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2021 Fish Barrier Prioritisation – Mackay Whitsunday Region

Final Report

February 2022

Acknowledgements

Catchment Solutions recognises that the area surveyed is the Traditional Lands of the Yuwibura, Kolnmerburra, Barada Barna, Wirl, Ngarom Gia and Juru Peoples. We would like to acknowledge their enduring spiritual and cultural connection to the land and waterways, and their commitment to care for country.

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Cover Image: Fish barriers from the Mackay Whitsunday region (Carmila Creek – top left & top right, Jolimont Creek – bottom left, Marklands Wetland – bottom right) and several migratory fish species which inhabit local waterways (left-right – jungle perch, bullrout, mangrove jack & barramundi).

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Glossary

Diadromous	Diadromous fish 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 fish which migrate to sea to breed.
Amphidromous	Diadromous fish 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.
Marine Vagrant	Marine vagrants are fish which are generally associated with marine or estuarine habitats, but occasionally move into freshwater. Freshwater incursions are often opportunistic and short in duration.
Potamodromous	Fish species whose migrations occur wholly within freshwater for breeding and other purposes
Ontogenetic Migration	Migrations associated with specific life stages
Downstream Limit	The transition between freshwater and estuarine habitat within a coastal stream.
Headloss	The height difference between the headwater (upstream) and tailwater (downstream) of a structure.
Drown-out	When flow increases to a point where there is no significant drop between the headwater and tailwater of a structure. Under drown-out flows fish passage is considered unimpeded.

Acronyms

CS	Catchment Solutions
DEM	Digital Elevation Model
FBP	Fish Barrier Prioritisation
HAT	Highest Astronomical Tide
LiDAR	Light Detection and Ranging
RCL	Reef Catchments Limited
NRM	Natural Resource Management
WQ	Water Quality
GIS	Geographic Information System
GPS	Global Positioning System
FFSP	Fish Friendly Scour Protection
WOFS	Water Observations From Space

Executive Summary

The objective of the Mackay Whitsunday Fish Barrier Prioritisation (FBP) update was to identify and re-assess the large number of anthropogenic barriers that prevent, delay or obstruct fish migration. This work builds on the previous Mackay Whitsunday FBP which was undertaken by Catchment Solutions in 2015. Barriers identified through this process were ranked in order of priority, accounting for the level of impact each barrier was having on fish communities within the region.

Fish migration is an essential life-history adaptation utilised by many freshwater fish species in coastal catchments in the Mackay Whitsunday region. Migration strategies between key habitats have evolved for a variety of reasons, including feeding and reproduction purposes, predator avoidance, nursery habitat utilisation, maintaining genetic diversity, and population dispersal. Barriers which reduce connectivity impact fisheries productivity and create environmental conditions favourable for invasive pest fish. Significantly, approximately half of the freshwater fish species of the region undertakes ontogenetic shifts in habitat use between estuarine and freshwater environments. Remediating barriers which reduce connectivity within the stream networks is critical to maintain freshwater fish community condition and improve overall aquatic ecosystem health.

This project aimed to address such issues, through identifying and ranking fish passage barriers throughout the Mackay Whitsunday region. The project also aimed to address the under representation of coastal wetland fish barriers of the previous regional barrier prioritisation. A complimentary prioritisation was performed on the wetland barriers incorporating additional habitat characteristics (e.g., wetland area), which are not considered in standard stream barrier prioritisations.

Specific aims of the project are listed below.

Stream barrier prioritisation update:

1. Acquire and process new spatial data for stream barrier prioritisation update.
2. Using latest hi-resolution photographic imagery, update the potential barrier layer.
3. Remove remediated barriers from the potential barrier layer.
4. Perform the Stage 1 spatial analysis to provide a preliminary desktop ranking of priority barriers.
5. Undertake Stage 2 ground truthing, focusing on priority barriers which were not visited or were known to have changed since the 2015 stream barrier prioritisation.
6. Perform Stage 2 spatial analysis, removing non-barriers and incorporating physical barrier and site-specific stream condition information.
7. Collate data to produce the updated stream barrier prioritisation list for the region.

Wetland barrier Prioritisation:

1. Develop framework and spatial analysis methodology for prioritisation of fish barriers on coastal wetlands.
2. Using latest hi-resolution photographic imagery identify all potential barriers on coastal wetlands within the region.
3. Perform the Stage 1 spatial analysis to provide a preliminary desktop ranking of priority barriers.
4. Undertake Stage 2 ground truthing, focusing on highest ranked barriers identified through Stage 1 spatial analysis.
5. Perform Stage 2 spatial analysis, removing non-barriers and incorporating physical barrier information.
6. Collate data to produce the wetland barrier prioritisation list for the region.

The FBP process identified potential barriers using 2019 high-resolution (20 cm) aerial imagery across the RCL region. In total, 9738 potential barriers were identified on streams and wetlands within the project area (9,000 km^2) at a rate of 1.082 potential barriers per km^2. A Geographic Information System (GIS) based stream network analysis tool (RivEx) was used to assess and prioritise the high number of potential barriers using a collective optimisation rank-and-score approach.

In this prioritisation assessment, the authors and Reef Catchments Limited (RCL) Natural Resource Management (NRM) project staff ground-truthed the top priority ranked potential barriers based on the GIS desktop assessment. The resultant FBP report and associated priority ranked fish barrier list will assist RCL NRM, environmental groups and, local and state government decision-makers in determining where to best allocate remediation funds to ensure the greatest fish passage and ecosystem health outcomes for the RCL region.

Introduction

Fish passage barriers such as dams, weirs, causeways, culverts, earthen bunds, floodgates, weed chokes, and eutrophied habitats 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 most coastal catchments throughout Australia and have been implicated in the decline of many iconic native fish species, in particular diadromous species.

Diadromous species which require good access between fresh and saltwater habitats are often of the highest socioeconomic importance, being of key commercial, recreational, and cultural value, as well as being key assets within the trophic ecology of their associated waterways. Species such as barramundi, jungle perch, mangrove jack, tarpon, long-finned eel, and snakehead gudgeon all have life-cycle strategies which require good 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 barriers to movement, and further compounded by the degradation of any remaining available habitats.

Through modern insight and a greater understanding of various life-cycle requirements, fish passage restoration works have seen the remediation of many barriers. In most instances the barriers are considered critical infrastructure and cannot be removed to improve connectivity. Fishways or fish ladders are generally identified as the key method to offset the impacts of barriers on ecological integrity. State legislation requires adequate fish passage provisions to be incorporated into new instream infrastructure. Additionally, an increasing number of existing barriers are having fishways retrofitted, often to the immediate benefit of the aquatic assemblages of the waterways they impede.

The objective of the Mackay Whitsunday FBP update was to identify, assess and prioritise actions to remediate the large number of anthropogenic barriers that impede fish migration. Fish barriers identified through this process were ranked in order of priority, accounting for the interactive effects of biological, geographic, and ecological factors associated with each barrier. The current prioritisation builds on the existing FBP undertaken in the Mackay Whitsunday region in 2015 (Moore 2015). It also complements other FBPs conducted throughout the State over recent years. These include: The Southern Gulf catchments prioritisation (O'Brian et al, 2010), the Daintree to Barron prioritisation (2022), the Herbert and Lower Murray prioritisation (Moore et al 2021), Fitzroy FBP update (Marsden, 2019), Sunshine Coast prioritisation (Moore and McCann 2018), Greater Brisbane prioritisation (Moore et al, 2018), and the Gold Coast prioritisation (2022).

In addition, a sub-set prioritisation focusing on wetland fish barriers was conducted to compliment the stream barrier prioritisation. Historically, wetland barriers scored relatively poorly in traditional stream barrier prioritisations due to the focus on stream order as a proxy for available fish habitat. Barriers on wetlands fed by small streams generally scored relatively low, despite the wetlands containing expansive fish habitats. The wetland barrier prioritisation aims to overcome this shortfall by incorporating area as a proxy for fish habitat, in addition to stream order. The elevation of wetlands was incorporated to complement distance to the estuary as a proxy for catchment position. Water permanence also features in the wetland prioritisation to ensure that refuge habitat is available for fish once the barriers are remediated.

The objectives for this project were to:

Stream barrier prioritisation update:

1. Acquire and process new spatial data for stream barrier prioritisation update.
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Fish Migration

Fish that migrate are most often defined within the broad groups 'diadromous' and 'potamodromous'. Diadromy includes subgroups 'amphidromous', 'catadromous', and 'anadromous', many varying definitions for each of these are a frequent cause for confusion. To alleviate this, we have defined migration only in the broader categories of diadromous, potamodromous, and marine vagrants. Additionally, species listed as 'unknown' or 'indeterminate' are species for which the migratory status is unknown or there is insufficient information to decide.

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 distributions and aquatic ecosystem health. Fish that undertake migrations between these two contrasting environments must 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 that 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 1998):

- Contribute to its abundance,
- Maintain its natural distribution, and
- Maintain aquatic ecosystem health.

Fish that are potamodromous are defined here as migrating wholly within and between freshwater habitats. And the same requirements listed above are applied to their migrations within the bounds of freshwater. Species listed as 'marine vagrants', are fish that do not require access between fresh and estuarine waters but may move between them given the opportunity.

Barriers to Fish Migration

Barriers to fish passage include any anthropogenic or environmental obstruction that prevent, delay, or impede the free movement of fish. For this prioritisation, environmental barriers such as weed chokes, low dissolved oxygen slugs and water temperature barriers were not included, even though anthropogenic factors may have contributed to their occurrence. Waterfalls were included in some aspects of the spatial analysis. This was to account for the natural variations in fish species distribution which result from significant waterfall barriers. Anthropogenic barriers identified in the prioritisation include structures such as causeways, weirs, dams, floodgates, barrages, and earthen bunds (Figure 1). These structures were 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 1. Barrier structures: a. irrigation supply weir (McGregor Creek), b. tidal floodgates (Constant Creek Tributary) c. Earth bund (Constant Creek floodplain), d. Pipe culvert causeway (Daintry Creek), e. box culvert causeway (Carmila Creek), f. Perched pipe culvert causeway (Gibson Creek).

Barriers impact fish communities in many ways, with large structures (e.g., dams) forming complete blockages, whereas small or medium structures (e.g., causeways, weirs), present partial or temporary barriers, restricting passage during some flow conditions. Even small vertical drops downstream of road crossings and culvert aprons (≥200 mm) are sufficient to form significant barriers for many fish, particularly juvenile and small-bodied species. Often single structures possess multiple-barrier types.

For example, it is common for culvert causeways to have a water surface drop barrier due to stream bed erosion on the downstream extent of the apron, while a hydraulic velocity barrier can be created as flows pass over the smooth concrete surfaces. Perched culverts or those without low flow channels installed below bed level can result in insufficient water depth barriers (i.e., low flows are spread out across multiple culvert barrels). Long culverts can also present a physiological barrier as some species are reluctant to swim into dark areas.

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 are comprised of 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 in central and south-east Queensland (QLD). In central QLD, the median size of native fish recorded successfully ascending the Gooseponds (Janes Creek, Mackay) (McCann and Moore 2018) and Alligator Creek (Townsville) (CS unpublished data) rock ramp fishways during low flow conditions was 31 mm (n= 35,924) and 34 mm (n= 927) respectively. In south-east QLD, the median size of native fish recorded successfully ascending Slacks Creek (McCann and Moore 2018a), Bremer River (McCann and Moore 2018b), and South Pine River (McCann and Moore 2018c) rock-ramp fishways during low flow conditions was just 25 mm (n= 6,548), 34 mm (n= 16,401) and 30 mm (n= 5,070) respectively.

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). For example, of the 35,924 fish recorded ascending the Gooseponds rock-ramp fishway, 85% of individuals were juvenile diadromous fish moving upstream after being spawned in the estuary.

The swimming abilities of different fish species plays a critical role in their ability to ascend fishways. Mallen- Cooper (1989) tested the swimming abilities of two iconic Australian diadromous fish species, barramundi (*Lates calcarifer*) and Australian bass (*Percalates novemaculeata*) through a vertical-slot fishway, and found that juvenile barramundi (43 mm) were only able to navigate velocities of around 0.66 m/sec, while Australian bass (40 mm) were able to navigate slightly faster velocities of around 1.04 m/sec. Watson *et al*. (2019) tested the 'burst' speed (Usprint) of empire gudgeon (*Hypseleotris.compressa)* within the size range 44 – 78 mm and found that they could attain a mean Usprint of 0.51 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 most fish species can navigate greater velocities than has been recorded under controlled conditions. For example, sampling of a rock-ramp fishway on Fursden Creek in central QLD showed that juvenile empire gudgeon (*H. compressa)* within the size range of 15-82 mm were recorded passing through ridge slot velocities of 1.6 m/sec (Moore & Fries, 2021). The ability of fish to navigate faster velocities through rock-ramp fishways compared to laboratory flumes may be explained by the high degree of geometrical diversity of rock-ramps resulting from their irregular forms, which create interstitial spaces and micro-eddies (Wang 2008).

Many early Australian fishways were based on northern hemisphere designs which accommodated the swimming abilities of adult 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 greater than what coastal Queensland fish species are capable of ascending. In some instances, these early fishways have themselves become fish barriers. Figure 2 provides examples of several early fishways constructed in Queensland. McCann and Moore (2017) measured the velocity of a pool and weir fishway constructed in the 1960s on the Bremer River (Berrys Weir) and recorded a velocity of 3.3 m/sec at the fishway inlet (Figure 2 white circle), which was substantially faster than that recorded in the inlet of the rock ramp fishway (0.3 m/s) built on the same structure.

Figure 2. Examples of early fishways based northern hemisphere designs exhibiting hydraulic conditions greater than the swimming abilities of most native freshwater fish species. a. Denil fishway on Luscombe Weir (Albert River, QLD). b. 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. c. Pool and weir fishway located on Marian Weir (Pioneer River, QLD).

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 the passage of juvenile barramundi (*L. calcarifer*). However, the unique climbing abilities of juvenile long-finned eels (*Anguilla reinhardtii*) enables them to ascend ≥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
- Burst - <15 seconds

Burst speed is used by fish to traverse fast velocities (Webb 1984; Ch. 6) and one that fish species would most commonly use when attempting to migrate over small head loss barriers (≤200 mm) and through culverts during medium and high flow conditions (Watson et al, 2019). Burst speed is an energetically expensive and anerobic form of swimming, and as such cannot be sustained for long periods. Consequently, less obvious barriers such as culverts can become problematic for juvenile and small-bodied fish (Watson et al.,2019).

Generally, barriers can be defined into 6 types:

- Water surface drop – Vertical drops, off or within a structure. For example, the downstream side of weirs and causeway aprons (Figure 3).
- Turbulence – The motion of water having local velocities and pressures that fluctuate randomly. This is often observed downstream of causeway aprons and weirs (Figure 2), without proper provision of pool depth. Turbulence is most often encountered during medium and high flow conditions.
- Velocity – When the speed of water exceeds the swimming capabilities of fish attempting to pass the obstruction. High velocities often occur through culverts and across spillways and aprons during medium and high flow events (Figure 2).
- Water Depth – Shallow water depth of 5 mm - 100 mm depending on species, life-stage and morphology. Larger bodied demersal species are most affected. Shallow water is often experienced during low flow conditions through culverts and across aprons and spillways (Figure 3)
- Low Light – Darkness, shadows and reduced light conditions inside culverts/pipes, and under low bridges can present a phycological barrier for some species (Figure 3).
- 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 common in catchments with high proportions of intensive land use. Other chemical impacts include acid sulphate soil discharge and high temperatures associated with channel modification (e.g. channel straightening and widening works combined with the removal of riparian vegetation).

Figure 3. 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 (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 and O'Hanley, 2010). Passability formed an integral part of the current FBP scoring criteria when assessing barriers in the field. Barrier passability can be 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
- Stream flow – duration and volume
- Barrier type – box and pipe culverts, weirs, dams, flooded causeways, bunds, sand dams, etc.
- Barrier size – The latitudinal and longitudinal extent of the barrier within the waterway as well as its height in relation to the bank height.

For the purpose of the current FBP, passability was simplified based on barrier type.

1. Dams, weirs, bunds and
2. Culverts (box and pipe) and floodgates

Dams, Weirs and Bunds

Larger structures require higher flows to drown-out and allow unimpeded fish passage. Higher flows are less frequent which leads to larger dams' weirs and bunds having a greater impact on fish passage than smaller ones. Passability scores were assigned based on the degree of impact at each barrier site. For dams, weirs and bunds, this was achieved by using headloss as a proxy for passability (i.e., the higher the dam/weir the greater the score).

Culverts and Floodgates

Determining impacts on passability requires assessment of three main features associated with each structure:

1. Structure aperture as a proportion of the bank full cross-sectional area of the waterway,
2. Structure height measured from streambed invert on the downstream side to the top of the causeway (e.g., road deck to downstream invert level),
3. Headloss – the difference between water levels on the upstream and downstream side of the structure.

For example, culvert configurations with a small aperture (opening) in relation to the cross-sectional area of the stream score high. In these instances, stream velocities are likely to be in excess of the swimming abilities of many native fish, particularly juvenile and small-bodied species which possess lower burst speeds. Structure height is a proxy for how frequently the barrier reaches drown-out. Drown out conditions occur more frequently for low structures and provide an increased level of passability during the drown-out period.

Headloss provides valuable information for barriers comprising a water surface drop. In general, native fish are poor 'leapers', and therefore surface drops significantly impact the ability of fish to pass the structure. Culverts are typically designed with a longitudinal fall through the structure. This fall generates higher velocities and therefore forms an important component in the assessment of barriers. Below are typical criteria for low, medium and high passability structures.

Low Passability (Figure 4)Figure 7

- Rarely drowns out (e.g. average <5% of flow duration)
- Examples:
  - Dams and weirs >2 m head loss
  - Causeway >2 m high with pipe/culvert configuration <20 %, bankfull stream width & head loss >1m

Medium Passability (Figure 4)Figure 7

- Occasionally drowns out (e.g., average 5-50% flow duration)
- Examples:
  - Velocities through culverts/pipes exceed the 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 4)

- Frequently drowns out (>50% of flow duration)
- Examples:
  - Culverts/pipes that span >60 % of bankfull stream width
  - Wet 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 4. Examples of low (left), medium (mid) and high (right) passability fish barriers.

Study area

The Mackay Whitsunday region is located on the central Queensland coast and covers an area of 9000 square kilometres (Figure 5). The area supports a population of ~150,000 people (QGSO, 2022). The population is concentrated in the regional centres of Mackay, Airlie Beach and several smaller towns. 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.

This project incorporated the RCL NRM area, which consists of the Mackay Whitsunday coastal catchments and several catchments which extend into the Isaac region. The RCL area includes 33 sub-catchments from Eden Lassie Creek south of Bowen to Flaggy Rock Creek north of St Lawrence. The waterways within these catchments generally start in the coastal range and descend easterly through coastal plains before discharging 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 (e.g., Pioneer River, St Helens Creek and Repulse Creek).

Aquatic ecosystems of the Mackay Whitsunday 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. 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.

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 vegetation 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 Mackay Whitsunday region have been impacted by intensive land use practices, particularly sugarcane cropping. 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 & Marsden, 2007). Where in-stream and terrestrial habitats persist undisturbed, healthy populations and diverse fish communities remain.

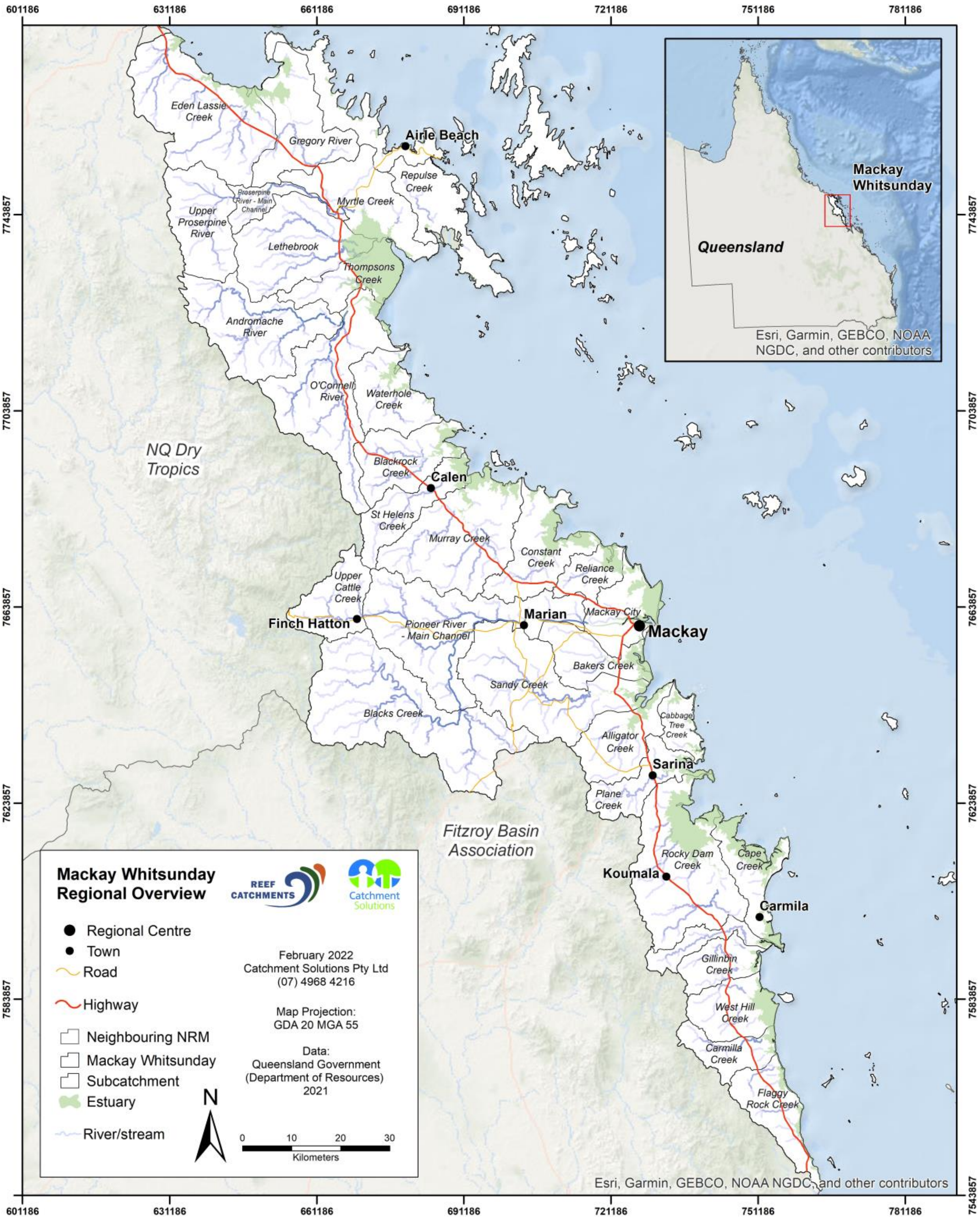

Figure 5. The Mackay Whitsunday fish barrier prioritisation study area – RCL NRM region.

Impacted fish communities

In undertaking the fish passage barrier prioritisation in the Mackay Whitsunday region, it was fundamental to the project outcomes to have a sound understanding of the fish species present within the region. This is because different life cycles, breeding strategies and migration characteristics of fish species, can exacerbate the impacts of certain barrier characteristics. This is particularly significant when it comes to diadromous fish species, which typically undertake migrations between marine, estuarine, and freshwater ecosystems (Harris 1988; Rolls et al. 2014).

A native species list was created from current verified records and published literature of species identified from waterways within the project area (Table 1). Fifty-seven species are known from these waterways, including diadromous, potamodromous, and marine vagrants. Many of the species found here are biologically dependant on both freshwater and marine/estuarine habitats (i.e. diadromous). This means they migrate between these ecosystems to breed, maintain geographic distributions, and sustain healthy populations. Some of the species found in regional waterways are dependant solely on freshwater habitats (i.e., potamodromous). Connectivity for these species is still important for the same reasons as diadromous species, though movements are confined to freshwater reaches only. This region is also home to several marine vagrant species which are usually found in estuaries but are known to enter lower reaches of freshwater streams. Of the 57 known and likely present species, over half (63%) undertake movements between saltwater and freshwater habitats, comprising 27 diadromous species and 9 marine vagrants. The remaining species include 16 potamodromous fish which undertake migrations wholly within freshwater, and 6 species for which their migration characteristics are unknown or indeterminate. Many of the native species found in the region's streams are socially, culturally, and economically valuable. Species including barramundi (*L. calcarifer*), jungle perch (*Kuhlia. rupestris*), sea mullet (*Mugil cephalus*), and Mangrove Jack (*Lutjanus argentimaculatus*) are all key diadromous species targeted by recreational, indigenous, and commercial fishers.

The number and type of barriers within aquatic ecosystems and the distance to the first low-passability barrier in each stream can often be an important factor impacting the health of a particular waterway's fish assemblage. The cumulative impact of barriers along streams can reduce upstream fish diversity, particularly for 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 low passability barrier is extremely important.

Table 1. Fish species recorded and likely present in the Mackay Whitsunday catchments, central Queensland. Where available, measured swim speeds are included. Note: letters after scientific name refer to species with a fish image in Figure 6 below.

Migratory status / Scientific name	Common name	Max swim speed (m/s)	Reference
Diadromous			
Anguilla obscura	Pacific shortfin eel		
Anguilla reinhardtii (a.)	Longfin eel	0.75a, 1.40b	a) Langdon & Collins 2000, b) Rolls & Sternberg 2015
Awaous acritosus (b.)	Roman-nose goby	0.45	Pusey et al. 2004
Butis butis	Crimsontip gudgeon		
Carcharhinus leucas	Bull Shark		
Chanos Chanos (c.)	Milkfish		
Elops hawaiensis	Giant Herring		
Eleotris melanosoma	Black spine-cheek gudgeon		

Migratory status Scientific name	Common name	Max swim speed (m/s)	Reference
Diadromous (continued)			
Gerres filamentosus (d.)	Threadfin silverbiddy		
Gerres subfasciatus	Common silverbiddy		
Giuris margaritacea (e.)	Snakehead gudgeon	0.22	Pusey et al. 2004
Glossogobius giuris (f.)	Tank goby		
Hypseleotris compressa (g.)	Empire gudgeon	1.0	Rolls & Strenberg 2015
Kuhlia rupestris (h.)	Jungle perch		
Lates calcarifer (i.)	Barramundi	1.4	Rolls & Sternberg 2015
Lutjanus argentimaculatus (j.)	Mangrove jack		
Megalops cyprinoides (k.)	Tarpon		
Monodactylus argenteus (l.)	Diamondfish		
Mugil cephalus (m.)	Sea mullet	1.26	Peterson 1975
Mugilogobius notospilus	Freshwater Mangrove goby		
Notesthes robusta (n.)	Bullrout	1.4	Rolls & Sternberg 2015
Planiliza subviridis	Greenback mullet		
Redigobius bikolanus	Speckled goby	0.38	Pusey et al. 2004
Scatophagus argus (o.)	Spotted scat		
Selenotoca multifasciata	Striped scat		
Terapon jarbua	Crescent perch		
Toxotes chatareus (p.)	Seven spot archerfish		
Potamodromous			
Ambassis agassizii (q.)	Agassiz's glassfish	0.39	Kern et al 2018
Amniataba percoides	Banded grunter	1.4	Rolls & Sternberg 2015
Craterocephalus fulvus	Unspecked hardyhead		
Craterocephalus stercusmuscarum	Flyspecked hardyhead	1.4	Rolls & Sternberg 2015
Glossamia aprion	Mouth almighty	0.84	Pusey et al. 2004
Hephaestus fuliginosus (r.)	Sooty grunter	0.43	Pusey et al. 2004
Hypseleotris species 1	Midgley's carp gudgeon	1.4	Rolls & Strenberg 2015
Leiopotherapon unicolor	Spangled perch	0.75	Rolls & Strenberg 2015
Melanotaenia splendida splendida (s.)	Eastern rainbowfish	0.56	Pusey et al. 2004
Mogurnda adspersa (t.)	Southern purplespotted gudgeon	0.7	Rolls & Sternberg 2015
Nematalosa erebi	Bony bream		
Neosilurus ater (u.)	Black catfish		
Neosilurus hyrtlii	Hyrtl's catfish	0.5	Rolls & Sternberg 2015
Oxyeleotris lineolata	Sleepy cod		
Porochilus rendahli	Rendahl's catfish		
Tandanus tandanus	Freshwater catfish	1.4	Rolls & Sternberg 2015
Marine vagrant			
Acanthopagrus australis (v.)	Yellow-fin Bream		
Acanthopagrus pacificus	Pikey Bream		
Ambassis vachellii	Vachell's glassfish		
Herklotsichthys koningsbergeri	Koningsbergers herring		
Hyporhamphus regularis	River garfish		
Leiognathus equulus (w.)	Common ponyfish		
Eleotris fusca	Brown spine-cheek gudgeon		
Redigobius chrysosoma	Spotfin goby		
Strongylura strongylura	Blackspot longtom		
Unknown/indeterminate			
Arrhamphus sclerolepis	Snubnose garfish		
Neoarius graeffei (x.)	Blue/salmon catfish		
Ophisternon bengalense	Onegill/Bengal eel		
Ophisternon gutturale (y.)	Swamp eel		
Pseudomugil signifier (z.)	Pacific blue eye	1.3	Rolls & Sternberg 2015
Strongylura kreftii	Freshwater longtom		

Figure 6. A selection of fish species occurring within the study area. See Table 1 for common and species name. Note: Capital letter provides a reference to each species in Table 1 (located after the scientific name).

Methods

Stage 1 Desktop identification and mapping

Streams

The first stage of the barrier prioritisation process involved extensive desktop identification. Barrier information was also acquired from local and state government structure inventories. All potential barriers within the study areas were identified using high-resolution aerial imagery (20 cm resolution captured in 2019, Google Earth Pro and Queensland Globe). This process systematically traced each individual watercourse and drainage line to visually identify potential barriers. Potential barriers were defined by the presence of an anthropogenic structure crossing or likely protruding into a mapped watercourse or drainage line. Structures included road crossings, bridges, weirs, bunds, earth dams, culverts, tidal barrages, floodgates, flow control structures, and gauging weirs. A unique feature point identifier was snapped to the watercourse line at the location of each potential barrier.

Occasionally, potential barrier point features were assigned along a waterway when likely barrier attributes were detected, but a structure was not visible. Key barrier traits in these scenarios include dead trees, which have potentially drowned and died due to the ponding of water caused by a downstream barrier, and large, lentic bodies of water that are out of character with the rest of the waterway. On occasions when river reaches were fully enclosed by canopy cover, potential barrier feature points were assigned where 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 sign indicating a structure e.g., causeway or bed level crossing.

Throughout the region, a considerable amount of fish passage monitoring has occurred over recent years at existing barrier remediation sites. Passage at several sites was found to be inadequate under some flow conditions. Typically, this was due to an inappropriate design (e.g., culverts were too small for stream flow), physical stream conditions had changed over time (e.g., tailwater had lowered creating a drop from the fishway outlet), or the fishway was inoperable (e.g., Dumbelton Weir). The decision was made to include all fishway sites as potential barriers unless there was recent fish passage monitoring to demonstrate high levels of passability at the site.

Each potential barrier feature point created in ArcMap (GIS) was assigned a unique identification number that remained with the potential barrier throughout the prioritisation process. Each potential barrier feature point contained geospatial data that stored location and geometry information. A desktop GIS process was then undertaken to efficiently investigate spatiotemporal habitat characteristics associated with each potential barrier on a whole of catchment basis.

Wetlands

The 'Queensland wetland area' layer was used as a base for the wetland identification process. Wetlands which were within the study area and associated with potential fish barriers on the stream networks were extracted. The extracted wetlands were inspected for alignment with aerial imagery. Where the mapped wetland extents were inconsistent with the extent of wetland habitat features (e.g., open water, wetland associated vegetation), the boundaries were manually modified. Each wetland was assigned a unique identification number which remained for the entire prioritisation. The potential barrier(s) associated with the wetland were scored using the conventual stream barrier criteria and received a rank for the stream barrier prioritisation. Wetland barriers were extracted from the stream barrier list and separately assessed against additional criteria specific to wetland habitats. This provided a priority ranked list of potential fish barriers on wetlands within the Mackay Whitsunday region.

Stage 1 Prioritisation

All potential barriers were assessed against six geospatial questions relating to the barrier's position in the catchment, available upstream habitat, stream hierarchy (Strahler stream order) proportion of intensive land use (e.g., cropping) in the sub-catchment, number of potential barriers downstream and distance to the estuary. Wetland barriers were assessed against three additional criteria including wetland size, water permanence and wetland elevation.

The 100K QLD east-coast ordered drainage stream network and 'QLD canal lines' layers were joined and utilised as the 'base' waterway data layer while identifying potential barriers. The network GIS processing tool 'RivEX' (Hornby 2021) was used to analyse the stream network layer, apply attributes, perform quality control checks, calculate distance between potential barriers, distance to the estuary, the distance of stream network upstream of the potential barrier and number of downstream barriers along the stream network. Each potential barrier was then assigned a score based on its attribute in relation to the criteria thresholds. Scores for all questions were totaled to determine a preliminary rank for Stage 1 (i.e., highest total score becoming the highest-ranking barrier after Stage 1).

The following attributes were fundamental for a potential barrier to be given a high score in Stage 1 of the selection process:

- Located on a high ordered stream,
- Minimal to no potential barriers downstream,
- Substantial length of all stream network (habitat) upstream of the potential barrier
- Large area of *available* upstream distance (habitat) to the next barrier or top of catchment,
- Good sub-catchment condition (i.e., minimal intensive land use practices),
- Barrier located in lower reaches or on the tidal interface (i.e., close to the estuary).
- Large size wetland (wetland barriers only),
- Expansive permanent water (wetland barriers only),
- Low elevation wetland (wetland barriers only).

As resources and time were limited, it was not possible to ground truth all potential barriers identified. Scoring criteria and questions from Stage 1 provided a preliminary assessment of potential barriers for further investigation. The scoring criteria and questions used in Stage 1 are listed and described below:

1. *Stream Hierarchy/Stream Order*

In this study, stream order was used as a proxy for water permanence and productivity potential of watercourses within the network. In practice, parts of the network attributed as stream order 0 are typically drainage features such as gullies, paddock drains and steep mountainous creeks. These features are often ephemeral with water flows occurring only during rainfall and for a short period (days) after rain events. They are therefore less valuable as habitat for most species of fish. Conversely, watercourses attributed with stream orders >5 have multiple smaller streams discharging into them and they often span large distances across lower elevations in the catchment. Generally, these high ordered waterways provide permanent water, providing excellent fish habitat throughout many life stages. Large, ordered waterways also provide a wide variety of habitat types and support a greater diversity of fish species when compared with smaller waterways. Waterways within the project boundaries were classified into five separate classes based on Strahler stream order. Scores were assigned to potential barriers based on the stream order they were situated on (Table 2). Potential barriers on high ordered waterways (>5) score highest. Potential barriers located on drainage features scored lowest.

Table 2: Strahler stream order categories and associated scores.

Option	Stream Order	Score
a	Strahler stream orders >5	10
b	Strahler stream orders 4	8
c	Strahler stream order 3	5
d	Strahler stream order 2	2
e	Strahler stream order 1	1
f	Drainage feature or Strahler stream order 0	0

2. Number of Potential Barriers Downstream

The number of potential barriers downstream assists in the prioritisation of barriers occurring in series along the same watercourse. Because passability is unknown in Stage 1, all barriers were assumed to be impassible under most conditions. Therefore, the first barrier in each series is the most critical to migration of diadromous species. The score was calculated as the number of potential barriers downstream along the stream network. For example, the first potential barrier upstream from the source (sea) receives a score of eight. The next barrier upstream receives a score of six. The sixth (or higher) barrier receives a score of one (Table 3).

Table 3. Number of potential barriers downstream and associated scores.

Option	Number of Barriers Downstream	Score
a	0	8
b	1	6
c	2	5
d	3	4
e	4	3
f	5	2
g	≥6	1

3. Upstream Catchment Excluded by the Potential Barrier

Accumulation of stream network upstream of barrier to the top of the catchment. Calculated as the cumulative length of the stream network (including drainage features) upstream of the potential barrier (Table 4). This question was a proxy for allochthonous inputs into the system (e.g., nutrients, woody debris) and stream flows. This differs from Stream Order (SO), as SO is not always representative of catchment size.

Table 4: Accumulated distance scoring criteria.

Option	Accumulated Distance (km)	Score
a	>100	5
b	>50 – 100	4
c	>10 – 50	3
d	>5 – 10	2
e	≤5	1

4. Distance to Next Barrier Upstream

The upstream accumulated length of accessible habitat (i.e., the distance from the potential barrier to the next potential barrier upstream, or the network is exhausted – top of catchment) indicates the amount of habitat made available upon remediation. This included stream networks which aggregate between two potential barriers. For example, where a tributary enters upstream of a barrier, the length of the tributary's network is also accumulated until the point where another barrier is encountered, or the network is exhausted. Criteria thresholds are provided in Table 5.

Table 5. Stream length 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	>20	3
b	2-20	2
c	<2	1

5. Catchment Condition – % Intensive Land Use

Catchment condition is an important factor as it is often linked to the risk of degraded habitats and poor water quality occurring, and broader ecosystem health. Intensive land uses such as cropping result in increased discharge of sediments, nutrients and pesticides into waterways. Further, they often coincide with the removal of riparian vegetation, straightening of creeks and excavation of drains to remove water from the landscape more efficiently. These changes cumulatively reduce the quality and quantity of aquatic habitats available. They may also increase the risk of eutrophic conditions which can cause fish kills or create chemical barriers to migration. The proportion of intensive land use in the sub-catchment in which a potential barrier was located, was therefore used as a proxy for catchment condition. For this study, the 2016 Australian ABARES land use classification dataset was used to determine the proportion of intensive land use within a sub catchment. Designations of 'intensive' or 'non-intensive' were assigned to the secondary classification types of the land use layer (Table 6). The accumulated area of 'intensive' land use within the sub-catchment, as a percentage of the total sub-catchment area, was then assigned to each barrier within the respective sub-catchment. Scoring criteria thresholds are provided in Table 7.

Table 6. Land use designations used to calculate percentage of 'intensive' land use within sub-catchments of the study area.

Land Use Type –Secondary (ABARES 2016)	Land Use Category
Channel/aqueduct	Intensive
Cropping	Intensive
Estuarine/coastal waters	Not Intensive
Grazing irrigated modified pastures	Intensive
Grazing modified pastures	Intensive
Grazing native vegetation	Not Intensive
Intensive animal production	Intensive
Intensive horticulture	Intensive
Irrigated cropping	Intensive
Irrigated perennial horticulture	Intensive
Irrigated plantation forests	Intensive
Irrigated seasonal horticulture	Intensive
Lake	Not Intensive
Land in transition	Intensive
Managed resource protection	Not Intensive
Manufacturing and industrial	Intensive
Marsh/wetland	Not Intensive
Mining	Intensive
Nature conservation	Not Intensive
Other minimal use	Not Intensive
Perennial horticulture	Intensive
Plantation forests	Not Intensive
Production native forests	Not Intensive
Reservoir/dam	Intensive
Residential and farm infrastructure	Intensive
River	Not Intensive
Seasonal horticulture	Intensive
Services	Intensive
Transport and communication	Intensive
Uncertain	Intensive
Utilities	Intensive
Waste treatment and disposal	Intensive

Table 7 Showing the proportion (%) of intensive land use and associated scores for each category.

Option	Proportion (%) Intensive Land Use Within the Sub-Catchment	Score
a	<30%	3
b	30-60%	2
c	>60%	1

6. Distance to Estuary

The distance to the estuary provides an assessment of the impact on diadromous fish which require access between fresh and estuarine/marine waters to breed and/or maintain viable populations. Barriers located on, or close to the tidal interface are particularly problematic as they can reduce or exclude access between each of these ecosystems. This may prevent life-cycle completion for some species. For this assessment, the estuary was delineated by the Highest Astronomical Tide (HAT) in most instances. Where the mapped HAT was inconsistent with the extent of habitat features (e.g., mangrove or salt marsh vegetation), the HAT limit was extended or reduced to represent the extent of the observed habitat features.

Table 8: Criteria and associated scores for the measured distance between each barrier and the estuary.

Option	Distance to Estuary	Score
a	In estuary or on tidal interface	5
b	<500m from tidal interface	4
c	500m-2km	3
d	2km-10km	2
e	10km-20km	1
f	>20km	0

7. Wetland Area

The size of wetlands varied considerably throughout the study area, ranging from <1 ha to >3,500 ha. While wetland area was an obvious criterion to include in the prioritisation, it was important to consider the ecological relevance of the categories used to assign scores. For example, a wetland area <1 ha would provide considerably less ecosystem services than wetland of 10 ha, but the services provided by a wetland of 100 ha are not likely to be comparably less than one of 110 ha. In this instance a category of 1-10 ha was warranted, but not for 100 – 110 ha.

Table 9. Category ranges and respective scores for wetland area.

Option	Wetland Area	Score
a	>1000 ha	10
b	>500 – 1000 ha	9
c	>100 – 500 ha	8
d	>50 – 100 ha	7
e	>10 – 50 ha	6
f	>5.0 – 10 ha	5
g	>2.0 – 5.0 ha	4
h	>1.0 – 2.0 ha	3
i	0.5 – 1.0 ha	2
j	<0.5 ha	1

8. Water Permanence (refuge potential)

In coastal wetland habitats the permanence of water is important. For fisheries that rely on wetland habitats as nursery grounds, having areas of permanent water are critical to provide refuge during dry seasons. Water Permanence was estimated from Water Observations from Space (WOFS) data. This data was based on satellite imagery from 1987 to present and provides a representation of the percentage of images that returned a water signature for a given location (cell) after being filtered of potential interference signals (e.g., cloud cover). Other spatial datasets (e.g., QLD wetlands layer) were also investigated to provide an indication of the relative permanence of water within the impact areas. These datasets were in vector format and the fields used to define water permanence were derived from multiple sources. It was decided to use WOFS as the data was in raster, making calculations straightforward, and the values were derived from a single data source which covered the entire project area.

It is important to note that for modified/artificial wetlands, WOFS data was influenced by the age of the impacting structures (e.g., bund or dam). Structures which were not in place from the start of the time series (i.e., before 1987), would not return a true representation of water permanence within the associated wetland. The mis-representation was proportionate to the age of the structure. That is, the longer the structure had been in place, the more accurate the permanence estimate. Despite this, the use of WOFS data still provided the most consistent indication of water permanence throughout the project area.

Two components of water permanence contributed to this criterion, the maximum permanence and the area of high permanence. The maximum permanence represented the single highest value within the wetland, which corresponded to a 30 m x 30 m grid cell. The area of high permanence corresponded to the number of cells within a wetland which contained water for >60% time. To ensure that water permanence did not bias the analysis by scoring the same criteria twice, scores were down weighted by 50%.

Although the maximum permanence and area of high permanence were chosen for the prioritisation criteria, values were also calculated for range, minimum and standard deviation. This information will be useful to inform technical considerations during the operational planning of any remediation or habitat improvement works at specific locations.

Table 10. Category ranges and respective scores for maximum water permanence.

Option	Maximum Permanence	Score
a	>90%	5
b	>80 – 90%	4.5
c	>70 – 80%	4
d	>60 – 70%	3.5
e	>50 – 60%	3
f	>40 – 50%	2.5
g	>30 – 40%	2
h	>20 – 30%	1.5
i	>10 – 20%	1
j	<10%	0.5

Table 11. Category ranges and respective scores for high water permanence area.

Option	Area of High Permanence	Score
a	>2.5 ha @ >80% permanence	5
b	>1.0 – 2.5 ha @ >80% permanence	4.5
c	>0.5 – 1.0 ha @ >80% permanence	4
d	>0.25 – 0.5 ha @ >80% permanence	3.5
e	>0 – 0.25 ha @ >80% permanence	3
f	>2.5 ha @ 60-80% permanence	2.5
g	>1.0 – 2.5 ha @ 60-80% permanence	2
h	>0.5 – 1.0 ha @ 60-80% permanence	1.5
i	>0.25 – 0.5 ha @ 60-80% permanence	1
j	>0 – 0.25 ha @ 60-80% permanence	0.5

9. Wetland Elevation

Wetland elevation complemented the 'distance to estuary' criteria for the impact of barriers on diadromous fish that require access between fresh and estuarine/marine waters. Wetlands located at low elevations provide critical nursery habitat for many diadromous fish. As elevation increases, wetland utilisation becomes more dominated by potamodromous fish, which can complete their lifecycles in freshwater.

For this assessment elevation data was extracted from a Digital Elevation Model (DEM) derived from Light Detection and Ranging (LiDAR) 5-meter grid. This DEM represented the finest scale elevation data which encompassed the entire study area. The elevation values were assigned to the potential wetland barriers, then categorised and assigned scores based on the thresholds in Table 12. Elevation values were assigned to the potential barriers rather than the wetlands, as it is the barrier which fish will need to overcome to access the wetland.

As 'distance to estuary' and 'wetland elevation' were both proxies for relative catchment position, 'wetland elevation' was down weighted by 50%. This was to ensure relative catchment position did not bias the results away from the other assessment criteria.

Table 12. Criteria and associated scores for the elevation of each wetland barrier.

Option	Wetland Elevation	Score
a	≤10m	5
b	10m-20m	4
c	>20m-30m	3
d	>30m-40m	2
f	>40m	1

Stage 2 Ground truthing

A ranked list of the potential barriers after Stage 1 was created following the desktop assessment. The list was used to guide ground truthing efforts. Efforts were focused on visiting the highest rank barriers first, particularly sites which were not visited during the 2015 prioritisation. Field staff aimed to ground truth the top 100 potential stream barriers and 50 wetland barriers identified in Stage 1. Where barriers were located on public land access was gained by designated roads or by foot where no established vehicle access was available. For sites on private land with known landholders, the land holder was first contacted to arrange site access. If no contact could be made or if the land holder was unknown, field staff drove to the property to reach the land holder. The number of barriers visited during Stage 2 is reported in the Results.

Onsite assessments of the highest-ranking potential barriers were undertaken during Stage 2. Additional information was collected at confirmed barrier sites which may assist in the development of remediation works. This included site access for machinery and landholder details. Both stream and wetland barriers were assessed against the same criteria in Stage 2.

It should be noted that every barrier investigated on-ground was assessed based on the flow conditions present at the time. As conditions vary, the passability of each barrier may change. Therefore, the study can only prioritise remediation based on the probable impact of each barrier under similar flow conditions.

10. Barrier Type and Passability

Barrier type and passability were assessed based on the configuration of the barrier. Impoundment structures such as dams, weirs and bunds were scored separately to culverts and floodgates. Dams, weirs and bunds were scored based on their height (headloss) alone, whereas culverts and floodgates were scored according to their span across the waterway (aperture), total structure height, and headloss. Table 13 details scores attributed to various configurations.

Table 13: Criteria used to assess barrier passability for various barrier types and associated scores

Option		Dam or Weir Only (no culverts)	Score
a		>2 m	7
b		>1 – 2 m	6
c		>0.5 – 1 m	5
d		>0.3 – 0.5 m	4
		<0.3 m	1
Box or Pipe Culverts (Including floodgates)			
Span			
A	a	Culverts/pipes that span <20% of stream cross-sectional area	3
	b	Culverts/pipes that span >20-40 % of stream cross-sectional area	2
	c	Culverts/pipes that span >40 -60% of stream cross-sectional area	1
	d	Culverts/pipes that span >60% of stream cross-sectional area	0
Causeway/Structure Height			
B	a	>2 m	2
	b	>1 - 2 m	1
	c	< 1 m	0
Headloss			
C	a	Headloss: >0.3 m	2
	b	Headloss: 0 – 0.3 m	1
	c	below bed level (no drop; upstream and downstream water levels equal)	0
***Notes: Headloss is the difference between upstream and downstream water levels**			

11. Stream Condition

Stream condition was assessed by visual observation at the barrier site, and later by desktop using high resolution imagery for extents upstream and downstream of the barrier for 1 km. This aimed to provide an approximate characterisation of the ecological health of the local riparian vegetation and the aquatic environment. Scoring was based on general observations of riparian clearing, presence of invasive weeds, erosion, and pollution (Table 14). It should be noted that scoring for this question was subjective and relied on the experience of field staff in identifying levels of disturbance.

Table 14: Criteria used to assess stream condition at the barrier site and associated scores

Option	Stream Condition	Score
a	Pristine-undisturbed (no apparent clearing of riparian vegetation, no bank degradation, exotic weeds or pollution)	5
b	Low disturbance (≤25% of observable upstream areas degraded)	4
c	Moderate disturbance (>25-50% of observable upstream areas degraded)	3
d	High disturbance (>50-75% of observable upstream areas degraded)	2
e	Very high disturbance (>75% of observable upstream areas degraded)	1

12. Water Supply

Assessment of streamflow characteristics was important in determining the permanence and quality of available habitat within the reach of the barrier site if remediation was to occur. Natural, permanent, and perennial flow regimes were scored highly given the increased chance of survival for any fish populations present. Ephemeral systems which are known to dry seasonally only provide habitat during part of the year and thus were scored lower (Table 15). The assessment of water supply was subjective, based on visual observations and local knowledge of each watercourse.

Table 15: Criteria used to assess water supply in the watercourse of each barrier and associated scores

Option	Water Supply	Score
a	Natural, permanent, perennial or tidal	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

13. Habitat for Migratory Fish Species Upstream of Barrier Site

Habitat available for migratory fish upstream of the barrier was assessed by visual observations conducted during site visits. These observations included the presence and abundance of natural woody debris in the watercourse, particularly within the low-flow channel, the diversity of habitats, and the presence of aquatic macrophytes. Diverse and structurally complex habitats provide refuge for various sizes and life stages of fish and are critical to the survival and productivity of many species. Sites with diverse and abundant fish habitat were scored highly (Table 16). Scoring for this question was subjective and relied on the experience of field staff in identifying levels of disturbance.

Table 16: Criteria used to assess habitat for migratory fish upstream of the barrier and associated scores

Option	Habitat for Migratory Fish Species Upstream of Barrier Site	Score
a	Excellent – Diverse and abundant fish habitat (large woody debris, run, riffle and pool habitats, aquatic plants.	5
b	Good – Reasonable amount of suitable fish habitat	4
c	Moderate – some suitable fish habitat present	3
d	Poor – little suitable fish habitat	2
e	Very poor – Scarce or no suitable fish habitat	1

Stage 2 Analysis

Fish barrier information acquired during ground-truthing were entered into a spatial database as attributes. Where information from the 2015 FBP was available for sites not visited in the current prioritisation, it was included and contributed to the final ranks of the fish barriers reported here. Where available, geotagged photos were loaded into the spatial database to provide additional reference for remediation works. Scores for Stage 2 questions were calculated based on the criteria detailed in the section above.

Potential barriers which were confirmed to not be barriers (e.g., bed level crossings, bridges, fallen logs etc.) were removed from the spatial dataset. The remaining barriers were then reassessed against the Stage 1 criteria with the scores for each respective question updated.

After all barriers had been re-analysed, scores were collated, with the highest scoring barrier over Stage 1 and Stage 2 becoming the top-ranked barrier in the study area.

Results

Stage 1 - Desktop

The initial desktop barrier identification resulted in 9,738 potential barriers (stream and wetland) being identified throughout the region at a density of 1.082/km^2. Potential barrier densities were highest in Reliance Ck (3.401/km^2). Plane Ck, Cabbage Tree Ck, Constant Ck and the Pioneer R – Main Channel had potential barrier densities ranging from 2.776 – 2.321/km^2 respectively. Potential barrier densities in the remaining catchments were below 2.0/km^2 (Table 17). Repulse Ck and the Upper Proserpine R catchments recorded the lowest density of 0.004/km^2, which represented a single barrier in each catchment.

Table 17. Potential barrier densities for catchments with the Mackay Whitsunday fish barrier prioritisation area.

Catchment	Potential Barrier Count	Catchment Area (km^2)	Potential Barrier Density (PB/km^2)
Reliance Creek	356	105	3.401
Plane Creek	443	160	2.776
Cabbage Tree Creek	225	84	2.670
Constant Creek	666	262	2.543
Pioneer River - Main Channel	1272	548	2.321
Sandy Creek	873	498	1.755
Bakers Creek	295	169	1.741
Rocky Dam Creek	900	519	1.735
Alligator Creek	332	208	1.595
Proserpine River - Main Channel	131	85	1.543
Murray Creek	684	459	1.490
O'Connell River	650	487	1.336
Blackrock Creek	294	230	1.281
Mackay City	233	184	1.267
Upper Cattle Creek	227	188	1.205
Carmilla Creek	149	127	1.171
Myrtle Creek	267	292	0.914
Flaggy Rock Creek	161	190	0.847
West Hill Creek	140	184	0.762
Lethebrook	242	373	0.648
Marion Creek	60	93	0.643
Eden Lassie Creek	352	553	0.636
St Helens Creek	109	180	0.607
Waterhole Creek	109	209	0.521
Gregory River	153	309	0.496
Thompsons Creek	83	174	0.477
Whitsunday Coast	76	195	0.390
Cape Creek	60	168	0.357
Gillinbin Creek	42	131	0.320
Andromache River	95	406	0.234
Blacks Creek	54	711	0.076
Repulse Creek	1	255	0.004
Upper Proserpine River	1	266	0.004

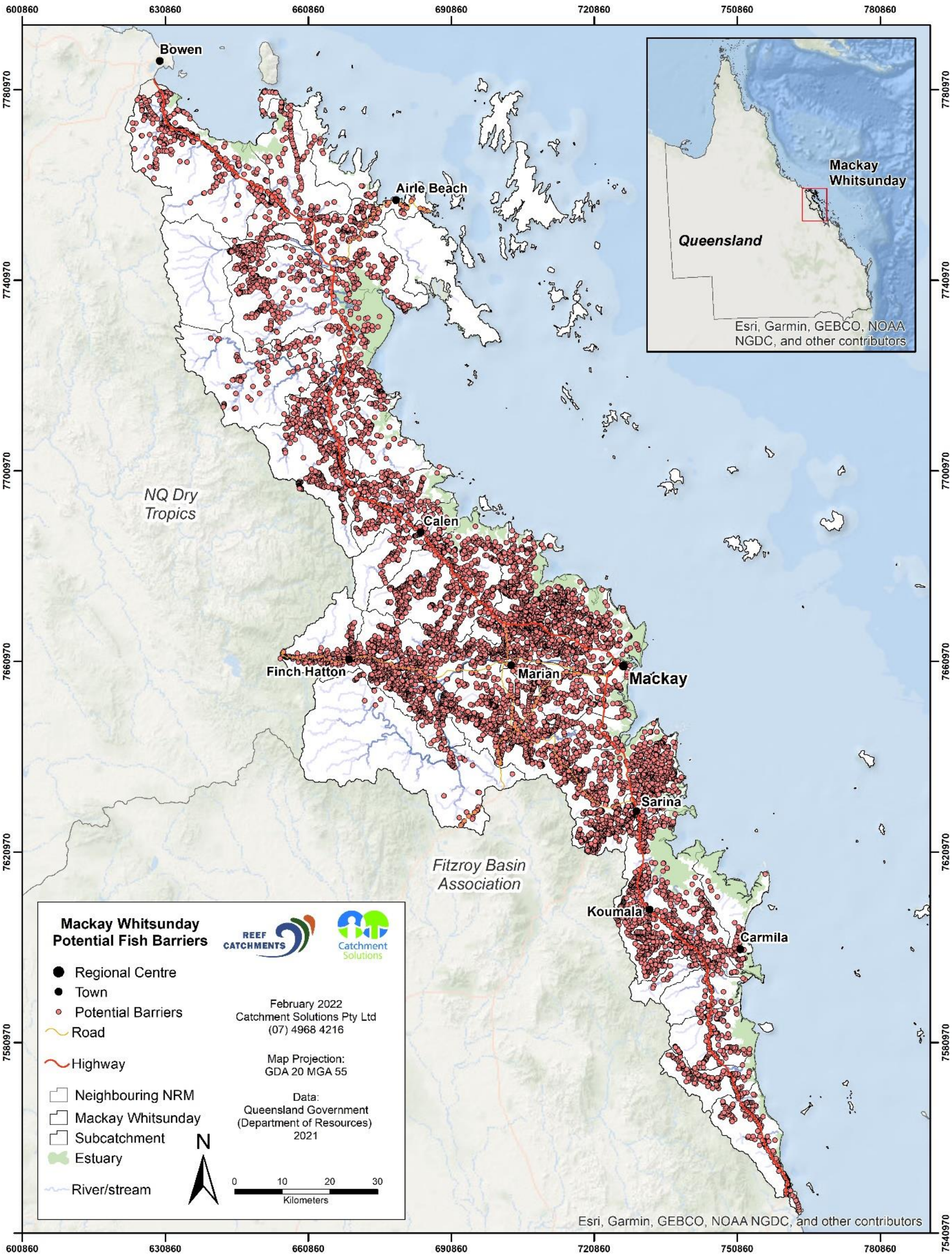

Figure 7. Distribution of potential barriers throughout the study area.

A total of 773 wetlands were mapped for this project. Of these, 291 were classed as 'off-stream' with no connection to the stream network used in the prioritisation. Primarily these represented irrigation storages, which water was pumped into to maintain levels. Only five off-stream wetlands were natural. Off stream wetlands were catalogued and attributed size and water permanence information but did not contribute further to the FBP.

Of the 9,379 potential fish barriers, 596 were associated with regional wetlands (Figure 9). These were mostly associated with artificial or modified wetlands where the stream channel had been impounded to increase water storage capacity. Only 24 potential barriers were located on natural wetlands.

The on-stream wetlands ranged in size from <1ha to >3,000 ha. Larger sized wetlands generally represented major water storage dams (e.g., Peter Faust, Teemburra and Kinchant dams) or ponded pastures (e.g., Tedlands, Marklands or Goorganga wetlands). It should be noted that only wetlands which were associated with fish barriers were assessed in this project. The region contains numerous expansive mangrove and salt marsh wetlands and several large freshwater wetlands which were not affected by barriers to fish movement.

Water permanence (refuge potential) also varied considerably amongst the wetlands. Again, the larger water storages returned the highest and most expansive areas of permanent water. Notably, there were several smaller wetlands which recorded relatively large areas of permanent water (Figure 8). Ponded pastures, which represented the largest wetland coverage, contained a relatively small area of permanent water. Within these complexes, the more permanent areas tended to correspond with existing creek channels (Figure 8).

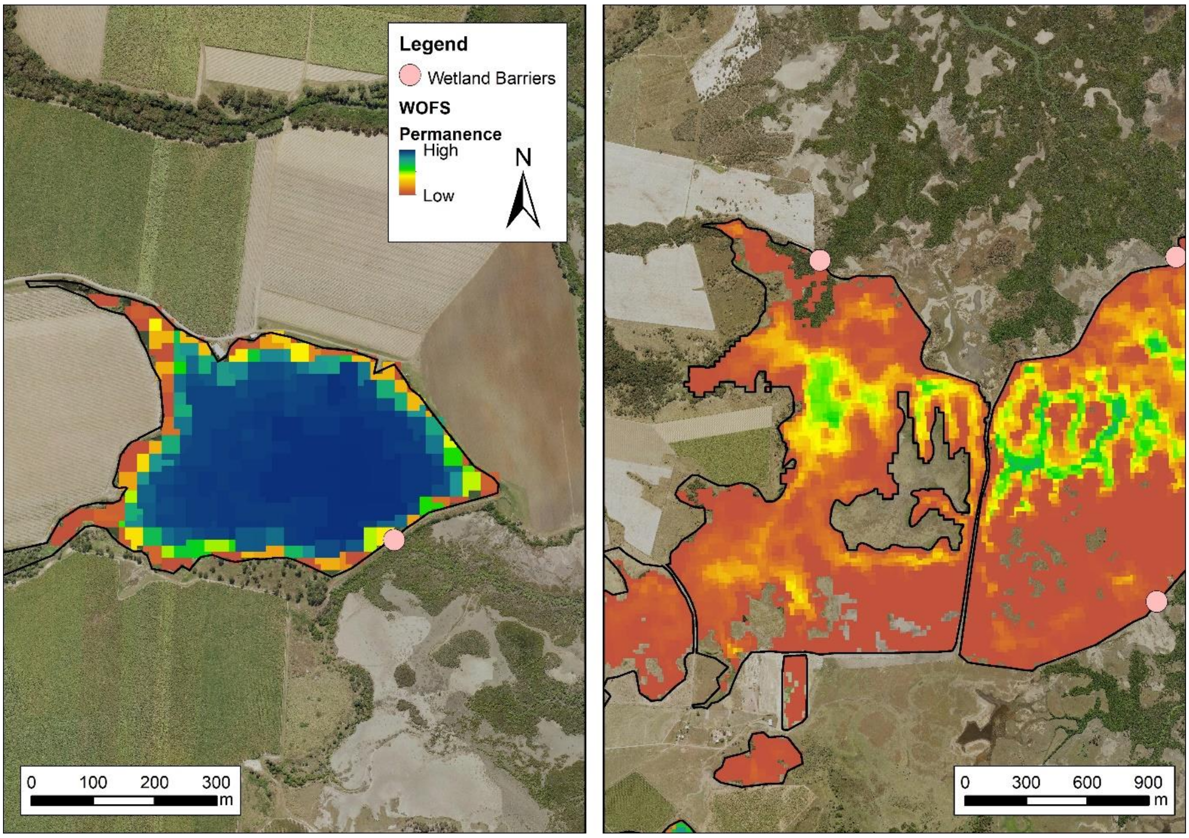

Figure 8. Examples of variations in water permanence among wetlands in the Rocky Dam Creek Catchment. The wetland on the irrigation dam on left is considerably smaller than the ponded pasture on the right yet provides a greater degree of refuge potential for fish which may access the wetland.

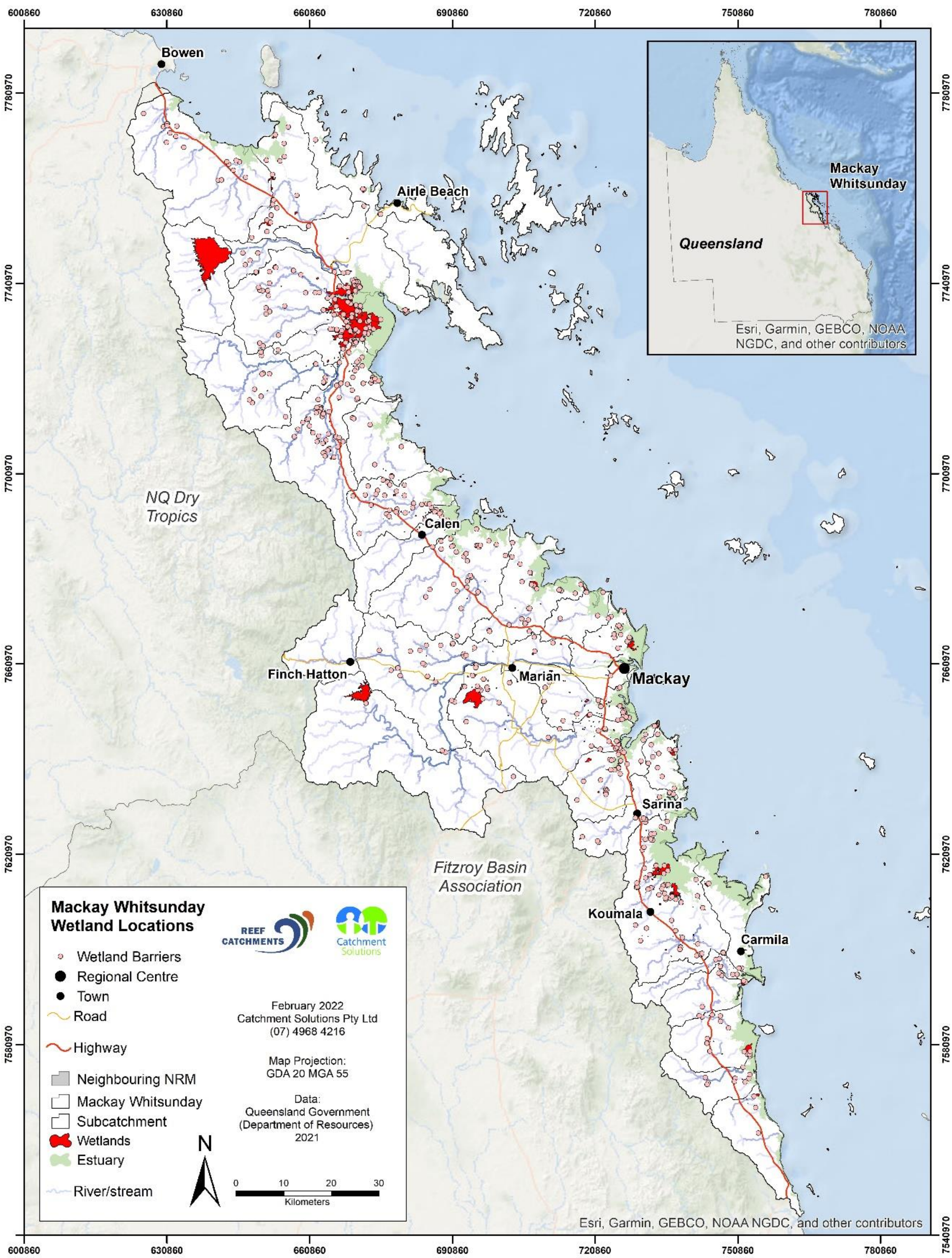

Figure 9. Distribution of potential fish barriers associated with regional wetlands. Note: Wetland locations are represented by potential barrier markers, only larger wetlands can be distinguished at the represented map scale.

Stage 2 - Ground Truthing

During Stage 2, 187 potential barriers were inspected, comprising 133 stream barriers and 55 wetland barriers. 149 of the potential barriers visited (~80%) were confirmed as barriers to fish passage. Most stream barriers were causeways, while bunds and dams made up most wetland barriers (Figure 10). Potential barriers validated in the field that were assessed as not impacting aquatic connectivity included bed level crossings, bridges, and natural features such as fallen trees (Figure 11). Several of the potential wetland barriers were derelict bunds which no longer created an impediment to fish movement.

Figure 10. Examples of typical fish barriers validated during ground truthing. Road causeway - left, weir - middle and bund - right.

Figure 11. Typical non-fish barriers validated during ground truthing. Bed level causeway - left, bridge - middle, fallen tree - right.

Following the removal of non-barriers and rescoring against Stage 1 criteria, the barriers received their final ranks. All barriers were ranked as stream barriers, while the subset which was associated with wetlands was also ranked relative to other wetland barriers. Figure 12 provides a regional overview for the location of top-ranking stream barriers and Figure 13 shows the location of wetlands associated with the top-ranking wetland barriers within the region.

Appendix 1 provides a list of the top 31 stream barriers, and Appendix 2 provides a list of the top 30 wetland barriers. Included in the lists are photos of the respective barriers, location details, remediation options and indicative costs. Appendix 3 provides the location and ranking for all fish barriers verified through the current prioritisation.

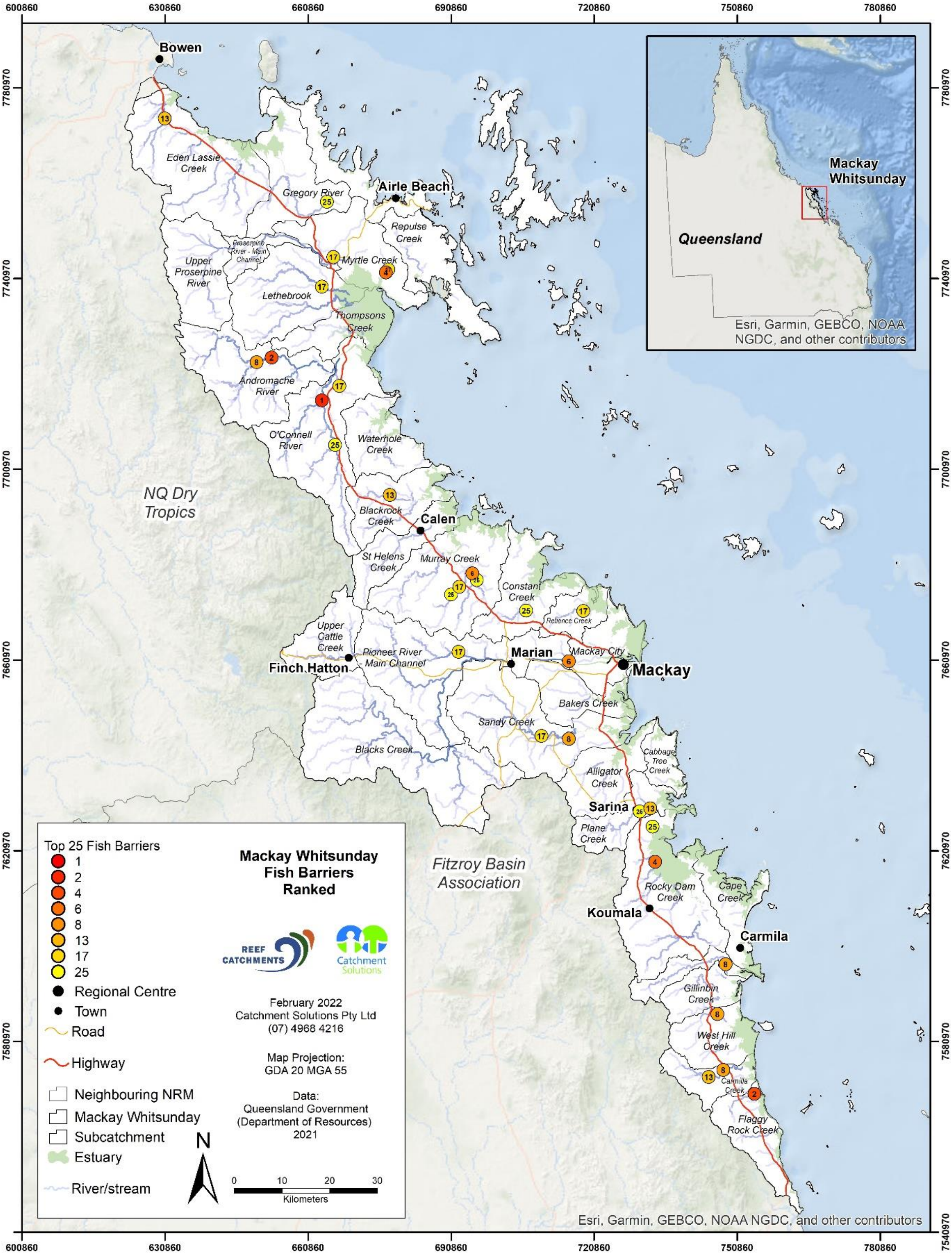

Figure 12. Top 31 ranking stream barriers within the study area. Note: several barriers were ranked equal based on the cumulative Stage 1 and stage 2 scores.

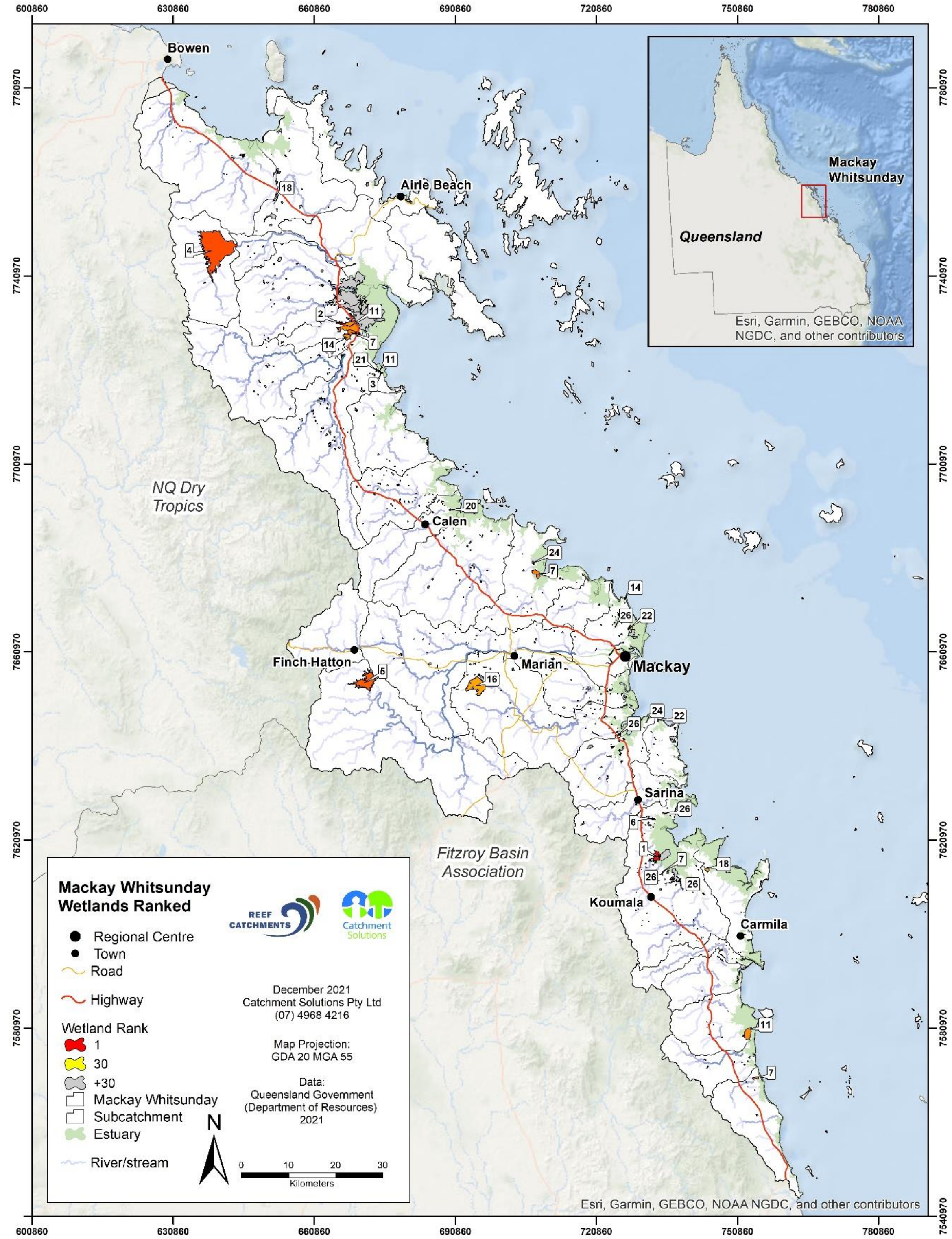

Figure 13. Top 30 ranking wetlands barriers within the study area. Note: several barriers were ranked equal based on the cumulative Stage 1 and stage 2 scores.

Highest Ranking Barriers

Stream Barriers

The highest priority stream barrier was the Stafford Rd causeway, located on the O'Connell River (Figure 14). This causeway comprised a single lane concrete deck with several small aperture culverts. Notably, this causeway and several others throughout the region were not included in the 2015 FBP as some fish passage remediation works had occurred at the site, and it was thought that no further actions were required. The works included the installation of a single culvert barrel 1.2 m x 1.2 m with vertical baffles. Fish passage monitoring at this site in 2019 found velocities through the culvert were too great (>2 m/s) under low flow conditions (McCann and Power 2019). Under moderate and high flow conditions this structure drowns out, but these flows only comprise a small proportion of the flow duration in this system.

As the causeway is considered critical infrastructure, removal is not a viable remediation option. Upgrade of the causeway in accordance with Queensland's waterway barrier works codes would provide the best outcome for fish passage. However, as this structure is fit for purpose and was built prior to the introduction of fish passage legislation, there is no statutory requirement to upgrade the causeway for the purpose of improving fish passage. The causeway upgrade in accordance with fish passage codes would likely be cost prohibitive ($1-2M), therefore consideration should be given to improve fish passage at this site within the constraints of the existing structure. This may include the addition of graded rock chutes to improve fish passage under flows where the causeway deck is overtopped, and possibly the addition of several larger aperture box culverts to improve passage under low flow conditions. Such works are still extensive and will require substantial funding ($150-500k) to undertake.

Figure 14. Staffords Rd causeway on the O'Connell R. looking west across the causeway (left) and showing the small pipe (mid) and box (right) culverts incorporated into this structure.

The second highest priority barriers were shared between the Flaggy Rock Creek Weir and the Andromache River Weir. Flaggy Rock Creek weir (Figure 15) was located at the tidal interface. The weir is moderately sized and consists of a series of inter-meshed, rock-filled gabion baskets. A fishway is present at this site, however erosion of the downstream bed has caused the tailwater to lower and a drop to form at the outlet of the fishway. As the weir provides a source of irrigation water for surrounding agriculture, removal is not a viable remediation option. Extending the existing fishway is the most appropriate remediation option for this site and would be relatively cost effective ($75-100k).

Figure 15. Flaggy Rock Creek Weir in 2007 (left) and 2021 (mid). Extensive vegetation has established on the crest of the weir which would assist with fish passage when flow is overtopping the crest. During low flows fish passage is significantly impacted as the fishway outlet is 0.5 m above the tailwater level.

Andromache River Weir (Figure 16) is used to gauge river flow for the Department of Regional Development, Manufacturing and Water (DRDMW). The weir is considered critical infrastructure and removal is unlikely to be supported. However, stream gauging sites often utilise natural channels which are resistant to change in morphology (e.g., rock bars). The gauging weir maintains a relatively consistent channel profile which reduces the frequency at which the site needs to be gauged to maintain flow rating curves. This should not preclude the consideration of weir removal as there are other viable options for gauging stream flow in the Andromache R. Both weir removal or the retrofit of a fishway would require considerable investment ($250-750k) depending on the works involved and whether a new gauging site needs to be established.

Figure 16. The Andromache R gauging weir under low flow conditions.

Wetland Barriers

The tidal floodgates on Pond 2 of Marklands Wetlands ranked highest amongst the wetland barriers. Notably, this barrier ranked relatively high (forth) against stream barriers as well. The barrier comprises a set of flood gates and concrete headstock which prevents tidal intrusion up the main channel of Boundary Creek. The structure is part of a larger system of bunds which were constructed to improve pasture for cattle grazing (ponded pastures). Extensive fisheries remediation work has occurred on these wetlands, including the construction of two fishways on the larger Pond 3 and a bed level crossing on the bund between Pond 1 and Pond 2. The bunds are considered crucial to the property’s cattle operations, so removal for the purpose of improving connectivity is unfeasible. The construction of a fishway like those already in place on pond 3 will significantly increase utilisation of the wetlands and provide additional connectivity to the freshwater reaches of Boundary Creek and several tributaries which enter the wetland. The fishway is likely to cost between $75-90k.

While Marklands Wetland scored highest on the wetland prioritisation, water permanence within the complex was relatively low. Several artificial refuge pools have been constructed in Pond 3 as part of the fisheries improvement works already undertaken. It is recommended that additional refuge pools be constructed in Pond 2 in conjunction with the construction of a fishway. This will provide additional benefits in dry years when the wetlands dry considerably.

Figure 17. The floodgates on pond 2 of Marklands Wetlands (left), typical habitat within the wetland complex (middle), and the cone fishway constructed in 2015 on the large Pond 3 (right).

Thompson Creek upstream wetland is a large irrigation dam and was ranked second highest of the wetland barriers. This structure comprises an extensive earth dam, approximately 4 m high and 1,200 m long. The structure captures flow from Thompson Ck before it overtops a large grass-lined spillway. The gradient of the spillway is low (~1:40) and fish passage during high flows would be possible. Low flows pass solely through a standpipe located midway along the dam wall, making the structure impassable under these conditions. To improve fish passage at this site, it is recommended that the standpipe be decommissioned to allow all flows to pass through the spillway. Fortification of the spillway may be required to reduce the risk of erosion caused by prolonged flow periods. Rock lining the spillway with a low flow channel and a series of resting pools will further improve fish passage at this site. The cost of such works will range between $100-200k.

Figure 18. Looking across the dam wall (left) of Thompson Creek upstream wetland and the inlet (middle) and outlet (right) of the stand pipe which currently passes low flows.

It should be noted that several barriers located on prominent wetlands could not be verified in the field. This included those on Goorganga Wetlands, a large, ponded pasture complex located in the lower Thomson and Lethebrooke catchments. Contact with the land holder was established, however permission to assess the bunds for passability assessment was not granted. Fish barriers on the bunds of Goorganga Wetlands would have likely ranked high in the wetland prioritisation. It is recommended that efforts be made to build a working relationship with the property owner.

Discussion

The Mackay Whitsunday region is comprised of diverse aquatic habitats with numerous natural and anthropogenic factors impacting fish passage. High priority fish barriers were identified across a range of unique ecosystem contexts. These included moderate sized rivers and creeks originating in the coastal ranges, to numerous small creeks and drainage features emanating from the floodplains. Many of the smaller watercourses were associated with coastal wetlands.

The overall number and density of potential barriers in the Mackay Whitsunday region increased from the 2015 FBP to the current prioritisation. In 2015, 3,974 potential barriers were identified compared with 9,738 potential barriers in the current study. Only a small fraction of this increase can be contributed to the construction of new fish barriers. Much of the increase was the result of using wider coverage, higher resolution imagery and more accurate stream networks. For the 2015 prioritisation the coverage of high-resolution imagery was limited to urban centres. The wider coverage used for the current prioritisation allowed the identification of potential fish barriers which were not previously distinguishable (Figure 19). The current prioritisation adopted the use of the NE coast water course and canals layers as the base network for analysis. Compared with the DAF waterway barrier stream layer used in 2015, the NE coast watercourse and canals layer better defined the sinuosity of the region's streams (Figure 20). This resulted in a longer overall network and a greater number of potential barriers throughout the network. Regional streams are well defined by the network used for the current study and provides a good baseline on which future fish barrier numbers can be compared.

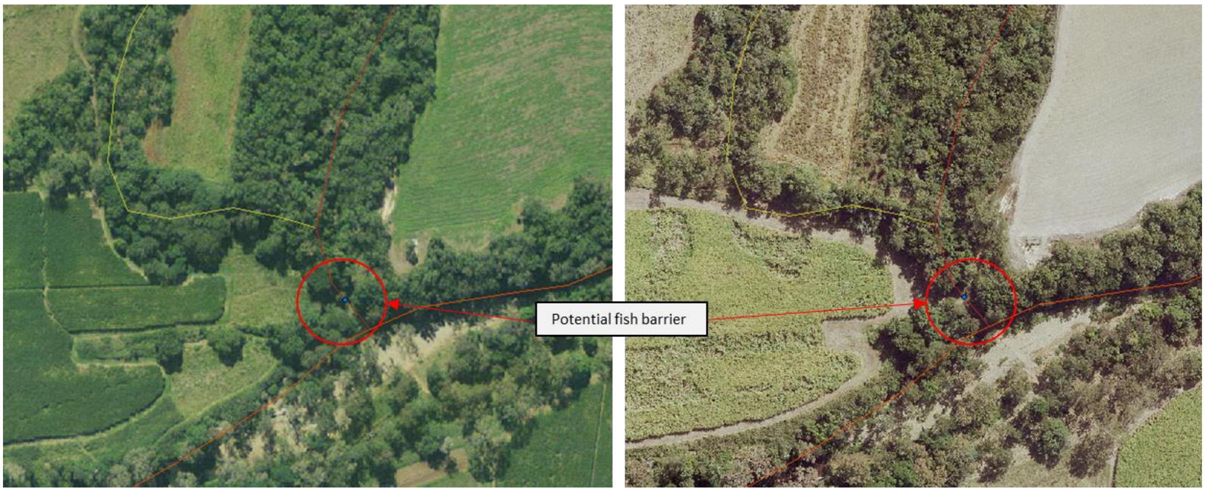

Figure 19. The higher resolution (20 cm) of the 2019 imagery on the right allowed for better identification of potential fish barriers compared to the lower resolution (50 cm) 2013 imagery used for the 2015 fish barrier prioritisation.

Figure 20. An example of the network coverage differences between the DAF waterway barrier works stream layer (dark blue) used in 2015, and the NE coast and canals layers (light blue) used to form the stream networks for the current prioritisation.

The current prioritisation also differed from the 2015 prioritisation as it removed the Stage 3 criteria from the ranking process. Stage 3 included the technicality of remediation works and associated costs. This favoured sites which were relatively inexpensive and easy to repair, at the cost of environmental benefit. The current approach ranks barriers solely on the environmental benefit gained through remediation. By doing so it provides better guidance to those undertaking remediation works. For instance, a group looking to improve fish passage can look at the prioritisation and choose a site which delivers the greatest outcome for the level of funds they have available. Stage 3 also included criteria for threatened or endangered species, and economic benefit (fisheries resource productivity). No listed, threatened or endangered fish species occurs in the Mackay Whitsunday, so its inclusion would not provide any additional benefit to the prioritisation. There is insufficient data available to objectively determine the economic benefit of restoration activities on fisheries productivity. Previously this criterium was weighted towards commercial species which utilise freshwater habitat at some stage in their lifecycle (e.g., barramundi). Without clear determination of which species should be included and their natural distribution throughout the catchments, the authors believed there was too much subjectivity in its current form. There is scope to include economic benefit into future prioritisations when more information is available on this matter.

There was some variation in the relative ranking between the priority fish barriers of the 2015 and current prioritisations (Table 18). Some of this variation may be attributed to the exclusion of Stage 3. Other contributing factors may include new sites identified in the current prioritisation and the remediation of priority barriers from 2015. The rank of the current top 31 priority barriers in relation to the 2015 ranks are provided in Appendix 1.

Table 18. 2015 Priority ranked fish barriers relative to their ranking in the current prioritisation.

Barrier Name	2015 Bar ID	2015 Rank	2021 Rank	2021 Bar ID
O'Connell River - Sand Dam (Tidal bund)	6367	1	Barrier Removed - 2016	
Flaggy Rock Creek - Weir - Cone Ramp	2769	2	2	160
Saltwater Creek - Vitanza Rd	3792	2	4	6951
Marion Creek - Private Causeway	3573	4	8	523
Sandy Creek - Palm Tree Rd	111	4	Barrier Remediated - 2020	
Constant Creek - Freds Weir	2630	4	25	5955
St Helens Creek - Russell Rd Crossing	2593	7	48	8628
Jolimont Creek - Mulherins Rd Crossing (Ellwoods Weir)	2614	7	6	9096
Black Rock Creek - Old Bowen Rd	2588	7	Barrier Remediated - 2016	
Constant Creek - 1938 Weir	2631	7	32	5956
Carmila Creek - Gauging Weir	3965	11	8	2736
Marion Creek - Marion Settlement - Notch Point Rd	3574	11	39	524
Tedlands Wetland - Tidal bund	3120	13	Barrier Remediated - 2015	
Cherry Tree Creek - East Inneston Rd	3174	13	32	1170
Marklands Wetland - Tidal Bund	3981	13	Barrier Remediated - 2015	
Goorganga Creek (Trib) - Private Causeway	327	13	140	9554
Mares Nest Creek - Station Rd	393	13	8	7541
Lethe Brook Creek - Private Causeway	3881	18	17	7335
Hay Gully - Tidal Bund	3331	18	32	6396
Reliance Creek - Neills Rd	2636	18	17	5444
Marklands Wetland - Tidal Bund	3988	18	Barrier Remediated - 2020	
Jolimont Creek - Narpi Rd	2616	18	25	9097
Andromache River - Gauging Weir	3999	24	2	6364
Carmila Creek - Jacksons Rd	2750	24	13	258
Bakers Creek - Weir	83	26	83	3512
Macquarie Creek - Weir	2610	26	17	9005
Tedlands Creek - Private Causeway	3127	26	70	1067
Thompson Creek - Bund	3928	26	65	9648
Macquarie Creek - McKays Rd	2575	26	25	9014
Proserpine River - WRC Causeway	3673	26	32	7179

Of the barriers ground truthed, many were private and public causeways. Most of these causeways utilised culverts which were insufficiently sized to provide adequate fish passage. Current Queensland legislation incorporates provisions which require the construction or upgrade of instream infrastructure to provide adequate fish passage. The implementation of these provisions was highlighted at several of the sites visited where causeways had been upgraded and included features that assist fish to pass the barrier. An example of these features can be found at Streeters Rd causeway on Carmila Creek (Figure 21). This causeway was identified as a priority barrier (ranked 33) in the 2015 prioritisation. Upgrade of the causeway was undertaken by the Local Government with the design incorporating several key features. These included wide aperture culverts which extend across most of the channel, the lowering of the culvert floor to allow the accumulation of natural bed material, and the installation of roughening elements on the outer culvert walls to reduce velocities during higher flow conditions. Similarly, the upgrade of another priority barrier from the 2015 prioritisation (Clews Rd on Murray Creek – ranked 37), incorporated other features to provide adequate passage at the site (Figure 22). At Clews Rd, the upgrade saw the construction of a wet causeway, which allow all flows to pass over the structure and removes the potential for a velocity barrier associated with water flowing through culverts. To ensure that the headloss across the causeway did not impede fish passage, a full width rock ramp was constructed on the downstream side. The rock ramp formed a series of small (100 mm) steps and deep (400 mm) pools which provided fish opportunities to rest as they move past the structure. Works such as these are a good demonstration of the adoption of fish passage requirements for instream infrastructure.

Figure 21. Streeters Rd causeway on Carmila Creek, prior to the upgrade (left) and after replacement with a fish friendly causeway (mid). Note the combine aperture of the culverts and floor depth. Vertical baffles were also installed on the outer cell walls to reduce velocity during higher flows (right).

Figure 22. Clews Rd causeway on Murray Creek, prior to the upgrade (left) and after the causeway was rebuilt following flood damage (mid). Note that all flows pass over the causeway and fish passage is provided by the full width rock ramp on the downstream side. During high flows the entire fishway is engaged and under low flow conditions the flow is concentrated to the central pool and ridge low flow channel (right).

While there were several examples of instream infrastructure being upgraded to accommodate fish passage, there were also some new/upgraded structures which had insufficient fish passage provisions. The majority of these were private causeways, however there were examples of public causeways which appeared to be recently upgraded without consideration for fish passage (Figure 23). This suggests that there is still a lack of knowledge regarding the fish passage responsibilities that asset owners have when dealing with instream infrastructure.

Figure 23. Recently constructed/upgraded causeways which do not meet current statutory requirements for fish passage in Queensland waterways.

The use of wetland area complemented stream order as a proxy for available habitat. Sites which ranked high overall tended to have a large wetland area in conjunction with a higher ordered stream draining through the wetland. Remediation work at such locations has an added benefit of increasing connectivity to both the wetland and additional habitat upstream of the wetland.

The WOFS provided an objective measure of water permanence within the wetlands. This is an important characteristic when considering increasing connectivity to wetlands, as refuge through prolonged dry periods is critical for the survival of fish. While the WOFS dataset was useful and provided the best representation of refuge potential, there were some limitations to its use. As the data reports the proportion of water signatures from a time series of images, there is potential for water permanence to be underestimated if the water body has not been in place for the entire length of the time series. In the current prioritisation, it was evident that several wetlands were underrepresented for water permanence (Figure 24). Review of historical imagery identified these sites to be recently constructed, typically within the last 10 years.

Elevation data was incorporated into the wetland prioritisation to complement the distance to estuary as a proxy for relative catchment position. Barriers on wetlands closer to the coast are considered more impactful to diadromous species which require access to undertake lifecycle dependent migrations. Elevation provided a useful tool to prioritise wetland barriers. With the increased coverage of high resolution DEMs, consideration should be given to incorporating this criterion into future stream barrier prioritisations as well.

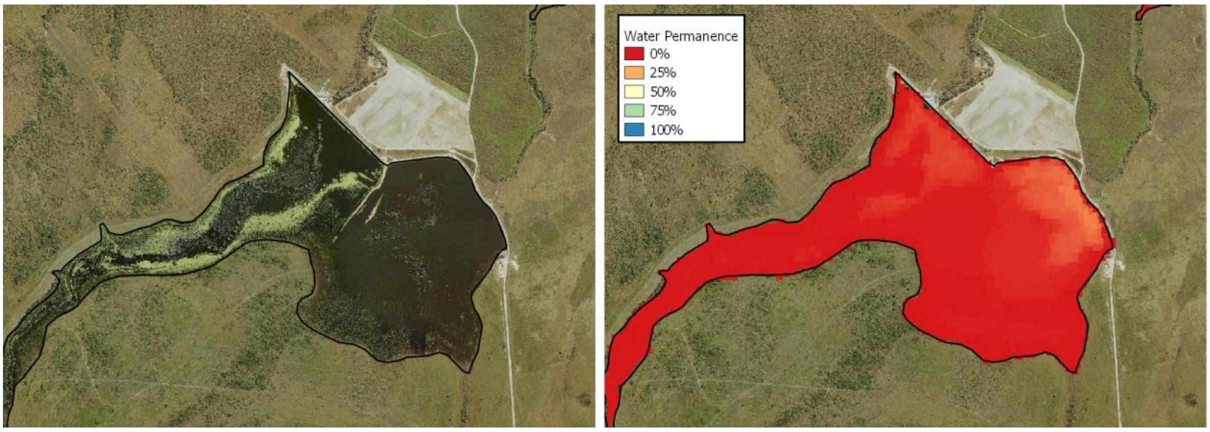

Figure 24. WOFS returning a low water permanence signature despite the substantial amount of deep water in this irrigation dam. Review of historic images revealed this dam was constructed in 2016, a relatively short period compared to the 36 years of imagery used for the time series.

Approaches to Fish Barrier Remediation

There are several approaches which can be adopted when undertaking remediation works. This prioritisation ranks sites based on environmental benefit of remediating a barrier in isolation. That is, if a group can only undertake works at one site, which site would deliver the best outcomes for the funds available. An alternative approach may be to remediate a series of barriers within a single catchment, which may be favoured for local catchment groups. The ranks reported in this prioritisation do not consider the cumulative benefits of remediating barriers in series. Should this approach be adopted, it is recommended that the highest-ranking barrier within the catchment be remediated first if funds permit.

In general, the removal of a barrier which impedes fish passage should be considered the preferred option for remediation. There are instances however, where the barrier is providing some benefit to fish communities and consideration should be given to choosing an appropriate remediation option which maintains that benefit. For example, ponded pastures are created when earth bunds are constructed on coastal plains. While modified, the wetlands which are created can provide valuable fish habitat and contribute to overall productivity. Removing the bund may improve connectivity at the cost of upstream fish habitat. An alternative approach may be to retrofit a fishway to the bund to improve connectivity while maintaining upstream fish habitat (Figure 25). Where the removal of a bund is to reinstate tidal waters to assist with the control of invasive weeds (e.g., hymenachne), then consideration may be given to lowering the bund to a level which allows tidal exchange but maintains some depth for fish refuge.

In most instances, the structures which form fish barriers are considered critical infrastructure and removal is not supported. Under these circumstances the retrofit of a fishway is considered the most appropriate remediation action. Careful consideration needs to be given to the type of fishway used and fish passage specialists should be consulted to provide guidance.

In Queensland the retrofit of fishways to existing fish barriers is itself considered waterway barrier works and generally requires State approval. This process can be lengthy and adds to the costs of remediation works. Such cost should be factored into works budgets or funding applications. Once a site is identified for remediation it is recommended that pre-lodgement advice is sought from the State Assessment and Referral Agency, the coordinating department for State development permits.

Figure 25. A rock ramp fishway constructed to remediate a road causeway (water surface drop) on Tedlands wetlands in Koumala, central QLD (left). Young of the year barramundi recruits captured successfully ascending the fishway during post-const construction monitoring (top right). This is the typical size of juvenile barramundi undertaking life-cycle dependant migrations from saltwater to freshwater. Thousands of juvenile empire gudgeon (and a few barramundi) recorded in a single trap set successfully ascending the fishway (bottom right). These empire gudgeon and barramundi were migrating from saltwater to freshwater.

Conclusion

The Mackay Whitsunday region is comprised of diverse aquatic habitats with numerous natural and anthropogenic factors impacting fish passage. High priority fish barriers were identified across a range of unique ecosystem contexts. These included moderate sized rivers and creeks originating in the coastal ranges, to numerous small creeks and drainage features emanating from the floodplains. Many of the smaller watercourses were associated with coastal wetlands.

The current prioritisation represents the first in-depth assessment of wetland fish barriers in the Mackay Whitsunday region. Sub-setting the wetland barriers was necessary as these habitats contain distinct characteristics which are not captured by the traditional stream barrier prioritisation GIS assessment. This is highlighted in Appendix 2 where the stream barrier ranking for the top 30 wetland barriers is typically much lower.

Given the historical modifications and associated impacts to waterways and fish passage within the Mackay Whitsunday region, a concerted and long-term strategy for habitat and barrier remediation is required to return fish stocks to healthy, resilient levels. This long-term strategy should also include educational aspects for landholders and asset managers (e.g., water boards, Local Government infrastructure departments). Education should focus on the impacts caused by fish barriers, and the statutory requirements for fish passage provisions during the construction or upgrade of instream infrastructure. Subsequent fish passage barrier prioritisation studies are necessary to track and evaluate changes in regional and local fish passage conditions.

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Appendix 1. Top 31 Stream Fish Barriers

Note: Fish barrier remediation costs are preliminary estimates only and are based upon similar fish passage projects undertaken by the authors. Costs may vary depending on remediation option, site constraints, development approvals, and engineering requirements.

Overall Priority	Rank 1 - 2021	Not assessed - 2015
Barrier ID	6367	
Stream Name	O'Connell River	
Location	663769.0217 E	7715398.408 N
Barrier Type	Causeway	
Barrier Name	Staffords Rd	
Remediaiton Aproach	Culverts/ FFSP	
Approx. Cost	$150-500k	

Overall Priority	Rank 2 - 2021	Rank 2 - 2015
Barrier ID	160	
Stream Name	Flaggy Rock Creek	
Location	754479.8796 E	7569970.701 N
Barrier Type	Weir	
Barrier Name	Flaggy Rock Weir	
Remediaiton Aproach	Extension of existing fishway	
Approx. Cost	$75-100k	

Overall Priority	Rank 2 - 2021	Rank 25 - 2015
Barrier ID	6364	
Stream Name	Andromache River	
Location	653243.3905 E	7724381.201 N
Barrier Type	Weir	
Barrier Name	Andromache Gauging Weir	
Remediaiton Aproach	Removal/rock ramp	
Approx. Cost	$250-750k	

Overall Priority	Rank 4 - 2021	Rank 3 - 2015
Barrier ID	6951	
Stream Name	Saltwater Creek	
Location	677190.6561 E	7742233.771 N
Barrier Type	Causeway	
Barrier Name	Vitanza Rd	
Remediaiton Aproach	FFSP/Culverts	
Approx. Cost	$60-80k (FFSP) 750k (Culverts)	

Overall Priority	Rank 4 2021	Not assessed - 2015
Barrier ID	9384	
Stream Name	Marklands Wetlands	
Location	733655.553 E	7618610.32 N
Barrier Type	Floodgates	
Barrier Name	marklands floodgates	
Remediaiton Aproach	Rock ramp bypass	
Approx. Cost	$60-80k	

Overall Priority	Rank 6 - 2021	Not assessed - 2015
Barrier ID	3696	
Stream Name	Pioneer River	
Location	715596.2 E	7660690.888 N
Barrier Type	Weir	
Barrier Name	Dumbelton Weir	
Remediaiton Aproach	Annual maintenance/Additional fishway	
Approx. Cost	$5-10k/yr (maint.) $2-5M (fishway)	

Overall Priority	Rank 6 - 2021	Rank 7 - 2015
Barrier ID	9096	
Stream Name	Jolimont Creek	
Location	695331.8752 E	7679103.951 N
Barrier Type	Weir/causeway	
Barrier Name	Ellwoods (Jolimont) Weir	
Remediaiton Aproach	Rock ramp & Culverts	
Approx. Cost	$500k	

Overall Priority	Rank 8 - 2021	Not assessed - 2015
Barrier ID	446	
Stream Name	West Hill Creek	
Location	746729.4327 E	7586680.122 N
Barrier Type	Causeway	
Barrier Name	Private Causeway	
Remediaiton Aproach	Bed level/culverts	
Approx. Cost	$100-150k	

Overall Priority	Rank 8 - 2021	Rank 4 - 2015
Barrier ID	523	
Stream Name	Marion Creek	
Location	748457.2963 E	7597161.294 N
Barrier Type	Causeway	
Barrier Name	Private Causeway	
Remediaiton Aproach	Culverts	
Approx. Cost	$150-200k	

Overall Priority	Rank 8 - 2021	Not assessed - 2015
Barrier ID	2583	
Stream Name	Frenchmans Creek	
Location	715576.3249 E	7644417.06 N
Barrier Type	Causeway	
Barrier Name	Private Causeway	
Remediaiton Aproach	Culverts	
Approx. Cost	$150-200k	

Overall Priority	Rank 8 - 2021	Rank 11 -2015
Barrier ID	2736	
Stream Name	Carmila Creek	
Location	747950.3179 E	7574969.797 N
Barrier Type	Weir	
Barrier Name	Carmila Gauging Weir	
Remediaiton Aproach	Removal/rock ramp	
Approx. Cost	$100-150k	

Overall Priority	Rank 8 - 2021	Rank 13 - 2015
Barrier ID	7541	
Stream Name	Mares Nest Creek	
Location	650093.4649 E	7723403.278 N
Barrier Type	Causeway	
Barrier Name	Station Rd	
Remediaiton Aproach	Culverts	
Approx. Cost	$500-750k	

Overall Priority	Rank 13 - 2021	Rank 25 - 2015
Barrier ID	258	
Stream Name	Carmila Creek	
Location	744871.932 E	7573503.629 N
Barrier Type	Causeway	
Barrier Name	Jacksons Crossing Rd	
Remediaiton Aproach	Bed level/culverts	
Approx. Cost	$100-300k	

Overall Priority	Rank 13 - 2021	Rank 34 - 2015
Barrier ID	1526	
Stream Name	Plane Creek	
Location	732658.5614 E	7629832.039 N
Barrier Type	Causeway	
Barrier Name	Brooks Rd	
Remediaiton Aproach	Culverts/bridge	
Approx. Cost	$1.2-2M	

Overall Priority	Rank 13 - 2021	Rank 43 - 2015
Barrier ID	6439	
Stream Name	Duck Creek	
Location	630827.8328 E	7774513.098 N
Barrier Type	Causeway	
Barrier Name	Mookara Rd	
Remediaiton Aproach	Culverts	
Approx. Cost	$500-750k	

Overall Priority	Rank 17 - 2021	Rak 32 - 2015
Barrier ID	2735	
Stream Name	Sandy Creek	
Location	709803.9551 E	7645044.105 N
Barrier Type	Weir	
Barrier Name	Sandy Gauging Weir	
Remediaiton Aproach	Removal/rock ramp	
Approx. Cost	$250-750k	

Overall Priority	Rank 17 - 2021	Rank 91 - 2015
Barrier ID	4655	
Stream Name	McGregor Ck	
Location	692447.9977 E	7662677.07 N
Barrier Type	Weir	
Barrier Name	McGregor Creek Weir	
Remediaiton Aproach	Rock ramp	
Approx. Cost	$500-750k	

Overall Priority	Rank 17 - 2021	Rank 18 - 2015
Barrier ID	5444	
Stream Name	Reliance Creek	
Location	718594.1457 E	7671253.093 N
Barrier Type	Causeway	
Barrier Name	Neils Rd	
Remediaiton Aproach	Baffles	
Approx. Cost	$5-10k	

Overall Priority	Rank 17 - 2021	Not assessed - 2015
Barrier ID	6365	
Stream Name	Proserpine River	
Location	666188.9929 E	7745457.937 N
Barrier Type	Causeway	
Barrier Name	Biggs Rd	
Remediaiton Aproach	Refurbish existing fishway	
Approx. Cost	$200-250k	

Overall Priority	Rank 17 - 2021	Rank 61 - 2015
Barrier ID	6952	
Stream Name	Saltwater Creek	
Location	746729.4327 E	7742857.371 N
Barrier Type	Causeway	
Barrier Name	Ceda Creek Falls Rd	
Remediaiton Aproach	Culverts	
Approx. Cost	$300-500k	

Overall Priority	Rank 17 - 2021	Not assessed - 2015
Barrier ID	8062	
Stream Name	Gibson Creek	
Location	667207.6688 E	7719426.831 N
Barrier Type	Weir/causeway	
Barrier Name	Gibson Ck Weir	
Remediaiton Aproach	Rock ramp	
Approx. Cost	$100-150k	

Overall Priority	Rank 17 - 2021	Rank 18 - 2015
Barrier ID	7335	
Stream Name	Lethebrook Creek	
Location	663754.2173 E	7739271.302 N
Barrier Type	Causeway	
Barrier Name	Private Causeway	
Remediaiton Aproach	Culverts	
Approx. Cost	$200-300k	

Overall Priority	Rank 17 - 2021	Rank 26 - 2015
Barrier ID	9005	
Stream Name	Maquarie Creek	
Location	692599.5223 E	7676323.486 N
Barrier Type	Weir	
Barrier Name	Maquarie Ck Weir	
Remediaiton Aproach	Rock ramp	
Approx. Cost	$300-500k	

Overall Priority	**Rank 25 - 2021**	**Not assessed - 2015**
Barrier ID	1446	
Stream Name	Elizabeth Creek	
Location	733129.8635 E	7626000.588 N
Barrier Type	Causeway	
Barrier Name	Private Causeway	
Remediaiton Aproach	Bed level/culverts	
Approx. Cost	$100-300k	

Overall Priority	**Rank 25 - 2021**	**Not assessed - 2015**
Barrier ID	1544	
Stream Name	Plane Creek	
Location	730428.0783 E	7629200.652 N
Barrier Type	Weir	
Barrier Name	Plane Ck Lower Weir	
Remediaiton Aproach	Rock ramp	
Approx. Cost	$400-600k	

Overall Priority	**Rank 25 - 2021**	**Rank 4 - 2015**
Barrier ID	5955	
Stream Name	Constant Creek	
Location	706598.2199 E	7671337.48 N
Barrier Type	Weir/causeway	
Barrier Name	Freds Weir	
Remediaiton Aproach	Rockramp/culverts	
Approx. Cost	$300-500k	

Overall Priority	**Rank 25 - 2021**	**Not assessed - 2015**
Barrier ID	6366	
Stream Name	Gregory River	
Location	664813.7315 E	7757042.761 N
Barrier Type	Causeway	
Barrier Name	Patullo Rd	
Remediaiton Aproach	Refurbish existing fishway	
Approx. Cost	$80-120k	

Overall Priority	**Rank 25 - 2021**	**Not assessed - 2015**
Barrier ID	6369	
Stream Name	O'Connell River	
Location	666561.13 E	7706059.892 N
Barrier Type	Causeway	
Barrier Name	Ellis Rd	
Remediaiton Aproach	Rock ramp/Culverts	
Approx. Cost	$150 (fishway) $750k (Culverts)	

Overall Priority	**Rank 25 - 2021**	**Rank 26 - 2015**
Barrier ID	9014	
Stream Name	Maquarie Creek	
Location	690873.3261 E	7674700.027 N
Barrier Type	Causeway	
Barrier Name	McKay Rd	
Remediaiton Aproach	Culverts	
Approx. Cost	$500-750k	

Overall Priority	**Rank 25 - 2021**	**Rank 18 - 2015**
Barrier ID	9097	
Stream Name	Jolimont Creek	
Location	696277.3675 E	7677720.959 N
Barrier Type	Causeway	
Barrier Name	Narpie Rd	
Remediaiton Aproach	Baffles & FFSP	
Approx. Cost	$5-100k	

Appendix 2. Top 33 Wetland Fish Barriers

Note: Fish barrier remediation costs are preliminary estimates only and are based upon similar fish passage projects undertaken by the authors. Costs may vary depending on remediation option, site constraints, development approvals, and engineering requirements.

Wetland Barrier Rank	**1**	
Stream Barrier Rank	4	
Barrier ID	9384	
Stream Name	Marklands Wetlands	
Location	733655.553 E	7618610.32 N
Barrier Type	Floodgates	
Barrier Name	Marklands Floodgates	
Remediaiton Aproach	Rock ramp bypass	
Approx. Cost	$60-80k	

Wetland Barrier Rank	**2**	
Stream Barrier Rank	65	
Barrier ID	9648	
Stream Name	Thompson Creek	
Location	667470.6949 E	7730729.102 N
Barrier Type	Dam	
Barrier Name	Upstream Wetland	
Remediaiton Aproach	Rock ramp spillway	
Approx. Cost	$100-200k	

Wetland Barrier Rank	**3**	
Stream Barrier Rank	65	
Barrier ID	9756	
Stream Name	Laguna Quays	
Location	675427.1226 E	7720459.689 N
Barrier Type	Floodgates	
Barrier Name	MarklandsFfloodgates	
Remediaiton Aproach	Remove floodgates	
Approx. Cost	$20-40k	

Wetland Barrier Rank	**4**	
Stream Barrier Rank	77	
Barrier ID	7187	
Stream Name	Proserpine River	
Location	644343.9609 E	7747129.804 N
Barrier Type	Dam	
Barrier Name	Peter Faust Dam	
Remediaiton Aproach	Fishlift	
Approx. Cost	10M+	

Wetland Barrier Rank	**5**	
Stream Barrier Rank	59	
Barrier ID	3800	
Stream Name	Teemburra Creek	
Location	672721.2672 E	7652720.318 N
Barrier Type	Dam	
Barrier Name	Teemburra Dam	
Remediaiton Aproach	Fishlift	
Approx. Cost	10M+	

Wetland Barrier Rank	**6**	
Stream Barrier Rank	100	
Barrier ID	9389	
Stream Name	Elizabeth Creek	
Location	733307.4418 E	7625307.371 N
Barrier Type	Bund	
Barrier Name	Shmidtkes Wetland	
Remediaiton Aproach	Rock ramp bypass	
Approx. Cost	$100-150k	

Wetland Barrier Rank	**7**	
Stream Barrier Rank	90	
Barrier ID	9376	
Stream Name	Rocky Dam Creek Trib	
Location	735406.2105 E	7614482.961 N
Barrier Type	Bund	
Barrier Name	Doownstream Dam	
Remediaiton Aproach	Rock ramp bypass	
Approx. Cost	$100-200k	

Wetland Barrier Rank	**7**	
Stream Barrier Rank	90	
Barrier ID	9583	
Stream Name	Billie Creek	
Location	669568.9811 E	7728970.088 N
Barrier Type	Bund	
Barrier Name	Downstream Bund	
Remediaiton Aproach	Rock ramp bypass	
Approx. Cost	$60-80k	

Wetland Barrier Rank	**7**	
Stream Barrier Rank	100	
Barrier ID	9689	
Stream Name	Constant Creek Trib	
Location	707500.8224 E	7677634.672 N
Barrier Type	Bund	
Barrier Name	Pitkin Bunds	
Remediaiton Aproach	Rock ramp bypass	
Approx. Cost	$60-80k	

Wetland Barrier Rank	**7**	
Stream Barrier Rank	90	
Barrier ID	191	
Stream Name	Flaggy Rock Creek Trib	
Location	754248.9845 E	7570100.382 N
Barrier Type	Dam	
Barrier Name	Private Dam	
Remediaiton Aproach	Rock ramp bypass	
Approx. Cost	$100-200k	

Wetland Barrier Rank	**11**	
Stream Barrier Rank	77	
Barrier ID	9581	
Stream Name	Billie Creek	
Location	667384.1176 E	7729772.193 N
Barrier Type	Causeway	
Barrier Name	Private Causeway	
Remediaiton Aproach	Bed level/culverts	
Approx. Cost	$60-100k	

Wetland Barrier Rank	**11**	
Stream Barrier Rank	90	
Barrier ID	9692	
Stream Name	Laguna Quays	
Location	674608.5829 E	7720870.258 N
Barrier Type	Bund	
Barrier Name	Middle Wetland	
Remediaiton Aproach	Rock ramp bypass	
Approx. Cost	$60-100k	

Wetland Barrier Rank	**11**	
Stream Barrier Rank	109	
Barrier ID	344	
Stream Name	Blind Creek	
Location	753416.3108 E	7578580.28 N
Barrier Type	Floodgates	
Barrier Name	Private floodgates	
Remediaiton Aproach	Rock ramp bypass	
Approx. Cost	$60-80k	

Wetland Barrier Rank	**14**	
Stream Barrier Rank	100	
Barrier ID	9697	
Stream Name	Dolphin Heads	
Location	726926.4985 E	7672147.042 N
Barrier Type	Bund	
Barrier Name	Dolphin Heads Lagoon	
Remediaiton Aproach	Rock ramp bypass	
Approx. Cost	$80-150k	

Wetland Barrier Rank	**14**	
Stream Barrier Rank	104	
Barrier ID	9584	
Stream Name	Billie Creek	
Location	668455.0277 E	7728426.129 N
Barrier Type	Dam	
Barrier Name	Private Dam	
Remediaiton Aproach	Rock ramp bypass	
Approx. Cost	$100-200k	

Wetland Barrier Rank	**16**	
Stream Barrier Rank	90	
Barrier ID	9647	
Stream Name	Thompson Creek	
Location	667541.7479 E	7730886.539 N
Barrier Type	Causeway	
Barrier Name	Private Causeway	
Remediaiton Aproach	Bed level/culverts	
Approx. Cost	$60-100k	

Wetland Barrier Rank	**16**	
Stream Barrier Rank	109	
Barrier ID	3077	
Stream Name	Sandy Creek	
Location	697239.2442 E	7653650.455 N
Barrier Type	Dam	
Barrier Name	Kinchant Dam	
Remediaiton Aproach	Fishlift	
Approx. Cost	$5M+	

Wetland Barrier Rank	**18**	
Stream Barrier Rank	48	
Barrier ID	9509	
Stream Name	Ten Mile Creek	
Location	653191.9202 E	7758517.471 N
Barrier Type	Dam	
Barrier Name	Private Dam	
Remediaiton Aproach	Rock ramp bypass	
Approx. Cost	$500-700k	

Wetland Barrier Rank	18	
Stream Barrier Rank	109	
Barrier ID	9369	
Stream Name	Loyds Wetland	
Location	744716.2521 E	7614806.031 N
Barrier Type	Bund	
Barrier Name	Loyds Wetland	
Remediaiton Aproach	Rock ramp bypass	
Approx. Cost	$60-80k	

Wetland Barrier Rank	20	
Stream Barrier Rank	120	
Barrier ID	9622	
Stream Name	Murray Creek Trib	
Location	689815.2133 E	7691170.417 N
Barrier Type	Bund	
Barrier Name	Private Bund	
Remediaiton Aproach	Rock ramp bypass	
Approx. Cost	$80-100k	

Wetland Barrier Rank	21	
Stream Barrier Rank	86	
Barrier ID	9600	
Stream Name	Laguna Quays	
Location	674158.3037 E	7721191.858 N
Barrier Type	Bund	
Barrier Name	North Wetland	
Remediaiton Aproach	Rock ramp bypass	
Approx. Cost	$60-80k	

Wetland Barrier Rank	**22**
Stream Barrier Rank	86
Barrier ID	6464
Stream Name	Walkabout Wetlands
Location	728238.3966 E / 7666442.621 N
Barrier Type	Causeway
Barrier Name	Walkabout Wetlands
Remediaiton Aproach	Pedestrian Bridge
Approx. Cost	$40-60k

Wetland Barrier Rank	**22**
Stream Barrier Rank	109
Barrier ID	9402
Stream Name	Louisa Creek Trib
Location	733977.6855 E / 7646158.644 N
Barrier Type	Bund
Barrier Name	Dudgeon Point Eastern Wetland
Remediaiton Aproach	Rock ramp bypass
Approx. Cost	$80-150k

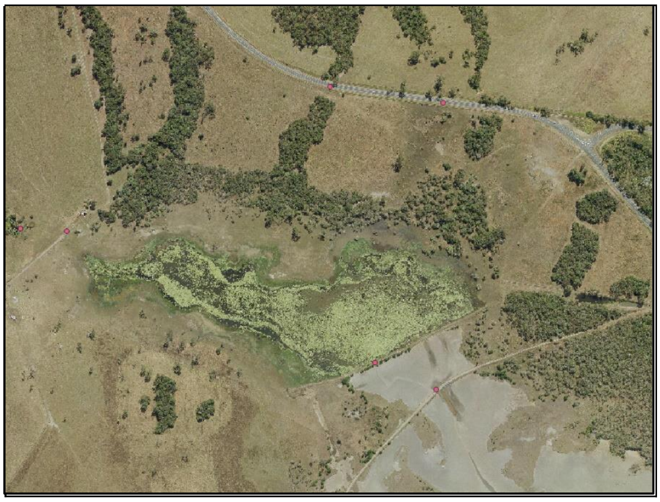
Wetland Barrier Rank	**24**
Stream Barrier Rank	109
Barrier ID	9404
Stream Name	Sandy Creek Trib
Location	731441.0999 E / 7646129.143 N
Barrier Type	Bund
Barrier Name	Dudgeon Point Western Wetland
Remediaiton Aproach	Rock ramp bypass
Approx. Cost	$80-150k

Wetland Barrier Rank	**24**	
Stream Barrier Rank	133	
Barrier ID	6273	
Stream Name	Constant Creek Trib	
Location	707149.5264 E	7680154.522 N
Barrier Type	Dam	
Barrier Name	Private Dam	
Remediaiton Aproach	Rock ramp bypass	
Approx. Cost	$100-200k	

Wetland Barrier Rank	**26**	
Stream Barrier Rank	70	
Barrier ID	1064	
Stream Name	Tedlands Wetlands	
Location	738939.897 E	7610893.096 N
Barrier Type	Causeway	
Barrier Name	Private causeway	
Remediaiton Aproach	Culverts	
Approx. Cost	$50-80k	

Wetland Barrier Rank	**26**	
Stream Barrier Rank	90	
Barrier ID	9476	
Stream Name	McCreadys Creek	
Location	724952.3474 E	7666498.388 N
Barrier Type	Causeway	
Barrier Name	Golflinks Rd	
Remediaiton Aproach	Culverts	
Approx. Cost	$1-2M	

Wetland Barrier Rank	**26**	
Stream Barrier Rank	109	
Barrier ID	9391	
Stream Name	Oonooie Wetlands	
Location	735421.6044 E	7626472.715 N
Barrier Type	Bund	
Barrier Name	Private bund	
Remediaiton Aproach	Refurbish existing fishway	
Approx. Cost	$60-80k	



Wetland Barrier Rank	**26**	
Stream Barrier Rank	120	
Barrier ID	9419	
Stream Name	Bradfords (Macs) Wetland	
Location	725459.8424 E	7643512.242 N
Barrier Type	Bund	
Barrier Name	Macks Truck Stop	
Remediaiton Aproach	Rock ramp bypass	
Approx. Cost	$60-80k	

Wetland Barrier Rank	**26**	
Stream Barrier Rank	133	
Barrier ID	9377	
Stream Name	Rocky Dam Trib	
Location	735127.3296 E	7614322.167 N
Barrier Type	Bund	
Barrier Name	Upstream Wetland	
Remediaiton Aproach	Rock ramp bypass	
Approx. Cost	$80-100k	

Appendix 3. Verified barriers

Barrier ID	Barrier Name	Rank Stream	Rank Wetland	Easting	Northing
6367	O'Connell R - Staffords Rd	1		663769.022	7715398.41
160	Flaggy Rock Ck - Weir - Cone Ramp	2		754479.88	7569970.7
6364	Andromache R - Gauging Weir	2		653243.391	7724381.2
6951	Saltwater Ck - Vitanza Rd	4		677190.656	7742233.77
9384	Boundary Ck - Marklands Wetland	4	1	733655.553	7618610.32
3696	Pioneer R - Dumbelton Weir	6		715596.2	7660690.89
9096	Jolimont Ck - Ellwood Weir (Jolimont Weir)	6		695331.875	7679103.95
446	West Hill Ck - Private Causeway	8		746729.433	7586680.12
523	Marion Ck - Private Causeway	8		748457.296	7597161.29
2583	Frenchmans Ck - Private Causeway	8		715576.325	7644417.06
2736	Carmilla Ck - Gauging Weir	8		747950.318	7574969.8
7541	Mares Nest Ck - Station Rd	8		650093.465	7723403.28
258	Carmila Ck - Jacksons Crossing Rd	13		744871.932	7573503.63
1526	Plane Ck - Brooks Rd Tidal Causeway	13		732658.561	7629832.04
6439	Duck Ck - Mookara Rd	13		630827.833	7774513.1
8392	Alligator Ck - Old Wintons Rd causeway	13		678032.461	7695593.16
2735	Sandy Ck Gauging Weir	17		709803.955	7645044.11
4655	McGregor Ck - Sunwater Weir	17		692447.998	7662677.07
5444	Reliance Ck - Neills Rd	17		718594.146	7671253.09
6365	Proserpine R - Biggs Rd - Old fishway	17		666188.993	7745457.94
6952	Saltwater Ck - Ceda Ck Falls Rd	17		677729.135	7742857.37
7335	Lethebrooke Ck - Private causeway	17		663754.217	7739271.3
8062	Gibson Ck - Wilmar Weir/Causeway	17		667443.087	7718433.67
9005	Macquarie Ck - Large Weir	17		692599.522	7676323.49
1446	Elizabeth Ck - Private Rd	25		733129.864	7626000.59
1544	Plane Ck - Lower Weir	25		730428.078	7629200.65
5955	Constant Ck - Freds Weir	25		706598.22	7671337.48
6366	Gregory R - Patullo Rd - Old Fishway	25		664813.732	7757042.76
6369	O'Connell R - Ellis Rd	25		666561.13	7706059.89
9014	Macquarie Ck - Mckay Rd	25		690873.326	7674700.03
9097	Jolimont Ck - Narpi Rd	25		696277.368	7677720.96
702	Green Swamp Ck - Riley Rd	32		743052.75	7602454.49
1170	Cherry Tree Ck - East Inneston Rd	32		733630.071	7614708.65
3712	Pioneer R - Marian Weir	32		701056.9	7661086.1
5956	Constant Ck - 1938 Weir	32		706069.76	7671326.24
6396	Hay Gully - US of Bruce Hwy	32		630460.098	7777702.08
7179	Proserpine R - Sewage Treatment Weir	32		651149.229	7748762.57
8063	Gibson Ck - Private Causeway	32		667207.669	7719426.83

Barrier ID	Barrier Name	Rank Stream	Rank Wetland	Easting	Northing
294	Carmila Ck - Majors Rd	39		742586.786	7574249.21
457	Hall Ck - Private Causeway	39		743222.697	7585253.17
524	Marion Ck - Marion Settlement Rd	39		747865.785	7598134.63
807	Rocky Dam Ck - Old Weir	39		738191.351	7602026.17
2761	Sandy Ck - Vellas Weir	39		705263.956	7646611.9
3396	McClennan Ck - Private Causeway	39		720083.953	7653293.41
3427	Rocky Ck - Abbots Rd	39		718662.781	7653445.03
3512	Bakers Ck - Historic weir - Pre 1960	39		717938.085	7655774.7
9099	Jolimont Ck - McClannen Weir	39		694568.929	7675816.14
161	Flaggy Rock Ck - Upper Flaggy Rock Rd	48		749859.788	7567594.79
213	Feather Ck - Private Rd	48		750921.643	7573667.61
2289	Bell Ck - Private Causeway	48		718786.24	7637126.64
2601	Rocky Ck - Cousens and Brands Rd	48		714877.471	7643562.99
6767	Gregory River - Collingvale Rd	48		658401.363	7755560.42
8066	Gibson Ck - Wilmar Causeway	48		667443.087	7718433.67
8350	Zamia Ck - Mentmore Rd	48		682128.895	7695023.31
8427	Alligator Ck - Tolcher Rd	48		673490.43	7695912.62
8628	St Helens Ck - Russels Crossing	48		681160.149	7686615.15
9509	Ten Mile Ck - Private Dam	48	18	653191.92	7758517.47
9901	Sandy Ck - Private Causeway	48		706135.454	7646420.18
303	Carmila Ck - Barbours Rd	59		740251	7575280.68
1549	Plane Ck - Pirie Rd	59		728924.164	7628774.33
3711	Pioneer R - Gauging Weir Marian	59		701463.516	7661071.28
3724	Pioneer R - Mirani Weir	59		689948.703	7657184.16
3800	Teemburra Ck - Teemburra Dam	59	5	672721.267	7652720.32
7172	Proserpine R - Spruce Rd	59		655930.962	7749973.73
1545	Plane Ck - Mill Weir	65		729503.817	7628664.92
1550	Plane Ck - Middle Weir	65		728757.753	7628194.8
9026	Macquarie Ck - Geeburg Buthara Rd	65		689783.017	7672357.85
9648	Thompson Ck - Upstream Wetland	65	2	667470.695	7730729.1
9756	Laguna Quays - South Tidal Wetland	65	3	675427.123	7720459.69
88	Turners hut Ck - Bruce Hwy	70		757998.727	7557271.19
144	Stockyard Ck - McLeods Rd	70		753975.094	7568392.83
1064	Tedlands Ck - Private Causeway	70	26	738939.897	7610893.1
1555	Plane Ck - Upper Council Weir	70		728182.565	7627420.97
2338	Alligator Ck - Private Causeway	70		721968.435	7634666.12
6370	O'Connell R - Cathu Rd	70		667893.861	7696217.66
6377	Adelaide Point - Private Causeway	70		631297.713	7779492.39

Barrier ID	Barrier Name	Rank Stream	Rank Wetland	Easting	Northing
78	Sand Fly Ck - Bruce Hwy	77		759637.252	7554951.56
631	Daintry Ck - Cape Palmerston Rd	77		751191.842	7605220.78
3723	Pioneer R - Gauging Weir Mirani	77		690078.917	7657265.04
4424	Finch Hatton Ck - Gauging Weir	77		669806.677	7664564.33
6018	Constant Ck - Low Causeway	77		704666.191	7670657.25
7187	Proserpine R - Peter Faust Dam	77	4	644343.961	7747129.8
9501	Duck Ck Trib - Wetland	77	31	630892.111	7774455.64
9581	Billie Ck - Private Causeway	77	11	667384.118	7729772.19
9755	Constant Ck Trib - Flood Gates	77		708550.42	7680585.84
6500	Barramundi Ck - Heronvale Rd	86		633590.277	7776460.42
6614	Kangaroo Ck - Private Causeway	86		640824.062	7768339.23
9464	McCreadys Ck - Walkabout Wetlands	86	22	728238.397	7666442.62
9600	Laguna Quays - North Wetland	86	21	674158.304	7721191.86
191	Flaggy Rock Ck - Private Dam	90	7	754248.985	7570100.38
3522	Bakers Ck - Anne St Causeway	90		714572.192	7658420.08
5283	Janes Ck - Hicks Rd	90		723955.496	7662342.4
8238	Stoney Ck - Lindeman Dr	90		671200.764	7712729.81
9370	Cape Palmerston Wetland	90	39	756736.664	7616319.14
9376	Rocky Dam Ck Trib - Downstream Dam	90	7	735406.211	7614482.96
9476	McCreadys Ck - Golflinks Rd	90	26	724952.347	7666498.39
9583	Billie Ck - Middle Wetland	90	7	669568.981	7728970.09
9647	Thompson Ck - Private Causeway	90	16	667541.748	7730886.54
9692	Laguna Quays - Middle Wetland	90	11	674608.583	7720870.26
1563	Plane Ck - Rifle Range Rd	100		727754.886	7626456.73
9389	Elizabeth Ck - Wetland	100	6	733307.442	7625307.37
9689	Constant Ck - Pitman Wetland	100	7	707500.822	7677634.67
9697	Dolphin Heads - Wetland	100	14	726926.499	7672147.04
658	Two Mile Ck - Riley Rd	104		744374.113	7608429.47
6060	Constant Ck - Edmonds Rd	104		701780.572	7670113.21
9392	Oonooie Station - Private Causeway	104		735548.445	7626416.38
9584	Billie Ck - Upstream Wetland	104	14	668455.028	7728426.13
9708	Bakers Ck - McEwans Beach Rd	104	37	727369.743	7649858.81
344	Blind Ck - Ponded Pasture	109	11	753416.311	7578580.28
3077	Sandy Ck - Kinchant Dam	109	16	697239.244	7653650.46
6272	Constant Ck Trib - Private Causeway	109		708216.96	7680581.58
6423	Mookarra Ck - Rail crossing	109		628743.638	7775356.46
9369	Rocky Dam Coastal - Lloyds Wetland	109	18	744716.252	7614806.03
9391	Oonooie Station Wetland	109	26	735421.604	7626472.72

Barrier ID	Barrier Name	Rank Stream	Rank Wetland	Easting	Northing
9402	Dudgeon Pt Wetland	109	22	733977.686	7646158.64
9404	Dudgeon Pt Wetland	109	24	731441.1	7646129.14
9429	Bakers Ck - South Wetland	109	47	726807.261	7649511.34
9456	Rocky Dam Ck - Neilsons Wetland	109	31	736201.079	7614591.12
9488	Reliance Ck - Thompsons Wetland	109	31	721433.515	7671139.56
1412	Boundary Ck Trib - Mervs Wetland	120	84	730805.306	7621902.36
8240	Stoney Ck - Whitsunday Dr	120		670170.612	7710937.08
8594	St Helens Ck Trib - Private Dam	120	40	687469.449	7693366.09
9413	Saltwater Ck - Gruffunder wetland	120	40	724645.015	7640878.52
9419	Sandringham Ck - Macs Truck Stop - Bradfords North Wetland	120	26	725459.842	7643512.24
9458	Vines Ck Trib - Big 4 Wetland	120		728432.117	7663756.86
9618	Home Ck - Downstream Wetland	120	45	688398.784	7692934.11
9622	Murray Ck - Coastal Wetland	120	20	689815.213	7691170.42
1692	Middle Ck Dam	128	37	718208.614	7624670.9
9415	Alligator Ck - Balbera Wetland	128	49	725749.744	7641927.5
9428	Bakers Ck - McEwans Wetland	128	49	728017.524	7649721.88
9619	Home Ck - Upstream Wetland	128	51	687948.938	7692857.94
9701	McCreadys Ck - Kerisdale Wetland	128	60	724830.024	7667238.93
259	MCafferty Ck - Carmila West Rd	133		744822.646	7573299.77
2272	Alligator Ck - Hacketts Rd	133		724370.837	7638746.42
3377	Sandy Ck - Drysdales Wetland	133	44	723057.379	7647163.52
6273	Constant Ck Trib - Farquar Wetland	133	24	707149.526	7680154.52
8165	Laguna Quays Trib	133	31	673755.12	7720035.76
9377	Rocky Dam Ck Trib - Upstream Dam	133	26	735127.33	7614322.17
9490	Reliance Ck - North Wetland	133	31	719102.36	7676032.78
9406	Alligator Ck - Wetlands	140	60	726245.182	7640632.67
9411	Alligator Ck Trib - Sheler wetland	140	31	724160.022	7638751.78
9554	Gorganga Ck Trib - private causeway	140		663857.757	7735001.75
6465	Duck Ck Trib - Roma Peak Rd	154		631332.949	7773478.1
9414	Saltwater Ck - Gruffunder wetland	154	73	724320.8	7640765.94
9597	O'Connell R Trib - Watts Wetland	154	47	667180.289	7724336.54
9698	Alligator Ck - Bradfords South Wetland	154	51	726935.583	7642386.89
9475	McCreadys Ck - Caledonian Dr	165	85	726221.634	7667133.35
3180	Draper Ck - De Moleyns Lagoon	204	144	697461.388	7657775.75
9418	Sandringham Ck - Bradfords Dam	284	85	676819.019	7699344.58

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