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Mackay Regional Council Fish Barrier Prioritisation

June 2015

Matt Moore

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For further information contact:

Matt Moore

Project Officer

Catchment Solutions – Fisheries and Aquatic Ecosystems

Ph: (07) 4968 4214

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Enquires should be addressed to:

Manager

Catchment Solutions Pty Limited

PO Box 815, Mackay Qld 4740

Tel: 07 4968 4200

Email: info@catchmentsolutions.com.au

Cover Figure: From top, left to right (barriers): Lower Jolimont Creek Weir; Mckays Rd culverts and apron drop, Macquarie Creek; Station Rd pipe causeway, Mares Nest Ck (O'Connell Catchment); Porters Rd pipe causeway, O'Connell River. Freshwater diadromous fish species: snakehead gudgeon, jungle perch, barramundi & mangrove jack.

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Glossary of Terms

Diadromous - Diadromous fishes are truly migratory species whose distinctive characteristics include that they (i) migrate between freshwaters and the sea; (ii) the movement is usually obligatory; and (iii) migration takes place at fixed seasons or life stages. There are three distinctions within the diadromous category: catadromous, amphidromous and anadromous.

- Catadromous - Diadromous fishes which spend most of their lives in fresh water, and migrate to sea to breed.
- Amphidromous - Diadromous fishes in which migration between freshwater and the sea is not for the purpose of breeding, but 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

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

Acronyms

RCL -	Reef Catchments Limited
NRM -	Natural Resource Management Group
MW -	Mackay Whitsundays
WQIP -	Water Quality Improvement Plan
MRC -	Mackay Regional Council
WRC -	Whitsunday Regional Council
MWFBPP -	Mackay Whitsunday Fish Barrier Prioritisation Process
FBPP -	Fish Barrier Prioritisation Process
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

Executive Summary

This report was commissioned by Mackay Regional Council (MRC) to identify and prioritise the large number of anthropogenic barriers that prevent, delay or obstruct fish migration in the MRC region. The following report comprises a three stage fish barrier prioritisation process (FBPP) that comprehensively ranks barriers to fish passage based on a number of key biological, geographic and economic considerations.

The prioritisation process initially utilised Geographic Information System (GIS) software to rapidly assess thousands of potential barriers before undertaking a collective optimisation rank-and-score approach. Importantly, key socio-economic 'flow on' benefits of improving aquatic ecosystem connectivity have been considered i.e. increasing fisheries productivity and conserving vulnerable fish species.

Fish migration is an essential life history adaptation utilised by many fish species that occur in the MRC region. Migration strategies between key habitats have evolved for a variety of reasons, including for feeding and reproduction purposes, to avoid predators, to utilise nursery areas and maintain genetic diversity.

Barriers preventing connectivity in the MRC region impact fisheries' productivity and create environmental conditions favourable for invasive fish species. Significantly, approximately 48% of MRC region fish species undertake ontogenetic shifts in habitat use between near-shore marine and freshwater environments. Low transparency barriers located on high ordered streams close to the tidal interface have the greatest impact, preventing and impeding juvenile diadromous species from undertaking important longitudinal and lateral life-cycle dependant migrations into critical nursery habitats.

Key socio-economic species such as barramundi, sea mullet, mangrove jack, jungle perch, tarpon and long-finned eels are significantly affected. Barriers in the MRC region impact freshwater fish communities, affect aquatic ecosystem resilience and reduce the vicarious values the local community places on waterways flowing into the Great Barrier Reef Marine Park.

In many parts of the world remediation of barriers with appropriately designed fishways is one of the most successful management tools utilised by government agencies and natural resource management groups to help reduce the impacts of barriers. However, objectively choosing the 'right' barriers to remediate in order to obtain the greatest benefits requires a holistic prioritisation process. The following three stage MRC barrier prioritisation process achieves this by investigating the cumulative impacts barriers have on the environment, fishery, economy and local community. The resultant priority ranked list will assist natural resource managers and decision makers in determining where best to allocate limited funding opportunities to ensure the greatest environmental and socio-economic outcomes for the MRC region.

The aims of the project were to:

1. Comprehensively identify all potential barriers to fish passage in the MRC region (2929),
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 – validate, score and rank priority barriers based on transparency, type, 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 30 priority ranked barriers to fish passage in the MRC region - including remediation options and indicative cost.

Introduction

The majority of freshwater fish species of the MRC region migrate at some stage during their life history. Some of these migrations are short and confined wholly to freshwater habitats, while some migrations occur across vast distances and between varying habitats, including between freshwater and near-shore marine environments. Of the 48 freshwater fish species recognised as occurring in the MRC region (Moore, 2007), almost half (48%) require unimpeded access between freshwater and estuarine habitats to complete their life cycle or maintain sustainable populations.

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 Mackay Regional Council fish barrier prioritisation process (MRCFBPP) has been developed to assess and rank barriers having the greatest adverse impacts on MRC region fish communities. Barriers located on high ordered streams close to the sea significantly influence the structure of the regions fish communities, particularly diadromous species (fish that undertake ontogenetic shifts in habitat use between near-shore marine and freshwater habitats) and as such, the MRCFBPP has been structured to prioritise these barriers.

Diadromous species are of high socio-economic value to recreational, commercial and indigenous fisheries and play a significant role influencing the health and well-being of local communities. Queensland's two most important and iconic in-shore commercial net species, barramundi and sea mullet (Williams, 2002) (Figure 1), require unimpeded access between freshwater and estuarine habitats to maintain sustainable populations (Mallen-Cooper, 2000), and occur in the MRC region (Moore and Marsden, 2007). 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.

The MRCFBPP involves a three stage rapid assessment process that ensures limited 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 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 optimisation and scoring-and-ranking methods in stage two and three.

This efficient approach allows limited resources to be directed towards assessing the highest ranking potential barriers after the initial GIS stage, rather than a 'scatter gun' approach of visiting random and potentially less significant barriers.

Important geo-spatial 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 laterally or longitudinally along the waterway,
- Large amount of habitat upstream of the potential barrier,
- Low proportion of intensive land use within the sub-catchment.

Figure 1. Diadromous fish species impacted by barriers: barramundi (left) and sea mullet (right). Important recreational, commercial and indigenous fishery species; sampled from freshwater habitat in Shoalwater Creek, central QLD.

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 purposes of this prioritisation process, environmental barriers such as weed chokes, waterfalls, low dissolved oxygen slugs and high water temperature barriers have not been included, even although anthropogenic factors may have adversely contributed to their frequency. Anthropogenic barriers included in this prioritisation process include structures such as culverts, pipes (Figure 2), road crossings, weirs (Figure 2), dams, flow gauging structures (Figure 2), bunds (or ponded pastures) and sand dams. These structures have been built for a variety of purposes such as irrigation supply, flow gauging and regulation, on-farm stock watering and irrigation supply, urban and industrial supply, flow management and flood control, prevention of tidal incursion, road crossings or simply for urban beautification and recreation facilities (Marsden *et al.* 2003).

Barriers impact fish communities in many ways, some barriers such as high dams form 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 enough to form barriers for many fish, particularly juvenile and small bodied species.

The swimming abilities of fish play a critical part in understanding the effects of barriers. 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. Pertinently, many juvenile diadromous species undertake significant upstream migrations into critical nursery habitats, and less obvious barriers such as culverts and pipes can create velocities in excess of the swimming abilities of many species.

Mallen-Cooper (1989) tested the swimming abilities of two iconic and recreationally important diadromous fish species, barramundi 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 gudgeons, a small-bodied diadromous species (Moore, 2007) (3.2-7.7 cm) and found that they were only able to sustain swimming speeds of ≤0.10 m/sec.

The velocities these important fish species are able to negotiate pales in comparison with their Northern Hemisphere counterparts, adult Atlantic salmon, which are able to negotiate velocities of at least 2.4 m/sec (Mallen-Cooper, 1989). Unfortunately, many early Australian fishways 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 Australian fish communities are capable of ascending on a regular basis, and have themselves become fish barriers e.g. Marian Weir vertical slot fishway (Figure 3).

Figure 2. Different barrier types: pipe culverts and concrete apron (downstream) (left); weir (top right) and V-notch gauging weir, (bottom right).

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 barramundi. However, the unique climbing abilities of juvenile long-finned eels enables them to ascend up and over >200 mm damp vertical surfaces (Jellyman, 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 -20 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 (<150 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 so problematic for juvenile and small bodied fish when stream flow conditions through smooth-surfaced structures like culverts >3 m in length exceed 0.3 m/sec (T.Marsden 2015, pers. comm). Generally barriers can be defined into 6 types:

- Water surface drop/Excessive head loss – Vertical drop off road crossings, weirs and culvert aprons that are greater than 200 mm in waterways close to the freshwater/estuarine interface and 350 mm in top of catchment/high gradient streams.
- 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.

Figure 3. Northern Hemisphere designed pool and weir fishway on Marian Weir (Pioneer River, QLD). Excessive turbulence and velocity produced by this 'fishway' acts as a barrier to most Australian native fish.

- 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).
- Shallow Water – Shallow water depth of 5 mm - 100 mm depending on species, size and morphology. Larger bodied demersal species are affected more. Shallow water is often experienced during low flow condition across road crossings, through culverts and across culvert aprons (Figure 4).
- Behavioural – Dark 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 (in the MW region). 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 (Patullo Road, Gregory River) 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; Blackrock Creek pipe causeway displaying velocity and behavioural barriers (dark shadows/insufficient lighting in pipe) and water surface drop barrier (Sandy Creek Tributary).

Barrier Transparency

Barrier transparency is one of the main factors that influence the ability of fish to migrate past a barrier, and forms an integral part of the current MRCFBPP scoring criteria when assessing barriers in the field (Stage 2). Barrier transparency, sometimes referred to as barrier passability or barrier efficiency, describes the extent to which in-stream barriers impede fish passage (Kemp and O'Hanley, 2010). Barrier transparency can be extremely complicated, with many dynamic temporal and spatial ecophysical characterises influencing the extent and magnitude of barriers at different scales (Bourne *et al.* 2011). The four overarching characteristics and their associated influences 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

For the purposes of the current rapid assessment MRCFBPP, barrier transparency was simplified into three categories.[1]

Low Transparency (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 >1 m.

Medium Transparency (Figure 5)

- Occasionally drowns out (e.g. average 2-10 times/yr),

[1] It is imperative that experienced fish biologists or environmental officers 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 this criteria.

- 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 Transparency (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 transparency barrier (Macquarie Ck Weir), Medium transparency barrier (Palm Tree Rd causeway, Sandy Ck), High transparency barrier (Myrtle Ck).

Mackay Regional Council Fish Migration and Freshwater Fish Community Condition

Fish Migration

Fish migration in the MRC region is intrinsically linked to large seasonal variations in the annual hydrological regime. This regime is largely driven by monsoonal low pressure systems which trend southwards from northern Australia during the summer months. The annual 'wet season' increases stream flow conditions and creates an abundance of transitional wetland habitats (Figure 6). The largest king and spring tides also occur at this time of year (Bureau of Meteorology (2015) http://www.bom.gov.au/australia/tides/#!/qld-mackay-outer-harbour. Weaker swimming 'young of the year' diadromous species such as barramundi and tarpon have evolved life history migration strategies to coincide with the exacerbated summer flow conditions and higher tides. They utilise these favourable conditions to enter into and out of inter-tidal supra-littoral habitats before migrating upstream longitudinally into low ordered streams and laterally into lowland wetlands (Russell and Garrett, 1985).

Wetland nursery habitats offer seasonally plentiful conditions characterised by abundant prey items, complex in-stream habitat and minimal high order piscavorous predators - other than themselves. The ontogenetic shifts in habitat use displayed by juvenile diadromous species in the MRC region highlights the importance of providing fish passage past barriers, especially barriers located close to the tidal interface.

The number and type of barriers located both longitudinally and laterally 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 MRC region generally contain diverse and abundant fish communities, with a high proportion of diadromous species (Moore, 2007). 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 upstream to the first barrier is extremely important. Simply, the greater the amount of connected in-stream habitat, the greater the diversity and abundance of diadromous species resulting in better condition fish communities.

The number of in-stream barriers located laterally and longitudinally significantly reduces the ability of diadromous species to reach upstream nursery areas. On occasions diadromous species may be able to utilise 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. Therefore, the cumulative impact of barriers, and amount of connected in-stream habitat between barriers, are extremely important spatial attributes influencing the composition of MRC region fish communities.

Mackay Regional Council Freshwater Fish Community Condition

The MRC region encompasses a diverse range of freshwater fish species (48) with almost half (48%) of these species requiring free access between freshwater and estuarine habitats to complete their life cycle or maintain sustainable populations. Fish species of socio-economic importance to recreational, commercial and indigenous fisheries make up a significant proportion of the diadromous fish community, including: barramundi, sea mullet, mangrove jack, jungle perch, tarpon and long-finned eels.

A comprehensive baseline fish community monitoring project undertaken by Moore (2007) found that surrounding land use had the greatest influence on fish community structure and abundance in freshwater reaches. The fish community monitoring program covered 14 of the Mackay Whitsunday region's 33 sub-catchments, incorporating a diverse range of stream types. [2]10 of the 14 sub-catchments fell within the MRC region boundary. Catchments were chosen based on their surrounding land use as a percentage of intensive cropping (chiefly sugarcane), within the total sub-catchment area (Figure 6)**.** Sampling was undertaken across three distinct seasons, encompassing pre and post-wet season conditions in 2006/07 and pre-wet season conditions in 2007/08. Both boat and backpack electrofishing were used to survey fish communities.

Using this data, Moore (2015) applied three fish community health indicator metrics to determine freshwater fish community condition of each of the 14 sub-catchments. The condition of the region's fish communities were used to establish fish health report card scores and displayed in the Mackay Whitsunday Water Quality Improvement Plan (Folkers *et al.,* 2015) and can be viewed in Table 1. Fish health metrics were established on ecological fish fauna characteristics collected and analysed from the fish community monitoring rounds. The three health metrics used to determine the relative condition of the region's freshwater fish communities were:

1. Catch per unit effort (CPUE), i.e. the number of fish sampled per minute of electrofishing 'on' time (fish/minute);
2. Fish fauna richness, i.e. the total number of native species recorded from all river reaches (upper, middle & lower) across all sampling rounds (pre & post) for each sub catchment, and
3. Pest fish species richness.

Results showed that undisturbed 'bushland' catchments contained the healthiest fish communities, while sub-catchments dominated by intensive surrounding land use practices contained fish communities in 'poor' condition (Table 1). Repulse Creek, with an entirely bushland catchment, contains the healthiest fish communities in the region, scoring a 'Very Good', while the other two bushland sites, Finch Hatton and St Helens Creeks, as well as grazing and grazing and intensive cropping catchments, Carmila and Blacks Creek, received the equal second highest fish community health rating of 'good' (Report Card Score of B-). Intensive cropping catchments with >40% intensive cropping, Myrtle, Bakers and Sandy Creeks received the lowest fish community health ratings of 'poor' respectively (D-, D+ and D+ respectively).

[2] A small proportion (4) of the sub-catchments in this study fell outside the MRC region boundary (i.e. Basin Creek) but have been included in this section for regional context.

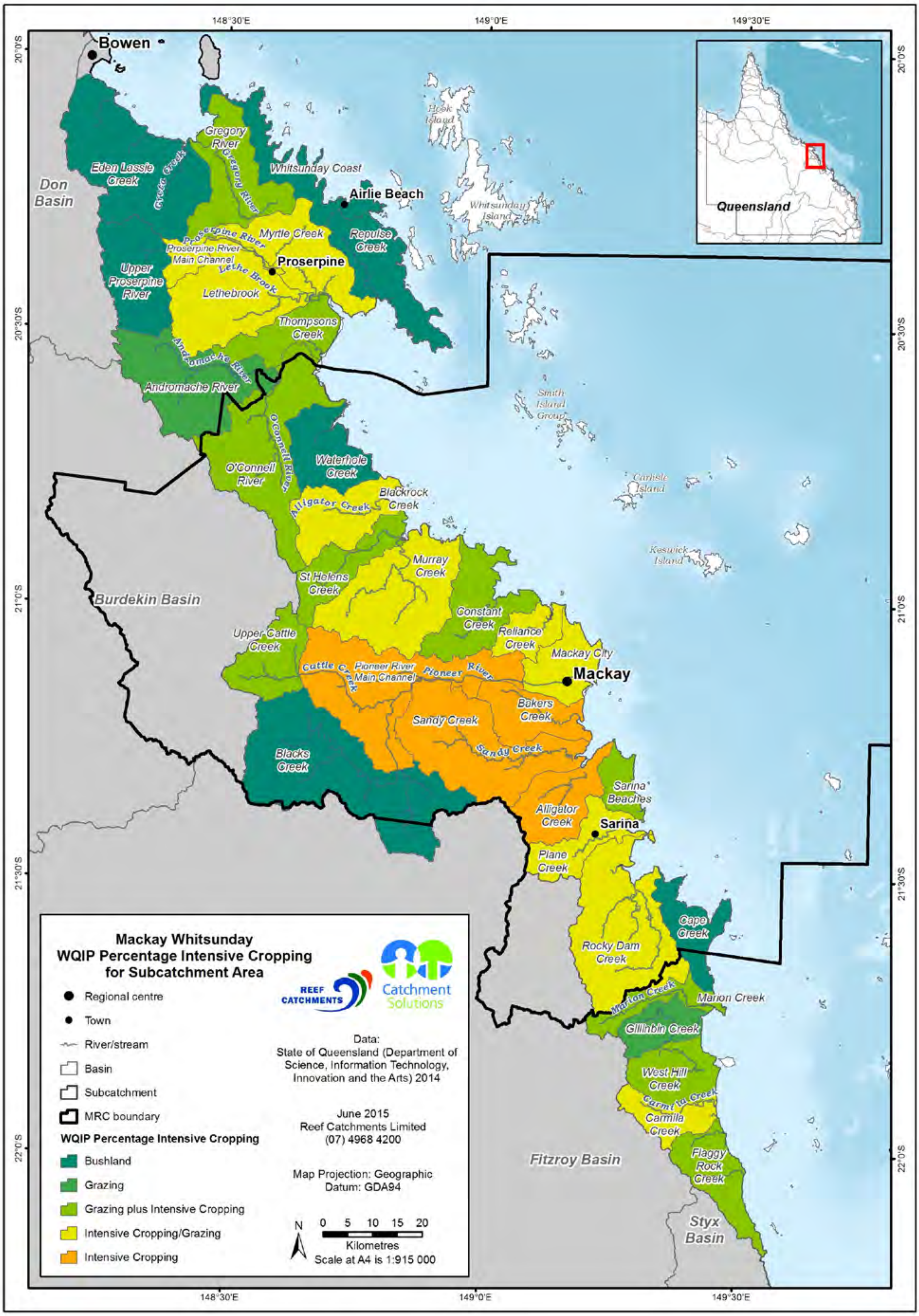

Figure 6. Showing MW sub-catchments colour coded based on their land use as proportion (%) of intensive cropping.

Table 1. Showing land use category as proportion (%) of intensive cropping, stream order, three fish health metrics: fish catch per unit effort (CPUE) and native and pest fish richness and associated results, subsequent fish community health rating derived from the metrics and overall fish health report card score for each sub-catchment.

Land use Category	% Intensive Cropping	Sub-catchment	Stream Order	CPUE (fish/min)	Native Species Richness	Pest Fish Richness	Fish Community Health Rating	Report Card Score
Bushland	0 – 2 %	Repulse Creek	4	29.55	9		Very Good*	A*
		Finch Hatton Ck	4	32.87	12		Good	B-
		St Helens	4	46.08	17	1	Good	B-
Grazing	2 - 4 %	Basin Creek	4	15.49	8		Moderate	C-
		Blacks Creek	5	31.24	15		Moderate	C+
Grazing/ Intensive Cropping	5 - 19 %	Plane Creek	4	16.17	16	1	Moderate	C-
		Carmila Creek	5	32.14	13		Good	B-
		Andromache R	6	23.76	17	1	Moderate	C-
Intensive Cropping/ Grazing	20 - 39 %	O'Connell River	6	22.63	20	1	Moderate	C+
		Rocky Dam Ck	4	8.31	13		Moderate	C-
		Pioneer River	6	19.69	17		Moderate	C-
Intensive Cropping	40 + %	Sandy Creek	5	9.69	18	2	Poor	D-
		Bakers Creek	4	11.86	13	2	Poor	D-
		Myrtle Creek	4	9.93	14	3	Very Poor	E+
Average				**22.10**	**14**		**Moderate**	**C-**

Condition of Freshwater Streams & Fish Habitat

Regional Overview

The MRC local government area is geographically positioned within the Mackay Whitsundays (MW) region. The MW region covers 940,000 ha incorporating 33 sub-catchments from Eden Lassie Creek south of Bowen to Flaggy Rock Creek north of St Lawrence (Table 1). The waterways within these catchments generally start on the high coastal range before ascending in an easterly direction and flowing into the Great Barrier Reef Marine Park. They are predominantly characterised as being short coastal ephemeral streams, with only a small number of perennial waterways, i.e. Pioneer River and St Helens Creek, and one sub-catchment in pristine condition, Repulse Creek in Conway National Park.

The Mackay Whitsunday region has seen dramatic catchment changes over the past hundred years, with large-scale agricultural development and increasing urban development affecting most catchments in the region. Prior to development, the region generally consisted of medium height eucalypt forests with a moderately closed canopy, while in mountainous regions rainforest was the dominant forest type. Only small areas in near coastal regions north of Proserpine and south of Carmila had open low forest type vegetation (Arthington *et al*. 2001).

Many aquatic ecosystems of the MW region have been impacted by intensive surrounding land use practices. Impacts include poor water quality runoff, degraded riparian and in-stream habitats, flow modification and barriers to fish migration. The cumulative impacts of these and other modifications has led to changes in the condition of the region’s fish communities, adversely impacting fish abundance, species richness, fish community composition and exacerbating the prevalence of pest fish species (Moore, 2007). Significantly, where in-stream and terrestrial habitats persist undisturbed, healthy populations of diverse fish communities remain.

The fish habitats within the streams have been maintained in relatively good condition, except in streams that have undergone extensive modification in the name of river improvement. Streams such as Cattle Creek in the upper reaches of the Pioneer River have been reshaped on a regular basis to protect land adjacent to the stream. Marsden *et al.,* (2006) suggests that this has led to a decrease in the quantity and quality of habitat available for fish in these reaches, leading to a corresponding decline in fish numbers. Barriers to migration have had the greatest effect on the fish communities of the region, affecting access that fish have to the various habitats upstream and disrupting reproductive cycles (Marsden *et al.,* 2006).

Catchment overview

Aquatic ecosystems of the MW region boast a diverse range of habitat types, from lowland wetland complexes surrounded by sugar cane fields to small rainforest streams draining the uniquely diverse Eungella National Park. The condition and health of these aquatic ecosystems is often closely related to the nature and intensity of surrounding land use practices. Many of the region's rivers and wetland habitats are surrounded by intensive land use and have suffered from habitat degradation, poor water quality, barriers to migration and altered flow regimes (Figure 7). However, a small proportion of aquatic habitats within or surrounded by national parks and pristine vegetated areas still contain excellent in-stream and riparian habitats, good water quality, unmodified flow regimes and no barriers to fish migration.

Figure 7. Upper Bakers Creek, a highly modified intensive cropping catchment. Showing a sugarcane farm (background), barrier (pipe causeway) to fish passage constructed to haul sugarcane, altered flow regime (irrigation flows for sugarcane), cleared riparian habitat, no shade, straightened channel and declared class 2 aquatic pest plant species; hymenachne.

Methods

Mackay Regional Council Area

The MRC region is located on the central Queensland coast and covers an area of 7261 square kilometres (Figure 8). The area supports a population of 110,000 (Mackay Regional Council Corporate Plan, 2009-2014) people centred on Mackay and Sarina. The region boasts a tropical climate, typified by long hot summers and mild winters, with a pronounced wet season occurring in summer and dry season occurring in winter. It is the largest sugar-producing region in Australia and nearly a third of Queensland's export goods originate from the Mackay region.

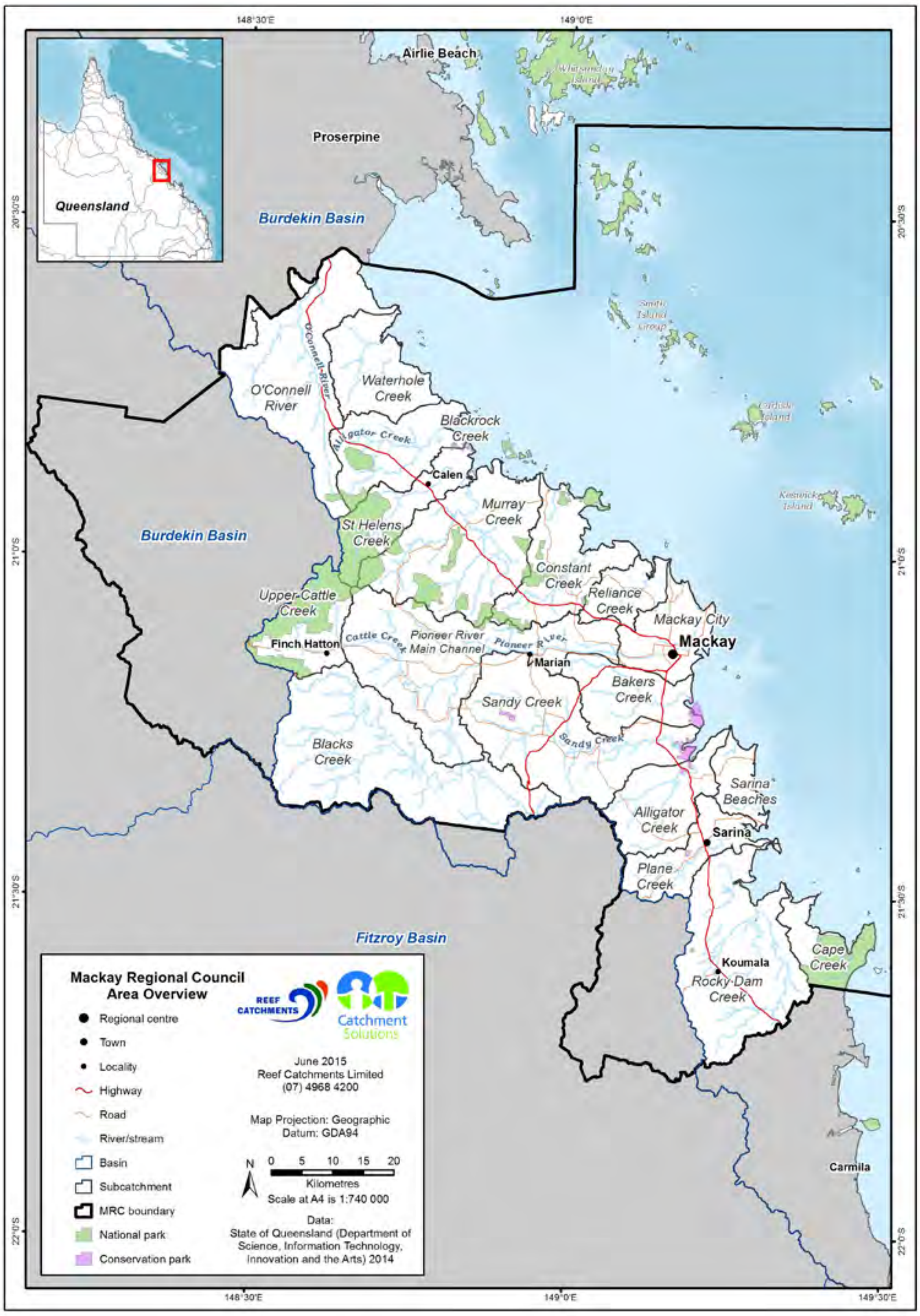

Figure 8.Map of the Mackay Regional Council Area showing regional centres and sub-catchments.

Land use

The MRC region has some of the most intensively developed agricultural areas in Queensland, with some catchments in the region having over 50% of their area intensively cropped**.** The dominant agricultural industry within the region is sugar cane cropping, however agricultural land is also used for rangeland beef grazing, orchards, market gardening and horticulture.

The region's fertile plains have enabled extensive agricultural development based on sugar cane to flourish, with numerous small townships and communities radiating out from the central hubs of Mackay and Sarina. On the fringes of the sugar producing areas there are widespread cattle grazing areas that also contribute to the agricultural base of the region. The MRC region also supports mining, fisheries and tourism industries.

It is estimated that within the Pioneer catchment about 20% of land is used for cane, 16% for grazing, 15% for other purposes and the remaining 49% is rainforest, steep open forest or steep woodland (Arthington *et al*., 2001). Many of the districts plains have been cleared for agricultural purposes, with the majority of the forests occurring in the mountainous regions where cultivation is not undertaken. Waterways in these locations are still in good condition (Figure 9).

Despite having large areas of forest, only a small area of the region's catchments are conserved within National Parks (Usher, 1997). Mackay is the largest urban centre in the study area with a population of 87,324 (Mackay Whitsunday Isaac Natural Resource Management Plan, 2014 -2024). Other rural townships are scattered throughout the region and include, Finch Hatton, Garget, Marian, Mirani, Walkerston, Bakers Creek, Eton, Sarina and Carmila.

Figure 9. Good quality riparian and in-stream habitat; lower Rocky Dam Creek, Koumala.

Fish Barrier Prioritisation Process

Due to the extremely large project area and high number of barriers encountered during the study it was important to prioritise potential barriers so limited resources could be utilised in the most appropriate manner. To achieve this, a three stage selection criteria process used by Moore and Marsden (2008) was refined and enhanced with the latest innovative river network analysis technology by Hornby (2015); RivEX. The three stages involved evaluating the biological, social and economic benefits of providing free fish passage past the barrier for the environment and local community. The final result of the prioritisation process after taking these considerations into account is a prioritised list of all actual and potential barriers and a further detailed priority ranked list of the top 40 ranked barriers showing remediation options and indicative cost.

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

Stage 1 of the barrier prioritisation incorporates a desktop GIS process to efficiently investigate spatial and temporal habitat characteristics associated with each potential barrier on a whole of catchment basis. The initial utilisation of GIS enables the prioritisation process to assess thousands of potential barriers and systematically rank them in order of importance. This first step is critical to the prioritisations success, as it allows resources to be directed towards assessing the most important potential barriers first.

This initial GIS process allows 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 200 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. However, due to the large geographic area, high numbers of barriers and limited funding streams for fisheries based riverine restoration projects, this 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 highly important.

Stage one of the prioritisation process utilised ArcMap 10.2 GIS software. To initially identify potential barriers raster data in the form of satellite imagery and aerial photography was used in ArcMap combined with high resolution satellite imagery in Google Earth Pro (GEP). Vector data in the form of stream and road network shapefiles were then acquired and imported into ArcMap and GEP to assist in identifying potential barriers.

Potential barrier waypoints were created at the intersection of road and stream networks in ArcMap and GEP. Waypoints were also created at the intersection of waterbodies and roads that were not part of the data set but easily identified using imagery. Waypoints were assigned to obvious barriers such as dams and likely potential barriers such as small weirs. In-addition to potential barriers identified using raster and vector data sets, further potential barrier information was obtained from a range of sources, including government departments, water board authorities and local communities. Each potential barrier waypoint created in ArcMap and GEP 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. Note: All 'barriers' are potential barriers until they have been identified in the field as actual barriers in stage two of the process.

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), proportion of intensive land use (e.g. sugar cane) and number of barriers downstream. The specialised river network GIS processing tool 'RivEX' (Hornby 2015) was used to analyse the 100K Queensland 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 one determined, i.e. highest total score becoming the highest ranking barrier after stage one. The following attributes were fundamental for a potential in-stream barriers 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 MRC region were classified into five separate classes based on three stream characteristics: Strahler stream order, stream gradient (slope) and stream type (estuarine or freshwater). These three stream characteristics are strongly correlated with fish diversity and fish composition, i.e. high stream orders (4-7) with low gradients (slope) close to or within estuarine habitats have highly migratory and diverse fish communities as opposed to low ordered streams (1-2) with steep gradients (slope) at high elevations (Fisheries QLD, 2015). The stream classification system (Table 2) is based on Fisheries QLD 'Waterway Barrier Works Stream Layer' which is used to determine fish passage requirements on each of Queensland's waterways (stream order >1).

Note: Due to the large number of barriers (3974) the first step was to remove all potential barriers on stream order 1's that did not intersect with the estuary. All potential barriers on stream order 1's that intersect with estuarine habitats remain in the prioritisation. After this first step in the process, 1737 potential barriers remained and were prioritised against the full suite of stage 1 selection criteria.

Table 2: The five stream classes and associated scoring system for Question 1.

Option	Stream classification (represented by colour code)	Stream characteristics	Scoring System
a.	Purple	Strahler stream orders 4-7	10
b.	Red	Strahler stream orders 2-3 with low gradient Strahler stream order 3 with medium gradient	5
c.	Amber	Strahler stream order 3 with high gradient Strahler stream order 2 low/medium gradient	3
d.	Green	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. Sub-catchments (n=33) derived from the Mackay Whitsunday Water Quality Improvement Plan (Folkers *et al.,* 2015) (Table 3). Example: Intensive land use, i.e. sugar cane, consists of 65.5 % of the Bakers Creek sub-catchment. Potential barriers located in this sub-catchment receive a score of 0.

Table 3. 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). 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 4).

Table 4. 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 no barriers) i.e. amount of available upstream habitat if the barrier is remediated. Example: 15 kms of stream length (habitat) from barrier 1 to barrier 2, then barrier 1 receives a scores of 4 (Table 5).

Table 5. 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 (habitat) 'cut off' by 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 of the stream network to the potential barrier as a proportion (%) of the total stream length in the whole sub-catchment. Barriers close to the tidal interface that prevent connectivity to the rest (high proportion) of the catchment score high.

Example: Barrier 1 is situated in a sub-catchment that contains 100 kms of stream network. Barrier 1 is located 10 km upstream along the stream network from the DDL. 90 kms of stream length (habitat) is located upstream of barrier 1. Therefore, stream length upstream of barrier 1 (90 kms) as a proportion of the total sub-catchment stream length (100 kms) equates to 90% (90/100*100 = 90%) and a score of 5 points (Table 6).

Table 6. Distance (km) of stream network upstream of the barrier (cut off by barrier) as a proportion (%) of the total sub-catchment stream network (km).

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 two of the prioritisation involves field validation of the top 200 - 300 ranked potential barriers after stage one 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, vital information regarding the barrier's physical characteristics were collected. Important barrier parameters collated included: the type of barrier, number of culverts/pipes, head loss, length, height and width of structure and apron dimensions. Photos and additional site constraint information relating to access for heavy machinery and barrier ownership were noted.

Detailed ecological information on the stream (Table 8) and flow condition (Table 9), in-stream habitat condition for migratory fish upstream of the barrier (Table 10) and distance from the tidal interface (Table 11) were assessed. Barriers were assigned a score of 1-5 for each of the ecological criteria. Scores were collated and added to stage one scores to obtain an overall score and rank after stage two of the prioritisation. 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 7.

Table 7. Barrier type assessment criteria and associated score.

Option	Barrier Type	Score
a.	Tidal barrage or bund.	5
b.	Dam or weir >3m.	4
c.	Dam or weir 1.5 – 3m high.	3
d.	Dam or weir <1.5m high or culvert or pipes <60% of bankfull stream width.	2
e.	Culverts/pipes that span >60% of bankfull stream width.	1
f.	No barrier – DO NOT SCORE REMAINING CRITERIA	

Question 7. Stream/Riparian Condition

Pristine-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 8.

Table 8. Stream/riparian condition assessment criteria and associated score.

Option	Stream/Riparian Condition	Score
a.	Pristine-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 9.

Table 9. Stream flow classification assessment criteria and associated score.

Option	Water Supply/Quantity	Score
a.	Natural, permanent, perennial flow.	5
b.	Natural, permanent via supplemented flow.	4
c.	Stream 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 assessment criteria options and scores are displayed below in Table 10.

Table 10. 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 snags, 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 11.

Table 11. 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 the top ranked barriers after stage two. Barriers that can be remediated with low cost fishways while increasing fisheries productivity score high, whereas large 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 MRC region. The end result of the third stage is a priority ranked list of the top 30 barriers to fish migration in the MRC region.

The following attributes were fundamental for in-stream barriers to score well in the third stage:

- Low cost to remediate,
- Suitable site access for heavy machinery
- Landholder permission to remediate barrier (if known),
- Low technical fishway with minimal engineering required,

- Fishway to benefit listed or restricted species,
- High commercial, recreational or indigenous fishery productivity benefits (if barrier is remediated).

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 12. Fishway and fish community monitoring *not* included in cost estimates.

Table 12. Estimated remediation cost assessment criteria and associated score.

Option	Estimated Remediation Cost	Score
a.	Low cost: $0 - $30 k i.e. Small rock-ramp (RR) or short culvert baffles (CB)	5
b.	Low- moderate cost: $30 - $60 k i.e. Medium R.R /high CB, small pre-cast cone (PCC)	4
c.	Moderate cost: $60 - $100 k i.e. High RR/small-medium size PCC or vertical-slot (VS)	3
d.	Moderate- high cost: $100 - $200 k i.e. Large size/ technical PCC or VS	2
e.	High cost :> $200 k i.e. Large size/high height technical 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 creek rehabilitation project. 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 (if known). Assessment criteria options and scores for question 12 'community and in-kind support' are displayed below in Table 13.

Table 13. 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. – Technical viability

Technical viability - How difficult is the fishway (or barrier removal) to design, construct and maintain. Assessment criteria options and scores for question 13 'technical viability' can be seen below in Table 14.

Table 14. Technical viability assessment criteria and associated score.

Option	Technical Viability	Score
a.	Simple installation of current design with limited engineering & low maintenance requirement i.e. rock-ramp fishway	5
b.	Modest installation of current design with engineering, moderate level maintenance requirement i.e. vertical-slot fishway	3
c.	Complex installation & engineering, new design, high maintenance requirement i.e. fish lift	1

Question 14. – Fisheries Productivity and Economic Benefits

Productivity benefits - Will species benefited improve commercial harvest or recreational fishing opportunities or increase revenue to local businesses (consider the % improvement on current fish passage as well). Assessment criteria and scores for question 14 are shown below in Table 15.

Table 15. Fisheries Productivity and economic benefit assessment criteria and associated score.

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

Question 15. – Conservation Significance

Conservation significance - Will improved connectivity have a positive impact on the conservation of listed species? Assessment criteria and scores for question 15 'conservation significance' are displayed below in Table 16.

Table 16. 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

Results

Stage 1 - Catchment Scale GIS Analysis

A total of 2929 potential in-stream barriers were assessed during stage one of the prioritisation. 1192 potential barriers were scored and ranked (Figure 10), while 1737 potential barriers located on stream order 1's that did not intersect estuarine habitats were removed from further stages. The highest stage one score was 30 out of a possible 32 points, which was attained by the O'Connell River sand dam and Russell's crossing causeway on St Helens Creek.

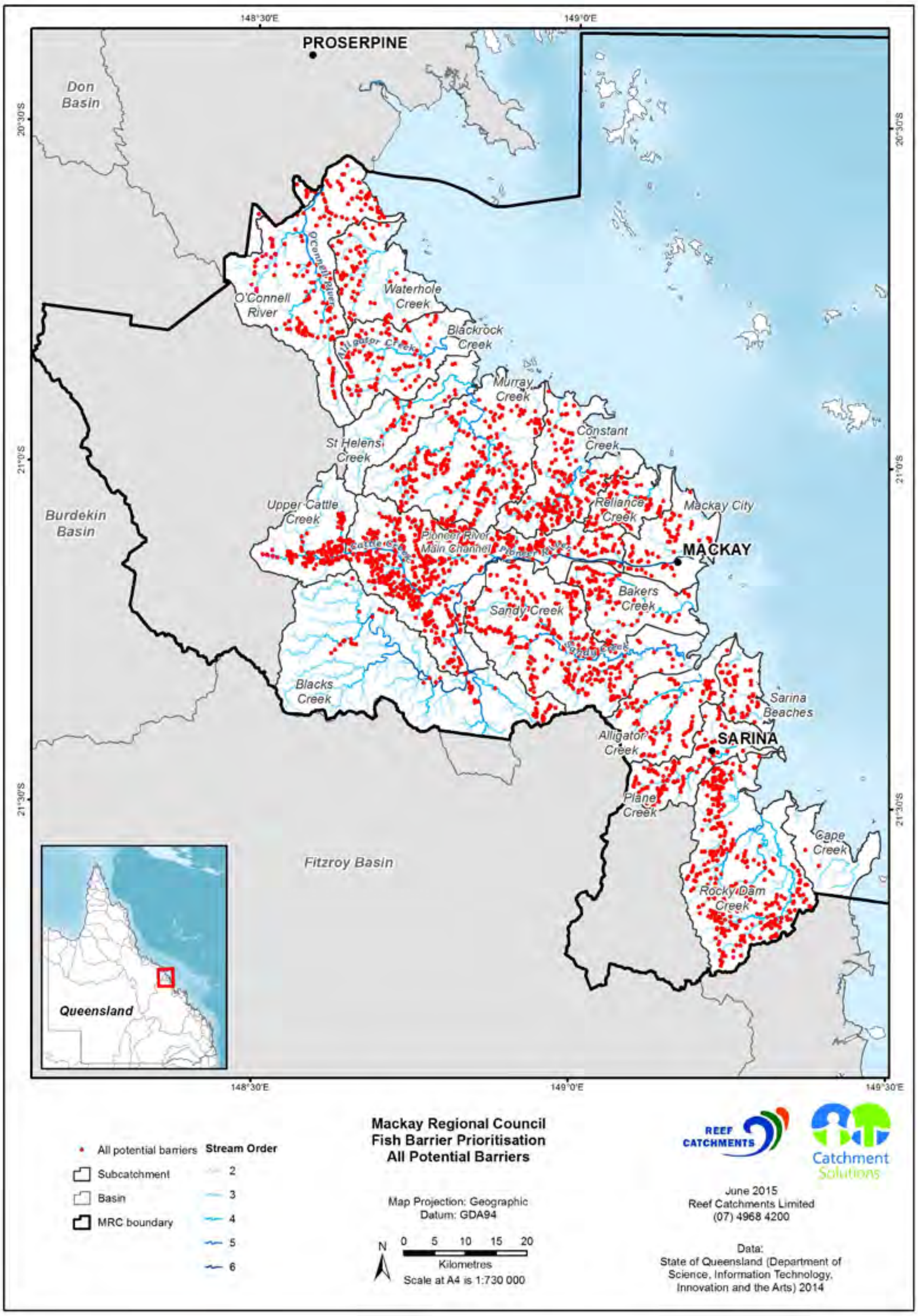

Figure 10. Map showing the location of 2929 identified potential barriers in the MRC region

Stage 2 - Fine Scale Site Specific Ecological Assessment

A total of 203 potential barriers were assessed in the field during the second stage of the prioritisation. Actual barriers to fish passage accounted for 113 (56 %) of the field validated potential barriers, the remaining 90 non-barriers predominantly consisted of bed level creek crossings and bridges. The 113 barriers (Figure 11) were assessed against site specific ecological criteria set out for stage two, before advancing to stage three of the prioritisation process.

A sand dam (barrier ID 3931) barrier on the estuarine/freshwater interface of the O'Connell River was the highest scoring barrier in stage two of prioritisation, scoring 21 out of a maximum 25 points, to bring its overall combined stage two score to 51 points and a ranking position of 1 (Table 17). A large low passability weir immediately upstream from the tidal interface on Jolimont Creek obtained the second highest score (20), followed by two tidal bund barriers on Boundary Creek (ID 3988 & 3981) scoring 19.

Table 17. Showing the top 54 (n=63 - 11 barriers shared the same rank of 53) ranked barriers after stage two including barrier name/type, barrier ID, waterway the barrier is located on and combined stage one and two total score.

Stage 2 Rank	Barrier ID	Waterway	Barrier Name	Stage 2 Score
1	3931	O'Connell R	Sand Dam on tidal interface	51
2	2593	St Helens Ck	Russels Crossing Road Causeway	44
2	2614	Jolimont Ck	Mulherin Rd - Large Weir close to Tidal interface	44
2	2636	Reliance Ck	Neills Rd Causeway - 3 Culverts - Tidal interface	44
5	111	Sandy Ck	Palm Tree Rd Causeway + Culverts	43
5	2630	Constant Ck	Freds Lower Weir	43
5	3120	Tedlands Ck	Tidal Bund on Tedlands wetland	43
8	2588	Blackrock Ck	Old Bowen Rd Causeway + Culverts	42
8	2631	Constant Ck	1938 Weir U/Strm of Freds Weir	42
8	3174	Cherry Tree Ck	East Inneston Rd Causeway Culverts	42
8	10	Pioneer R	Marian Weir	42
12	3981	Boundary Ck	Borg Tidal interface Wetland Bund Main Channel	41
12	3942	Boundary Ck (O'Connell)	Dougherty's Rd Causeway Culverts	41
12	3988	Boundary Ck	Borg Tidal interface Wetland Bund DS	41
15	2616	Jolimont Ck	Narpi Rd 2 Pipe Causeway	40
15	83	Bakers Ck	Weir (1.5 m) Irrigation 1900s	40
15	2544	Plane Ck	Brooks Rd Tidal Causeway Culverts	40
18	2610	Macquarie Ck	Large Weir	39
18	3127	Tedlands Ck	Tedlands wetland - 1 Sml Culvert	39
18	41	Pioneer R	Mirani Weir	39
18	202	Teemburra Ck	Teemburra Dam	39
18	3329	Plane Ck	Lower Weir off Brewers Rd – behind treatment plant	39
23	2601	Murray Ck	Clewss Rd Causeway	38
24	2575	Macquarie Ck	Mackays Rd Causeway Culverts	37
24	3990	Sandy Ck	Gauging Weir	37
26	1214	Leila Ck	Sants Rd Pipe Causeway	35
26	2586	Alligator Ck	Tolcher Rd - 2 Pipe Causeway	35

Table 17.Continued from previous page

Stage 2 Rank	Barrier ID	Waterway	Barrier Name	Stage 2 Score
26	2568	Macquarie Ck	Geeberga Buthurra Rd - 2 Pipe Causeway	35
26	*184*	*Bell Ck*	Cane Crossing - Seasonal pipes	35
26	*3966*	*Bakers Ck Sth Arm*	Abbots Rd Causeway Culvert	35
31	2713	Boundary Ck	Borgs Upstream Bund	34
31	3958	O'Connell R	Porters Rd	34
31	3960	Sandy Ck	G. Vella Large Weir U/S Coles Weir	34
31	99	Maclennan Ck	Estuary - 4 pipes	34
31	3985	Blackrock Ck	Dittons Rd Causeway	34
31	3952	Horse Ck	Seasonal Pipe Crossing	34
31	1332	Bassett Basin	Vines Ck Bassett Basin wetlands train crossing	34
31	3979	Bakers Ck	Bailey St - 1 pipe	34
39	1316	McReadys Creek	Golf Links Rd C/way - 2 Sml Culverts + Apron Drop	33
39	2703	Plumtree Ck	Causeway D/S rail crossing	33
39	3989	Boundary Ck	Borgs bund culverts	33
39	2583	Zamia Ck	Mentmore Rd Causeway	33
39	2587	Alligator Ck	Wagoora Yalboroo Rd Causeway + culverts U/S	33
39	25	McGregor Ck	High Weir	33
39	198	Alligator Ck trib	Of Munburra Rd	33
39	2633	Constant Ck	Low Causeway Culvert	33
39	2968	Unnamed	Tidal Causeway - Hay Pt Rd –Alligator Ck Sth Trib	33
48	1338	Fursden Ck	Rock Weir D/S Marajuy Yakapari Rd	32
48	2595	Blackrock Ck	2nd Barr Rise and Shine Rd -2 Sml culverts	32
48	2613	Niddoe Ck	Mulherins Rd Causeway - 2 Pipes	32
48	84	Bakers Ck	Drop Board Regulator	32
48	3955	2 Mile Ck	Dempster Ck Trib, Lindeman Dr - 1.5m apron drop	32
48	2564	Cabbage Tree Ck	Grass Tree Rd Causeway Culverts	32
54	2590	Blackrock Ck	1st barrier Rise and Shine Rd -1 Pipe Causeway	31
54	3970	Fursden Ck	Rock weir under train bridge & D/S large wetland	31
54	2574	Blackrock Ck	3rd Barr Rise & Shine Rd – 2 Pipe Causeway	31
54	2573	Blackrock Ck	4th Barrier Rise & Shine Rd -2 Pipe Causeway	31
54	3579	Boundary Ck	Causeway - 2 small Culverts - Nth Inneston Rd	31
54	2618	Jolimont Ck	Alan Maclean Lower Large Weir	31
54	2620	Jolimont Ck	Alan Maclean U/S Large Weir	31
54	144	Sandy Ck	Shane Coles Weir/Causeway	31
54	2584	Catherine Ck	Wagoora Yalboroo Rd Causeway	31
54	102	Maclennan Ck	1 Pipe Causeway on Tidal Interface	31
54	2566	Cabbage Tree Ck	Rock Causeway 100 m U/S Grasstree Rd	31

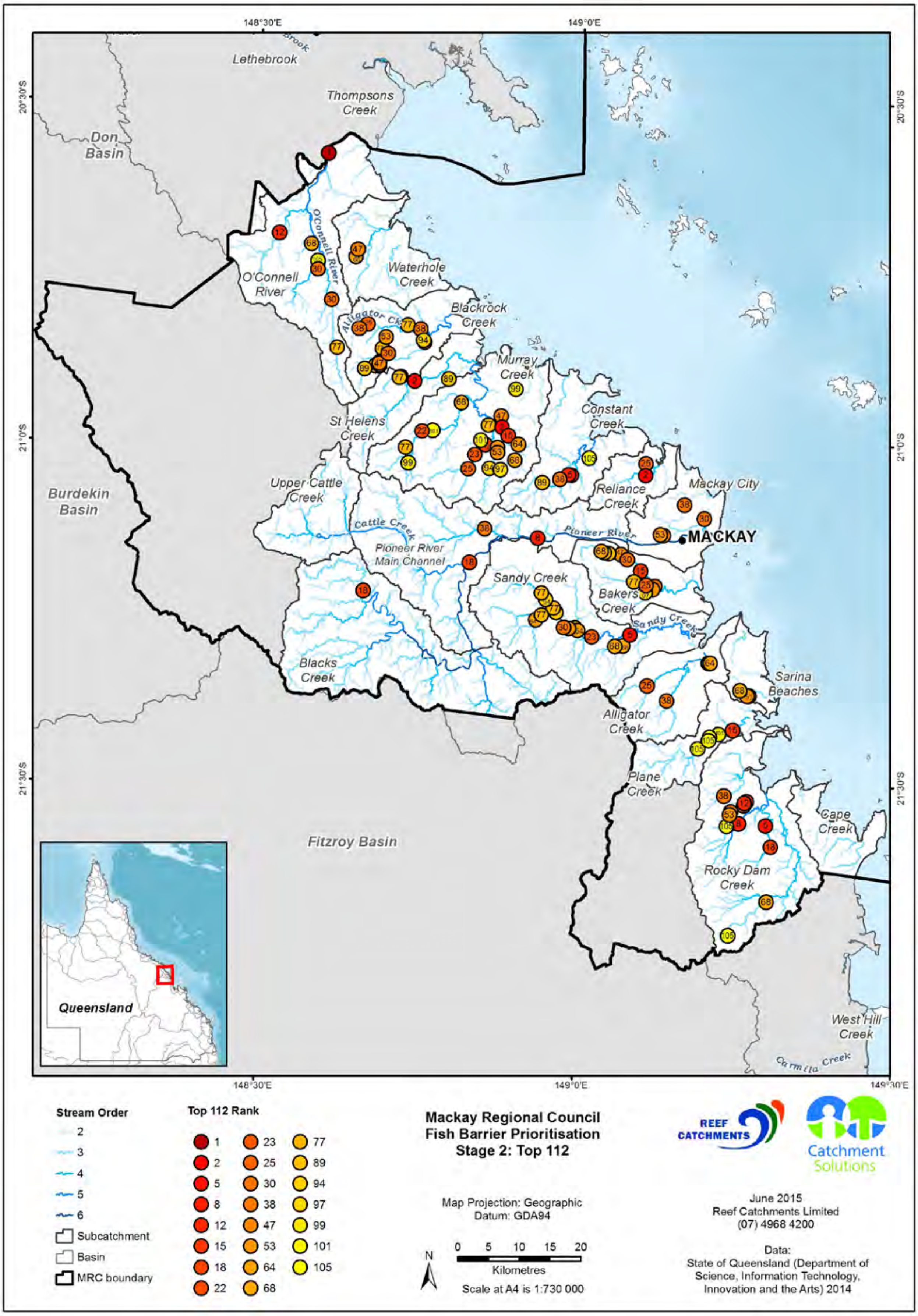

Figure 11. Showing the location of the top 112 barriers after stage two of the prioritisation.

Stage 3 – Social, Economic and Fisheries Productivity Prioritisation

The final stage involved assessing the top 112 ranked barriers after stage two. The end product is a priority ranked list of the top 30 ranked barriers (n=36, 7 barriers shared a score of 30) to fish passage in the MRC region (Table 18). The location and priority rank of the top 30 barriers is displayed in Figure 12.

Table 18. Top 30 (n=36) priority ranked barriers to fish migration in the MW region.

Final Rank	Barrier ID	Waterway	Barrier Name/Type	Total Score (3 stages)
1	3931	O'Connell R	Sand Dam - Tidal Interface	74
2	111	Sandy Ck	Palm Tree Rd Causeway + Culverts	65
2	2630	Constant Ck	Freds Lower Weir	65
4	2593	St Helens Ck	Russels Crossing Road Causeway	64
4	2614	Jolimont Ck	Mulherin Rd Weir	64
4	2588	Blackrock Ck	Old Bowen Rd Causeway	64
4	2631	Constant Ck	1938 Weir U/Strm of Freds weir	64
8	3120	Tedlands Ck	Wetland Tidal Bund	62
8	3174	Cherry Tree Ck	East Inneston Rd Causeway Culverts	62
8	3981	Boundary Ck	Borg Bund Main Channel	62
11	2636	Reliance Ck	Neills Rd Causeway - 3 Tidal Culverts	61
11	3942	Boundary Ck (O'Connell)	Dougherty's Rd Causeway Culverts	61
11	3988	Boundary Ck	Borg Bund DS	61
11	2616	Jolimont Ck	Narpi Rd - 2 Pipe Causeway	61
11	2610	Macquarie Ck	Large Weir	61
16	83	Bakers Ck	Weir (1.5 m) Irrigation 1900s	59
16	2575	Macquarie Ck	Mackays Rd Causeway Culverts	59
16	3127	Tedlands Ck	Tedlands wetland - 1 Sml Culvert	59
19	10	Pioneer R	Marian Weir	58
19	3990	Sandy Ck	Gauging Weir	58
21	2544	Plane Ck	Brooks Rd Tidal Causeway Culverts	57
22	2601	Murray Ck	Clewss Rd Causeway	56
22	1214	Leila Ck	Sants Rd - Pipe Causeway	56
22	1316	McReadys Creek	Golf Links Rd Causeway - 2 Sml Culverts	56
25	3966	Bakers Ck Sth Arm	Abbots Rd Causeway Culvert	55
25	2586	Alligator Ck	Tolcher Rd - 2 pipe Causeway	55
27	41	Pioneer R	Mirani Weir	54
27	1338	Fursden Ck	Rock Weir (under) Marajuy Yakapari Rd	54
27	3985	Blackrock Ck	Dittons Rd Causeway	54
30	2568	Macquarie Ck	Geeberga Buthurra Rd -2 pipe Causeway	53
30	2713	Boundary Ck	Borgs Upstream Bund	53
30	3958	O'Connell R	Porters Rd Causeway, Pipes + Apron Drop	53
30	3960	Sandy Ck	G. Vella Weir U/S Coles Weir	53
30	2590	Blackrock Ck	1st barr Rise & Shine Rd -1 pipe Causeway	53
30	3329	Plane Creek	High Lower Weir behind wtr treatment	53
30	3970	Fursden Ck	Rock Weir under train bridge D/S wetland	53

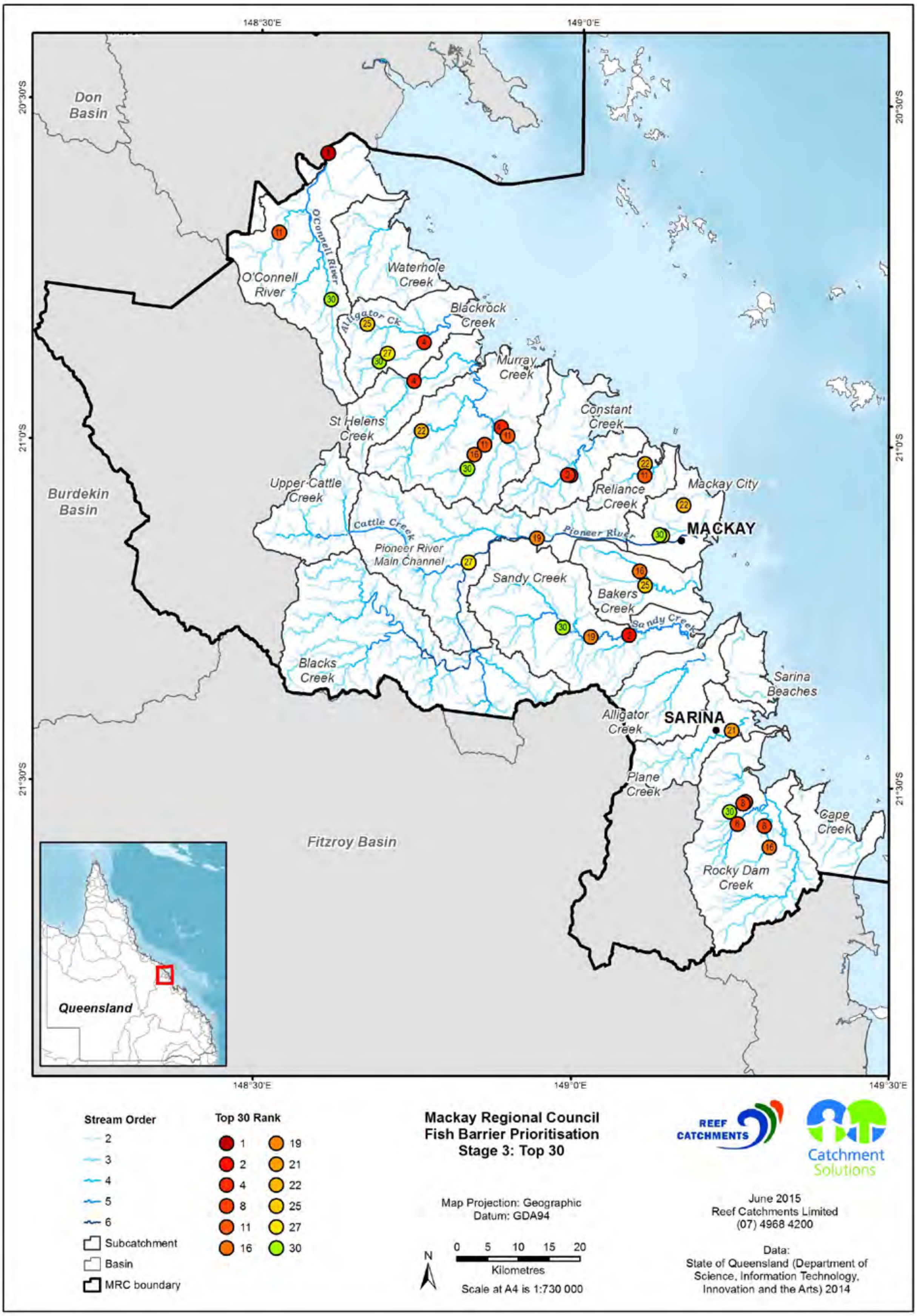

Figure 12. Location and overall priority rank of the top 30 (n=36) fish barriers in the MRC region

Discussion

The desktop study of the MW region identified a total 2929 potential in-stream barriers. Just over half of these (59%) are located on small ephemeral, Stream Order 1 waterways that provide minimal fish habitat. As a result of this, Stream Order 1s that did not intersect with estuarine habitats were removed in stage one. Stream Order 1s in close proximity (intersecting) or within estuarine environments were determined to contain higher fish habitat values than top of catchment Stream Order 1s, and therefore remained in the prioritisation process. Potential barriers on low ordered (1) streams (ranked between 1193 and 2929) remain on file. These potential barriers can be further assessed into the future if required, e.g. if the ~1000 higher priority ranked potential barriers are assessed and remediated (or removed from the list if determined not to be a barrier).

A total of 1192 potential barriers were assessed and ranked in accordance with the spatial and temporal habitat characteristic criteria set out in stage one. This was achieved using the analytical GIS stream network processing tool, RivEX. Due to time and funding constraints, 203 high ranking barriers were visited in the field. Of the 202 ground-truthed potential barriers, 113 were determined to be barriers that prevent, delay or obstruct fish migration. The remaining 90 potential barriers were assessed as not affecting fish passage. These consisted of bed level stream crossings (Figure 13) and structures such as bridges.

Figure 13. Natural bed level crossing on Macquarie Creek, Mt Ossa, QLD.

Through the prioritisation process barriers were ranked according to the impact they have on MRC 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 guide to the most likely places that targeted rehabilitation of fish passage will have the greatest benefit to fish communities of the region. The list contains many significant barriers in the region such as: Marion Weir, as well as a number of smaller barriers that while having less impact are cheaper and simpler to fix. The list also contains a number of structures that have functioning fishways installed on them, however it should be recognised that some of these are older fishways that may not be passing the whole fish community and as such the barrier is still partially there.

With the prioritisation now completed and a list of potential sites for rehabilitation of fish passage recommended, MRC can move forward with an investment program that looks to gain funds for 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 real-world realities may make some sites more or less practical.

In all cases, rehabilitation of a site should be investigated thoroughly prior to any investment being undertaken to ensure that the investment expenditure is being spent in the right place.

Off –Stream Wetland Barriers

Although off-stream barriers to fish migration were not part of the project objectives, they were considered to be very important fish habitats, therefore, potential barriers on these lentic habitats were identified during the initial desktop study. Following the identification process potential barriers were taken through one stage of selection criteria. The nature and extent of wetlands, consisting of low lying areas inundated by wet season rainfall events, combined with their predominantly freehold land tenure, means that on-site access to validate the presence and type of barrier can be challenging. Accurately assessing wetlands using GIS based stream network processing tools is also inherently problematic, as wetlands are generally not part of the stream network. Because of these difficulties, the authors recommend that a separate barrier prioritisation process specifically for wetland barriers is conducted in the future.

Many anthropogenic barriers have been created on important wetlands in the MRC region to prevent saltwater intrusion and pond freshwater to grow pasture including the Class 2 invasive weed species, *Hymenachne*. Further investigation is required to determine the extent of barriers in wetland areas, particularly ponded pasture bund walls (Figure 14), but also to examine potential *Hymenachne* weed choke barriers. It is critically important that off-stream barriers are considered for future investigations as many of these habitats are located on coastal wetlands which are important nursery areas for many socio-economic diadromous species such as barramundi.

Figure 14. Ponded pasture tidal wetland bund, Amity Creek sub-catchment, St Lawrence. Freshwater wetland on the left hand side, estuarine salt pan on the right hand side

Conclusion

The 2929 potential barriers within the MRC region were successfully identified and distilled down to a list of the highest priority sites within the region. These sites represent the areas where the greatest return can be achieved with the least expenditure. By remediating fish passage at these sites extensive areas of fish habitat will be opened up to migratory fish species. This will ensure the successful maintenance of fish populations in many of the region’s waterways, while investing rehabilitation funds in the most efficient manner.

Recommendations

- Development of an investment strategy for a fish migration barrier remediation program targeting the top 30 ranked barriers to fish passage identified in this report. This program would include:
    - Preparation of an investment strategy for the highest priority sites based on information in this report
    - Negotiation with structure owners to permit rehabilitation of highest priority sites
    - Detailed survey of the sites and production of design documents for suitable fishways
    - Construction of agreed fishway designs
    - Establishment of ongoing maintenance agreements with local structure owners
    - 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.
- Instigation of an off-stream wetland barrier prioritisation project aimed at the region’s wetland habitats. In particular the numerous coastal and tidal interface pondage pastures. This is particularly important because of the potential fisheries and biodiversity benefits these wetland habitats can provide for the environment if free passage is provided.
- Further fish community monitoring of the region’s waterways to better understand fish communities and their migration requirements.

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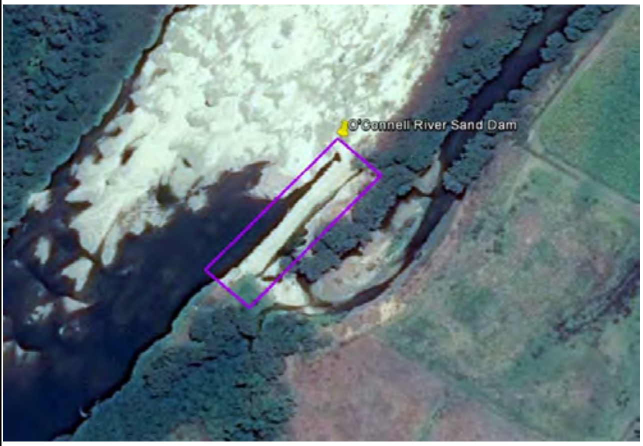
Appendix 1

Overall Priority	**1**	
Stage 1 & 2 Priority	Stage 1	Stage 2
	1	1
Barrier ID	3931	
Stream Name	O'Connell R	
Location	20° 34.722'S	148° 36.249'E
Barrier Type	Sand Dam (Tidal Bund Weir)	
Barrier Name	Sand Dam	
Fishway Type Needed	Rock Ramp	
Approx. Cost of Fishway	$100-200k	



Overall Priority	**2**	
Stage 1 & 2 Priority	Stage 1	Stage 2
	6	5
Barrier ID	111	
Stream Name	Sandy Ck	
Location	21° 16.842'S	149° 4.945'E
Barrier Type	Causewy + Culvert	
Barrier Name	Palm Tree Rd Crossing	
Fishway Type Needed	Rock Ramp	
Approx. Cost of Fishway	$75-80k	

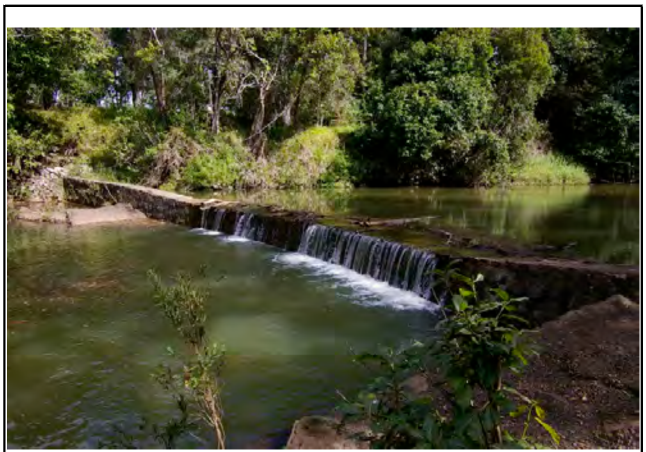
Overall Priority	**2**	
Stage 1 & 2 Priority	Stage 1	Stage 2
	9	5
Barrier ID	2630	
Stream Name	Constant Ck	
Location	21° 2.847'S	148° 59.299'E
Barrier Type	Weir/Causeway	
Barrier Name	Freds Weir	
Fishway Type Needed	Pre-cast/Rock Ramp	
Approx. Cost of Fishway	$60-80k	

Overall Priority	**4**	
Stage 1 & 2 Priority	Stage 1	Stage 2
	1	2
Barrier ID	2593	
Stream Name	St Helens Ck	
Location	20° 54.714'S	148° 44.513'E
Barrier Type	Causeway	
Barrier Name	Russell Rd Crossing	
Fishway Type Needed	Rock Ramp	
Approx. Cost of Fishway	$25-30k	

Overall Priority	**4**	
Stage 1 & 2 Priority	Stage 1	Stage 2
	12	2
Barrier ID	2614	
Stream Name	Jolimont Ck	
Location	20° 58.698'S	148° 52.734'E
Barrier Type	Weir	
Barrier Name	Mulherin Rd Crossing	
Fishway Type Needed	Pre-Cast/Rock Ramp	
Approx. Cost of Fishway	$150-200k	

Overall Priority	**4**	
Stage 1 & 2 Priority	Stage 1	Stage 2
	4	8
Barrier ID	2588	
Stream Name	Blackrock Ck	
Location	20° 51.307'S	148° 45.426'E
Barrier Type	Causeway/Culvert	
Barrier Name	Old Bowen Rd Crossing	
Fishway Type Needed	Rock Ramp	
Approx. Cost of Fishway	$60-70k	

Overall Priority	4	
Stage 1 & 2 Priority	Stage 1	Stage 2
	8	4
Barrier ID	2631	
Stream Name	Constant Ck	
Location	21° 2.836'S	148° 58.997'E
Barrier Type	Weir	
Barrier Name	1938 Weir	
Fishway Type Needed	Pre-cast/Rock Ramp	
Approx. Cost of Fishway	$70-90k	



Overall Priority	8	
Stage 1 & 2 Priority	Stage 1	Stage 2
	6	5
Barrier ID	3120	
Stream Name	Tedlands Wetland	
Location	21° 33.470'S	149° 17.914'E
Barrier Type	Tidal Earth Bund	
Barrier Name	Tedlands Eastern Bund	
Fishway Type Needed	Rock Ramp/Precast Cone	
Approx. Cost of Fishway	$75-85k	

Overall Priority	8	
Stage 1 & 2 Priority	Stage 1	Stage 2
	3	8
Barrier ID	3174	
Stream Name	Cherry Tree Ck	
Location	21° 33.311'S	149° 15.379'E
Barrier Type	Culverts	
Barrier Name	East Inneston Rd	
Fishway Type Needed	Baffles	
Approx. Cost of Fishway	$10-20k	

Overall Priority	**8**	
Stage 1 & 2 Priority	Stage 1	Stage 2
	23	12
Barrier ID	3981	
Stream Name	Boundary Creek/Wetlands	
Location	21° 31.499'S	149° 15.879'E
Barrier Type	Earth Bund/Causeway	
Barrier Name	Tidal Bund	
Fishway Type Needed	Rock Ramp/Precast Cone	
Approx. Cost of Fishway	$80-90k	

Overall Priority	**11**	
Stage 1 & 2 Priority	Stage 1	Stage 2
	12	12
Barrier ID	3942	
Stream Name	Boundary Ck (O'Connell R)	
Location	20° 41.756'S	148° 31.704'E
Barrier Type	Road Crossing/Culverts	
Barrier Name	Doughertys Rd Crossing	
Fishway Type Needed	2 x Rock Ramp + Baffles	
Approx. Cost of Fishway	$30 - 40 k	

Overall Priority	**11**	
Stage 1 & 2 Priority	Stage 1	Stage 2
	6	2
Barrier ID	2636	
Stream Name	Reliance Ck	
Location	21° 2.797'S	149° 6.217'E
Barrier Type	Road Crossing	
Barrier Name	Neills Rd Crossing	
Fishway Type Needed	Baffles	
Approx. Cost of Fishway	$15-25k	

Overall Priority	11	
Stage 1 & 2 Priority	Stage 1	Stage 2
	23	12
Barrier ID	3988	
Stream Name	Boundary Creek (R.Dam)	
Location	21° 31.372'S	149° 16.103'E
Barrier Type	Concrete Bund/Causeway	
Barrier Name	Tidal Bund - Boundary wetlands	
Fishway Type Needed	Rock Ramp/Pre-cast Cone	
Approx. Cost of Fishway	$70-80k	

Overall Priority	11	
Stage 1 & 2 Priority	Stage 1	Stage 2
	12	18
Barrier ID	2610	
Stream Name	Macquarie Ck	
Location	21° 0.221'S	148° 51.181'E
Barrier Type	Weir	
Barrier Name	Private	
Fishway Type Needed	Pre-Cast/Rock Ramp	
Approx. Cost of Fishway	$150-200k	

Overall Priority	11	
Stage 1 & 2 Priority	Stage 1	Stage 2
	12	15
Barrier ID	2616	
Stream Name	Jolimont Ck	
Location	20° 59.429'S	148° 53.303'E
Barrier Type	Culvert Road Crossing	
Barrier Name	Narpi Rd Crossing	
Fishway Type Needed	Baffled Culverts/ R.Ramp	
Approx. Cost of Fishway	$60-80k/$30-40k	

Overall Priority	**16**	
Stage 1 & 2 Priority	Stage 1	Stage 2
	19	15
Barrier ID	83	
Stream Name	Bakers Ck	
Location	21° 11.181'S	149° 5.899'E
Barrier Type	Weir	
Barrier Name	Bakers Ck Weir	
Fishway Type Needed	Rock Ramp/Precast Cone	
Approx. Cost of Fishway	$100-130k	

Overall Priority	**16**	
Stage 1 & 2 Priority	Stage 1	Stage 2
	9	18
Barrier ID	3127	
Stream Name	Tedlands Ck	
Location	21°35'20.34"S	149°18'24.51"E
Barrier Type	Culvert Causeway	
Barrier Name	Tedlands	
Fishway Type Needed	R.Ramp + Baffles/Culverts	
Approx. Cost of Fishway	$15-20k/$30-40k	

Overall Priority	**16**	
Stage 1 & 2 Priority	Stage 1	Stage 2
	19	24
Barrier ID	2575	
Stream Name	Macquarie Ck	
Location	21° 1.117'S	148° 50.197'E
Barrier Type	Culvert/Apron drop	
Barrier Name	McKays Rd Crossing	
Fishway Type Needed	Rock Ramp	
Approx. Cost of Fishway	$40-50k	

Overall Priority	**19**	
Stage 1 & 2 Priority	Stage 1	Stage 2
	4	8
Barrier ID	10	
Stream Name	Pioneer R	
Location	21° 8.430'S	148° 56.168'E
Barrier Type	Weir	
Barrier Name	Marian Weir	
Fishway Type Needed	Vertical Slot	
Approx. Cost of Fishway	~$2 m	

Overall Priority	**19**	
Stage 1 & 2 Priority	Stage 1	Stage 2
	23	24
Barrier ID	3990	
Stream Name	Sandy Ck	
Location	-21.284437°	149.022404°
Barrier Type	Weir	
Barrier Name	Sandy Ck Gauging Weir	
Fishway Type Needed	Precast Cone	
Approx. Cost of Fishway	$75-85k	

Overall Priority	**21**	
Stage 1 & 2 Priority	Stage 1	Stage 2
	12	15
Barrier ID	2544	
Stream Name	Plane Ck	
Location	21° 25.110'S	149° 14.707'E
Barrier Type	Tidal Bund/Pipe Crossing	
Barrier Name	Brooks Rd Crossing	
Fishway Type Needed	Baffled Culvert/Rock Ramp	
Approx. Cost of Fishway	$50-70k/$40-50k	

Overall Priority	**22**	
Stage 1 & 2 Priority	Stage 1	Stage 2
	19	23
Barrier ID	2601	
Stream Name	Murray Creek	
Location	20° 59.124'S	148° 45.248'E
Barrier Type	Causewaay	
Barrier Name	Clewss Road	
Fishway Type Needed	Rock Ramp/Culvert Baffles	
Approx. Cost of Fishway	$40-60k	

Overall Priority	**22**	
Stage 1 & 2 Priority	Stage 1	Stage 2
	72	26
Barrier ID	2601	
Stream Name	Leila Creek	
Location	21° 1.740'S	149° 6.233'E
Barrier Type	Pipe Causeway	
Barrier Name	Sants Rd	
Fishway Type Needed	Rock Ramp	
Approx. Cost of Fishway	$15-25k	

Overall Priority	**22**	
Stage 1 & 2 Priority	Stage 1	Stage 2
	115	39
Barrier ID	1316	
Stream Name	McCreadys Creek	
Location	21° 5.327'S	149° 9.922'E
Barrier Type	Culvert Causeway	
Barrier Name	Golf Links Rd (MRC)	
Fishway Type Needed	Rock Ramp + Baffles	
Approx. Cost of Fishway	$30-40	

Overall Priority	25	
Stage 1 & 2 Priority	Stage 1	Stage 2
	72	26
Barrier ID	3966	
Stream Name	Bakers Creek Sth Arm	
Location	21° 12.450'S	149° 6.392'E
Barrier Type	Tidal Culvert Causeway	
Barrier Name	Horse & Jockey Rd	
Fishway Type Needed	Culvert + Baffle	
Approx. Cost of Fishway	$50-60k	

Overall Priority	25	
Stage 1 & 2 Priority	Stage 1	Stage 2
	23	26
Barrier ID	2586	
Stream Name	Alligator Ck	
Location	-20.828466°	148.667042°
Barrier Type	Pipe Culvert Road Crossing	
Barrier Name	Tolchers Rd Crossing	
Fishway Type Needed	Culvert + Baffle/R.Ramp	
Approx. Cost of Fishway	$30-40k/$20-30k	

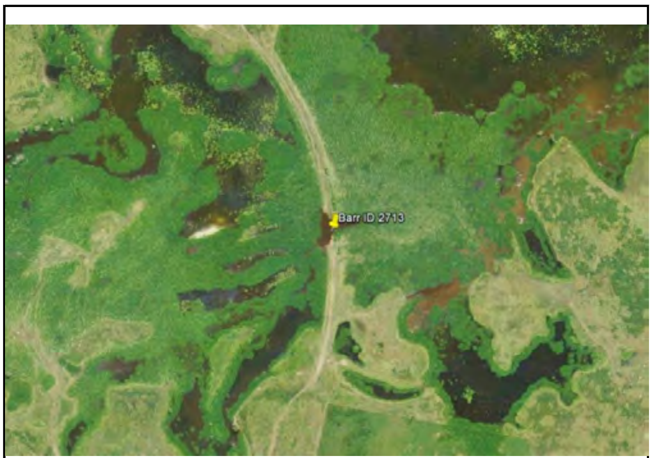
Overall Priority	27	
Stage 1 & 2 Priority	Stage 1	Stage 2
	9	18
Barrier ID	41	
Stream Name	Pioneer R	
Location	-21.176798°	148.829620°
Barrier Type	Weir	
Barrier Name	Mirani Weir	
Fishway Type Needed	Fish Lock	
Approx. Cost of Fishway	$2-4M	

Overall Priority	27	
Stage 1 & 2 Priority	Stage 1	Stage 2
	115	48
Barrier ID	41	
Stream Name	Fursden Ck	
Location	-21.176798°	148.829620°
Barrier Type	Rock Weir	
Barrier Name	Marajuy Yakapari Rd	
Fishway Type Needed	Rock Ramp	
Approx. Cost of Fishway	$20-30k	

Overall Priority	27	
Stage 1 & 2 Priority	Stage 1	Stage 2
	23	31
Barrier ID	3985	
Stream Name	Blackrock Creek	
Location	-21.018537°	148.836743°
Barrier Type	Causeway/Apron drop	
Barrier Name	Dittons Rd	
Fishway Type Needed	Rock Ramp	
Approx. Cost of Fishway	$30-40k	

Overall Priority	30	
Stage 1 & 2 Priority	Stage 1	Stage 2
	23	26
Barrier ID	2630	
Stream Name	Macquarie Ck	
Location	21° 2'23.31"S	148°49'35.36"E
Barrier Type	Pipe Culvert/Apron Drop	
Barrier Name	Geeberga Butharra Rd	
Fishway Type Needed	R.Ramp/Culvert Baffle	
Approx. Cost of Fishway	$40-60k	

Overall Priority	**30**	
Stage 1 & 2 Priority	Stage 1	Stage 2
	37	31
Barrier ID	2713	
Stream Name	Boundary Ck	
Location	21° 32.153'S	149° 14.998'E
Barrier Type	Ponded Pasture/Bund	
Barrier Name	Wetland Bund	
Fishway Type Needed	Rock Ramp	
Approx. Cost of Fishway	$35-45k	



Overall Priority	**30**	
Stage 1 & 2 Priority	Stage 1	Stage 2
	51	31
Barrier ID	3958	
Stream Name	O'Connell River	
Location	20° 47.605'S	148° 36.659'E
Barrier Type	Pipe Causeway + Apron Drop	
Barrier Name	Porters Rd	
Fishway Type Needed	Rock Ramp	
Approx. Cost of Fishway	$85-90k	

Overall Priority	**30**	
Stage 1 & 2 Priority	Stage 1	Stage 2
	51	31
Barrier ID	3960	
Stream Name	Sandy Ck	
Location	21° 16.239'S	148° 58.701'E
Barrier Type	Weir	
Barrier Name	Vella Weir	
Fishway Type Needed	Rock Ramp/Pre-cast Cone	
Approx. Cost of Fishway	$150-200k	

Overall Priority	30	
Stage 1 & 2 Priority	Stage 1	Stage 2
	51	54
Barrier ID	2590	
Stream Name	Blackrock Ck	
Location	20° 52.782'S	148° 43.680'E
Barrier Type	Pipe Causeway	
Barrier Name	1st Barr Rise & Shine Rd	
Fishway Type Needed	Rock Ramp	
Approx. Cost of Fishway	$40-50k	

Overall Priority	30	
Stage 1 & 2 Priority	Stage 1	Stage 2
	164	54
Barrier ID	3970	
Stream Name	Fursden Ck	
Location	21° 7.984'S	149° 7.665'E
Barrier Type	Rock Weir	
Barrier Name	Under Train Bridge D/S wetland	
Fishway Type Needed	Rock Ramp	
Approx. Cost of Fishway	$35-40k	

Overall Priority	30	
Stage 1 & 2 Priority	Stage 1	Stage 2
	23	18
Barrier ID	3329	
Stream Name	Plane Ck	
Location	21° 25.505'S	149° 13.390'E
Barrier Type	Weir	
Barrier Name	High Weir -Off Brewers Rd	
Fishway Type Needed	Pre-cast Cone	
Approx. Cost of Fishway	$1-2 million	

Appendix 2

Indicative Fishway Remediation Costs

Indicative fishway remediation costs (Table 8) to improve current barrier condition rating to the target rating are based on a number of factors. These include but are not limited to:

- **Head loss -** Height of the fish barrier, i.e. the difference between headwater (upstream water level) and tailwater (downstream water level). This measurement fundamentally determines the type and size of the fishway. Greater the head loss, the larger and more technical the fishway and indicative cost.

- **Barrier location -** Top or bottom of catchment. Bottom-of-catchment fishways require 'drops' between pools to be smaller than top-of-catchment fishways, i.e. lower catchment streams should have drops between 60 – 80 mm and higher catchments streams between 80 – 120 mm. This is because fish communities that occupy lower catchment habitats comprise high proportions of diadromous and juvenile fish species. These fish generally possess weaker swimming abilities than potamodromous (wholly freshwater species) and adult fish. Therefore lower catchment fishways comprise more 'pool' and 'drop' sections, consequently these fishways are longer and require more materials which increases cost.

- **Substrate -** Sandy substrate streams require a greater amount of rock and/or concrete to lock and secure the fishway in place than substrates comprised of bedrock. Additional construction materials represent higher fishway construction costs.

- **Infrastructure -** Barriers located on strategic infrastructure such as roads or water storage weirs generally require a greater degree of engineering and consultation than barriers on private property or disused infrastructure. The greater the engineering and consultation, the greater the cost.

- **Approvals -** Under the Fisheries Act, waterway barrier works approvals are required depending on the size and type of stream the barrier is located on. Barriers located on 'Major' and 'High' impact streams according to Fisheries QLD spatial data layer 'Queensland waterways for waterway barrier works' comprise approval costs up to ~$9k. The larger the stream order, the higher the approval cost to construct the fishway.

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PHONE (07) 4968 4200
EMAIL info@catchmentsolutions.com.au
WEB www.catchmentsolutions.com.au
ADDRESS Suite 4/85 Gordon St | Mackay Queensland 4740