' events is fish passage potentially available past this barrier, but only if migrating fish are located below the weir at the time of 'drown out' and possess swimming abilities in-excess of the velocities experienced at the barrier site.

Boat electrofishing surveys were undertaken upstream and downstream of this barrier to detect any differences in fish community condition. The survey results demonstrated the barrier was significantly impacting upstream fish communities, with the catch rate (56.97 fish/min) of diadromous fish species downstream of the barrier more than four times higher than upstream of the barrier (12.37 fish/min) (Moore, 2017).

Table 1. Showing fish species, size range and catch per unit effort of fish (fish/day) successful at ascending the fishway

Migration Classification	**Common Name**	**Species Name**	**Size Range** (mm)	**CPUE** (Fish/day)
Diadromous	Empire gudgeon	*Hypseleotris compressa*	19- 81	18.22
	Long-finned eel	*Anguilla reinhardtii*	60- 800	1.08
	Sea mullet	*Mugil cephalus*	38- 51	15.62
	Striped gudgeon	*Gobiomorphus australis*	38- 51	1.3
Potamodromous	Hypseleotris species	*Hypseleotris sp.*	20- 43	77.44
	Unspecked hardyhead	*Craterocephalus fulvus*	20- 71	54.66
Pest Fish	Mosquito fish	*Gambusia holbrooki*	15- 35	8.68
	Platy	*Xiphophorus maculatus*	64	0.22
	Tilapia	*Oreochromis mossambicus*	329	0.22
		Total Species and Overall CPUE	**9**	**177.66**

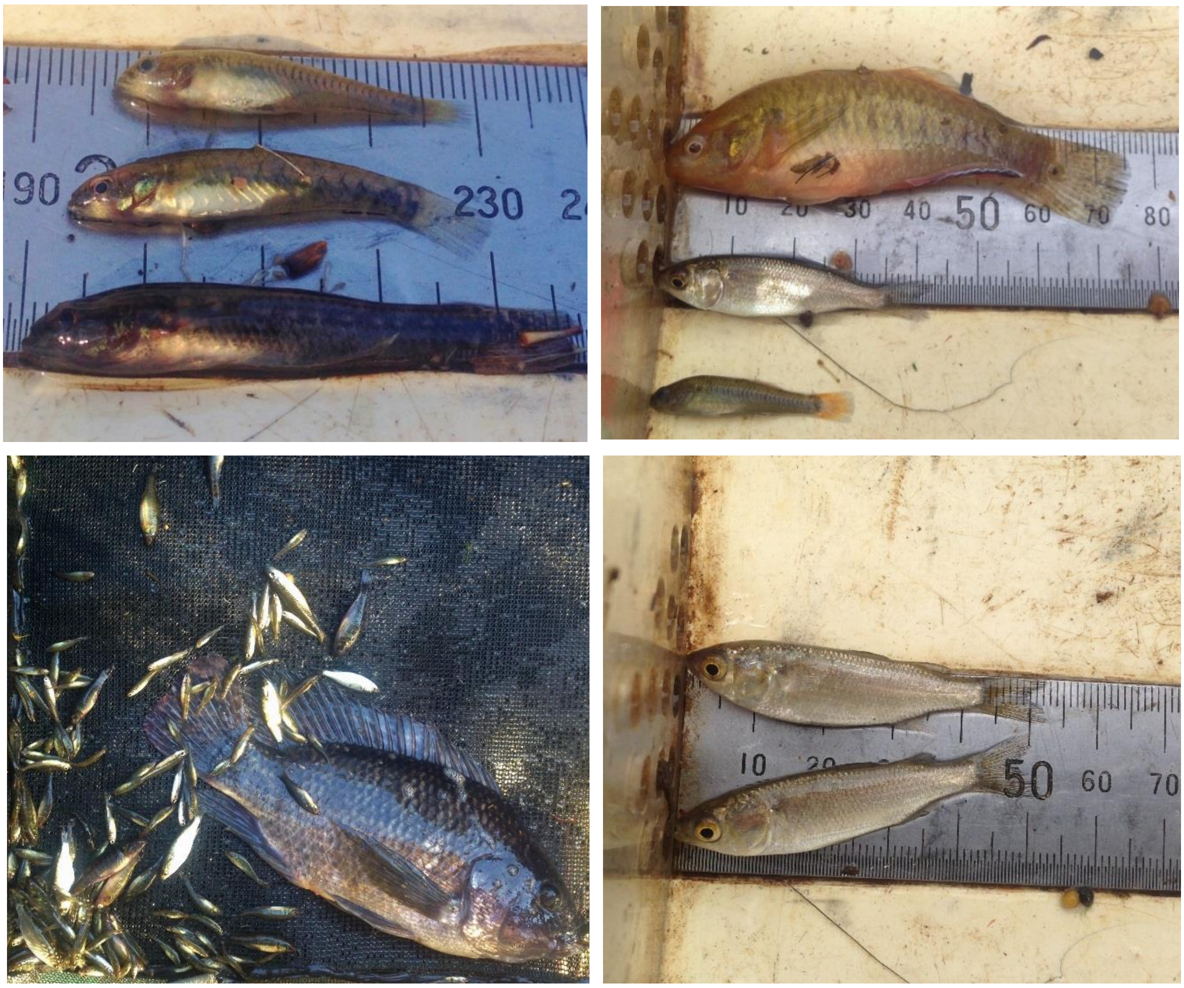


Figure 30. Showing Hilliards Creek fishway monitoring catch results.

Figure 31. Left; showing an adult tarpon captured immediately upstream of the barrier site post fishway construction. tarpon are a highly prized recreational fishing species, which breed in estuarine waters before migrating upstream into freshwater as juveniles. Barriers significantly impact the distribution and population of this species. Right; Fellmonger Park pedestrian causeway fish barrier. A Hilliards Creek fish community study found this barrier to be significantly impacting fish populations within Hilliards Creek , particular diadromous species.

Appendix 3 - Barriers of Each LGA

Brisbane City Council LGA

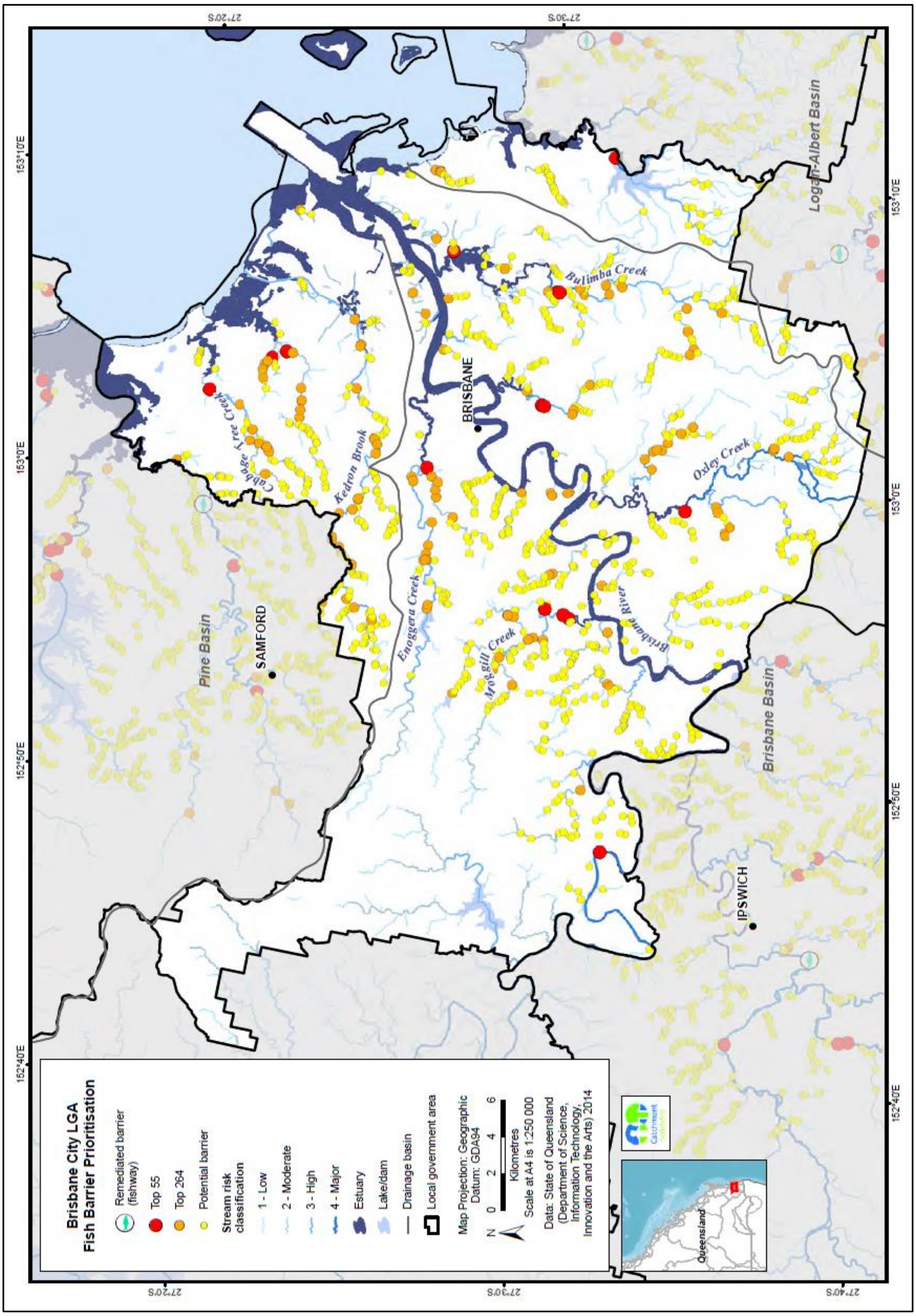


Figure 32. Brisbane City Council LGA barriers, broken down into top 55 (red), top 264 (orange), potential barriers (yellow) and remediated barriers (green)

Gold Coast City Council LGA

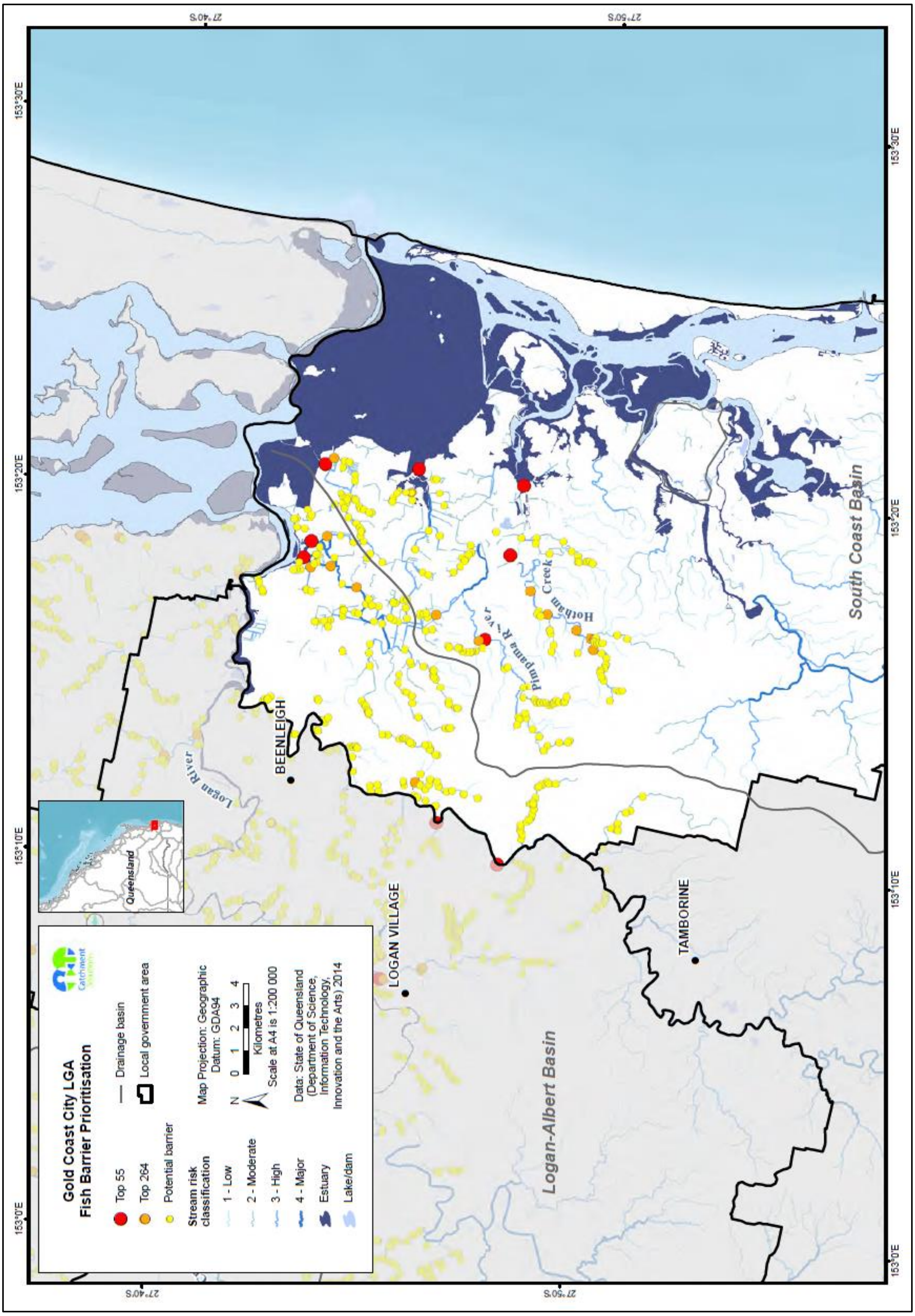


Figure 33. Gold Coast City Council LGA barriers, broken down into top 55 (red), top 264 (orange), potential barriers (yellow) and remediated barriers (green)

Ipswich City Council LGA

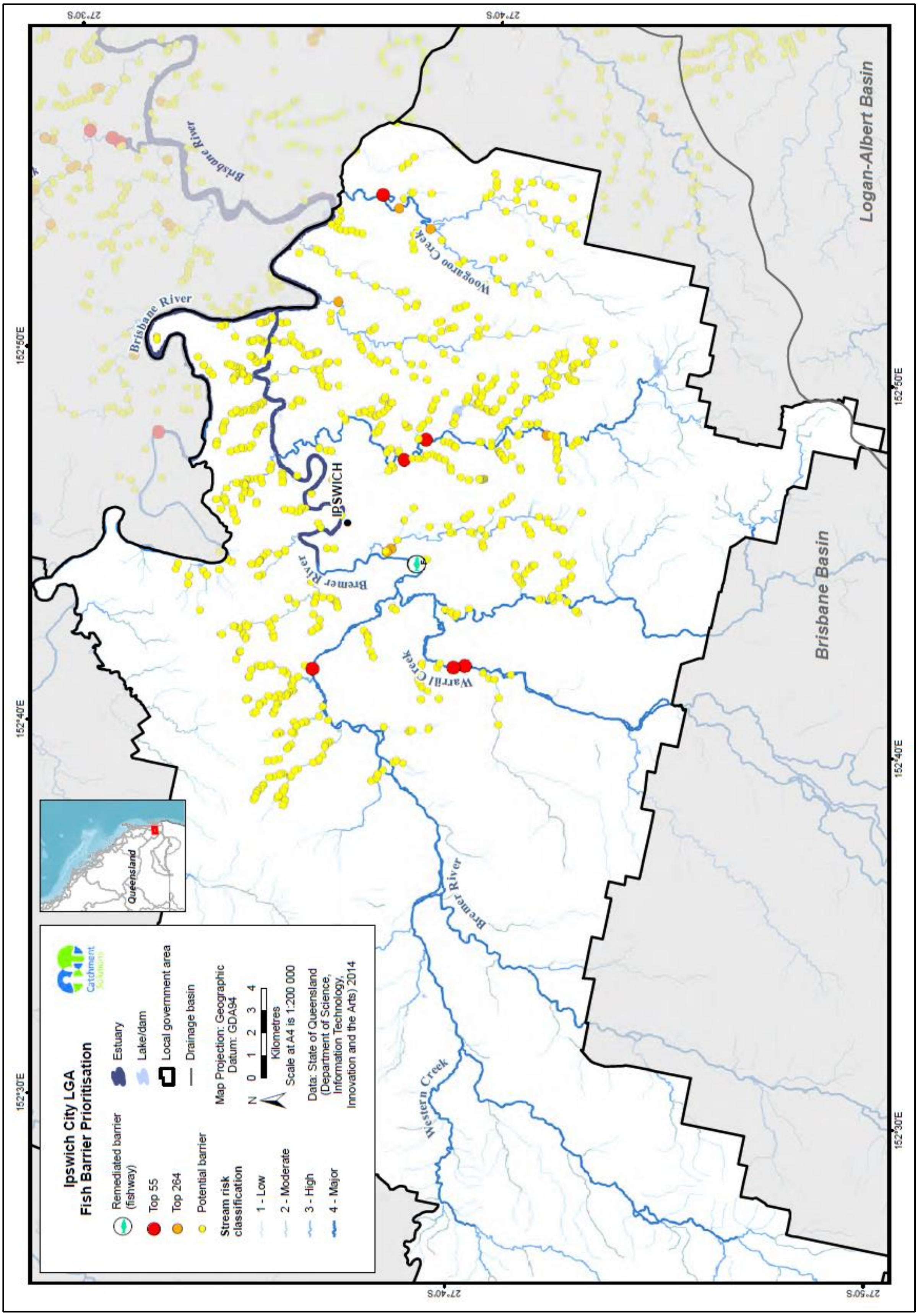


Figure 34. Ipswich City Council LGA barriers, broken down into top 55 (red), top 264 (orange), potential barriers (yellow) and remediated barriers (green)

Logan City Council LGA

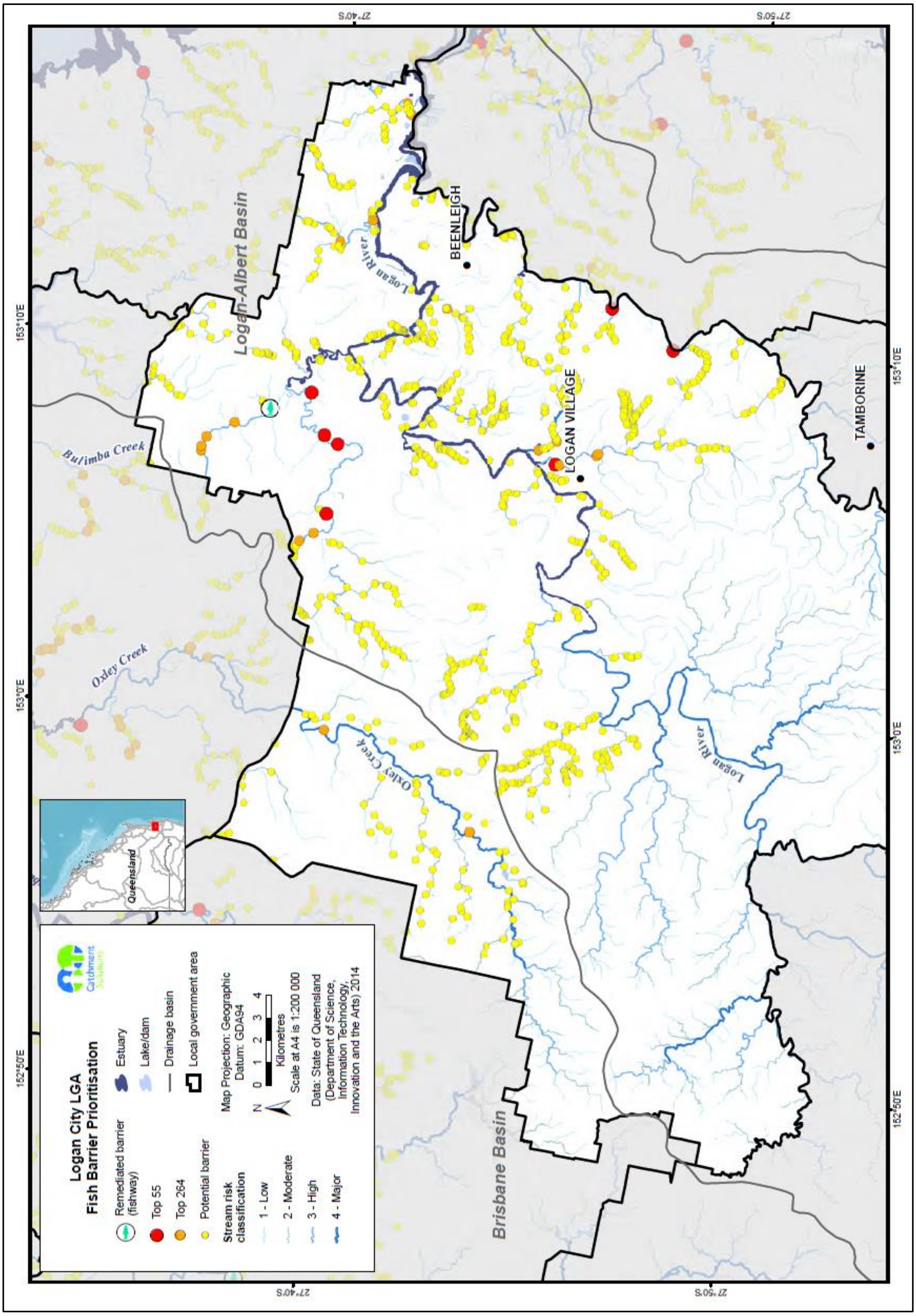


Figure 35. Logan City Council LGA barriers, broken down into top 55 (red), top 264 (orange), potential barriers (yellow) and remediated barriers (green)

Moreton Bay Regional Council LGA

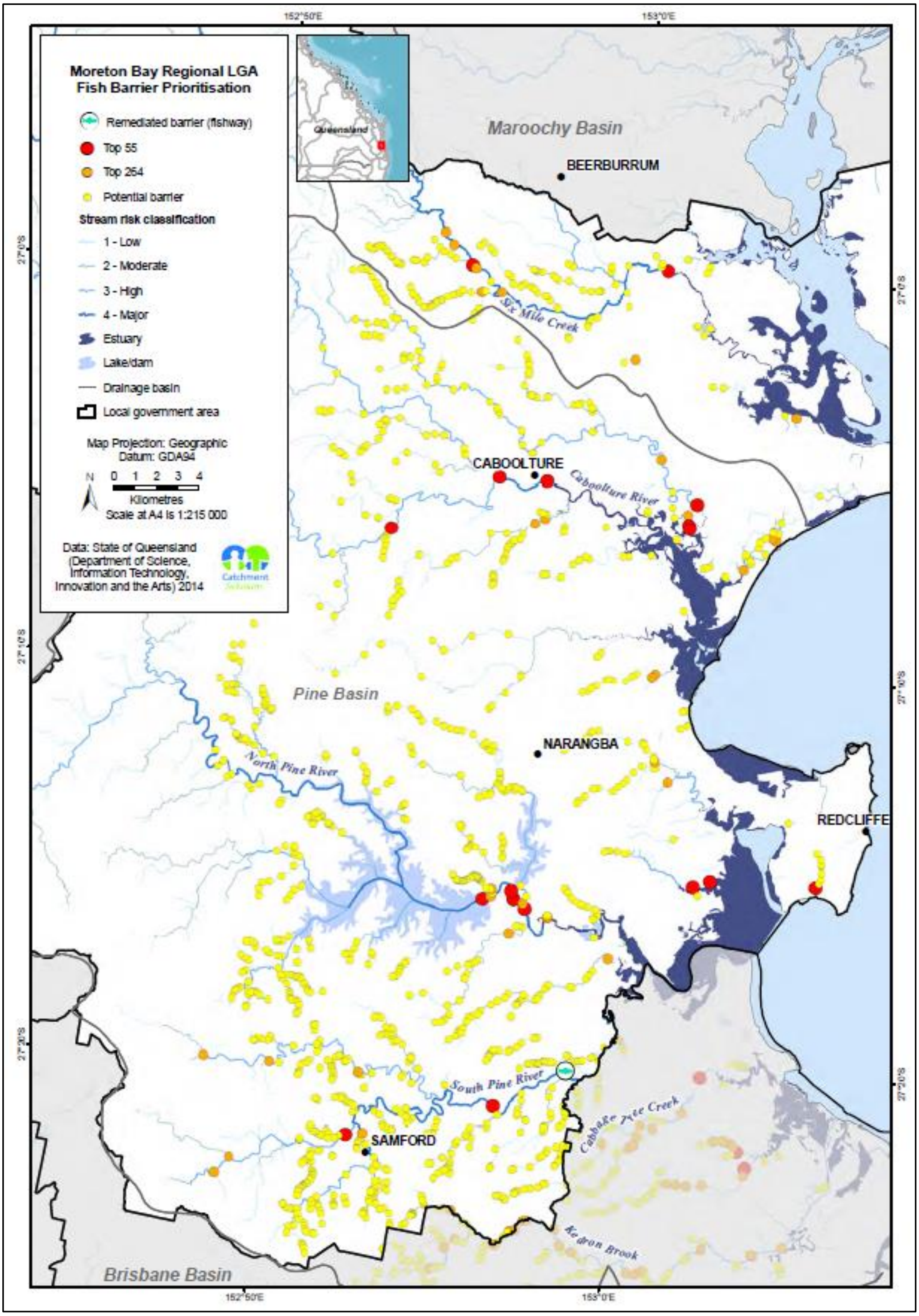


Figure 36. Moreton Bay Regional Council LGA barriers, broken down into top 55 (red), top 264 (orange), potential barriers (yellow) and remediated barriers (green)

Redland City Council LGA

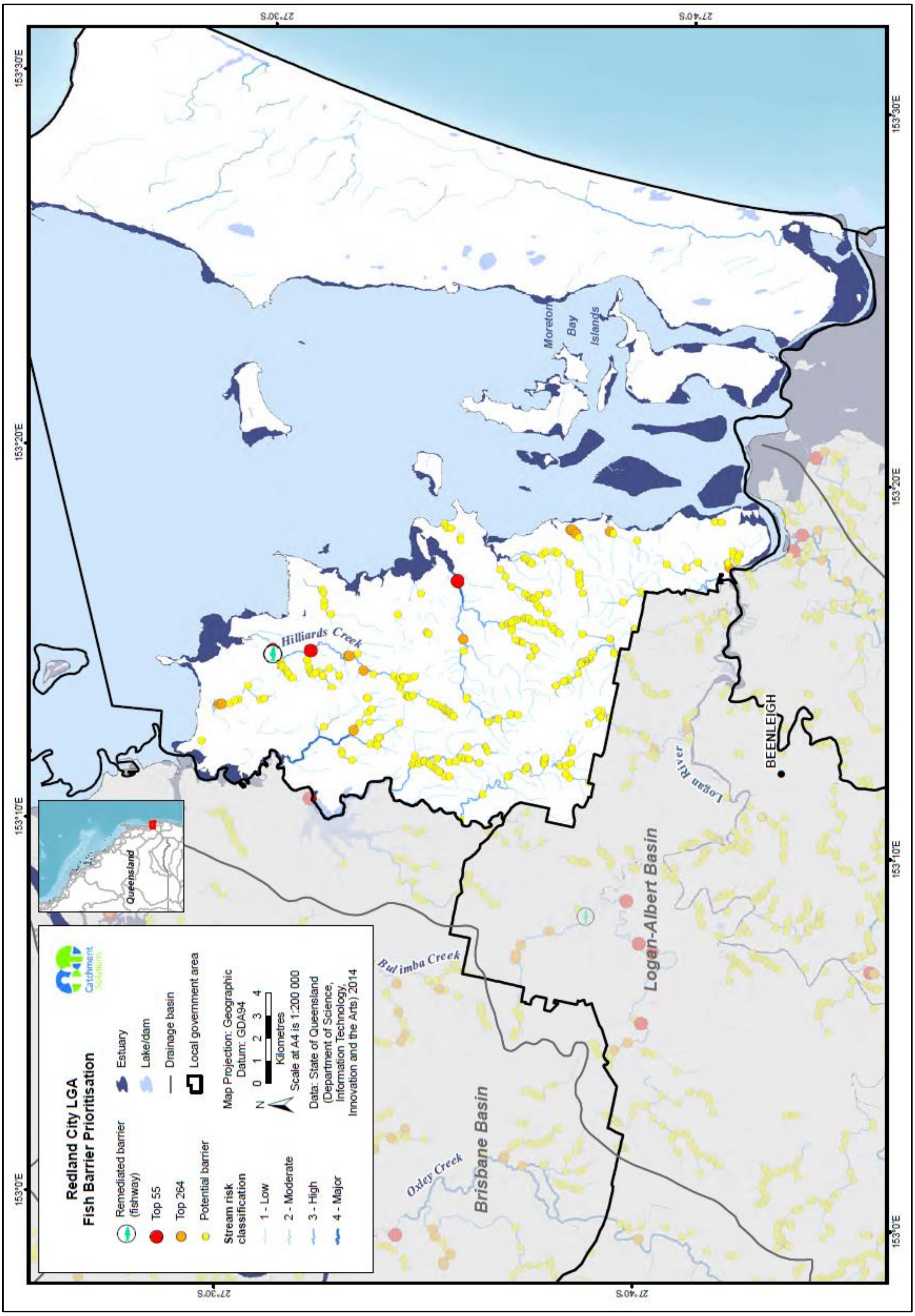


Figure 37. Redland City Council LGA barriers, broken down into top 55 (red), top 264 (orange), potential barriers (yellow) and remediated barriers (green)

Appendix 4. Example Informative Fishway Sign

Hilliards Creek Fishway, Redland City Council

Figure 38. Example informative fishway sign which could be installed at a fish passage remediation site to inform the local community regarding the many benefits of improved aquatic connectivity and describe how fishways operate.
Fishway Sign designed and installed by Redland City Council.

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