FISH AND FLOWS | AQUATIC HABITAT REHABILITATION

Mapping the Macintyre River – Macintyre-Dumaresq Confluence to Mungindi

Aquatic habitat mapping to inform water management

Report prepared for the Commonwealth Environmental Water Office (Project 3600003798)

Commonwealth Environmental Water Office

aquatic habitat rehabilitation

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Mapping the Macintyre River – Macintyre-Dumaresq confluence to Mungindi: Aquatic Habitat Mapping to Inform Water Management

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Cover image: Rock pool (indurated sediment), lined with melaleucas, on the Macintyre River 1.9 km upstream of the Macintyre-Weir River junction, in the Kanowna Management Reach, 5/5/2020. Flow rate was 113 ML/day.

More information

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Executive Summary

The purpose of this report is to identify the environmental flow requirements for native fish in the regulated Macintyre River for the Commonwealth Environmental Water Office (CEWO). Fish habitat was mapped along a 327 km stretch of river, from Toomelah Weir to Mungindi Weir. This included inundation heights for fish habitat features – such as large woody habitat (LWH), in channel benches and wetland entry/exit points. This information, in addition to existing information on flow requirements for native fish can be used to inform the protection of critical flows and/or releases of water held in storages for the environment. Hydrographs can be designed based on this information to inundate a quantified area or amount of habitat, providing measurable outcomes for supporting and increasing fish populations in the Macintyre River.

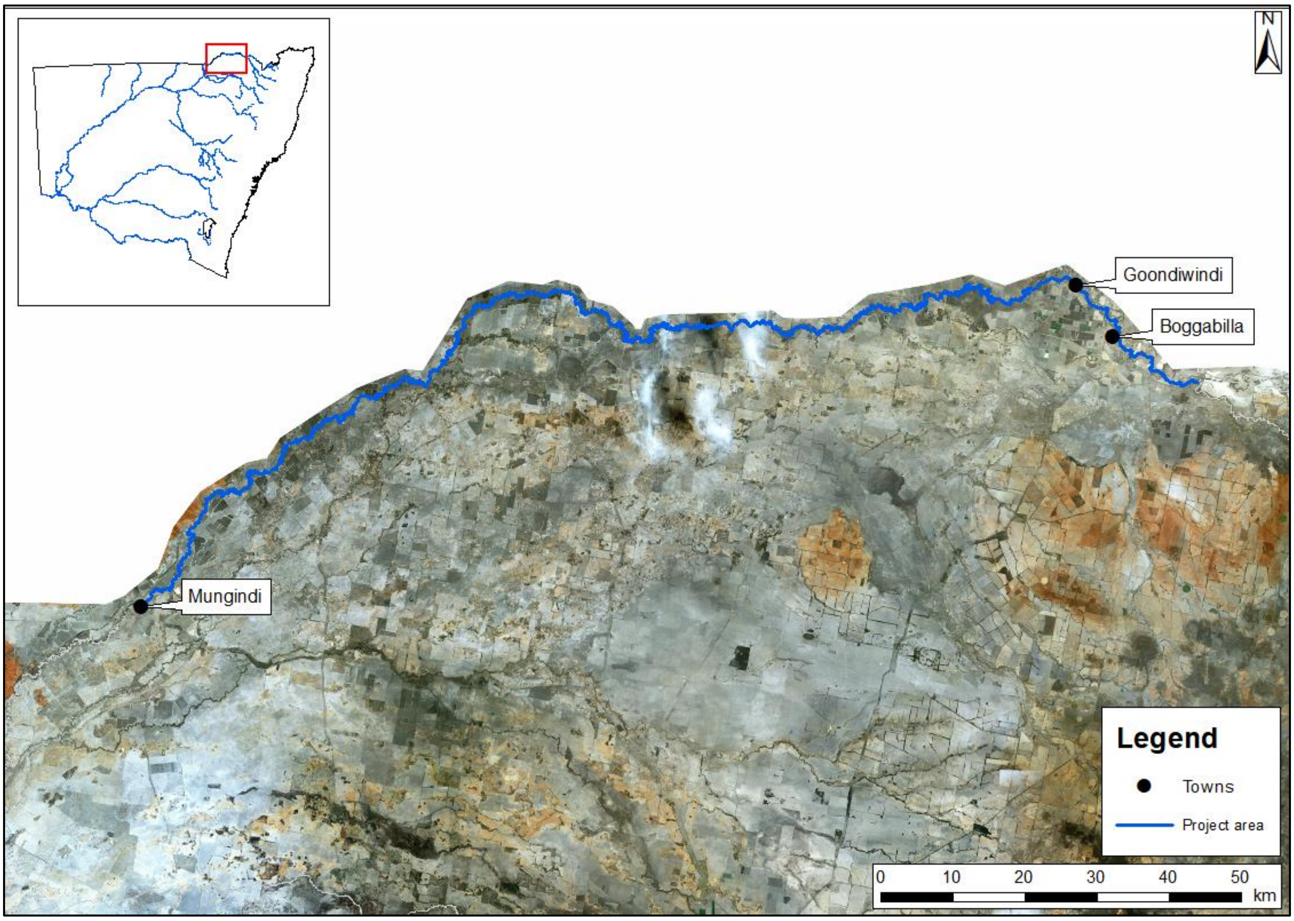

Figure 1. Project area location and extent

Native fish species of the Murray-Darling Basin have adapted to the highly variable conditions in its aquatic ecosystems. Many of the fish species native to the Basin have specific flow requirements adapted to these conditions. The evolutionary and biological rhythms of fish are often linked to flow so that opportunities for spawning, growth and dispersal are synchronised to maximise recruitment. With the development of the Basin's river systems and subsequent regulation, many of the natural flow regimes have been altered and fish communities have suffered significant declines.

Under the 2012 Murray-Darling Basin Plan, opportunities exist for fish communities to recover from impacts associated with river regulation. Flows can be developed, delivered or protected to enhance spawning, recruitment, and movement outcomes for native fish. Flows can also be used to increase productivity in the system to improve the condition of native fish and overall river health, as well as connectivity between aquatic habitats. Information in this report informs the CEWO of flow requirements for fish species in the Macintyre river.

The relationship between river height and habitat availability is an important part of flow needs for fish. Higher flows provide increased access to favourable breeding habitats and inundate benches and connected wetlands, increasing the availability of carbon in the system and driving productivity and increasing food availability. Increases in river height can also connect the river to other watercourses and wetlands (lateral connection), increasing fish distribution and improving genetic diversity. It can also increase system productivity and provide favourable conditions for spawning for some species including the iconic golden perch (*Macquaria ambigua*). The relationship between river flow height and habitat availability is therefore essential in determining the magnitude of flow needed to promote fish spawning and recruitment, or the addition of new individuals to the population of a species (Gaillard *et al*. 2008).

Native fish species of the Murray-Darling Basin have developed a range of spawning and recruitment behaviours, consequently, it is highly unlikely a single flow regime would provide equal benefits for the fish community of a system (Baumgartner *et al.* 2013a; NSW DPI, 2013a). The exact flow requirements to deliver healthy and robust native fish communities are unknown (Bunn and Arthington, 2002). What can be assumed is that native fish have adapted to cope and thrive with the high level of natural flow variability experienced in the project area and as such the system should be managed to maintain a level of variability.

To enhance native fish outcomes, fish species can be classified into functional groups based on flow related attributes (Baumgartner *et al.* 2013a). This has been recognised as a method for simplifying flow requirements for fish allowing more effective management of environmental flow delivery and/or flow protection from extraction (Baumgartner *et al.* 2013a; Mallen-Cooper and Zampatti, 2015).

During the Northern Basin Fish and Flows project, NSW Department of Primary Industries (DPI) - Fisheries developed four functional groups of native fish (including two sub groups) combining elements of the reproductive spawning-movement and eco-hydraulic guilds (Mallen-Cooper and Zampatti, 2015; NSW DPI, 2015; Ellis *et al*. 2016). The functional groups identified for species in the Macintyre River were adapted from the Northern Basin Fish and Flows report with consideration of more recent work for defining stable low-flow spawning fish (Kerr *et al.*, 2017). Functional groups were established in consultation with experts to assist in the development of specific long-term environmental watering requirements and flow related management actions (NSW DPI, 2015). The elements considered in development of these groups in the Northern Basin Fish and Flows project (NSW DPI, 2015) included:

1. Cues for migration (dispersal and recolonization) and spawning (temperature and/or flow).
2. Spatial scales of spawning and dispersal movements (10’s – 100’s of m; 100’s of m – 10’s of km; 10’s – 100’s of km).
3. Reproductive mode and fecundity (e.g. broadcast spawning, nesting species, adhesive eggs).
4. Spawning habitats in still/slow-flowing water or in fast-flowing habitats.
5. Egg hatch time (short 1 – 3 days; medium 3 – 10 days; long > 10 days) and egg morphology.

6. Scale of larval drift and recruitment.

Four groups, plus two subgroups were developed. These were as follows:
Group 1: Flow-dependent specialists
Group 2: In channel specialists
  Group 2A: Flow-dependent
  Group 2B: Flow-independent
Group 3: Floodplain specialists
Group 4: Generalists

These functional groups were used to identify critical flow requirements which was coupled with the detailed habitat inundation information to be used to develop environmental water requirements (EWRs) for fish in the Macintyre River.

In the habitat mapping undertaken on the Macintyre River between the Macintyre-Dumaresq confluence and Mungindi Weir, commence to inundate heights were recorded and analysed for LWH, in channel benches, rootballs and entry points to connected wetlands. This information indicates the flows (megalitres (ML)/day) required to inundate these features. The project area was separated into five Management Reaches based on the nearest WaterNSW river gauge and patterns in the river channel. The Management Reaches used for this project are outlined in Table 1.

Table 1: Key habitat features within each Management Reach for the Macintyre river project area

Management Reach	Reference gauge	Reach length (km)	LWH	Rootballs	Benches	Connected wetland entry points	Refuge pools
Boggabilla	416002	35.5	707	94	167	31	3
Terrewah	416047	88.7	5505	456	1272	180	5
Boomi	416043	91.0	5347	356	498	231	17
Kanowna	416048	81.9	5124	654	423	220	2
Mungindi	416001	29.8	1154	107	397	95	12

Recommendations and future directions

Flows for native fish

The analysis conducted on the Macintyre River as part of the *Mapping the Macintyre* project, focuses on the flow relationships of in channel habitat features and the fish communities of the project area, including the most abundant native species and modelled threatened species distribution for the area. This analysis allows the knowledge of key native fish species in the Macintyre River, including their flow requirements during critical life history stages.

This information builds upon existing knowledge and recommendation within existing strategies, such as Long-Term Water Plans and the Basin Wide Environmental Watering Strategy and should be incorporated into further developing EWRs for fish in the Macintyre River.

The proposed fish-specific EWRs focus on in channel flow requirements based on flow-ecology relationships for fish and habitat inundation in the Macintyre River to provide greater opportunity for spawning, recruitment, maintenance and condition outcomes for native fish. The implementation of these EWRs would achieve significant native fish outcomes, especially target species and fish with specific life-cycle requirements for flow events, including in channel specialists, by providing improved spawning and recruitment opportunities. The EWRs would also enhance the maintenance and condition of all native fish functional groups.

Flow targets have been described for EWRs that will achieve beneficial outcomes for native fish. It is hoped that this will help guide management actions in the project area by recognising the value of all water in the system that will contribute to the ecological objectives, including planned environmental water, Commonwealth environmental water holdings and natural flows, which could be supplemented to contribute to greater inundation of key habitat features.

The recommended EWRs are targeted at various levels of longitudinal and lateral connection (see Figure 60). Longitudinal connectivity can be achieved or enhanced by in-channel flows including baseflows but may require high flow levels where barriers exist. Lateral connection generally requires bankfull and overbank flows which inundate off stream wetlands and distributary streams. Minor increases in lateral connection can be achieved with smaller flows that inundate connected wetlands, benches and low-lying floodplains, however ecologically significant lateral connection requires higher flows especially overbank events. The Basin Plan attempts to achieve improvements for both longitudinal and lateral connectivity.

Stable low-flow specialist species as described by Kerr *et al.* (2017) do not require pulse events, rather require flow to be sustained at a level that does not significantly fluctuate (>5cm) during the spawning and development phase (~3 weeks). There is no proposed flow for these species however flow may be targeted at maintaining stable river levels under baseflows for these species by filling ‘gaps in the hydrograph from water extraction. Stable low-flow specialist species include the threatened purple spotted gudgeon and olive perchlet, both priority species within the project area.

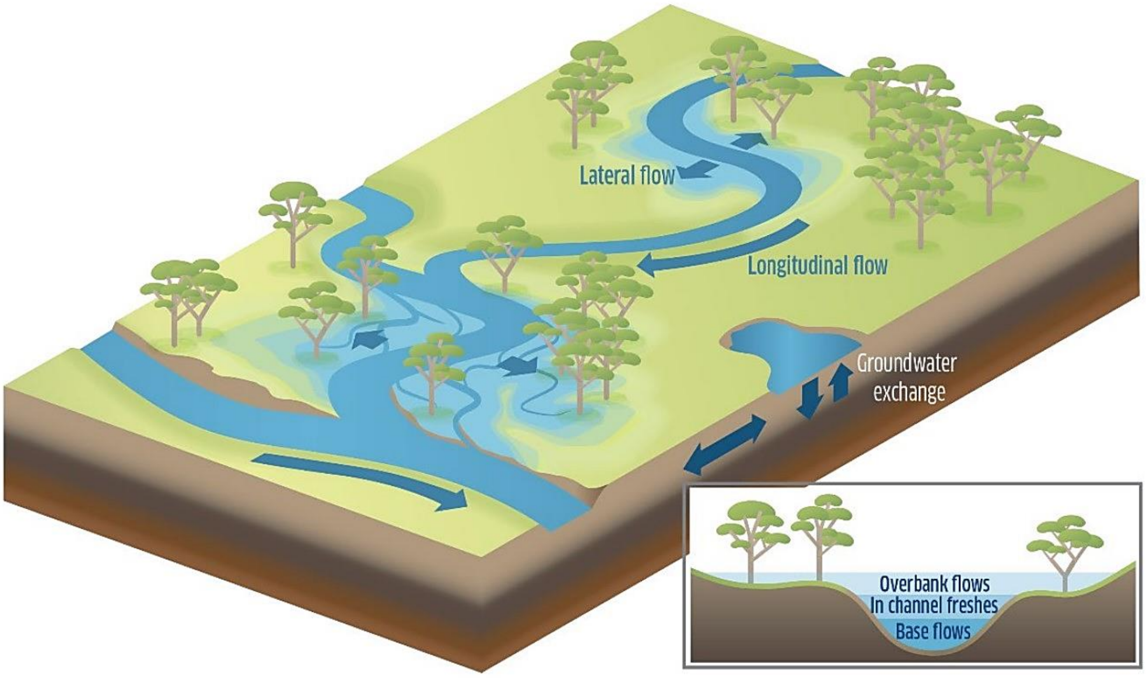

Figure 2. Hydrological connectivity and flows (MDBA, 2014).

As part of these management activities, consideration should also be given to the requirements for timing of flow events. With many native fish species currently understood to have temperature cues for spawning, the impacts of cold-water pollution should be considered when delivering flows as releases may interrupt natural temperature cues for movement and spawning. Within the project area, cold-water pollution only effects the reaches upstream of Boggabilla weir. However, the impacts on upstream populations should be considered, including the Dumaresq, Macintyre Brook and the upper Macintyre River (Lugg and Copeland 2014). Where possible, supplementing natural flows can increase inundation of habitat features and mitigate impacts of cold-water pollution by dissipating the temperature variation of the water being released.

The existing Long-Term Watering Plan has a process outlined for reviewing and updating flow values. The EWRs outlined below are guidelines only and further review including local expertise should be considered before implementing any changes to flow values.

Enhanced in channel specialists spawning

Ecological objective

Provide flow regimes that enhance spawning opportunities for in channel specialist native fish species, focusing on Murray cod and freshwater catfish.

Improve the inundation and availability of key habitat features along the Macintyre River for in channel specialists (flow dependent – Murray cod), particularly LWH and rootballs.

Improve the inundation and availability of key habitat features along the Macintyre River for in channel specialists (flow independent – freshwater catfish), particularly gravel/cobble benches, and wetland entry points.

Improve the longitudinal connectivity along the Barwon River, enhancing localised movement opportunities for native fish.

Environmental water requirement

A small pulse event across the project area for a minimum of 14 days from September to April, every second year (ideally annually) with a maximum inter-event period of two years will provide significant outcomes for in channel species. Benefits would include increased spawning substrate, increased productivity and dispersion opportunities. A slow recession should be maintained to avoid stranding nests and nest abandonment.

Site specific flow indicators

The magnitude of flow required to achieve small pulse conditions varies between Management Reaches within the project area. Boggabilla Management Reach requires 3,100 ML/day to reach small pulse conditions, Terrewah requires 1,300 ML/day, Boomi requires 650 ML/day, Kanowna requires 900 ML/day and Mungindi requires 5,400 ML/day.

All inundation values below are be discussed in terms of flow component condition i.e. small pulse, rather than numeric flow values.

Rationale

Small in channel pulse events across Management Reaches within the project area would provide benefits for all functional groups of fish through improved habitat availability. Increasing flows from baseflow to small pulse conditions increases LWH inundation from 41% to 65% and bench area inundation from 5 % to 44%, and wetland connection from 8% to 22%; indicating that the current flow thresholds are adequately increasing habitat availability throughout the project area.

Research throughout parts of the Murray cod's range has suggested a strong association between the species and complex woody habitat (Koehn and Nicol, 2014). With the increase in availability of these habitats from this higher flow target there would be more opportunities for spawning.

This flow target would also have significant benefits for freshwater catfish with over 65% of benches inundated, which could result increased availability of breeding sites and nesting materials (gravel and cobbles).

The availability of these key habitat features provided by the small pulse events would allow regular maintenance and condition opportunities for all fish communities, as well as opportunities for short to moderate movements in the system through improved longitudinal connectivity. The proposed frequency of the events is especially important for short-lived fish, including those described as stable low-flow spawning fish by Kerr *et al*. (2017), as they need regular flow events to complete important life-cycle stages.

The minimum duration of 14 days is linked to pre-development natural hydrological patterns and the hatch time for eggs of the target species to ensure a stable flow when eggs are on the nest, with rapid changes in height and flow rate, either up or down, to be avoided to maximise spawning outcomes. The minimum of 14 days allows for enough time for in channel specialists (Murray cod) to select a nest, spawn, allow time for the eggs to develop and larvae to disperse (NSW DPI, 2015). The ideal length of this event is greater than 20 days with the main outcome being regular access to spawning habitat and movement opportunities for spawning outcomes. It is therefore considered appropriate for the event to occur during the prescribed spawning window for target species.

Held environmental water delivered from Glenlyon and/or Pindari Dams could be used to shape the hydrograph, adding to natural flow to reach the threshold or providing a stable recession while not impacting on water temperature. To maximise environmental outcomes, the held environmental water component of these types of flows would have to be actively managed once it leaves the regulated water sharing plan area from which it was delivered. Active management allows protection of held environmental water from extraction after it leaves the regulated system where it was delivered (NSW DPIE, 2019b).

Small pulse flows using held environmental water should be coordinated and aligned with downstream valley outcomes to leverage the increased productivity, habitat availability and recruitment generated with the Macintyre River project area. This has been successfully implemented in the past. For example, held environmental water was actively managed in 2019 for the Northern Fish Flow, using held environmental water delivered from the Border Rivers out of Glenlyon Dam and the Gwydir system out of Copeton Dam. The flows travelled down these systems before connecting with the Barwon River (CEWO, 2019b).

Large pulse events for flow dependent specialists

Ecological objective

Maintain large pulse events for spawning and recruitment of flow dependent specialists.

Large pulse flows provide significant longitudinal connection and provide an increased level of lateral connection inundating some wetland entry points and low-level floodplains providing spawning and recruitment opportunities for some floodplain specialists.

Flow connectivity with downstream reaches is also critical to the dispersal pelagic larvae of golden perch and silver perch into nursery habitats (Stuart and Sharpe 2020).

Environmental water requirement

This flow would generally not require delivery but protection of the integrity of natural events within the flow class. Natural flow events could be supplemented with held environmental water from tributaries. This is particularly important after long periods of no flow or extended period with no large pulses.

A large pulse event of 10,900 ML at Boggabilla for a minimum of 20 consecutive days from September to March, preferably every year but can be every second year, with a maximum inter-flow period of two years to enhance migration, spawning and recruitment outcomes for flow specialists and floodplain specialists.

The flow target could be adjusted to a small pulse flow rate of 840 ML at Boggabilla Weir while still achieving some of the objectives, although the effectiveness of outcomes may be compromised, with a timing shift from September to March enhancing spawning outcomes for in channel specialists (flow independent – freshwater catfish) species. Reducing flow rates may also not drown out barriers to fish passage and reduce the distance that pelagic larvae can disperse, both key ecological requirements of the threatened silver perch. The duration and frequency of flows should still be maintained.

Supplementing natural flows to reach heights of sufficient magnitude is problematic, as infrastructure becomes inundated and other third-party impacts become apparent. Complementary water delivery actions for floodplain specialists may be needed in some situations. In the absence of overbank flows, delivery of water to replenish floodplain wetlands may be required via pumping from the main channel to avoid drying of these habitats and subsequent localised extinctions; as is common within the Southern Murray-Darling Basin. The floodplain specialist species olive perchlet has been found in the project area and is of conservation significance, with protection of their population a priority.

Site specific flow indicators

The magnitude of flow required to achieve large pulse conditions varies between Management Reaches within the project area. Boggabilla Management Reach requires 10,900 ML/day to reach large pulse conditions, Terrewah requires 3,300 ML/day, Boomi requires 2,500 ML/day, Kanowna requires 2,500 ML/day and Mungindi requires 7,400 ML/day.

The flow rates required to achieve large pulse flows within each management drowns out all manmade and natural fish barriers across the project area except for Boggabilla Weir, which remains a barrier until flows of 28,500 ML/day. This indicates that fish passage can occur across the project area under large pulse conditions, however Boggabilla Weir prevents movement into upstream reaches and tributaries such as the Dumaresq and Severn Rivers.

Rationale

Large in-channel pulse events would provide benefits for all functional groups of fish through improved habitat availability and system productivity. LWH availability across the entire project area increases from 41% inundation under baseflow to 80% inundation under large pulse conditions. Likewise, bench area inundated increases from 5% at baseflow to 71% under large pulse conditions. Wetland connections also increases from 8% at to 44% inundation, connecting a total of 274 adjacent wetlands.

The availability of these core habitat features provided by the large pulse event would also improve the condition of emergent aquatic macrophytes such as cumbungi, phragmites and juncus/sedge, helping contribute to regular maintenance and condition opportunities for all fish communities, as well as opportunities for short to moderate movements in the system through improved longitudinal connectivity. The proposed frequency of the events is especially important for short-lived fish, including those described as stable low-flow spawning species by Kerr *et al*. (2017), as they need regular flow events into connected wetlands and anabranches to complete important life-cycle stages.

A large portion of the in channel food resources in lowland river systems comes from organic material on the floodplain (Vannote *et al.* 1980; Oliver and Merrick, 2006). Inundating areas out of the main channel increases availability of these resources and increases in channel productivity while increasing the condition and growing area for macrophytes. Inundation of benches mobilises carbon which stimulates river productivity. Wetland inundation provides a stimulus for plant germination and the emergence of invertebrates from resting life stages, many of which can become abundant within days of inundation (Kerr *et al*. 2017).

Although not the primary environmental objective, these flows may also provide some opportunities for spawning and recruitment outcomes for generalists, flow dependent specialists, in channel specialists and floodplain specialists that are more opportunistic and quicker to respond to the shorter duration event. Species that may respond include bony bream, golden perch, spangled perch and the threatened silver perch and olive perchlet.

The proposed duration of five days can be adjusted as needed, depending on hydrological and antecedent conditions. Flow duration is directly linked to productivity with diversity of in-stream communities decreasing with decreased floodplain inundation (Zeiringer *et al.* 2018). Due to the lowland nature of the project area flows generally consist of a more gradual rise and fall than systems in the slopes upland areas, as a result fish species in this area are adapted to these types of events. Events of a shorter duration provide limited time for fish to move but may provide a window of time when passing a barrier is possible or provide an opportunity to move to a more substantial refuge pool. Ideally this flow would occur leading up to and following the in channel specialist spawning flow. Very low flow and cease to flow events should be avoided between these events where possible to maintain connection through the system and support native fish recruitment.

This flow can be used to prime the system for spawning events when delivered in late winter to early spring or can be used to increase food availability and connectivity for larval and juvenile fish in mid-summer to mid-autumn. Late winter/early spring flows are intended primarily to support pre-spawning conditioning for all functional groups through inundation of in channel benches and aquatic habitat. Mid-summer to autumn peaks are intended to provide inundation of in channel benches and habitat to increase productivity and support larval and juvenile drift.

The main outcomes for this EWR are recruitment and dispersal of juveniles, increased in-stream productivity via bench inundation and increasing movement opportunities via barrier inundation. The timing of the event is during the spawning timeframes for the targeted species, taking into consideration any water quality issues such as destratification, cold-water pollution and downstream algae seeding.

Refuge replenishment and connection

Ecological objective

The ecological objective of this flow is to maintain critical water quality and quantity in refuge pools to avoid fish kills during sustained dry periods. This will also provide intermittent connection between refuge habitats. Maintaining refugia allows key ecosystem functions including cycling of nutrients and provision of carbon for productive food webs (MDBA, 2018).

Environmental water requirement

There is no recommended flow for this EWR as it varies depending on the specific conditions of downstream reaches during a prolonged cease to flow event. The persistence of refuge pools is estimated to be approximately 170 days per meter in depth (DSITI, 2015). Based on this analysis, three refuge pools of depths exceeding two meters will persist within the project area for 340 days, noting that water quality will deteriorate rapidly as pools reduce in depth. This ‘river restart’ event is delivered during critical dry periods to replenish refuge pools and provide a short period of connectivity between habitats. Natural flows can be supplemented to more efficiently achieve lateral connection.

In the absence of natural events, this flow can be delivered from regulated tributaries or releases from Boggabilla weir. Events like this have been delivered in 2018 and 2019. The longer the period of zero flow the greater the reduction in flow between gauges, meaning earlier delivery would be more efficient. Magnitude will depend on the amount of time and length of channel that has been dry. Extended dry periods will require more water to ‘restart’ the river with water infiltrating into the soil and ground water aquifers.

River restarts also need to be responsibly managed, as there are considerable risks to water quality of refuge pools. Deep water storages are prone to developing thermal stratification during warmer months, especially under lotic conditions. Stratification results in increased algae activity in surface water layers and anoxic conditions in deeper water layers (Vertessy, 2019). There may be significant risks of releasing poor quality water into downstream reaches, particularly for undershot weirs such as Boggabilla.

Released water can collect large quantities of sediment, organic matter and latent heat from dry riverbeds, typically forming a low-quality slug of hot water at the front of the flow. When connecting multiple refuge pools, particularly during summer, this restart flow can lead to fish kills as seen in the Lower Darling River and Gwydir River in 2019/20 (Charlie Caruthers pers. comms.; Iain Ellis pers. comms).

This risk can be mitigated in a number of ways, such as pre-emptively topping up refuge pools during cooler weather in preparation for an anticipated summer cease to flow event, delaying river restarts until cooler months and making the initial restart at a flow rate sufficient in magnitude to allow fish trapped in refugia to swim upstream past the low dissolved oxygen flow front.

Considerable data and knowledge were gained in 2019/20 cease-to-flow events across the Northern Murray-Darling Basin and this information should be made available to all technical advisory groups and river operators (Iain Ellis pers. comms).

Site specific flow indicators

Replenishment and connection of refuge pools

Distance of river to be reconnected will depend on the nature of the drying event and in flows, or lack of, from tributaries. The Lower Darling restart flow in March 2020 started at 3,000 ML/day release for seven days, before reducing to 400 ML/day, the equivalent of starting at small pulse flows and reducing to baseflow. The equivalent flow regime for a restart for the Macintyre project area would be a seven-day release from Boggabilla at 1,300 ML/day being reduced to 250 ML/day, noting that these values are indicative only and future planning should incorporate local technical and ecological expertise.

Maintain stable water levels during low-flow specialist nesting periods

The ecological objective of this EWR is to maintain stable water levels during the critical nesting period of short-lived fish that spawn during low-flow events. Two threatened species within the project area (purple spotted gudgeon and olive perchlet) spawn during stable low-flow events, attaching eggs to undercut banks, LWH and aquatic macrophytes. Rapid changes in water level due to water extraction or supplemented flows may threaten the viability of these populations by stranding spawning habitat and drying our eggs and larvae.

At present, there is no recommended EWR to address the needs of the stable low-flow guild within the Long-Term Water Plan, as they are currently included within the floodplain specialist functional group, which focusses on lateral connection with floodplain habitats.

Environmental water may be used opportunistically to fill in gaps operational water orders or smooth supplementary flows during spawning season, ensuring that water heights remain relatively stable and preventing the desiccation of eggs and larvae. Submerged aquatic macrophytes such as *Vallisneria spp* provide valuable spawning sites for stable low-flow specialists, as macrophytes will bend and remain underwater if flow recedes post-spawning (Kerr *et al.* 2017). Therefore, it is critical that aquatic macrophytes are also protected and maintained within the project area.

Olive perchlet breed from September to December and purple spotted gudgeon in December to February (Kerr *et al*. 2017). Further research is required to determine site-specific spawning periods and detection methods for the Macintyre River project area. This research should be further developed into a strategic framework to assist environmental water planners in delivering outcomes for stable low-flow spawning fish.

Maintain integrity of bankfull and overbank flows for flow dependent specialist and floodplain specialists

There is minimal potential for the CEWO to impact on this flow class, due to upstream holdings being too small to feasibly deliver the flow rates required to achieve bankfull flows within the project area, e.g. 10,000 ML/day at Boggabilla. However, protection should be advocated with other water management agencies to maintain its integrity in areas with connection points to significant wetland areas. Establishing the height at which significant wetland areas become inundated would be very valuable. This would require further analysis of where the connection points lead too, potential methods are discussed in the following section.

The protection, monitoring and management of these events is not considered to be the responsibility of the CEWO, however it is a responsibility of other agencies including NSW Department of Planning, Industry and Environment – Environment, Energy and Science; WaterNSW; Border Rivers Commission; Queensland Department of Regional Development, Manufacturing and Water; and the Queensland Department of Environment and Science. An Environmental Watering Advisory Group (EWAG) is currently being developed for the Border Rivers Valley and will include representatives from relevant community stakeholders.

Stakeholders will include the local Aboriginal community, farming sector and relevant government departments, alongside ecological experts.

The occurrence interval for these events varies significantly between target species. Longer-lived flow dependent specialist species such as golden perch and silver perch do not require as frequent recurrence intervals. Short-lived floodplain specialist species, such as olive perchlet, can suffer localised extinctions if these events do not occur for an extended period.

Activities to address the lack of natural inundation of off stream wetlands may need to be considered in some areas. This could be done by pumping water from the main channel, a method which has been used in areas of the Southern Murray-Darling Basin at several scales with varying levels of success (see NSW DPIE-EES, 2019).

Recommendations for future management in the Macintyre River

The Macintyre habitat mapping project has considerably advanced the available information and understanding for water management in the Macintyre River related to fish and river outcomes and enhanced the existing information for the already mapped stretch of the Barwon Darling from Mungindi to Wilcannia. However, knowledge gaps still exist that require attention to enhance the development of future environmental water requirements.

The outcomes of water management in the Macintyre River would be greatly enhanced through complementary aquatic habitat rehabilitation and adaptive monitoring programs. The recommendations outlined in the section below are the views of DPI - Fisheries and are not considered to be the sole responsibility of the CEWO but may be supported or progressed with other State and Federal government agencies.

Management Actions

To improve native fish populations and river health in the Macintyre River and throughout the Border Rivers, future management of water for the environment should consider management actions including:

1. Align complementary actions with the Northern Basin Toolkit recommendations

The Northern Basin Review (2016) established a framework for a series of 'toolkit measures' that are intended to meet environmental outcomes of the Murray-Darling Basin Plan, using complementary measures outside of water recovery. Measures included remediation of barriers to fish passage, cold-water pollution, pump-screening, threatened species recovery and improved management and coordination of existing environmental water (MDBA, 2020b).

The remediation of barriers to fish passage are a key measure recommended by the Northern Basin Toolkit. Seven in-stream barriers were observed within the project area, ranging in drown out flows from 495 ML/day (Toomelah Weir) to 28,500 ML/day (Boggabilla Weir). Remediation of fish passage at these barriers would increase fish movement through 455 km of aquatic habitat.

Cold-water pollution only affects the upper reaches of the project area, where Pindari Dam releases reduce temperatures to Boggabilla Weir. Tributaries immediately upstream of the project area are also impacted by cold-water pollution including the Dumaresq River (Glenlyon Dam) and Macintyre Brook (Coolmunda Dam). The combined influence of cold-water releases from tributaries may have negative effects on in-stream productivity, growth rates and recruitment (Lugg and Copeland 2014; Michie *et al*. 2020).

The project area contained 316 pumpsites, including 103 pumps exceeding 250 mm in diameter. Fine mesh screens installed on pump intakes have been demonstrated to reduce the loss of fish larvae and juveniles via irrigations diversions (Boys *et al.* 2012) and benefit irrigators via reduced maintenance costs.

Threatened species recovery is a key component of the Northern Basin Toolkit. The data gathered in this report should be used to inform water management, optimise flow regimes, guide protection and translocation of existing threaten populations and to prioritise complementary works such as barrier remediation and stock exclusion (Koehn *et al.* 2020a; 2020b).

The habitat mapping data can be used to provide direction on how to proceed with aquatic habitat restoration and protection initiatives. This information can be used by natural resource managers to prioritise areas for action increasing the benefits of environmental flow deliveries in the project area. For example, habitat mapping data could be used to improve the condition of riparian vegetation by showing where there are significant weed issues and where there is revegetation of native riparian species, allowing natural resource managers to make more informed decision when directing their resources.

Furthermore, this data should inform the protection and translocation of existing threatened fish species i.e. aquatic macrophyte presence or locations of refuge pools during prolonged cease to flow events.

A recent proposal from NSW DPI – Fisheries titled “Fish for the Future” intends to include the above complementary actions including:

- Reconnecting the Northern Basin – improved fish passage at 22 priority structures within the Barwon-Darling and Border Rivers.
- Addressing cold-water pollution – mitigation of cold-water pollution downstream below Pindari Dam.
- Fish friendly water extraction – targeted diversion screening program within the Border Rivers, Gwydir and Barwon Darling Valleys.
- Threatened species recovery – reestablishment of populations of four key threatened fish species in the Northern Basin.

2. Continued and sustained cross-disciplinary and inter-jurisdictional collaboration on information and knowledge of ecological relationships in the Barwon River and adjoining catchments

Current activities across the Murray-Darling Basin related to water management provide opportunities to effectively establish and foster linkages between relevant community, academic and government experts. The *Mapping the Macintyre River* project gathered a range of relevant knowledge, expertise and information related to fish and flow relationships in the Macintyre River. While much of this information is readily accessible, other material occurs in variable formats and is held by different institutions and agencies.

To support the proposed long-term adaptive management plan and Macintyre River fish management strategy, it would also be useful to review existing management and research needs, including data sharing arrangements and management actions relating to fish and flow information in the Macintyre River. This compiled information could be provided to the EWAG currently in development for the Border Rivers; promoting a collaborative and open approach to management of existing and future watering activities, including a shared commitment to identifying and addressing knowledge gaps.

Research and Monitoring

To improve native fish populations and river health in the Macintyre River and throughout the Border Rivers, future management of water for the environment should consider research and monitoring options such as:

1. Undertaking further habitat mapping to connect mapped areas in the Border Rivers, Gwydir and Barwon Darling River and secure additional data source

This habitat mapping project has connected a 1,916 km continuous reach of habitat inundation data from the Roseneath gauge on the Dumaresq River to Wilcannia on the Darling River. However, significant gaps still exist in our understanding of habitat features and their relationship to river flow across the Northern Basin, particularly regarding inter-valley flow connectivity. The Barwon-Darling River system downstream of the project area is highly dependent on regulated and protected unregulated releases from upstream tributaries, as demonstrated during the drought conditions of 2019/20 (NSW DPIE, 2020). As such, further mapping should be undertaken in the Macintyre and Gwydir Valleys and this data utilised to inform flow management at an inter-valley scale.

Priority mapping should include the Severn River downstream of Pindari Dam (~200 km) and the remainder of the upstream sections of the Macintyre River (~300km). This information, coupled with fish community details and water management activities, would allow critical flow thresholds to be identified for inundation values, structure drown out requirements, and bankfull capacity volumes, helping to develop specific water requirements and strengthen water management actions at an inter-valley scale.

To complement habitat mapping data, LiDAR could be used to assess wetland area associated with entry points. This would allow a wetland area to be attached to each entry/exit point recorded during on ground mapping. Further analysis could also be complete of these wetlands using satellite imagery to map vegetation extent.

2. Committing to a long-term, adaptive management plan driven by monitoring and evaluation

The hydrological and hydraulic variation required to restore key elements for fish in the Macintyre River will differ across functional groups. Whilst some benefits will be experienced across groups from different flow regimes, a long-term commitment to adaptive management is required to maximise outcomes. Management plans that consider flow, habitat and connectivity need to include objectives for each functional group to ensure benefits are experienced across all native fish communities over relevant spatial and temporal scales. The development and implementation of a rigorous monitoring program is essential to help validate program assumptions and measure the success of flow delivery/protection and water requirements against the program objectives.

Information about the use of habitat by fish and their response to certain flow delivery scenarios will allow management plans to be evaluated and flow hydrographs to be adapted ensuring that outcomes are optimised, whilst providing confidence in stakeholders that decision making is being informed by biological information. This has already been demonstrated in downstream reaches, where a refined hydrograph has delivered significant golden perch and Murray cod spawning in the lower Darling River (Stuart and Sharpe, 2020; Iain Ellis pers. comms.). It is important to establish long-term monitoring in the project area that can supplement other monitoring programs in tributaries and downstream in the Barwon-Darling River. This will ensure that outcomes from managing water for the environment across a range of different valley types are captured and used to guide management decisions. It is also essential that monitoring information and research outcomes are communicated and readily accessible to advance knowledge and management actions across related systems.

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Introduction

Aquatic habitat is an important element of the riverine environment and consists of stream features such as bed substrates, hydrology, pools, riffles, floodplains, in-stream and bank vegetation (macrophytes and riparian vegetation), large woody habitat (LWH), bank overhangs and rocky outcrops (Rutherford *et al.* 2000). These features along with billabongs, paleo-channels and off stream wetlands provide spawning, feeding, shelter and recruitment sites essential for the survival of aquatic biota, including native fish. The degradation of native riparian vegetation, the removal of LWH and the installation of in-stream structures that are barriers to fish passage are all listed as Key Threatening Processes under the NSW *Fisheries Management Act* (FM Act) 1994.

The project area follows 327 kms of the lower Macintyre River, extending from Toomelah Weir to Mungindi Weir. The lower Macintyre River lies within the Border Rivers catchment, a valley with historically variable flow, now regulated by upstream dams and in-stream re-regulating structures. This regulation gives the Commonwealth Environmental Water Office (CEWO) the capacity to target water deliveries that contribute to environmental outcomes with releases from Glenlyon Dam, Coolmunda Dam, Pindari Dam and supplementary entitlements from unregulated tributaries such as the Severn. Improved ecological conditions in the tributaries that the CEWO has a greater capacity to deliver in are likely to have benefits to the fish community in the project area.

The Macintyre River supports a relatively rich native fauna. Twelve native fish species have been recorded, including threatened species such as Murray cod, silver perch, olive perchlet, freshwater catfish and purple spotted gudgeon. Three alien fish species have been recorded within the project area: gambusia, European carp and goldfish (Lintermans 2009). The Sustainable Rivers Audit (Davies *et al*. 2012) concluded that the fish community of the Macintyre river is in moderate to good health, one of the best results for the northern Murray-Darling Basin. As such, the project area provides a strong platform for further improvement to native fish populations if appropriate management actions are implemented.

The Northern Basin Review suggests to further improve environmental outcomes in the Border Rivers, by improving coordination and protection of existing environmental water releases and to utilise complementary works such as improving fish passage and reducing cold-water effects of Pindari Dam and Glenlyon Dam (MDBA, 2016). Environmental assets and associated objectives and outcomes for the Macintyre River have been identified in the Basin-wide Watering Strategy and state-based investigations to inform Water Resource Plans and Long-Term Watering Plans. Based on these strategies and studies, the CEWO has identified key demands and outcomes being targeted by managing water for the environment in the Macintyre River. For native fish this includes increasing the frequency of pulses and bankfull events (CEWO, 2016).

To ensure these ecological outcomes are achieved with the most effective and efficient use of water for the environment in the Macintyre River it is critical that management decisions are guided by the best available information, including environmental water requirements for fish and hydrological thresholds for habitat availability.

NSW Department of Primary Industries – Fisheries (Department of Regional NSW) (NSW DPI – Fisheries) has completed work on the flow requirements of native fish in the Northern Murray-Darling Basin to achieve key life history stages (NSW DPI, 2015). This information is based on the latest science, literature and expert opinion for the Northern Murray-Darling Basin and can be used to guide management decisions to achieve fish outcomes from improved water management. However, in all valleys there is a need to relate these biological needs to system-specific ecological information that enhances management actions and ecological outcomes. This includes flow thresholds and other metrics (river height, flow rate, duration, volume) required to inundate key habitat features in the system that contribute to native fish, connectivity and productivity outcomes such as benches, wetland entry points, aquatic macrophytes and LWH.

Habitat mapping has already been completed in adjacent waterways such as the Barwon and Darling Rivers from Walgett to Wilcannia in 2015 under the Northern Basin Fish and Flows project (NSW DPI, 2015), the Dumaresq River in 2017 (NSW DPI, 2018a) and the Barwon River from Mungindi to Walgett in 2019 (NSW DPI, 2019a). This made the project area a high priority for mapping to further provide support for decision making in relation to water for the environment in the Border Rivers system. This habitat mapping project has now connected a 1,916 km continuous reach of habitat inundation data from the start of the Dumaresq River to Wilcannia on the Darling River, providing significant information regarding inter-valley flow management. Calculating hydrological thresholds for LWH, benches and wetland entry points based on detailed habitat mapping will significantly improve the CEWO’s ability to make decisions for water for the environment that meets environmental objectives under the BWS.

The conditions in the project area in the two years preceding fieldwork were at a serious point, with much of the Northern Murray-Darling Basin in critical drought. Across most of the project area, record low inflows were recorded at many gauges dating back to the 1980s, constituting previously unseen cease to flow conditions. These conditions and the likely increase in occurrence with climate change make this report as a whole and the recommendations for refuge replenishment flows, particularly valuable for water management in the project area.

Project scope and objectives

Project objectives

The primary objectives of the project are to:

- Calculate commence-to-inundate flow thresholds of select habitat features where feasible, including benches, wetlands entry/exit points and LWH.
- Document the stream bed morphology, including the location, length and depth of pools that may act as drought refugia, the in-stream habitat features (benches, wetland entry/exit points, aquatic macrophytes, substrate), and LWH loading;
- Document the riparian features of the Macintyre River between the Dumaresq-Macintyre confluence to Mungindi, focusing on native vegetation, weed infestation and existing management activities;
- Identify and map threats and processes that may influence the extent and condition of aquatic and riparian habitat features; and
- Make recommendations to improve water for the environment management actions in the Macintyre River, and to protect and improve stream health, threatened species habitat enhancement, weed control and other habitat features.

Project area

The Macintyre River is formed in the Great Dividing Range near Inverell, NSW. From there it flows through Inverell, Boggabilla and Goondiwindi and becomes the Barwon River at the confluence with the Weir River upstream of Mungindi (Figure 3). The Macintyre River drops in elevation from approximately 1,200 m above sea level at its inception, to less than 200 m at Mungindi, flowing in its lower section across floodplain (MDBA, 2015). The floodplain begins in the vicinity of the Macintyre-Dumaresq junction, with the project area found wholly on the floodplain.

The Macintyre floodplain is characterised by numerous anabranches, distributary channels and billabongs. In the 150 km reach between Goondiwindi and Boomi, 69 anabranch channels have been identified in a study by Thoms, Southwell and McGinness; these anabranch channels vary in length from 0.32 km to 113 km, most being shorter than 1 km, and connect at varying flow heights. The anabranch channels had a combined length of 236 km, which is 62 % of the mainstem channel length in the same reach (Thoms *et al*. 2005).

The Macintyre River is part of the Border rivers catchment, an area that encompasses the Darling Downs of south-east Queensland and the lower slopes of the New England Tablelands in north-east NSW (Bioregional Assessments, 2019). The rivers of this catchment form on the western slopes of the Great Dividing Range, and merge with one another to flow into the Macintyre River, the last tributary being the Weir River at which point it becomes the Barwon River. Sections of the Dumaresq, Macintyre and Barwon rivers form the NSW-Queensland border for 450 km (MDBA, 2020a).

The study area is the reach from the Dumaresq-Macintyre confluence, upstream of Boggabilla, to Mungindi, a distance of 327 km. Twenty-nine kilometres upstream of Mungindi, the Weir and Macintyre rivers join to become the Barwon River, so the study area includes the first 30 km of the Barwon River. Major tributaries in the study area are the Dumaresq River at the start of the project area, and the Weir River. Major anabranches are the Whalan and Callandoon creeks and the Boomi River (QDERM, 2013).

The project area is a part of the Lower Darling Endangered Ecological Community (EEC) listed under the Fisheries Management Act (NSW DPI, 2007). The EEC is characterised by variable and unpredictable patterns of high and low flows.

The EEC provides a variety of habitats for fish and invertebrates including pools, runs, riffles, backwaters and billabongs, in-stream woody habitats and aquatic plants (NSW DPI, 2007). One of the major causes of degradation to the EEC is the modification of natural flows as a result of river regulation (NSW DPI, 2007).

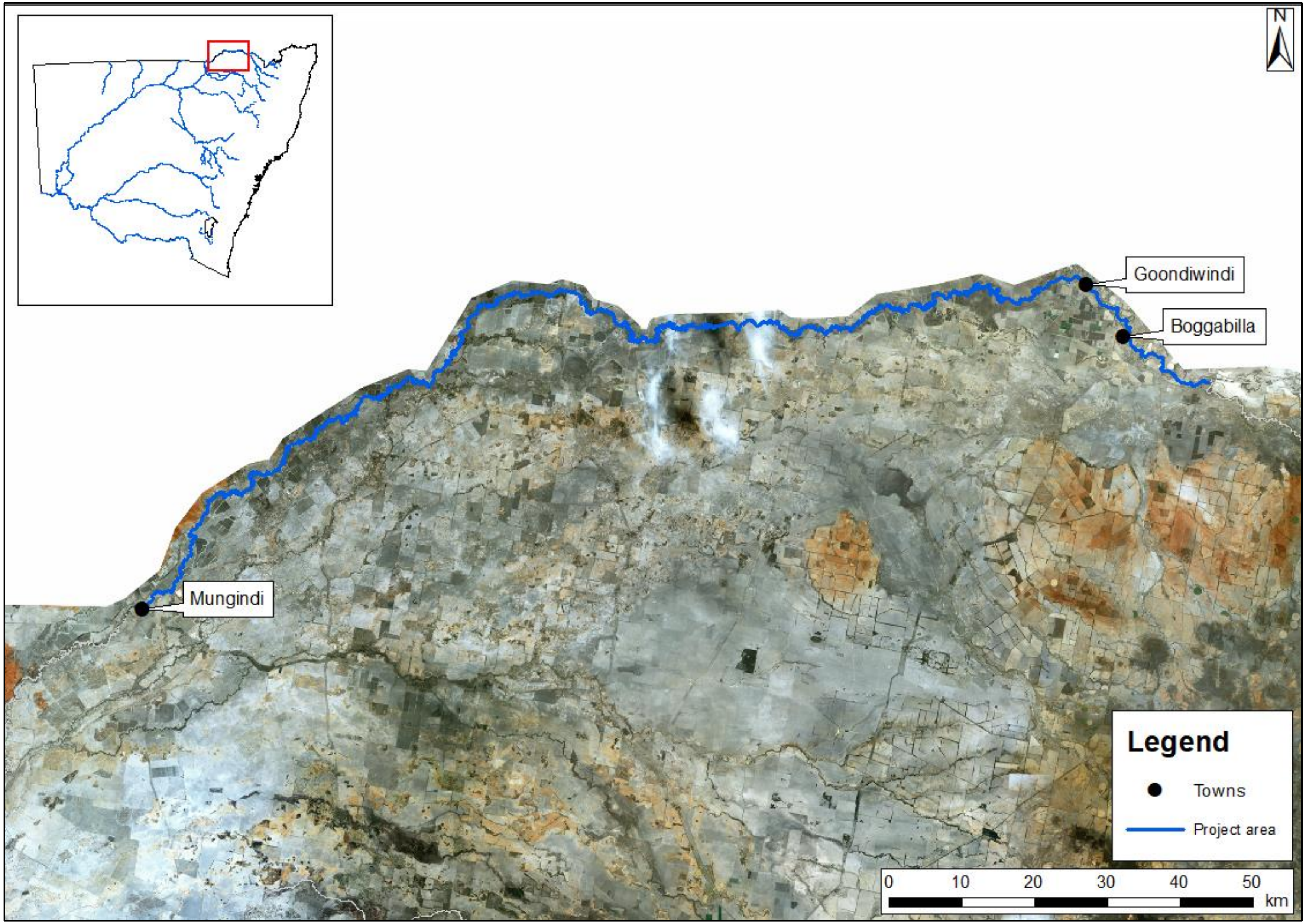


Figure 3. Extent of Macintyre River habitat mapping project area.

Hydrology

Flows in the Border Rivers catchment are highly variable, with inconsistent rainfall and both unregulated and regulated rivers. The Macintyre River, like many inland Australian rivers, is allogenic, originating in a high rainfall area and flowing to a low rainfall area, across the floodplain. The median (> 68 years) annual rainfall at Tenterfield is 1,100 mm and 480 mm at Mungindi. Most rainfall occurs between November and April (Thoms *et al*. 2005; BOM, 2018).

The section of the Macintyre River in which the project has been undertaken is part of the regulated system. Upstream of the project area, there are no major impoundments or regulating structures on the Macintyre River itself. However, there are regulating storages on the major tributaries upstream of the project area, namely the Severn River, which contains Pindari Dam (312 GL), the Dumaresq River, which is regulated by Glenlyon Dam (261 GL) on Pike Creek, and Coolmunda Dam (69 GL) on Macintyre Brook, which enters the Dumaresq River below Pike Creek. The Macintyre River is regulated from the Macintyre-Severn confluence downstream to the Barwon River. Within the project area, Boggabilla Weir is a re-regulating structure. See Figure 4 for the regulated rivers of the Border Rivers catchment in the *Water Sharing Plan for the NSW Border Rivers Regulated River Water Source 2009.*

Major unregulated watercourses that influence the study area are the Macintyre River upstream of the Macintyre-Severn confluence, Weir River and Ottleys Creek (both intermittent watercourses) (NSW DPIE, 2019a). Water also leaves the main channel of the Macintyre River when the anabranches and distributary channels connect at higher flows. The area of the anabranches – and therefore the uptake of water along these channels - is significant, being nearly as large as the area of the main channel of the Macintyre River. It has been calculated that the area of the main channel of the Macintyre River between Goondiwindi and Boomi is 658 ha, and that of the anabranches in the same reach is 586 ha (Thoms *et al*. 2005).

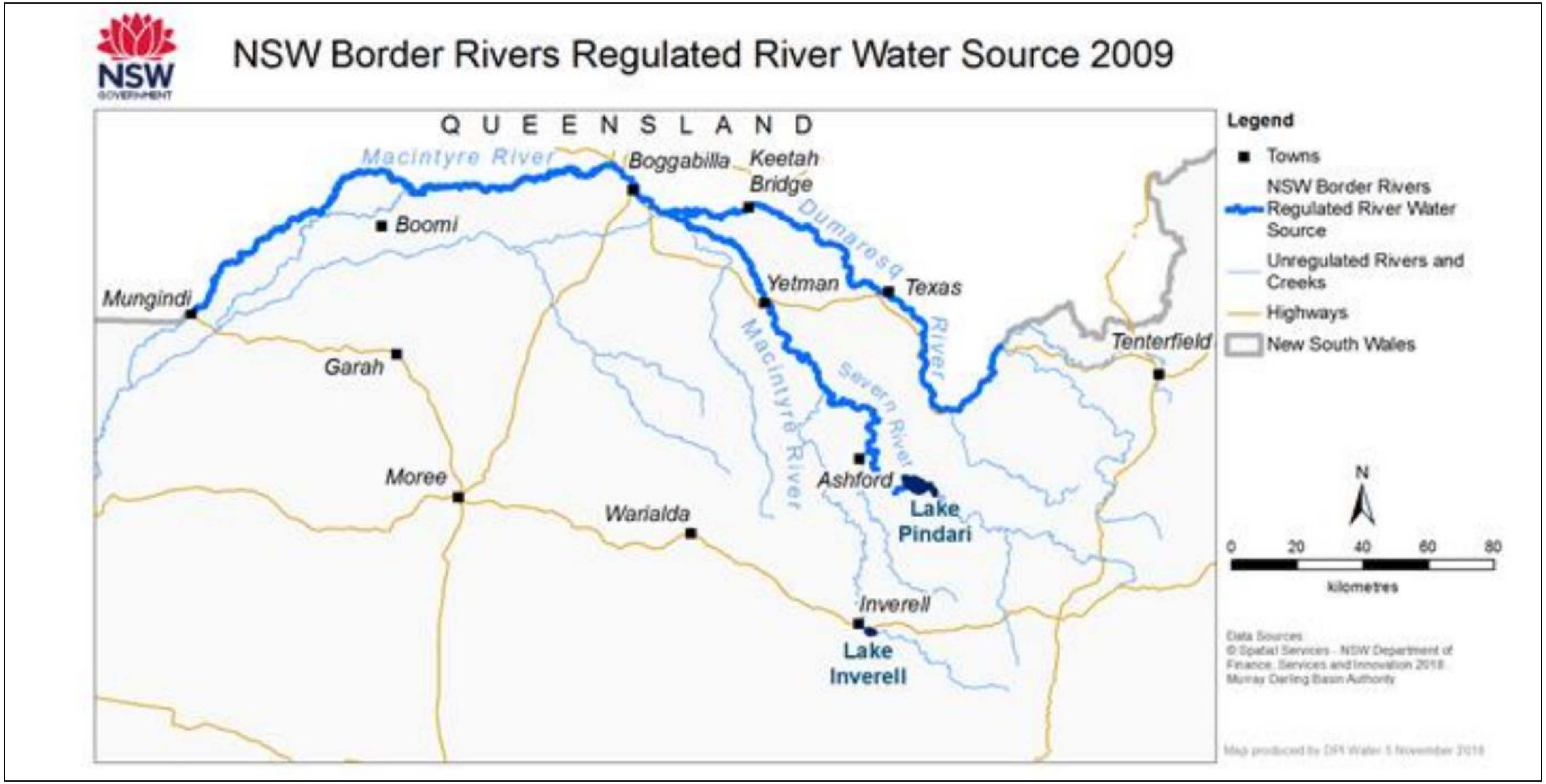


Figure 4. Regulated rivers / river sections in the Border Rivers catchment. Source: NSW Border Rivers Surface Water Resource Plan, Dec 2019.

Water in the study area is currently managed under the *Water Sharing Plan for the NSW Border Rivers Regulated River Water Source 2009*, with a draft Water Sharing Plan (*Water Sharing Plan for the NSW Border Rivers Regulated Water Source Order 2020)* awaiting authorisation.

Flows entering the study area are managed under the *Water Sharing Plan for the NSW Border Rivers Regulated River Water Source 2009* and the *Water Sharing Plan for the NSW Border Rivers Unregulated and Alluvial Water Sources 2012* for the NSW tributaries, and the *Queensland Border Rivers-Moonie Water Resource Plan* (September 2019) for the tributaries in Queensland. An agreement is in place between the governments of NSW and Queensland in relation to water sharing and infrastructure and is implemented by the Border Rivers Commission. The agreement in NSW was ratified by the *New South Wales-Queensland Border Rivers Act 1947* and in Queensland by the *New South Wales-Queensland Border Rivers Act 1946*. Flows from Glenlyon Dam are managed under the *Border Rivers Resource Operations Plan 2008*.

Six WaterNSW gauges on the Macintyre and Barwon rivers record flow data in the project area. The gauges are Boggabilla, Terrewah, Boomi, Boonanga Bridge, Kanowna and Mungindi. An additional gauge was installed at Eagle Farm in November 2019; calculations of flow rate from this gauge are not yet sufficiently tested to provide accurate data. Flows recorded by these gauges are influenced by the Boggabilla Weir re-regulating structure, and inflows from upstream tributaries, both regulated and unregulated.

Table 2 shows the estimated Commonwealth environmental water holdings under the water sharing plans. The water holdings are in all three in-stream dams (Pindari, Glenlyon and Coolmunda) of the Border Rivers (CEWO, 2019a). The NSW State Government does not have any environmental water holdings in the Border Rivers catchment (NSW DPIE, 2019b).

Table 2: Commonwealth environmental water holdings in the Border Rivers catchment

Security	Entitlement and location	Registered entitlements (ML)	Security
Medium	Regulated entitlement held in Glenlyon Dam and Coolmunda Dam	15,540	Medium
Unsupplemented (Qld)	Unregulated entitlements in the Qld Macintyre, Dumaresq and Severn rivers and Macintyre Brook	19,986	Unsupplemented (Qld)
Supplementary (NSW)	Unregulated entitlements in the NSW Severn River	1,437	Supplementary (NSW)
General (NSW)	Regulated entitlement held in Pindari Dam	2,806	General (NSW)
Total		**39,769**	

Water infrastructure

Seven non-regulating weirs restrict flow in the project area: Toomelah Weir (rock weir, private), Goondiwindi Weir (fixed crest, WaterNSW-owned), Boomi Weir (fixed crest, WaterNSW), Macintyre Blockbank A (blockbank, private), Macintyre Blockbank B1 and B2 (blockbanks, private) and Mungindi Weir (WaterNSW). There is one re-regulating structure, Boggabilla Weir – which is an undershot weir. Tributary inflows to the project area are highly regulated with major storages on the Severn River (Pindari Dam), Pike Creek (Glenlyon Dam) which flows into the Dumaresq River and Macintyre Brook (Coolmunda Dam) which also flows into the Dumaresq River.

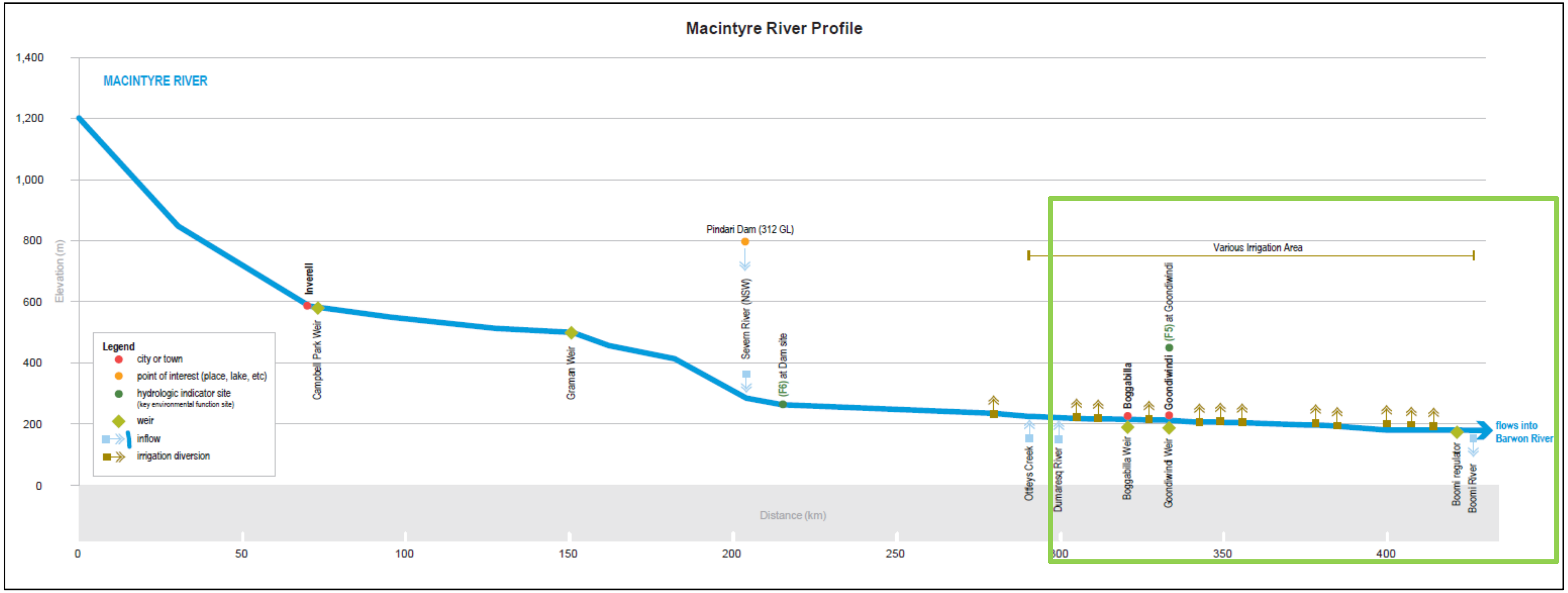


Figure 5. Macintyre River profile, with project area outlined in green, note that the project area extends into the next figure and ends at Mungindi Weir. Figure source (MDBA, 2020a).

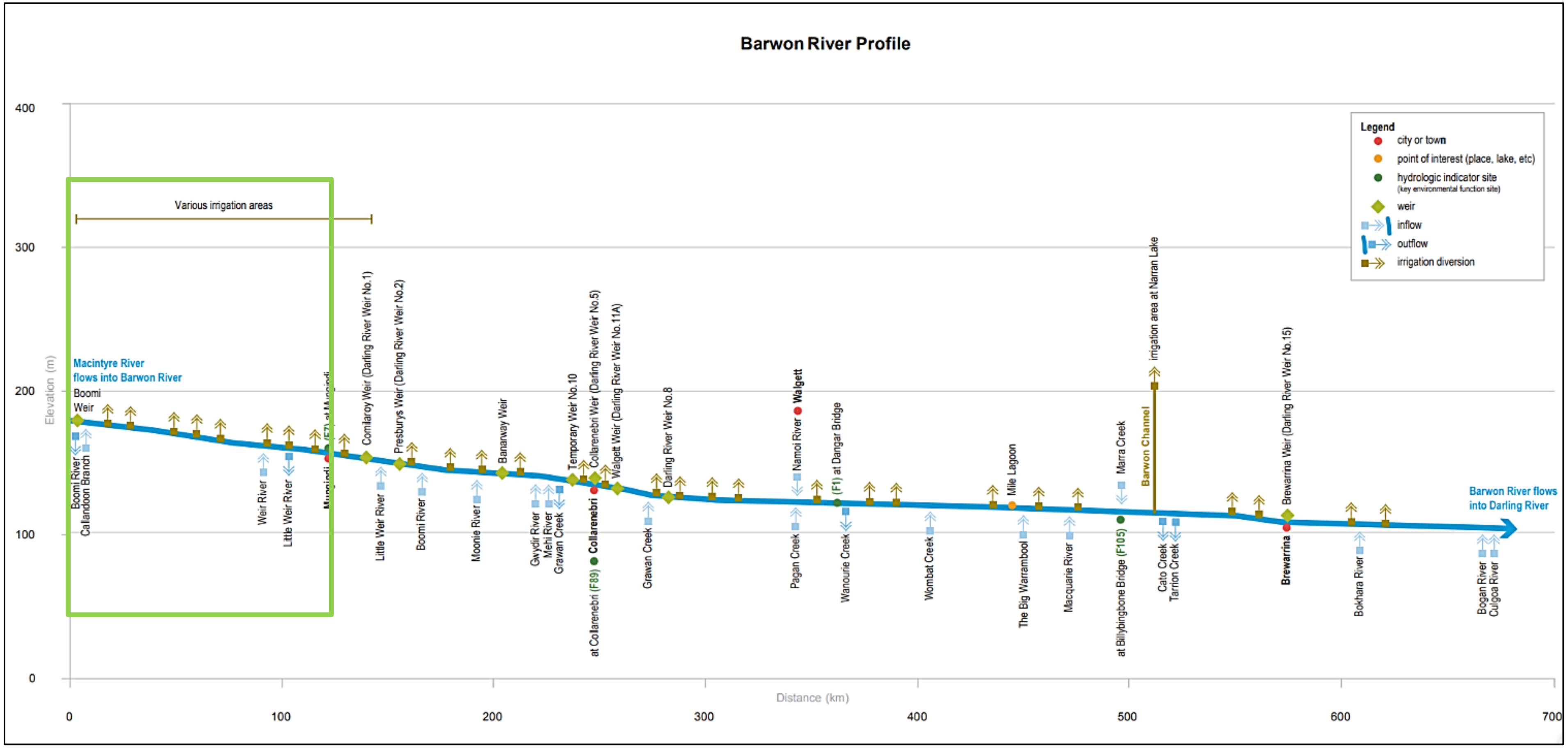


Figure 6: The Barwon River profile, with the remainder of the project area outlined in green (MDBA, 2020a).

Fish species in the Macintyre River

The fish community of the Macintyre River between the Macintyre-Dumaresq junction and Mungindi includes 12 native species and three alien species that have been recorded or are expected to occur in the project area (Lintermans 2009; Table 3). These species range in size at adult life stage from 5 mm to over 1 m. Five of the fish species and one mollusc species recorded or expected to occur in the Macintyre River are listed as threatened under the *Environmental Protection and Biodiversity Conservation Act* (EPBC Act) 1999 and/or the FM Act.

The fish community of the Macintyre River is in moderate to good health, and its condition is one of the best of all the rivers in the northern Murray-Darling Basin (NSW DPI, 2015) (Figure 7). Despite this, many factors have contributed to the deterioration of native fish in the Macintyre River, including barriers to fish passage, changes to water flow, degradation of in-stream habitat and riparian vegetation, poor land management, and the introduction of alien fish species (NSW DPI, 2007). Much of the fish community of the Macintyre is in a moderate to good condition, providing a strong platform for fish recovery, including improving the distribution, abundance and population structure of key species if management actions are developed and implemented appropriately.

Three alien species occur in the Macintyre River: gambusia, carp and goldfish (Lintermans, 2009). Carp are present in most lowland rivers and creeks of the Barwon-Darling system. NSW DPI carp recruitment hotspot modelling (NSW DPI, 2015) also identifies a number of hotspots in the lower section of the Macintyre River project area (Figure 7).

Three species present in the project area - silver perch, Murray cod, and golden perch - are known to undertake large-scale migrations, while others make short migrations to spawning sites (Butcher, 2007; Humphries and Walker, 2013). Many of these migrations are believed to be triggered in response to increases in flow, including small pulses (<15 cm) and large pulses (>2 m), however other factors including physiological (e.g. sexual maturation), behavioural (e.g. homing), environmental (e.g. weather) and biotic (interactions with other organisms) play an important role (Lucas and Baras, 2000; Mallen-Cooper, 2000; Humphries and Walker, 2013).

Golden perch have been recorded to migrate over large distances in excess of 1,000 km, however only a small proportion of fish undertake such extensive migrations and many return to a ‘home range’ (Reynolds, 1983; O’Connor *et al.* 2005; Marshall *et al.* 2016). Murray cod may undertake pre-spawning migration upstream to a spawning area before rapidly returning downstream often to their home territory (Moffat and Voller, 2002; Humphries and Walker, 2013). Murray cod migration in the area upstream of the project area tend to only move between pools, moving upstream to a spawning site, with few undertaking large scale migrations (Butler 2018, pers. com). This is also likely to be the case in the project area. Conversely, golden perch undertake large scale migrations often over hundreds of kilometres (Lintermans, 2009). Migration behaviour referred to in Table 4 refers solely to movement in relation to spawning and reproduction and does not consider other movements that some species may make during other life cycle stages.

The majority of species in the project area appear to have a preference for spawning between late August and March, which seems a trend across a number of catchments in the Northern Murray-Darling Basin (NSW DPI, 2015; Table 3). Some species exhibit more opportunistic spawning behaviour and will spawn during the winter months if conditions are favourable. For example, golden perch have long been presumed to spawn between October and April; however these species have also been found to have spawned in May in response to heightened water levels in Lake Malta (part of the Menindee Lakes system), suggesting that increases in latitude may increase the window for spawning (Ebner *et al.* 2009).

Murray cod, freshwater catfish and carp gudgeon occur in the project area and exhibit nesting behaviour and parental care. These species require stable flows during the nesting period which can vary from 2 to 14 days depending on the species (NSW DPI, 2015). River level fluctuations during the nesting period can lead to nest abandonment of the nest and desiccation of the eggs.

Table 3: Fish and significant crustacean and mollusc species expected to occur in the project area, their status, and life history requirements related to flow (Lintermans, 2009; Ponder *et al*. 2016).

Common name	Scientific name	Type	Status	Spawning method	Hatch time (days)	Migratory species	Spawning season	Larval drift
Murray cod	*Maccullochella peelii*	Large bodied native	Vulnerable (EPBC Act), however, appear to be common in the project area	Nesting with parental care	14	Yes	Aug – Nov	Yes
Golden perch	*Macquaria ambigua*	Medium bodied native	Common	Batch spawning, pelagic eggs	3	Yes	Oct – April, additionally recorded spawning during winter	Yes
Freshwater catfish	*Tandanus tandanus*	Medium bodied native	Endangered MDB population (FM Act)	Nesting with parental care	7	Yes	Sept – March	Yes
Silver perch	*Bidyanus bidyanus*	Medium bodied native	Vulnerable (FM Act) Critically endangered (EPBC Act)	Batch spawn, pelagic eggs	5	Yes	Oct – April	Yes
Spangled perch	*Leiopotherapon unicolor*	Medium bodied native	Common	Serial, non-sticky demersal eggs	2	Yes	Nov – Feb	Yes
Bony bream	*Nematalosa erebi*	Medium bodied native	Common	Serial, pelagic eggs	7	Yes	Oct – Feb	Yes
Australian smelt	*Retropinna semoni*	Small bodied native	Common	Batch spawning, sticky demersal,	10	Yes	Sept – Feb	Yes
Carp gudgeon	*Hypseleotris klunzingeri*	Small bodied native	Common	Nesting parental care	2	Yes	Sept – April	No
Murray Darling rainbowfish	*Melanotaenia fluviatilis*	Small bodied native	Common	Batch, sticky demersal eggs	7	Yes	Sept – Feb	Yes

Olive perchlet	*Ambassis agassizii*	Small bodied native	Endangered western population (FM Act)	Serial, sticky demersal eggs	7	No	Oct – Dec	?
Southern purple spotted gudgeon	*Mogurnda adspersa*	Small bodied native	Endangered species (FM Act)	Batch, parental care	9	?	Sept - Feb	No
Unspecked hardyhead	*Craterocephalus fulvus*	Small bodied native	Common	Batch, sticky demersal eggs	7	Yes	Sept – April	No
Darling river snail	*Notopala sublineata*	Aquatic snail	Critically endangered (FM Act)	Live barer	0	No		No
Yabby	*Cherax destructor*	Crayfish	Common	Parental care, eggs are attached to the underside of the female before hatching.	21	No	Sept-April	No
Freshwater mussel	*Alathyria jacksoni* *Velesunio ambiguous* *Velesunio wilsonii*	Mollusc	Common, however expected to be suffering population declines due to drought and associated extended cease to flow periods	Larvae brooded on adult females gills before being released and spending a period as a parasite on fish gills.	0	No	Unknown	Yes
Carp	*Cyprinus carpio*	Alien Species	Common exotic	Serial, sticky demersal eggs	6	Yes	Sept – March	Yes
Gambusia	*Gambusia holbrooki*	Alien Species	Common exotic	Batch spawning, live young	n/a	Yes	Sept – May	?
Goldfish	*Carassius auratus*	Alien Species	Common exotic	Serial, sticky demersal eggs	7	Yes	Oct – Jan	No

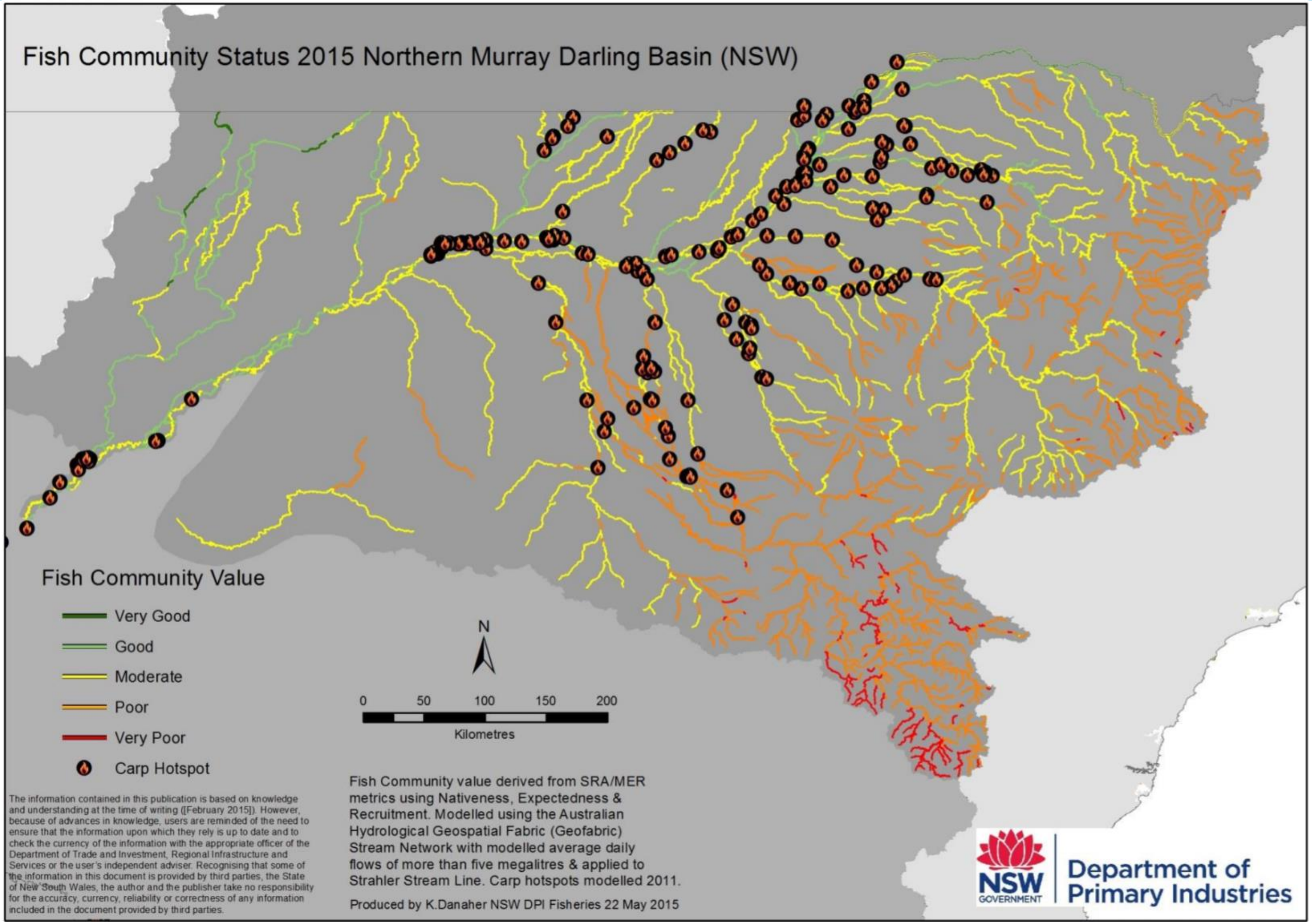


Figure 7. Fish community status for the Northern Basin, highlighting condition of fish communities, and the location of carp hotspots (NSW DPI, 2015).

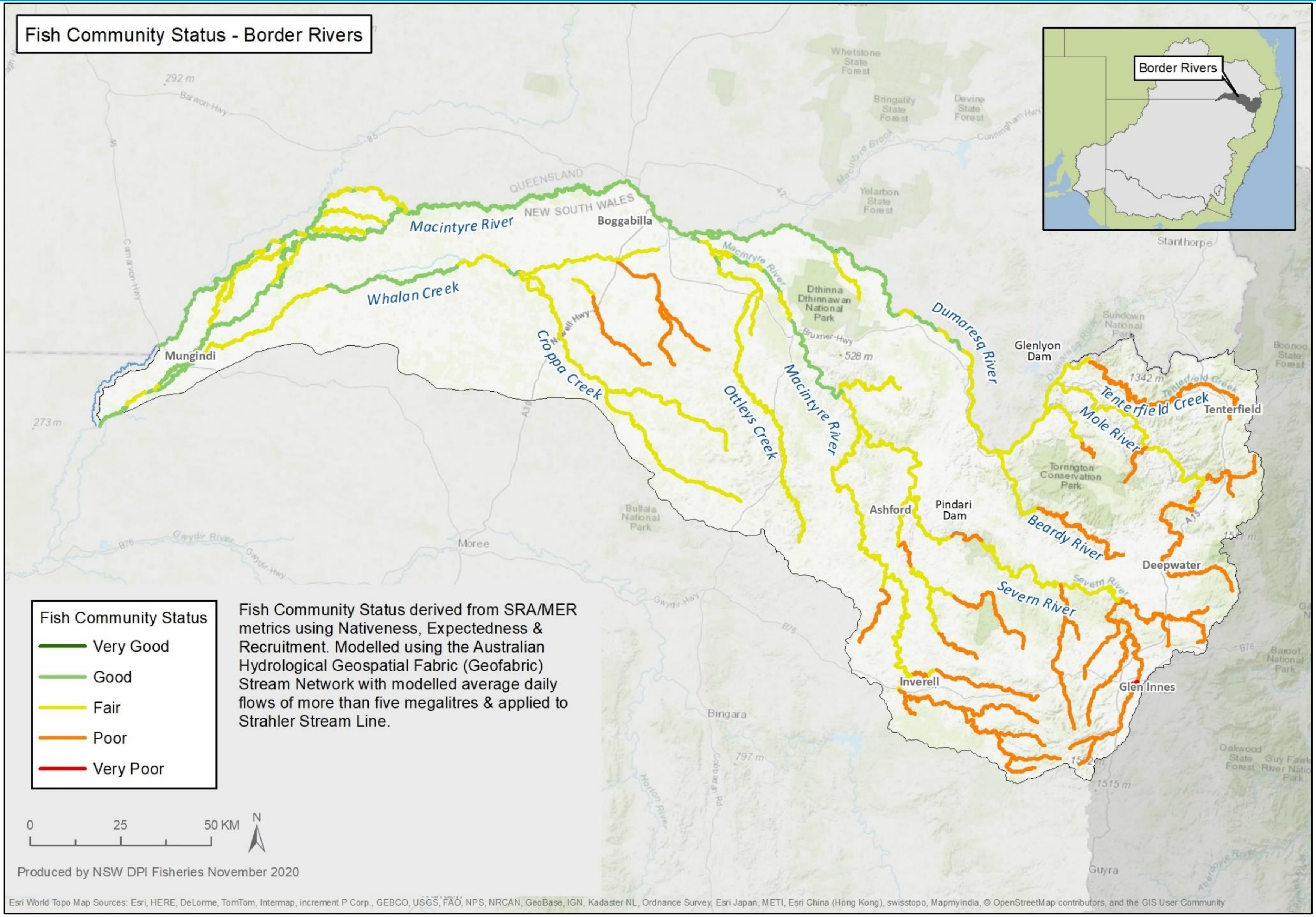


Figure 8. Fish community status for the Border Rivers, highlighting condition of fish communities (NSW DPI, 2020)

Fish functional groups in the Macintyre River

Native fish in the Murray-Darling Basin have evolved in a highly variable system that is characterised by extreme environmental conditions with diverse wetting and drying cycles (Humphries *et al.* 1999; Baumgartner *et al.* 2013a). As a result, native fish species of the Murray-Darling Basin have developed a range of spawning and recruitment behaviours, consequently, it is highly unlikely a single flow regime would provide equal benefits for the fish community of a system (Baumgartner *et al.* 2013a; NSW DPI, 2013a). Flows influence fish differently throughout their life history (Figure 9), as such it can be assumed is that native fish have adapted to cope and thrive with the high level of natural flow variability experienced in the project area and as such the system should be managed to maintain a level of variability.

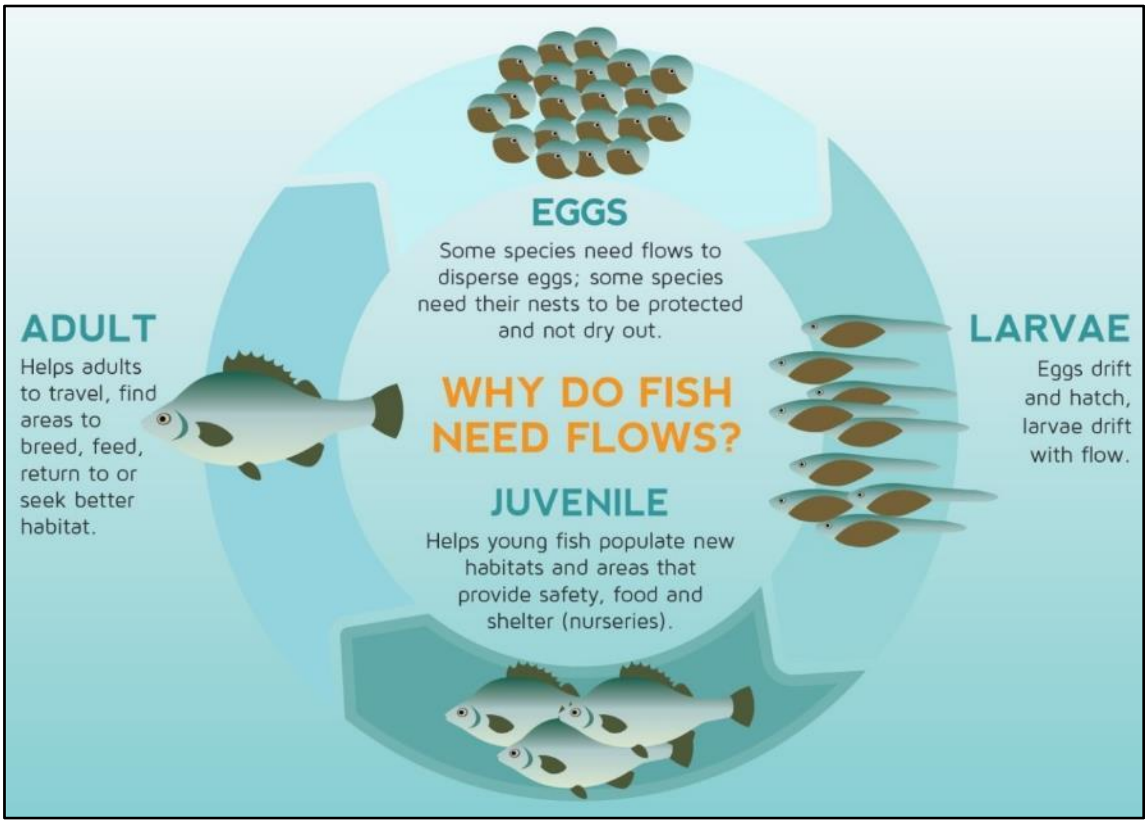


Figure 9: The influence of flows on the different stages within the life-cycle of a fish (adapted from MDBA, 2014).

To enhance native fish outcomes, fish species can be classified into functional groups based on flow related attributes (Baumgartner *et al.* 2013a). This has been recognised as a method for simplifying flow requirements for fish allowing more effective management of environmental flow delivery and/or flow protection from extraction (Baumgartner *et al.* 2013a; Mallen-Cooper and Zampatti, 2015).

During the Northern Basin Fish and Flows project, NSW DPI Fisheries developed four functional groups of native fish (including two sub groups) combining elements of the reproductive spawning-movement and eco-hydraulic guilds (Mallen-Cooper and Zampatti, 2015; NSW DPI, 2015; Ellis *et al*. 2016). The degree of benefit of an environmental flow depends on the species with the main drivers being the timing, volume and duration of the flow (Baumgartner *et al.* 2013a). Considering the environmental water requirements of a functional group allows flows to be developed that target specific groups of species with similar flow requirements.

The functional groups identified for species in the Macintyre River were adapted from the Northern Basin Fish and Flows report with consideration of more recent work by Kerr *et al.* (2017) and the Queensland Department of Natural Resources, Mining and Energy (2018) for defining stable low-flow spawning fish (Table 4). Functional groups were established in consultation with experts to assist in the development of specific long-term environmental watering requirements and flow related management actions (NSW DPI, 2015). The elements considered in development of these groups in the Northern Basin Fish and Flows project (NSW DPI, 2015) included:

1. Cues for migration (dispersal and recolonisation) and spawning (temperature and/or flow).
2. Spatial scales of spawning and dispersal movements (10’s – 100’s of m; 100’s of m – 10’s of km; 10’s – 100’s of km).
3. Reproductive mode and fecundity (e.g. broadcast spawning, nesting species, adhesive eggs).
4. Spawning habitats in still/slow-flowing water or in fast-flowing habitats.
5. Egg hatch time (short 1 – 3 days; medium 3 – 10 days; long > 10 days) and egg morphology.
6. Scale of larval drift and recruitment.

Knowledge gaps need to be acknowledged when using the functional groups approach. Assumptions and limitations must be considered when using this information, as well as noting that the fish functional groups should be reviewed and revised as needed when new information becomes available. As mentioned above the more recent work by Kerr *et al.* (2017) and DNRME (2018) have helped inform iterations for the functional groups.

Table 4: Fish guild groupings for species in the Macintyre River (adapted from NSW DPI, 2015).

Functional Group	Species	Attributes and implications for flow management
Group 1: Flow-dependent specialists	Golden perch Silver perch Spangled perch Hyrtl's tandan	• Flow pulses are needed to generate a spawning response. • Adult fish prepare for spawning in response to increasing water temperatures usually between spring and autumn, with research in the Northern Basin suggesting that the first post-winter flow pulse may be important for pre-spawning condition and migration in some northern systems (Marshall, *et al.* 2016), but timing is not predictable, with otoliths from golden perch captured in Menindee showing recruitment from a winter spawning event (Ebner *et al.* 2009). • Adult fish can undertake moderate to large scale migrations (100s of m to over 1000 km) in response to increased flows and temperature but can delay spawning if conditions are not suitable, with species being medium to long-lived and not necessarily requiring annual spawning and recruitment events. • Flow events do not have to be large pulses, with small, sharp rises in flow (as little as <15 cm) also providing benefits and eliciting responses from species; however movement responses may be greater with larger (>2m) increases in flow (Marshall *et al.* 2016). • Eggs are either buoyant and pelagic or non-sticky and demersal with a short hatch time of up to 5 days, relying on flows for dispersal. • Larvae drift downstream over long distances for up to 20 days post spawning in perennial and intermittent systems (potentially shorter in highly intermittent systems with smaller flow pulses), with recruitment relying on flows for dispersal and conditioning.
Group 2: In channel specialists (Group 2A: Flow-dependent) (Group 2B: Flow-independent)	Murray cod (2A) Freshwater catfish (2B) Southern Purple Spotted Gudgeon (2B)	• Adult fish are believed to prepare for spawning in response to increasing water temperature however other favourable conditions may trigger spawning events. • Group 2A adult fish can undertake short to large scale migrations (10s of metres to 100s of kilometres) for spawning. • Group 2B species can undertake short to moderate scale migrations (10s of metres to 10s of kilometres) for spawning. • Group 2A species have a predictable spawning period from mid-winter to the end of spring, involving movement to increasing temperature and flow. Species are long-lived and do not necessarily require annual spawning and recruitment events,but may take many years for noticeable population improvements due to low fecundity. • Group 2B species have a spawning period from spring to autumn, but most commonly between spring and summer, which is independent of flow. Species are medium to long-lived and do not necessarily require annual spawning and recruitment events, but may take many years for noticeable population improvements due to low fecundity. • Nesting species, or have specific spawning substrate requirements (freshwater catfish), with increases in flow helping to maximise breeding opportunities by inundating additional spawning habitat. • Eggs are demersal with a relatively long hatch time of up to 14 days, requiring stable flow events during this period to avoid nest abandonment, desiccation or premature dispersal. • These species may have active or passive larval drift over short to moderate scales for up to 10 days, with recruitment generally relying on flows for dispersal and conditioning.

Group 3: Floodplain specialists	Olive perchlet*	• Adult fish are believed to prepare for spawning in response to increasing water temperature however other favourable conditions may trigger spawning events. • Adult fish undertake short scale migrations (10s of metres to 100s of metres) for spawning, potentially to off-channel habitats, where spawning takes place in still or slow-moving environments. • Relatively short-lived and have low fecundities, requiring regular spawning and recruitment events, with spawning between spring and autumn. • Have specific spawning substrate requirements (aquatic macrophytes), with increases in flow helping to maximise breeding opportunities by inundating additional spawning habitat, especially off-channel, which may also be reliant on water clarity (low turbidity). • Eggs are sticky and demersal, with an estimated hatch time of up to 9 days. • Recruitment and dispersal rely critically on flows that reconnect the channel to the nursery habitat including floodplain areas, with large flow events required post spawning.
Group 4: Generalists	Australian smelt Bony herring Carp gudgeon Murray-Darling rainbowfish Unspecked hardyhead	• These species are generally more resilient to extended low flow conditions having developed more flexible spawning strategies, and as such may be poor indicators of environmental flow effectiveness (MDBA, 2015); however, these species provide an important component of productivity in a system and food source for medium and large bodied species. • Adult fish are believed to prepare for spawning in response to increasing water temperature. • Adult fish move short distances (10s of metres to 100s of metres) over a wide range of hydrological conditions and are known to recruit under low flows all year round; however, spawning is most common between spring and summer. Species are short to medium-lived requiring regular spawning and recruitment events but may take many years for noticeable population improvements due to low fecundity. • These species may spawn more than once during the year, with low to moderate flow events that inundate in channel habitat, enhancing spawning conditions, providing the greatest benefits to these species. • Eggs are sticky and demersal with a hatch time of up to 10 days. • Larval drift is exhibited by the majority of species (except carp gudgeon and unspecked hardyhead) over short to moderate scales, with the recruitment of these species reliant on flows for dispersal and conditioning. • This group largely encompasses species described by Kerr *et al.* (2017) to be stable low flow spawning fish. For these species stable flow during the spawning and development phase is critical. Kerr *et al*. (2017) recommends river level height fluctuations not to exceed 5cm for 3 weeks during these phases.

***Olive perchlet are described as low flow spawning fish by Kerr *et al.* (2017) so will also likely respond to different stable low flow conditions if favourable habitat (dense macrophytes) are present.**

Methodology

Habitat mapping

Habitat mapping was undertaken by NSW DPI - Fisheries staff and used methods developed and implemented for similar projects in the Macquarie River (Industry and Investment, 2010), Horton River (NSW DPI, 2013b), Little River systems (NSW DPI, 2014b), Barwon-Darling Rivers (NSW DPI, 2015), Lachlan River (NSW DPI, 2016), Dumaresq River (NSW DPI, 2018a), Cudgegong River (NSW DPI, 2018b), Barwon River (NSW DPI, 2020), Lower Macquarie River (NSW DPI in press), Gwydir, Mehi and Carole Rivers (NSW DPI in press) and Lower Darling River (NSW DPI in press).

Project staff completed seven field trips to collect the project data between March and August 2020. Flows ranged from 4 ML/day to 697 ML/day (Figure 10).

Trip 1: 9 – 13th March 2020. 61 km of waterway from the start of the project area to “Mundine”, downstream of Goondiwindi. Mapping was undertaken in the powered boat, with flows ranging from 424 ML/day – 697 ML/day (Boggabilla Gauge).

Trip 2: 3 – 9th May 2020. 46.5 km of waterway mapped, from “Allaru” to the end of the project area. Mapping was undertaken using the boat, kayaks and on foot with flows from 113 ML/day – 240 ML/day (Kanowna and Mungindi gauges).

Trip 3: 24 – 29th May 2020. 37.5 km of waterway mapped, continuing on from where Trip 1 finished at “Mundine”. Mapping was undertaken on foot with flows from 73 ML/day – 98 ML/day (Boggabilla Gauge).

Trip 4: 21 – 27 June 2020. 41 km of waterway mapped, on foot, from the start of “Avymore”/”Norlin” to the Water Reserve in the middle of “Maplemoor West”. Flows were 64 ML/day – 152 ML/day (Terrewah Gauge) for first three (3) days of mapping, and 4 ML/day – 5 ML/day (Boomi Gauge) for the 4th and 5th days of mapping.

Trip 5: 5 – 11 July 2020. 46.5 km of waterway mapped, from the Water Reserve to “Koramba” (1 km downstream of Boonanga Bridge). Boomi weir pool was mapped by boat for 13 km, with the remainder of mapping undertaken on foot. Flows were 4 ML/day – 5 ML/day (Boomi Gauge).

Trip 6: 19 – 24 July 2020. 50.5 km of waterway mapped, from “Koramba” to “Maxvale”. Flows were 3 ML/day (Boomi Gauge) for the first 3 days of mapping, and 51 ML/day – 56 ML/day (Kanowna Gauge) for the 4th and 5th days of mapping.

Trip 7: 2 – 7 August 2020. 43.5 km of waterway mapped, from “Maxvale” to “Allaru”, finishing where Trip 2 started. Flows were 26 ML/day – 27 ML/day (Kanowna Gauge).

Flow height variability is accounted for by subtracting the daily flow height above cease to flow at the relevant gauge, thereby determining a commence to inundate height for individual habitat features (i.e. LWH, benches, wetland entry exit, etc.). See sections “Management Reaches” and “Flow Relationships” for more information.

Where necessary, landholder permission was obtained to travel through and leave vehicles on their properties to access the river at the daily start and finish points. Subsequent opportunistic landholder liaison occurred by mapping staff as fieldwork progressed through the study area. All mapping on foot was undertaken on the NSW side of the river.

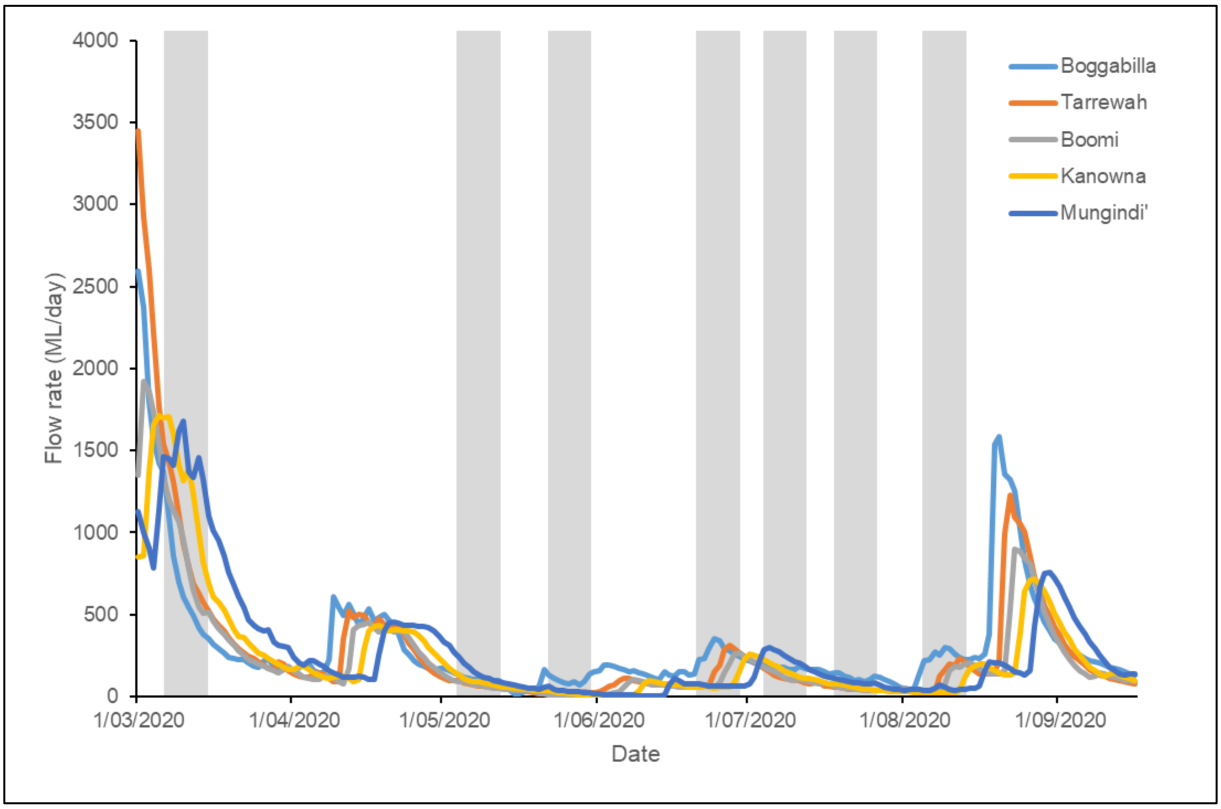


Figure 10: Flow plot analysis of the Macintyre River during field work component. Grey shading represents when field work took place.

Three methods of field data collection were used:

- GPS-equipped GIS interface for features above the water surface.
- When in the powered boat, a Hummingbird side-scanning sonar to identify refugia and generate sub-surface georectified imagery to identify Large Woody Habitat (LWH)
- When on foot and in kayaks, a Deeper Pro Smart Bluetooth equipped sonar to measure the depth of refugia

These three data compilation devices enabled the collection of all information necessary to record habitat features and their condition in both aquatic and riparian areas along the Macintyre River corridor in the project area (Figure 11).

Two 'Juno Nomad' Personal Digital Assistants (PDA) with GPS and GIS interface software, were used to record all relevant features visible above the water surface using the three spatial feature classes of point, line and polygon (Table 5).

To improve data collection efficiencies and standards, unique scripting codes were written by NSW DPI technicians to provide prescribed data entry drop-down menus specific to project requirements. This enabled all essential attributes for each recorded feature to be entered into the spatial database at the time of data collection.

Table 5: Typical features recorded on PDAs during habitat mapping.

Point Features	Line Features	Polygon Features
LWH - alignment, complexity, width, length, height Rootballs – height	Fence lines	Exotic riparian vegetation – type and extent
Pumpsites - pipe diameter		Aquatic vegetation – type and extent
Wetland/anabranch - height of entry/exit points		In-stream benches – height, substrate type and extent
Barrier to fish passage - barrier type, headloss		Refuge pools – depth and extent
General points of interest (e.g. boat launch sites, bushtucker)		Erosion
		Stock damage
		Riffles

Figure 11. Mapping Boomi weir pool. 6.5 km upstream of Boomi Weir, in the Boomi Management Reach, 6/7/2020. Flow rate was 151 ML/day.

Rootballs were defined as undercut/exposed root-masses of large trees located within the river channel, with the suitability of each rootball for fish habitat determined by the observer.

Wetland entries were recorded as the minimum stage height required for water from the main channel to inundate the entry into adjacent wetlands, including minor anabranches, billabongs, cuttings and creeks.

Area covered by exotic and native vegetation was recorded both in the aquatic and riparian zones of the project area. This included aquatic macrophytes, revegetation of native tree species and invasive weeds.

Aquatic refugia (refuge pools) were recorded as any section of channel equal to or deeper than three meters, as determined by sonar. Refugia were recorded in the field by observing stream geomorphology, when a pool was presumed to be deep enough to be considered a refuge the depth was measured using a Bluetooth-equipped sonar operated from the bank using a handline and smartphone, or when mapping was undertaken in the powered boat, channel depth was continually shown on the Humingbird sonar screen. The extent of refugia was recorded as a polygon, with its maximum depth also recorded. Post-fieldwork analysis was conducted and removed refugia within weirpool influence utilising data available in and existing Detailed Weir Review (DWR) (NSW DPI, 2006). The rationale for this removal is that refugia depth will vary significantly dependent on weir operations i.e. if the weirpool is drained completely to supply downstream reaches or kept as a drought reserve.

Benches were identified as areas of relatively flat substrate (vegetated and non-vegetated) within the main channel of the project area. The height, area and substrate type were recorded for each instance.

LWH were identified as anything larger than approximately 25 cm wide and 1.5 m long. The size, complexity and angle to the current of LWH was recorded. LWH complexity was recorded as more complex LWH provides exponentially greater protection to aquatic fauna from predators and flow, are more useful as breeding sites and have a greater influence on the creation and maintenance of refuge habitat (Boys, 2007 and Boys pers. comm. 2017). To capture this complexity data, each LWH was attributed a complexity grade 1 – 4, as determined by the guide shown in Figure 12.

Grade 1: Woody habitat stand - single trunk or branch

Grade 2: Woody habitat stand – trunk or branch with one or two branchings.

Grade 3: Woody habitat stand – one or more trunks with multiple branchings

Grade 4: Woody habitat stand – highly complex complete tree with multiple branchings, or accumulation of separate branchings

Figure 12: Structural complexity classes used to describe LWH during field work.

Management Reaches

Habitat features were separated into five Management Reaches according to the nearest gauging station. Table 6 and Figure 13 show the extent and location of Management Reaches.

Table 6: Project area Management Reach extent and the WaterNSW gauge used to determine daily flow and stage height.

Management Reach	Length (km)	WaterNSW gauge
Boggabilla	35.5	416002- Macintyre @ Boggabilla
Terrewah	88.7	416047- Macintyre @ Terrewah
Boomi	91.0	416043 - Macintyre @ Boomi
Kanowna	81.9	416048 - Macintyre @ Kanowna
Mungindi	29.8	416001 - Macintyre @ Mungindi

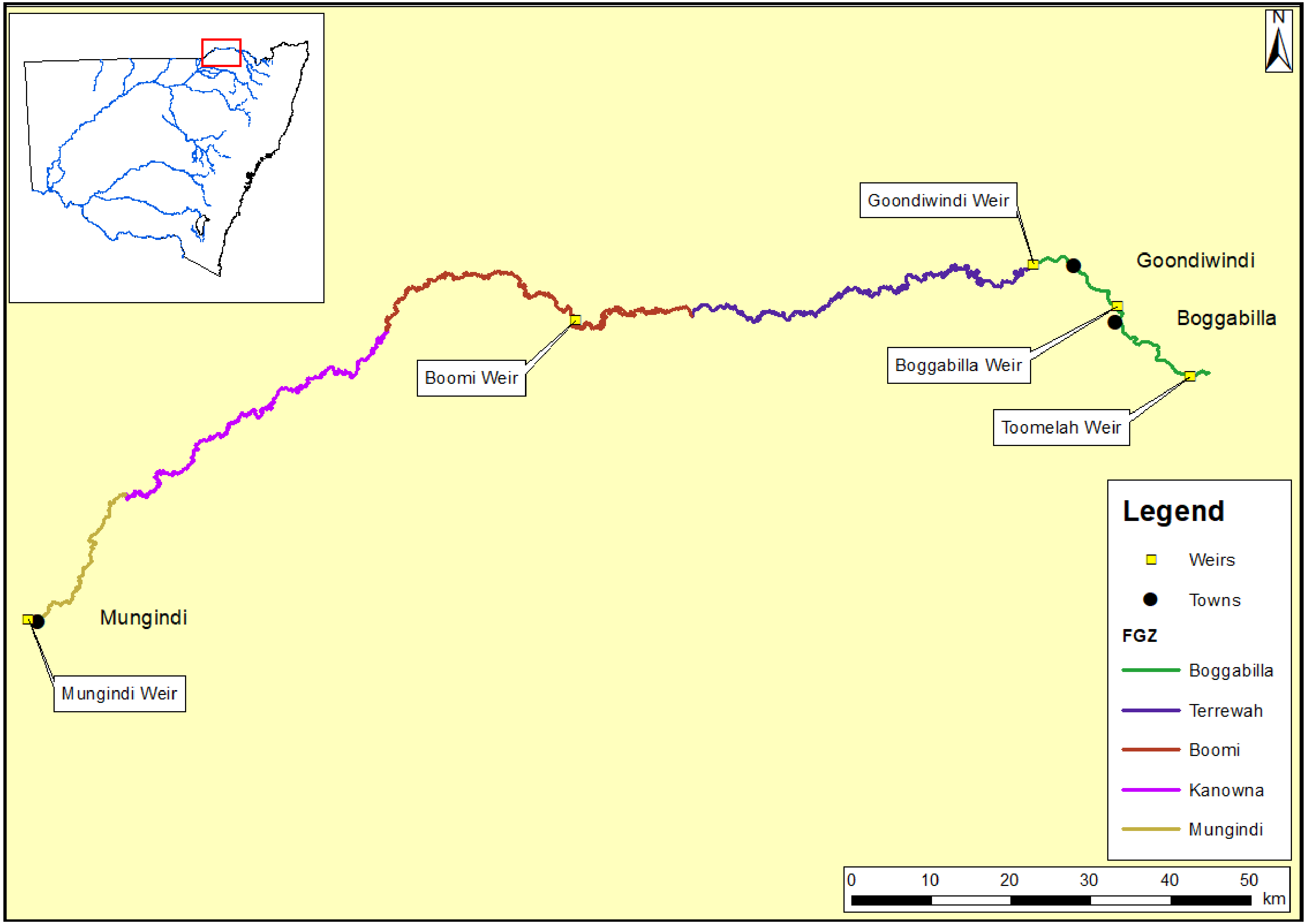


Figure 13: Management Reaches within the Macintyre habitat mapping project area

Flow relationships

To determine the inundation dynamics of LWH, benches and connected wetlands in the study area, the commence-to-inundate height (CTIh) was recorded during the habitat mapping component using methods established by Boys (2007) and Southwell (2008; Figure 14).

The method involved the use of a Haglof Vertex Laser VL400 hypsometer, which uses ultrasonic signals to obtain the range of the habitat feature from the instrument (r) and combines this with the angle of measurement obtained from a tilt sensor (a) to trigonometrically calculate the height of the feature above or below the instrument eye level (h_1), taking into consideration the height of the instrument above water level (o) to determine the height above water level (h_2).

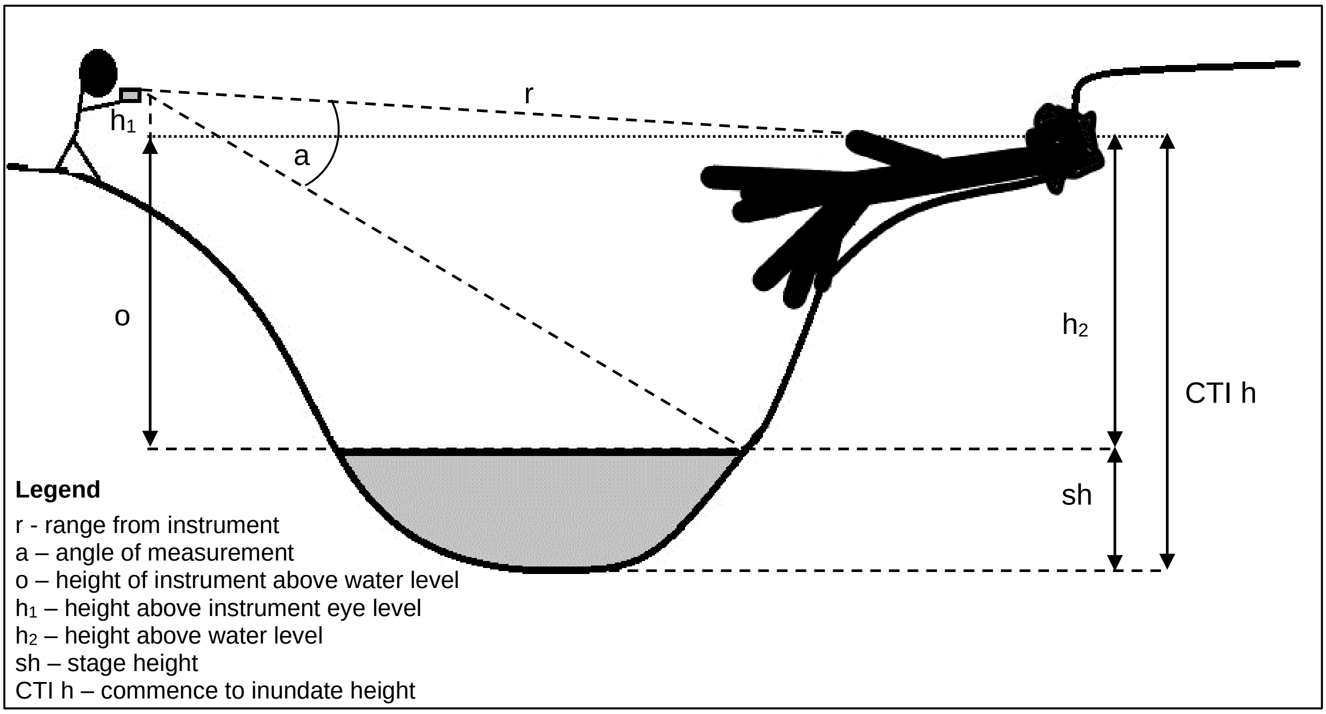


Figure 14: Schematic of methods used to calculate CTI heights of key habitat features along the Macintyre River.

LWH were recorded at the discretion of the observer, considering the geomorphology and knowledge of flow levels through the section of river; if a LWH was deemed too high to be inundated it was not recorded. The stage height (sh) of the river on the day of mapping was obtained from the relevant NSW gauging stations. The inundation height was then turned into an inundation level by using the known height/discharge curve for the relevant gauging station (Southwell, 2008).

It should be noted that due to the large distances encompassed in each of the Management Reaches, there is likely to be a decrease in confidence of accuracy in the inundation volume that is proportional to the distance from the relevant flow gauging station. Another potentially influence on calculating inundation volumes is the presence of weir pools of varying extents in each Management Reach, which may influence results due to persistently elevated water levels.

Habitat mapping results

Key findings

Riparian vegetation condition

- Excellent native vegetation coverage at all levels (upperstorey, midstorey and understorey) in the riparian zone.
- 12 gaps in native vegetation of more than 50 m.
- Common native vegetation species were:
  - Upperstorey: tea tree, river red gum, belah
  - Midstorey: tea tree, acacias, Lignum
  - Understorey: lomandra, Warrigal greens, spreading sneezeweed
- Good regeneration of tea tree; eucalyptus not seen successfully regenerating.

Exotic plant species

- Exotic species covered 16.7 ha, or 1.3% of the riparian zone area.
- Main species were castor oil plant, balloon vine, mesquite and mulberry.
- The following Weeds of National Significance were present: African boxthorn, prickly pear and tiger pear and crack willow.

Large Woody Habitat

- 17,837 LWH were recorded over the 327 km project area. This is an average load of 54.5 LWH/km.
- At baseflow, the availability of LWH was 7,261. This is an average load of 22.2 LWH/km.
- 6.2% of LWH were high complexity, 5.3 % grade 3 and 0.9 % grade 4.

Rootballs

- 1,761 rootballs were recorded over the 327 km project area. This is an average load of 5.4 rootballs/km.
- At baseflow, the number of rootballs available was 66, with 62 of these were in Boomi Management Reach.

Refugia

- 39 refuge pools were identified in the project area.
- Refugia are defined as ≥ 3 m at cease to flow level
- Average depth of refugia was 3.4 m.
- Distribution across the Management Reaches was not even, with Terrewah and Kanowna Management Reaches only having 5 and 2 refuge pools respectively.

Benches

- 2,757 benches were recorded across the project area, covering 116.8 ha.
- Most benches were comprised of silt. Sand benches were also common. Gravel, rock and cobble benches were present in smaller numbers.

Connected Wetlands

- 757 connected wetlands were recorded in the project area.
- These were mostly billabongs, anabranches, oxbow channels and longer floodrunners.

Aquatic macrophytes

- Aquatic macrophytes were present throughout the project area.
- Phragmites and lignum were the most abundant species, although most of the lignum recorded was on the floodplain, rather than the river channel.
- The Boggabilla and Terrewah Management Reaches had the largest extent of aquatic macrophytes.

Pumpsites

- A total of 316 pumps were recorded within the project area
- 103 pumps had intakes exceeding 250 mm, a result consistent with large-scale irrigation within the project area.
- Smaller pumps (< 250 mm) were concentrated around the townships of Goondiwindi and Boggabilla

Barriers to fish passage

- 9 artificial barriers were identified in the project area.
- Drown out flows ranged from 495 ML/day (Toomelah Weir) and 28,500 ML/day (Boggabilla Weir).
- 7 natural barriers were identified in the project area.
- Drown out flows varied from 89 ML/day to 855 ML/day.

Riparian vegetation condition

Riparian vegetation plays a key role in determining in-stream conditions with far reaching impacts on light penetration, water temperature and quality as well as habitat and food availability (Zalewski *et al.* 2001). Riparian vegetation also helps to buffer streams from catchment processes (Humphries and Walker, 2013), with fish abundance often associated with overhanging vegetation cover (Koehn, 2009). The presence of gaps in riparian vegetation has the potential to greatly impact fish populations with the loss of these processes and functions.

Based on the parameters used for the rapid appraisal of riparian condition method, gaps greater than 50 m in length were identified for this project; there were 12 gaps greater than 50 m in length of missing native riparian vegetation recorded. Five gaps were in the Boggabilla Management Reach, predominantly in proximity to the townships of Goondiwindi and Boggabilla. Seven gaps were located within the Terrewah Management Reach, predominantly on the outside bank of sweeping bends where heavy erosion was occurring. Upperstorey, midstorey and understorey native riparian vegetation was abundant and in good condition throughout most of the study area. Land use in the project area was mostly irrigated cropping, leaving a section of riparian zone between the irrigated paddocks and the river.

While a formal process was not used to identify or record plant species, the following observations were made by field staff during the habitat mapping component of the project:

Upperstorey native vegetation consisted mostly of tea tree (*Melaleaca* spp.), river red gum (*Eucalyptus camuldulensis*), and belah (*Casuarina cristata*) (Figure 15). Tea tree often lined the riverbanks and overhung the river; tea tree was also abundant on many lower benches, especially on the inside of bends. Belah occurred on the higher banks and lighter-coloured soil.

Midstorey species included tea tree, river cooba (*Acacia stenophylla*), lignum (*Duma florulenta*) and various other native shrubs.

Understorey vegetation included a mix of native and exotic forbs, grasses including lomandra (*Lomandra* spp.) and chenopods. Of the native forb species, the most common were warrigal greens (*Tetragonia tetragoniodes*) (Figure 16), spreading sneezeweed (*Centipeda minima* var. *minima*) (Figure 17) and knotweeds (*polygonum spp*.). During fieldwork the ratio of native to exotic forbs was observed to be approximately 50:50. Where the understorey contained lomandra, it often dominated and accounted for approximately 95% of understorey vegetation (Figure 18).

The habitat mapping was conducted on a receding flow, meaning that the banks had been wet prior to this study, and this may account for the proliferation of spreading sneezeweed as it tended to occur only on the sloping banks of the channel and the lower benches (Figure 17).

Warrigal greens occurred on benches of all levels of and lomandra was observed to occur mostly on higher benches. Chenopods (*Chenopodiaceae*) occurred on the higher banks.

The regeneration of key riparian species was recorded. Tea tree was observed to be successfully regenerating throughout the project area (Figure 20). Eucalyptus was not observed successfully regenerating; a small number of seedlings approximately 5cm high were observed, but no older seedlings or saplings were observed.

Patches of amulla (*Eremophila debilis*) were also observed, the larger of these patches being recorded for potential cultural interest (bush tucker fruit). Common twinleaf/gallweed (*Roepera apiculata*) was also observed growing beneath stands of belah (Figure 19).

Common exotic understorey species were: castor oil plant (*Ricinus communis)*, London rocket (*Sisymbrium irio*), lippia (*Phyla canescens*), wandering Jew (*Tradescantia fluminensis*), farmers friend/sticky beaks/cobblers pegs (*Bidens* spp.), blackberry nightshade (*Solanum nigrum*) and noogoora burr (*Xanthium occidentale*).

Figure 15. Tea trees overhanging the river, 9.2 km upstream of Mungindi Weir, 4/5/2020. Flow rate was 240 ML/day.

Figure 16. Warrigal greens and lignum providing ground cover in the riparian zone. 6.3 km downstream of Terrewah gauge, in the Terrewah Management Reach, 24/6/2020. Flow rate was 152 ML/day.

Figure 17. Spreading sneezeweed growing on the riverbank. 17.0 km downstream of Terrewah gauge, in the Boomi Management Reach, 25/6/2020. Flow rate was 9 ML/day.

Figure 18. Lomandra in the riparian zone. 6.8 km upstream of the Macintyre-Weir River confluence, adjacent to the property "Galtymore", in the Kanowna Management Reach, 8/5/2020. Flow rate was 91 ML/day.

Figure 19. Common twinleaf growing beneath belah in the riparian zone. Budelah Nature Reserve (2.4 km from the upstream nature reserve boundary), in the Kanowna Management Reach.

Figure 20. Melaleucas regenerating in the project area. 9.2 km upstream of Mungindi Weir (in the Mungindi weir pool), in the Mungindi Management Reach, 4/5/2020. Flow rate was 240 ML/day.

Exotic plant species

Exotic plant species compete with native vegetation, substantially changing the composition of riparian dynamics, impacting in-stream conditions and the fish communities present (NSW DPI, 2017b). Infestations of exotic plant species were noted throughout the project area, with several species recorded (Table 7). Where there were several species of exotics intermingled in large extents, they were recorded as mixed exotics, and this will slightly alter the data on the extent of the individual species, namely for boxthorn and mesquite. Residential gardens with various exotic species present were also recorded as mixed exotics.

No exotic aquatic plants were recorded during the fieldwork, although lippia – a floodplain invasive weed – was observed in depressions on the floodplain.

Exotic plant species were recorded throughout the project area, covering 16.7 ha, or 1.3 % of the riparian area. Castor oil plant was the most abundant exotic species, covering 5.0 ha and comprising 0.4 % of the riparian area; it frequently formed dense patches on lower benches on the inside of bends (Figure 21). Balloon vine was the second most abundant exotic species (Figure 22), covering 3.4 ha, followed by mesquite (2.8 ha) and mulberry (2.7 ha). Willows were predominantly located within the Boggabilla Management Reach, concentrated around the township of Goondiwindi.

Table 7: Exotic plant species and status in the study area.

Common Name	Scientific Name	Status
African boxthorn	*Lycium ferocissimum*	Prohibition on dealings** Regional Recommended Measure*** Weed of National Significance
Balloon vine	*Cardiospermum grandiflorum*	General Biosecurity Duty*
Black locust / false locust	*Robinia pseudoacacia*	General Biosecurity Duty*
Castor oil plant	*Ricinus communis*	General Biosecurity Duty*
Century plant	*Agave americana*	Not declared****
Fig	*Ficus carica*	Not declared
Giant reed	*Arundo donax*	Prohibition on dealings**
Lippia	*Phyla canescens*	General Biosecurity Duty*
Mesquite	*Prosopis spp.*	Regional Recommended Measure*** Weed of National Significance
Mulberry	*Morus spp.*	Not declared****
Noogoora burr	*Xanthium occidentale*	General Biosecurity Duty*
Palm	*Arecaceae spp.*	Not declared****
Prickly pear and *Opuntia* spp.	*Opuntia stricta* and *opuntia spp.*	Prohibition on dealings** Tiger pear (*Opuntia aurantiaca*) has a Regional Recommended Measure*** Weed of National Significance
Silky oak	*Grevillea robusta*	Not declared****
Wandering Jew	*Tradescantia fluminensis*	General Biosecurity Duty*
White cedar	*Melia azedarach*	Not declared****
Willows	*Salix spp.*	Weed of National Significance for crack willow Prohibition on dealings***: All species in the Salix genus have this requirement, except *Salix babylonica* (weeping willows), Salix x calodendron (pussy willow) and Salix x reichardtii (sterile pussy willow)

***General Biosecurity Duty**
All plants are regulated with a general biosecurity duty to prevent, eliminate or minimise any biosecurity risk they may pose. Any person who deals with any plant, who knows (or ought to know) of any biosecurity risk, has a duty to ensure the risk is prevented, eliminated or minimised, so far as is reasonably practicable.
****Prohibition on dealings**
Must not be imported into the State or sold
*****Regional Recommended Measure**
African boxthorn: Land managers should mitigate the risk of new weeds being introduced to their land. Land managers should mitigate spread from their land. Land managers reduce impacts from the plant on priority assets.
Mesquite: The plant should not be bought, sold, grown, carried or released into the environment. Exclusion zone: Land managers should mitigate the risk of new weeds being introduced to their land; the plant should be eradicated from the land and the land kept free of the plant. Core infestation: Land managers reduce impacts from the plant on priority assets.
Tiger pear: Land managers should mitigate the risk of new weeds being introduced to their land. Land managers should mitigate spread from their land. Land managers reduce impacts from the plant on priority assets. The plant should not be bought, sold, grown, carried or released into the environment.
******Not Declared**
While not having a status under the *Biosecurity Act 2015*, NSW DPI Fisheries recommends that these species be controlled due to the impact they are having on aquatic habitat

Figure 21. Castor oil plant growing on a low bench. 0.6 km downstream of Terrewah gauge, in the Terrewah Management Reach, 23/6/2020. Flow rate was 64 ML/day.

Figure 22. Balloon vine in the riparian zone of the Terrewah Management Reach. Image taken on 25/5/2020, flow rate was 9 ML/day.

Aquatic habitat

Large Woody Habitat

LWH is a major ecological and structural element of waterways, providing hiding and resting places for fish out the main flow of the river, and spawning sites and territorial markers for several native fish species (O'Connor, 1992; Lake, 1995; Crook and Robertson, 1999; NSW DPI, 2007; Koehn and Nichol, 2014). LWH also assist in developing scour pools and prevent erosion through bank stabilisation (Gippel, 1995; Brooks *et al*. 2004; NSW DPI, 2007). As in-stream wood breaks down it also provides food for benthic algae, invertebrates and microorganisms that form a large part of the food web for fish species (Treadwell, 1999; NSW DPI, 2007).

In the 327 km reach of the Macintyre River, 17,837 LWH were recorded, with an average loading of 54.5 LWH/km (Figure 23). The Terrewah, Boomi and Kanowna Management Reaches had a similar load of LWH/km (62.1, 58.8 and 62.5 LWH/km respectively), while the Boggabilla and Mungindi Management Reaches had a lower loading (19.9 and 38.7 LWH/km respectively). The relatively low loading of LWH within the Boggabilla and Mungindi Management Reaches may be the result of the large extent of deep weir pools within these reaches, which may reduce the rate of LWH deposition or inhibit observation. See Table 8 for the number and load (LWH/km) of LWH for each Management Reach. At baseflow, the availability of large woody habitat was 7,261 with an average loading of 22.2 LWH/km across the whole project area.

Most of the LWH recorded were simple complexity grade 1 and 2, with only a small amount (6.2%) being rated at grade 3 and 4, indicating that there is still room for improvement to maximise the benefits LWH provides in the system (Table 9; Table 10; Table 11; Table 12;

Table 13).

Table 8: Number of LWH identified in each Management Reach.

Reach	Reach Length (km's)	Number	Average per km
Boggabilla	35.5	707	19.9
Terrewah	88.7	5,505	62.1
Boomi	91.0	5,347	58.8
Kanowna	81.9	5,124	62.5
Mungindi	29.8	1,154	38.7

Table 9: Number and percentage of each LWH complexity group in the Boggabilla Management Reach.

Complexity	Number	Percentage (%)
1	578	81.8
2	110	15.6
3	19	2.7
4	0	0

Table 10: Number and percentage of each LWH complexity group in the Terrewah Management Reach.

Complexity	Number	Percentage (%)
1	3,720	67.6
2	1,520	27.6
3	224	4.1
4	41	0.7

Table 11: Number and percentage of each LWH complexity group in the Boomi Management Reach.

Complexity	Number	Percentage (%)
1	2,507	46.9
2	2,506	46.9
3	289	5.4
4	45	0.8

Table 12: Number and percentage of each LWH complexity group in the Kanowna Management Reach.

Complexity	Number	Percentage (%)
1	2,645	51.6
2	2,107	41.1
3	331	6.5
4	41	0.8

Table 13: Number and percentage of each LWH complexity group in the Mungindi Management Reach.

Complexity	Number	Percentage (%)
1	697	60.4
2	348	30.2
3	87	7.5
4	22	1.9

Figure 23. Grade 2 LWH available at very low flow in the project area. 30 km downstream of Goondiwindi Weir, adjacent to "Carbucky" in the Terrewah Management Reach, 28/5/2020. Flow rate was 21 ML/day at the Terrewah gauge.

Rootballs

Similar to LWH, rootballs provide important habitat to a range of terrestrial and aquatic species. Bank overhangs are often associated with rootballs and provide important cover and have been found to be used by Murray cod as breeding sites upstream of the project area in the Dumaresq River (Gavin Butler pers comm; Figure 24).

A total of 1,761 rootballs were recorded across the project area, with an average load of 5.4 rootballs/km. The Kanowna Management Reach had the highest load, with 8.0 rootballs/km, and the Boggabilla Management Reach had the lowest, at 2.6 rootballs/km. See Table 14 for the number and load (rootballs/km) of rootballs in each reach (Figure 25 - Figure 29)

At baseflow, 66 rootballs are available across the project area, although most (62) of these were in the Boomi Management Reach; some of these may have been formed before the weir was built and a weir pool (higher water level) was created.

The Boggabilla Management Reach, which was a wider channel and less sinuous reach, had the lowest load of both LWH and rootballs.

Table 14: Number of rootballs identified in each Management Reach

Reach	Reach Length (km's)	Number	Average per km
Boggabilla	35.5	94	2.6
Terrewah	88.7	456	5.1
Boomi	91.0	356	3.9
Kanowna	81.9	654	8.0
Mungindi	29.8	107	3.6

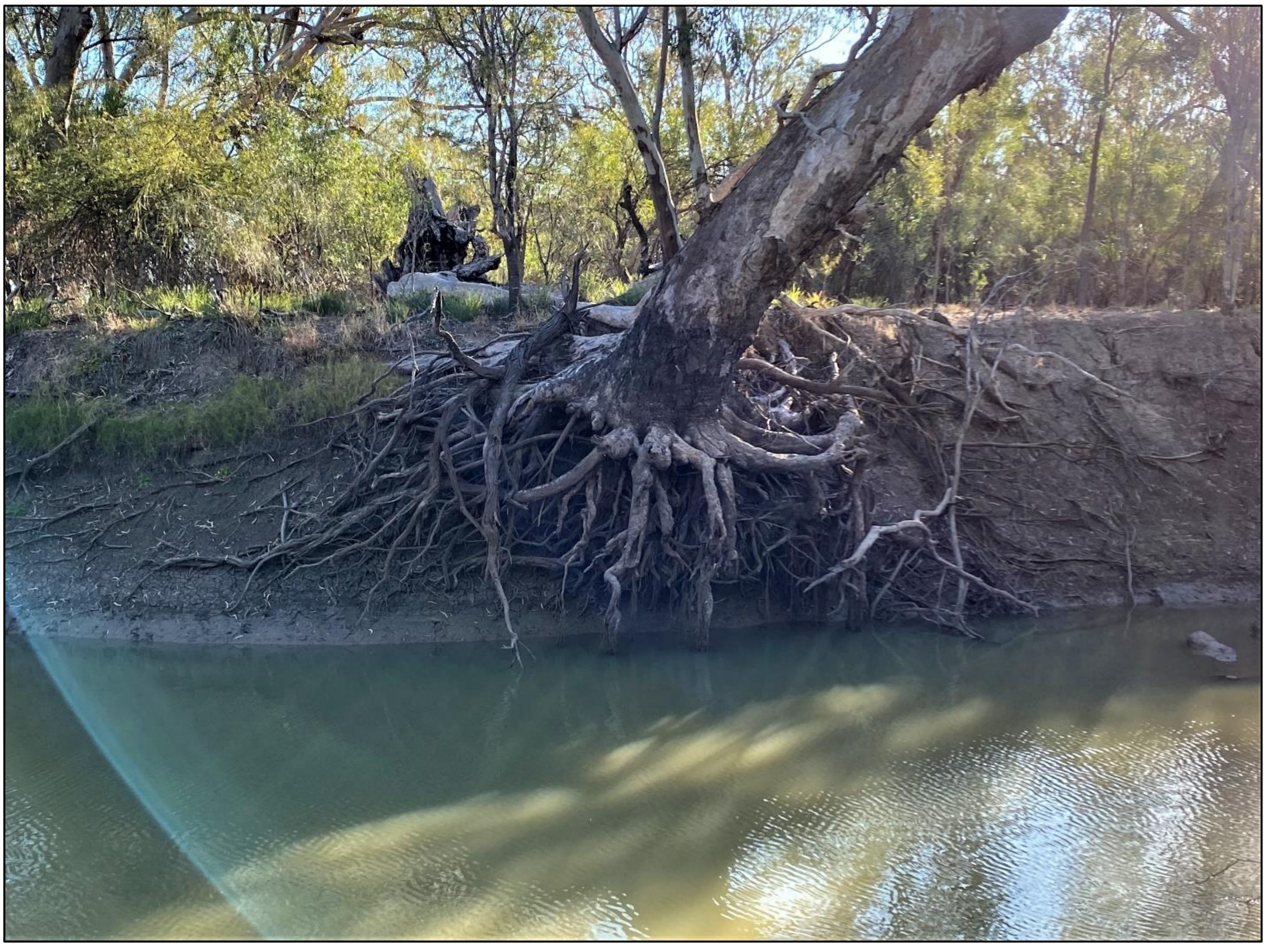


Figure 24. A rootball in the project area, 17.5 km downstream of the Kanowna gauge, in the Kanowna Management Reach. Image was taken on 3/8/2020, flow rate was 27 ML/day.

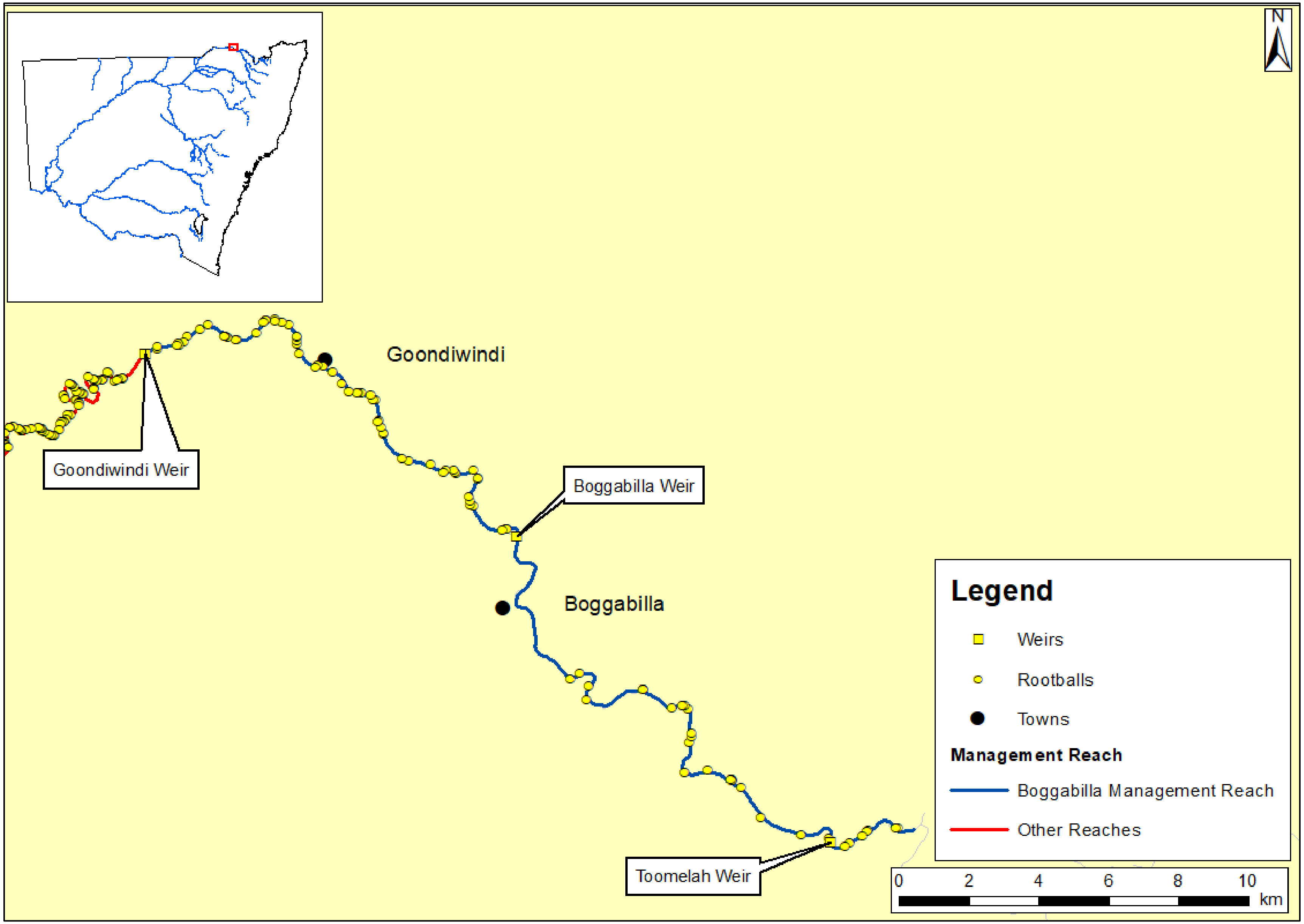


Figure 25: Location of rootballs recorded within the Boggabilla Management Reach

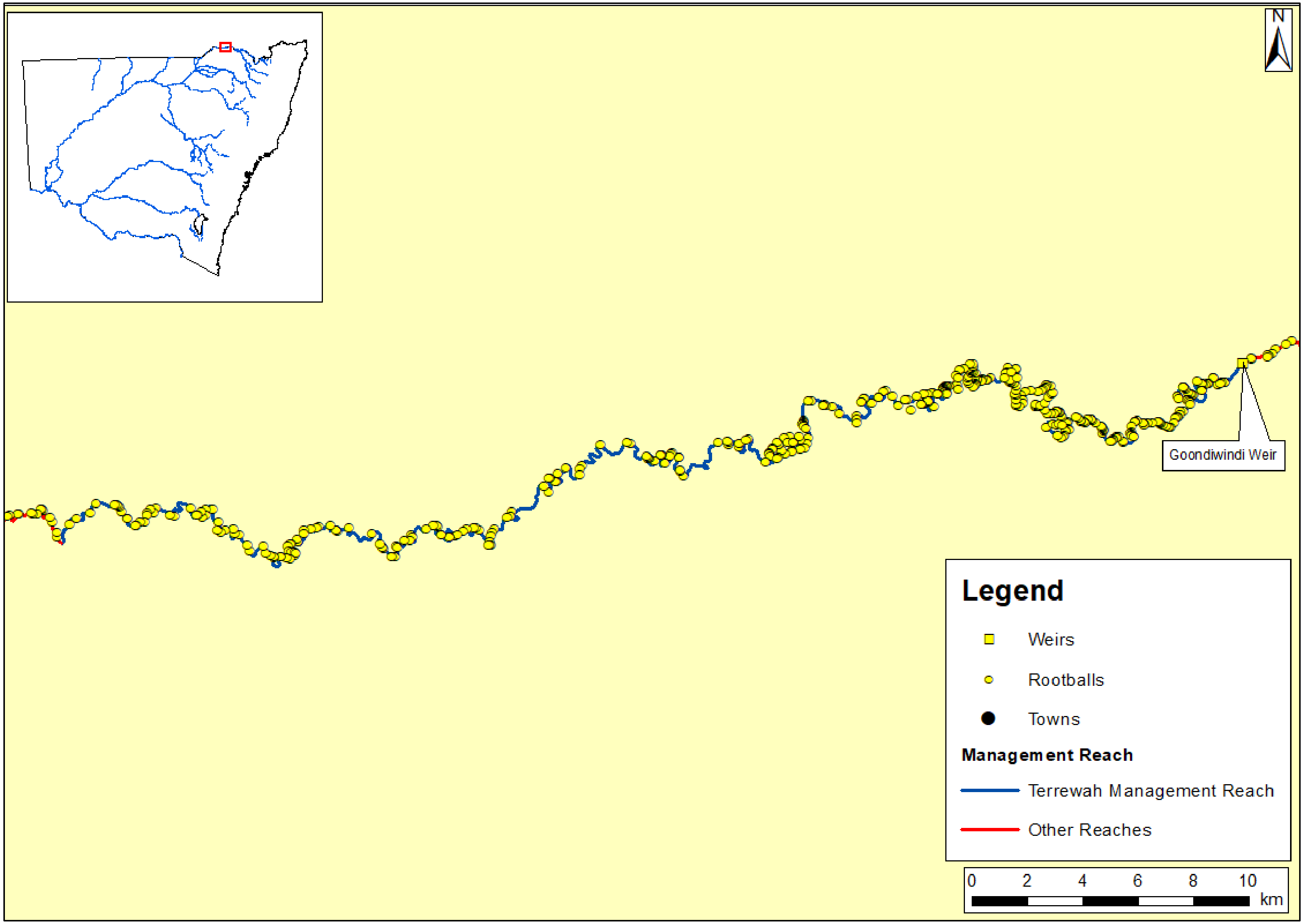


Figure 26: Location of rootballs recorded within the Terrewah Management Reach

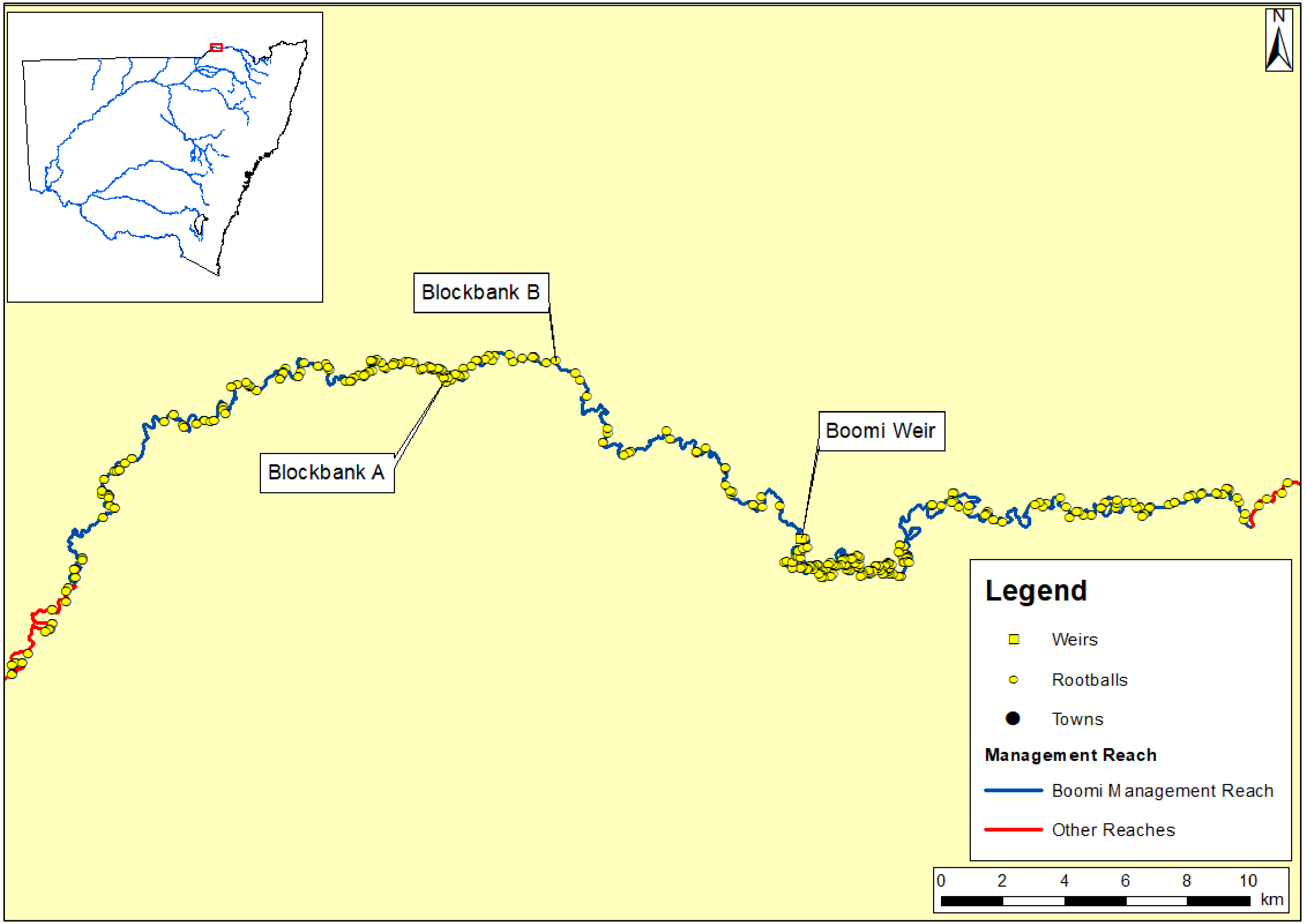


Figure 27: Location of rootballs recorded within the Boomi Management Reach.

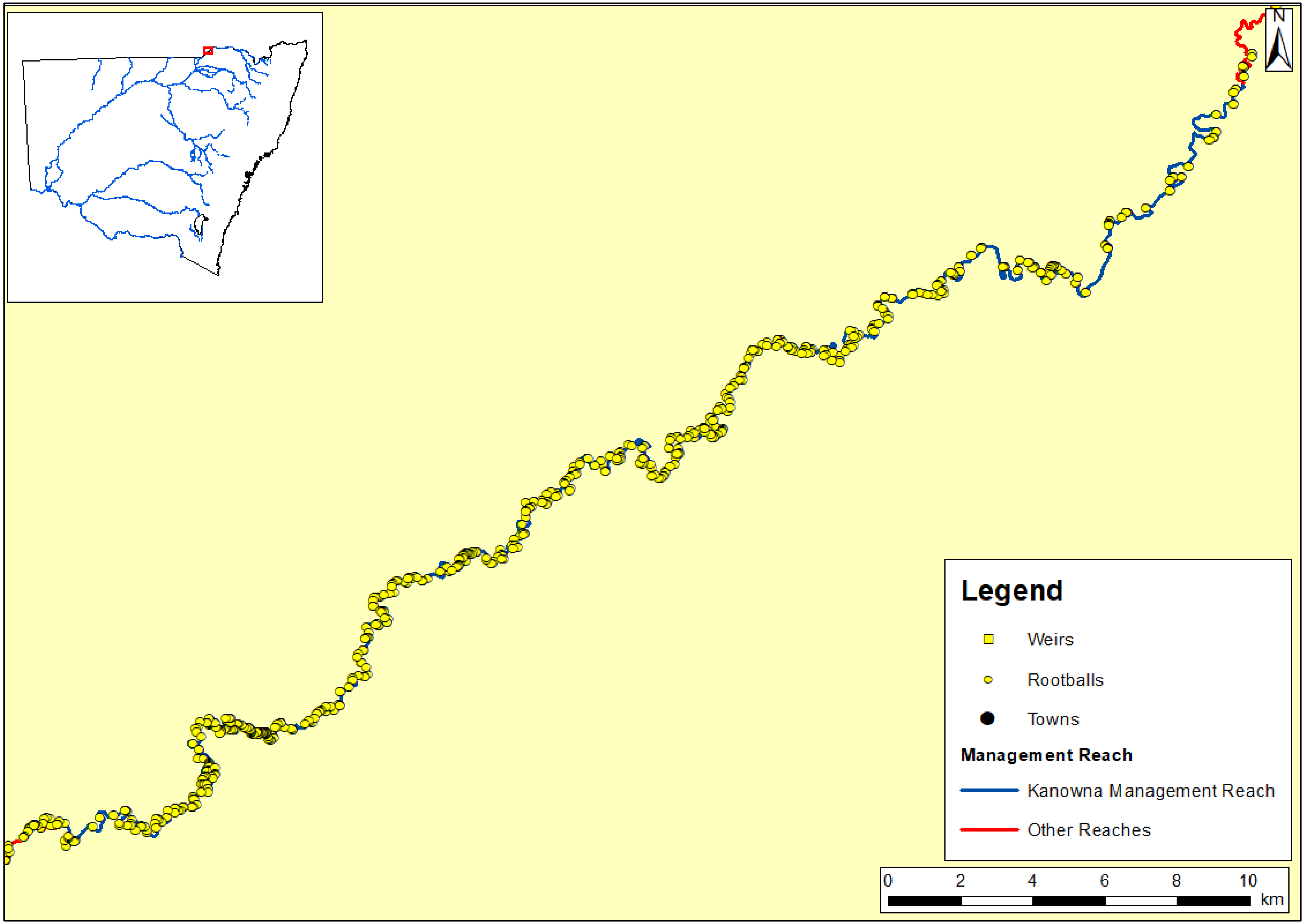


Figure 28: Location of rootballs recorded in the Kanowna Management Reach.

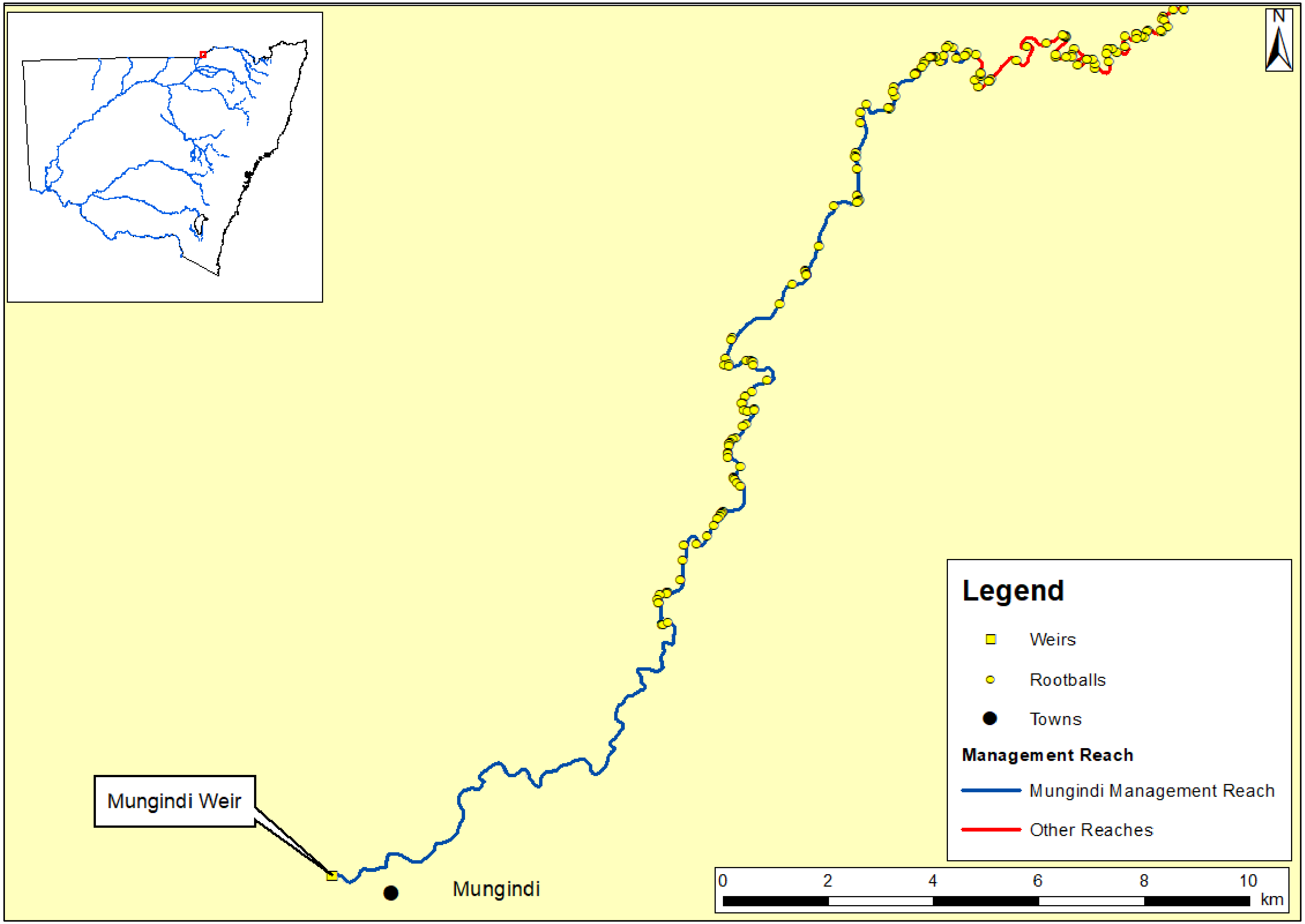


Figure 29: Location of rootballs recorded within the Mungindi Management Reach.

Refugia

For this project, refugia were defined as areas of water equal to or greater than three meters in depth during cease to flow conditions (Figure 30). Additionally, refugia located within weir pool influence were removed from the analysis due to difficulty in determining actual depth. Weir pools may provide significant refuge habitat to fish during cease to flow events, dependant on weir pool operations.

There were 39 potential drought refuge sites recorded across the project area, with an average depth of 3.4 m (Table 15 and Figure 31 - Figure 35). The locations of drought refugia were distributed across the project area, although distribution was not even. The Mungindi Management Reach had the highest occurrence of refugia, a total of 12 refugia covering a total of 16,804 m^2. Boomi Management Reach also had a high count of refugia at 17, however it had a lower density of refugia (97.8 m^2/km) than the Boggabilla management area (249 m^2/km). Kanowna had the lowest count of refugia, with only 2 refugia within its 82 km extent.

The average depth of refugia was consistent across all Management Reaches, ranging between 3.4 and 3.5 m. The deepest refugia recorded had a depth of 4.9 m and was located within the Boomi Management Reach.

Refuges are particularly critical in times of drought and understanding their location and extent allows targeted management actions to be implemented in a timely and efficient manner. Being able to target water quality monitoring at these refuge sites during dry spells would help the CEWO (and partner agencies) predict the likelihood of fish kills and critical times for drought replenishment flows. Refuge data from previous habitat mapping projects has played a key role in the NSW Native Fish Drought Response Framework as it has been used directly for targeting actions including the installation of aerators in identified refugia.

Table 15: Number, extent, extent/km and average depth of refugia identified in each Management Reach

Management Reach	Habitat count	Extent (m^2)	Average m^2 per km	Average depth (m)
Boggabilla	3	8,850	249.0	3.4
Terrewah	5	3,270	36.9	3.4
Boomi	17	8,894	97.8	3.5
Kanowna	2	276	3.4	3.4
Mungindi	12	16,804	563.1	3.5

Figure 30. Staff measuring the depth of a refuge pool using a portable depth sounder. 3.4 km upstream of the Macintyre-Gnoura Gnoura Creek confluence, in the Boomi Management Reach, 21/7/2020. Flow rate was 51 ML/day.

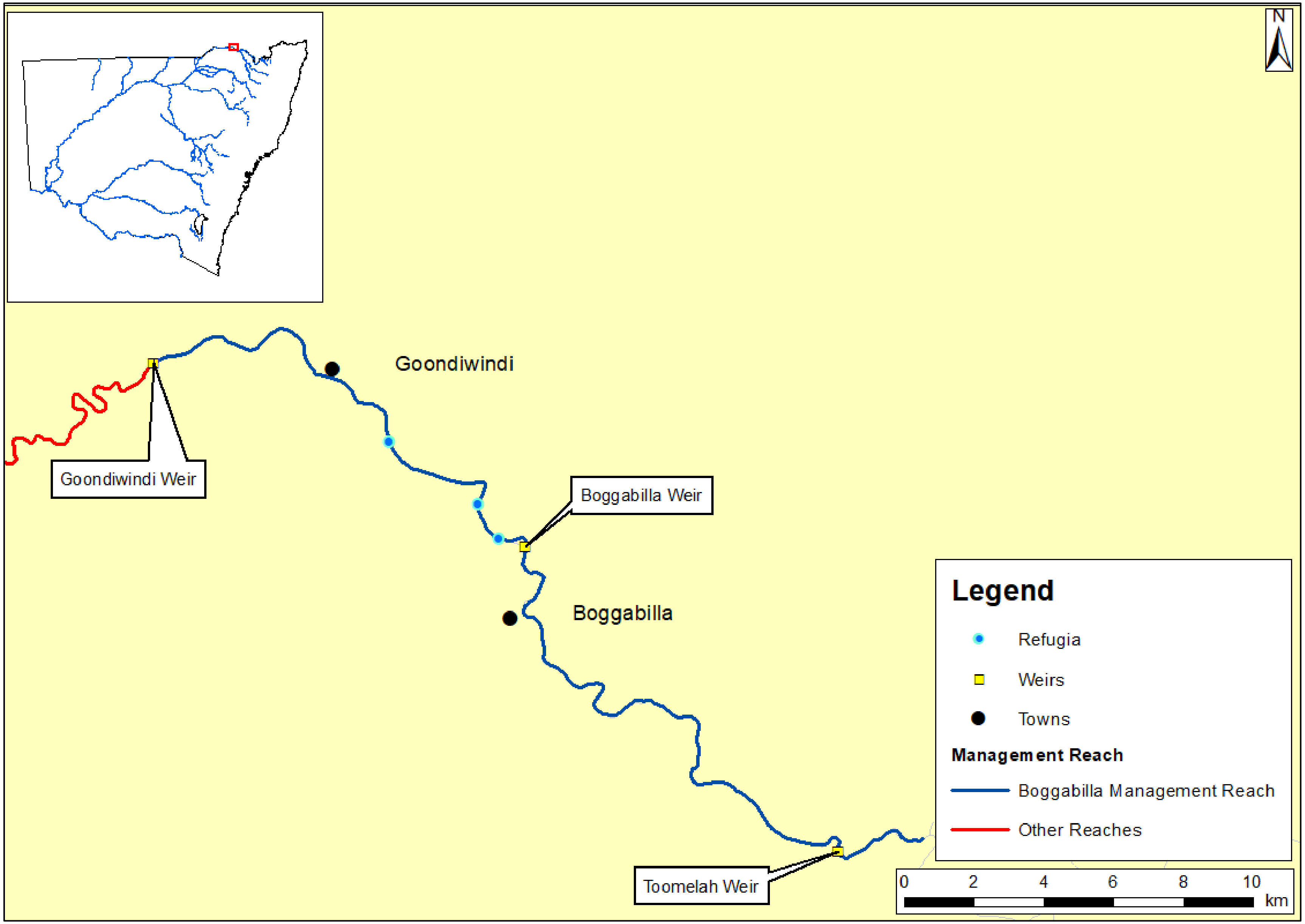


Figure 31. Location of refuge pools recorded within the Boggabilla Management Reach.

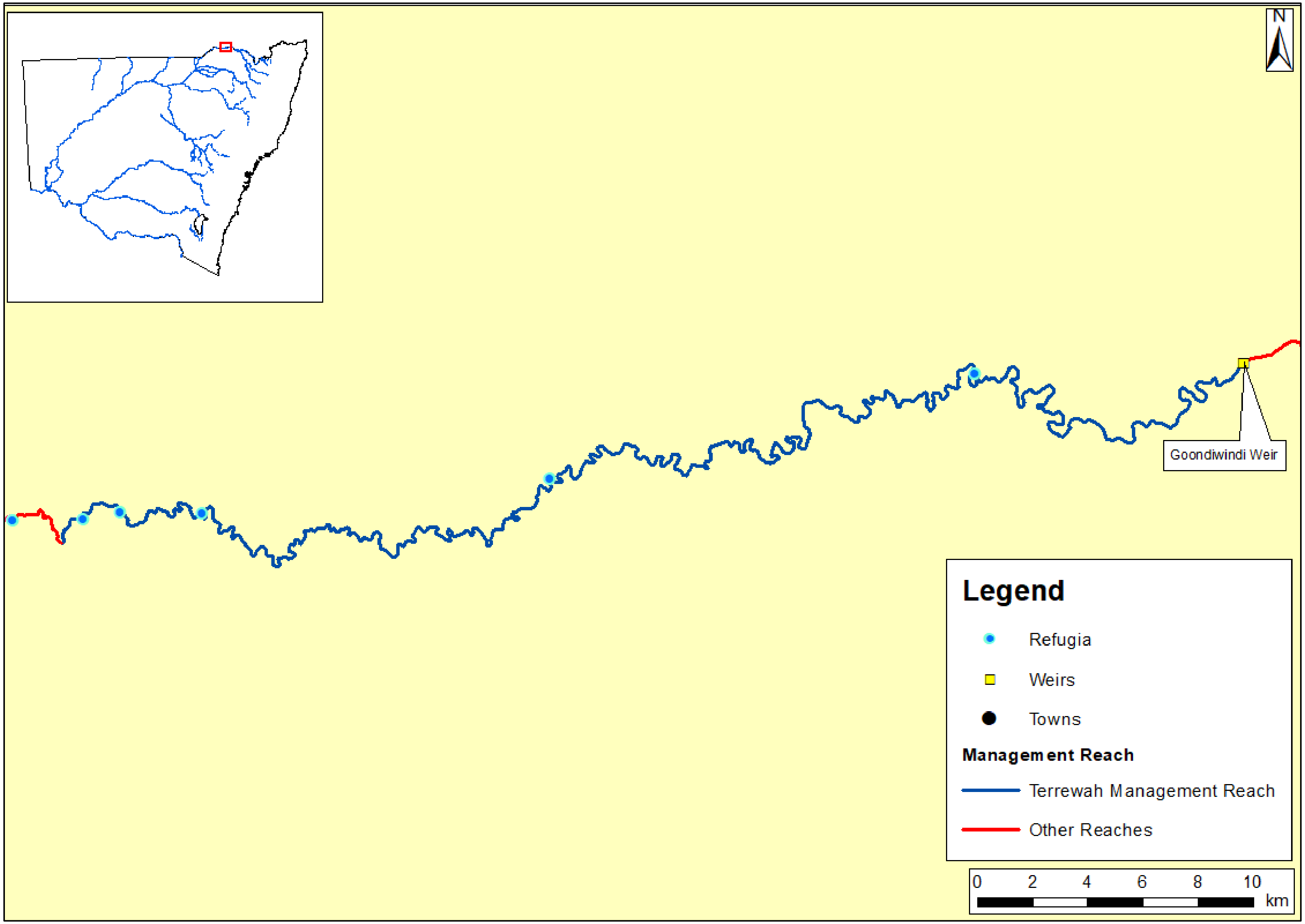


Figure 32. Location of refuge pools recorded within the Terrewah Management Reach.

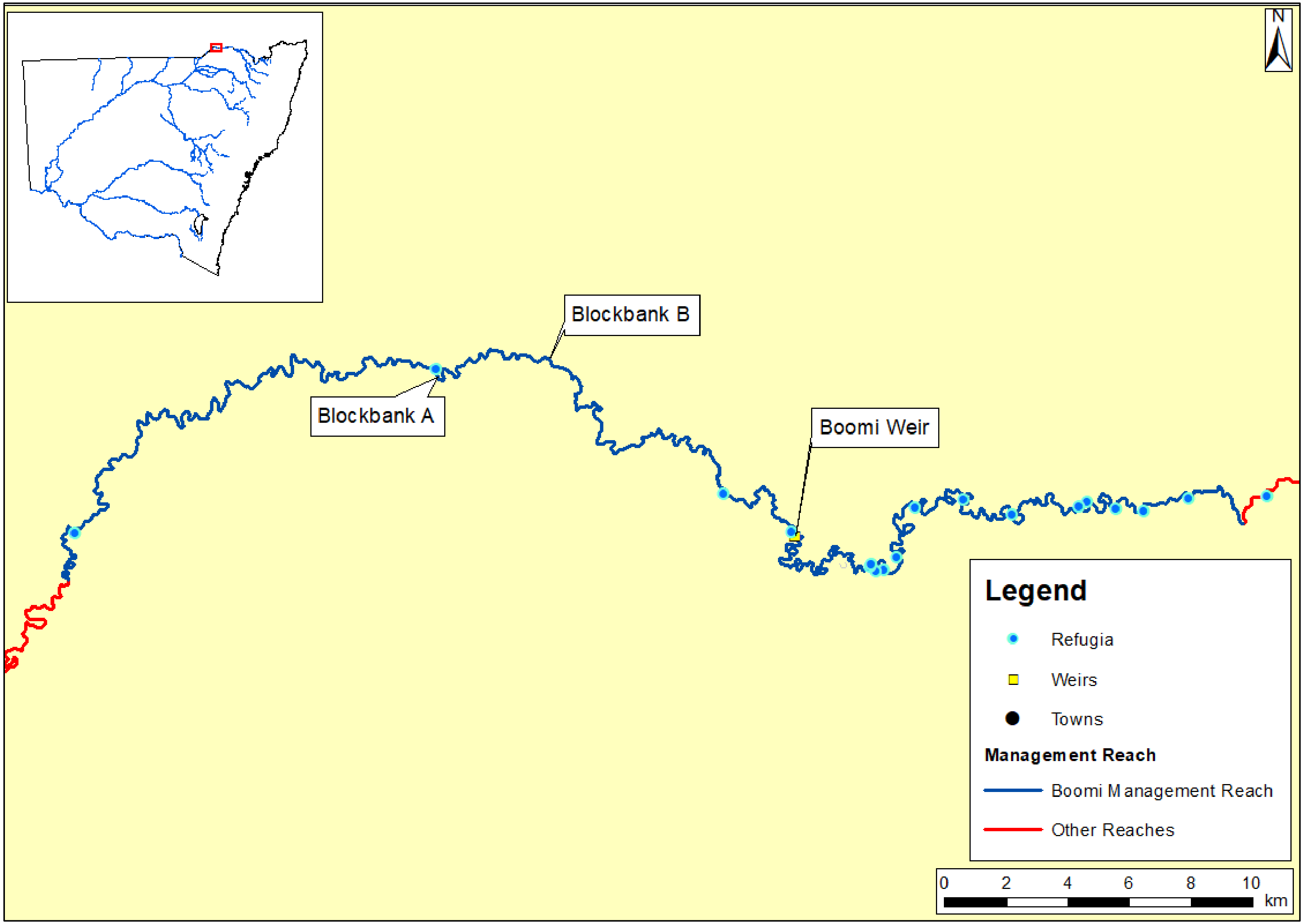


Figure 33. Location of refuge pools recorded in the Boomi Management Reach

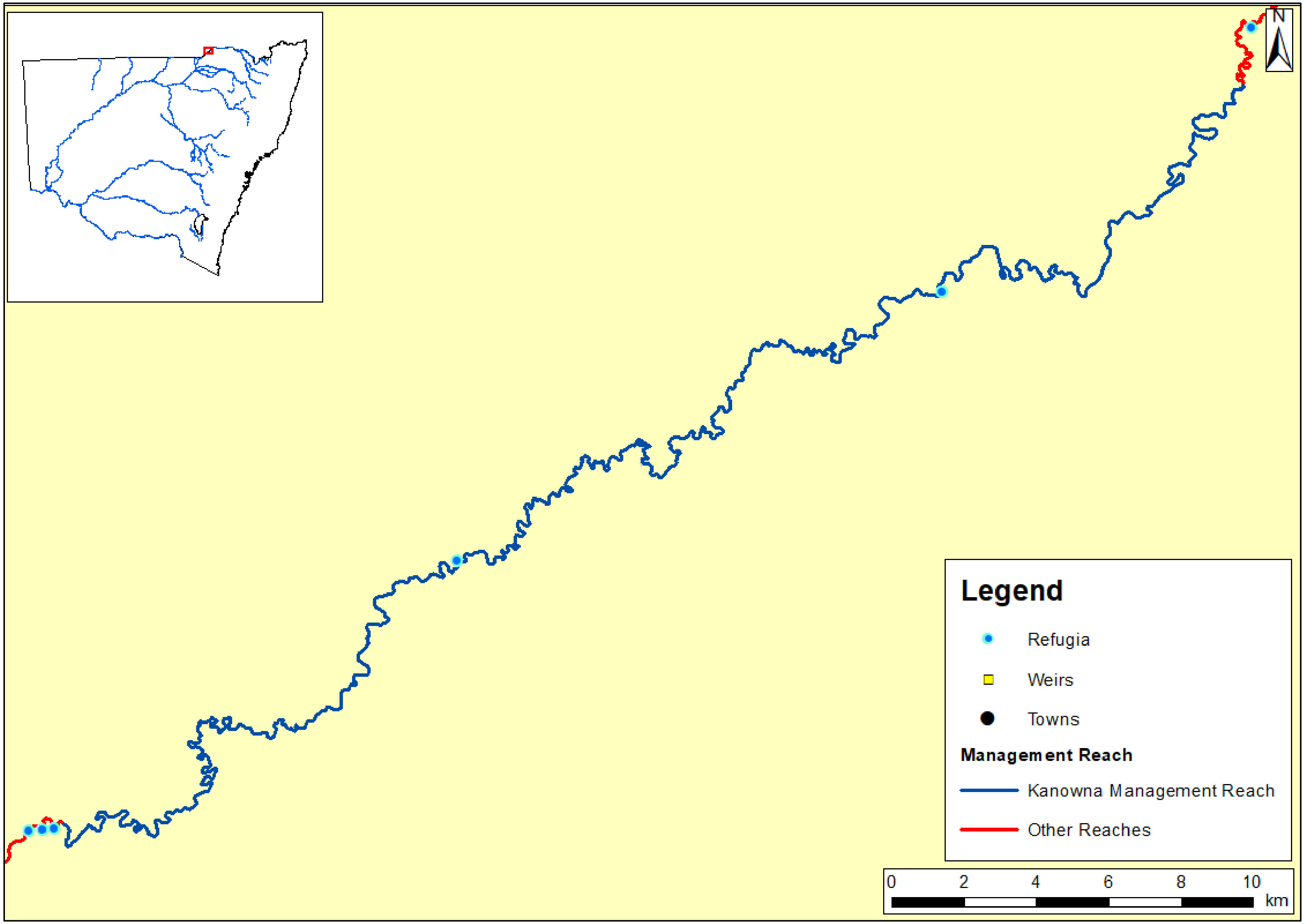


Figure 34. Location of refuge pools recorded in the Kanowna Management Reach.

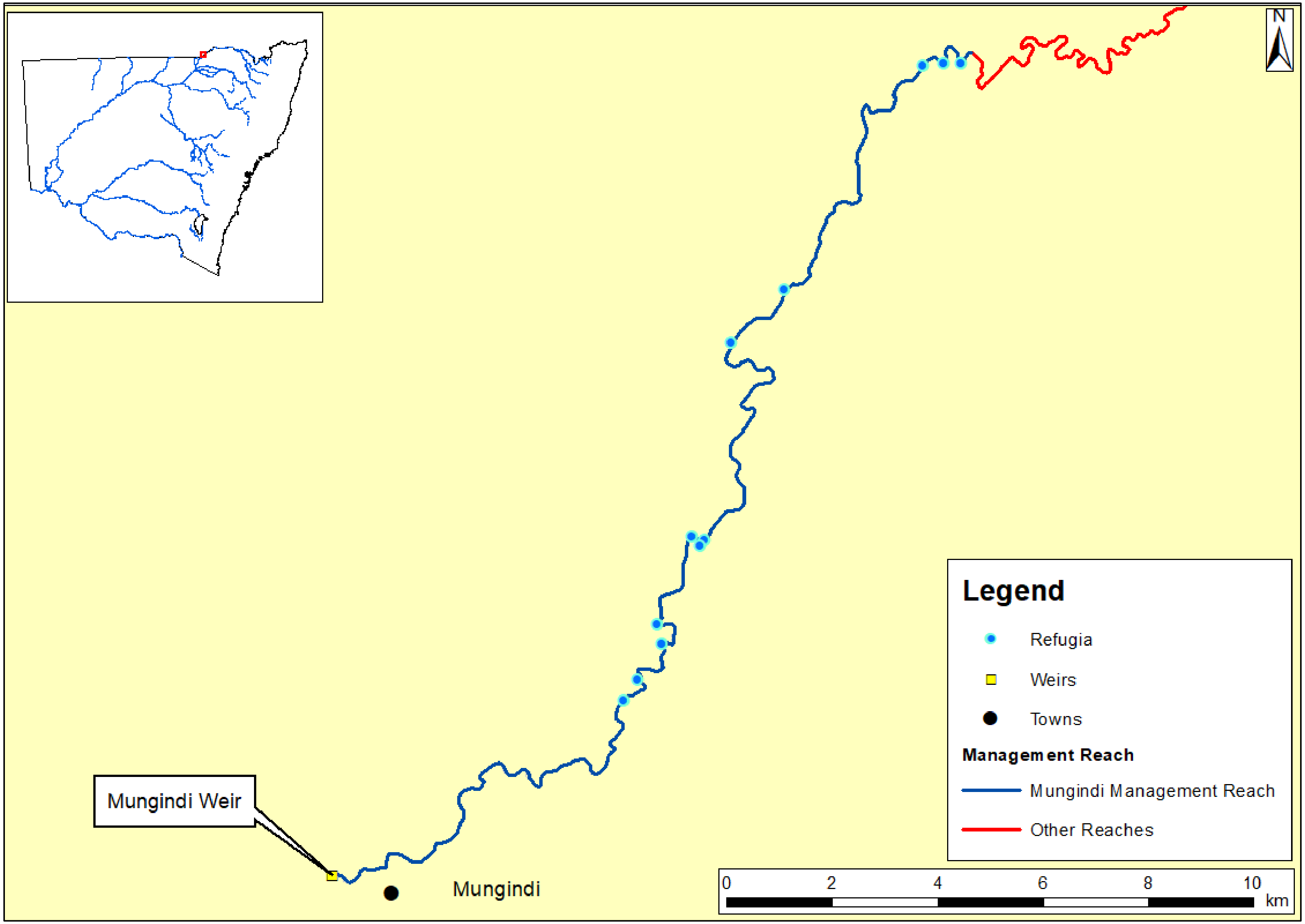


Figure 35. Location of refuge pools within the Mungindi Management Reach.

Benches

Benches are identified as areas of relatively flat sections within the main channel that play an important function in the aquatic environment by enhancing the diversity of habitat and contributing to productivity processes (NSW DPI, 2015). They are an actively accreting fine-grained bank attached feature within the river channel that influence flow and provide variation in water depth (Vietz *et al*. 2007). Benches play an important role in riverine ecology providing areas of varying levels that facilitate the accumulation of debris, sediment and nutrients, allowing the cycling of carbon, nutrients and food in the system (Southwell, 2008; Foster and Cooke, 2011).

There were 2,757 benches recorded in the project area covering a total of 116.8 ha. Benches were relatively evenly spread across the project area (

Table 16). The Boggabilla Management Reach had a much larger extent of benches, although this may be accounted for in part by mapping methodology. Most benches were comprised of silt, a large number consisted of sand, and a small number consisted of gravel, cobble or rock (indurated sediment). See Figure 36 for the different composition of benches. Gravel and cobble benches are particularly valuable in the project area as, when these benches are inundated, they provide the endangered freshwater catfish (Murray-Darling population) with material for constructing nests, where they lay and guard their eggs (Dyer *et al*. 2002). Figure 37 shows a cobble bed that is partially submerged, with higher flows this cobble bed could be used by freshwater catfish to build nest.

Table 16: Number and extent of benches identified in each Management Reach

Reach	Bench count	Extent (ha)	Extent (ha) per km
Boggabilla	167	34.6	7.4
Terrewah	1272	31.1	2.2
Boomi	498	11.0	2.0
Kanowna	423	16.4	3.2
Mungindi	397	23.7	1.8

Figure 36: Examples of silt and consolidated silt benches (top row), sand benches (2nd row), gravel benches (3rd row) and rock benches (bottom row) recorded in the project area.

Figure 37. Partially submerged cobble bench 43 km upstream of Terrewah gauge, in the Terrewah Management Reach, 26/5/2020. Flow rate was 21 ML/day.

Connected wetlands

Floodplain wetlands provide critical aquatic and riparian habitat for flood-reliant and flood tolerant flora and fauna, including important freshwater fish species such as olive perchlet, silver perch and golden perch (Rogers and Ralph, 2010; Saintilan and Overton, 2010). Wetland areas and associated smaller systems provide many imperative ecosystem functions, including filtering sediments, releasing nutrients and providing important breeding and nursery habitats for native fish (Beesley *et al.* 2012; Górski *et al.* 2013). Rolls and Wilson (2010) consistently found young of year golden perch and bony bream in floodplain wetlands, suggesting that they may be used as nursery habitats by flow dependent specialists (functional group 1) and generalists (functional group 4) species.

As noted in the Long-Term Water Plan, the anabranches of the Macintyre River are particularly important; situated below the floodplain, their wetting and drying cycles can maintain a base level of productivity to the mainstem of the river in between overbank flows (NSW DPIE, 2019b).

Most connected wetlands in the project area have a reduced inundation frequency due to river regulation. the benefits to fish and the critical ecological role they play may therefore have been diminished. In modelling developed by Thoms *et al.* (2005), the amount of organic carbon dissolved by anabranch connection (between Goondiwindi and Boomi) with the mainstem Macintyre between the simulated years 1900 and 1998 would be approximately 2,308 tonnes under natural conditions, compared to 908 tonnes if current conditions were applied to those years (Thoms *et al*. 2005). Recording the commence to inundate heights of wetlands and anabranches is particularly important for targeting lower-lying connected wetlands with environmental flows.

A total of 757 wetland entry and exit points were recorded in the project area. These were mostly billabongs, anabranches, oxbow channels, and floodrunners that were longer than approximately 50 m (Figure 38; Figure 39; Figure 40; Figure 41). Connected wetlands also included rivers and creeks. These different types of connected wetlands, with varying lengths and area, were not differentiated when recording the data. Most of the billabongs were connected to the river by a small (0.3 m – 0.8 m) depression in the riverbank and would be connected only on near bankfull flows and overbank floods or filled by rain events.

Connected wetlands were relatively evenly spread across the project area, except for the Boggabilla Management Reach having less than half the number of connected wetlands than the other reaches (Table 17 and Figure 42 - Figure 46). The river channel was wider in the Boggabilla Management Reach.

This reach is situated at the start of the floodplain and at a slightly higher elevation than the reaches downstream. The channel profile was likely to be having an influence on the lower number of connected wetlands recorded.

While there was no quantification of the wetland area attached to the entry and exit points recorded within this project, Thorns *et al.* 2005 identified 69 anabranches connection (total area of 586 ha) between Goondiwindi and Boomi Weir, covering nearly the equivalent surface area of the main channel (658 ha). Noting that Thorns *et al.* 2005 did not quantify additional connections such as billabongs and wetlands, it can be presumed that the connection of off stream habitat would significantly increase productivity and provide significant benefit to all native fish species, particularly floodplain specialist species. Future gains in spatial data (LiDAR) may assist in determining wetland area associated with wetland inundation points identified in this report.

Table 17: Number of connected wetlands identified in each Management Reach

Reach	Reach length (km)	Wetland count	Average per km
Boggabilla	35.54	31	0.87
Terrewah	88.71	180	2.03
Boomi	90.98	231	2.54
Kanowna	81.92	220	2.69
Mungindi	29.84	95	3.18

Figure 38: An oxbow channel. Approximately 7.5 km upstream of Terrewah gauge, in the Terrewah Management Reach, 22/6/2020.

Figure 39. Billabongs in the riparian zone on the floodplain. Left: 4.3 km upstream of Terrewah gauge, in the Terrewah Management Reach, 23/6/2020. Right: 19.4 km downstream of Terrewah gauge, in the Boomi Management Reach, 26/6/2020.

Figure 40. Billabongs in the riparian zone on the floodplain. Top: 15.4 km upstream of Terrewah gauge, in the Terrewah Management Reach, 22/6/2020. Bottom: The Water Reserve, 35 km upstream of Boomi Weir in the Boomi Management Reach, 26/6/2020.

Figure 41. Billabongs in the riparian zone on the floodplain. Top: 16 km upstream of Boomi Weir, in the Boomi Management Reach, 7/7/2020. Bottom: 0.1 km upstream of the start of Boomi River, in the Boomi Management Reach, 8/7/2020.

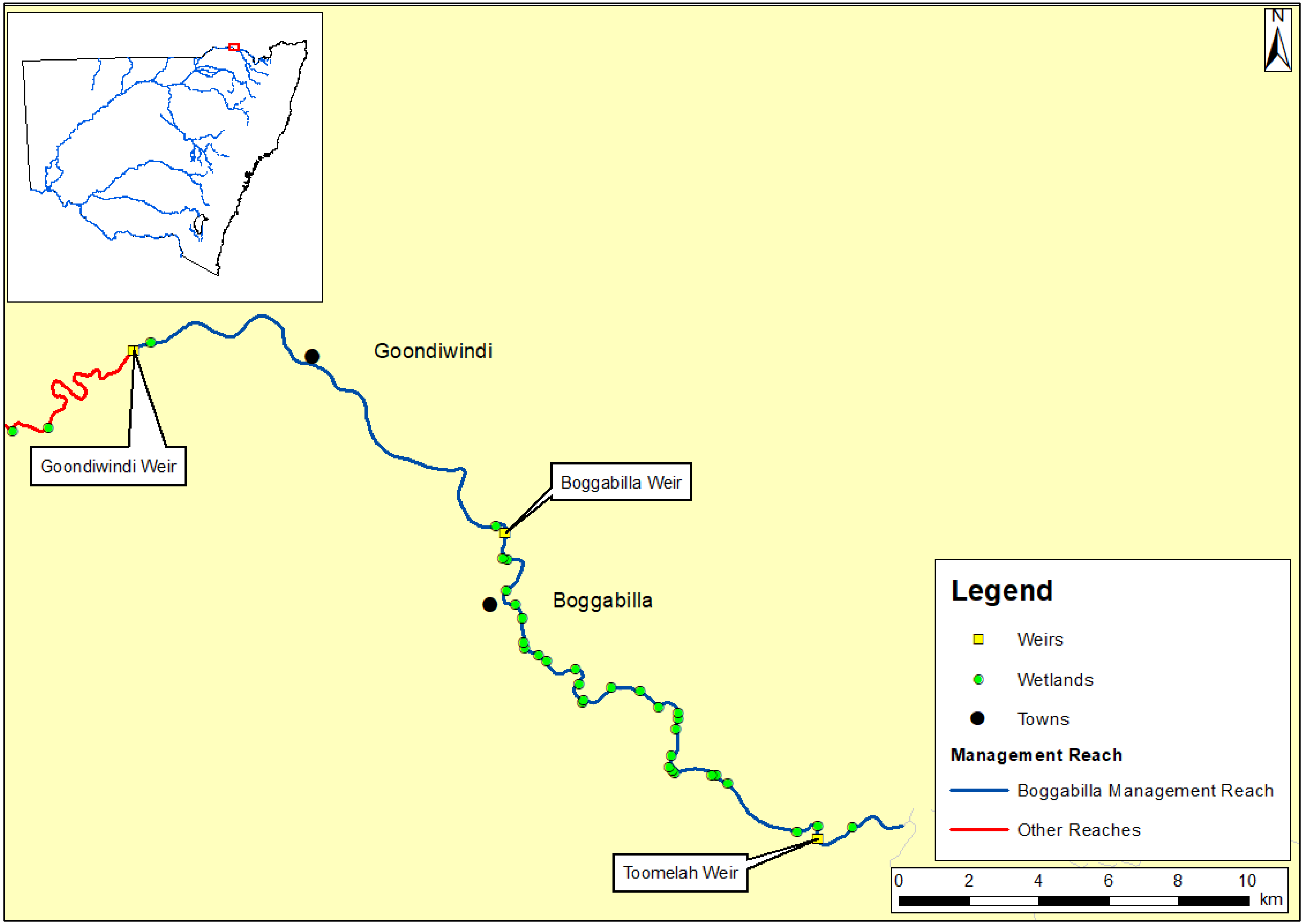


Figure 42. Location of wetland entry points recorded within the Boggabilla Management Reach

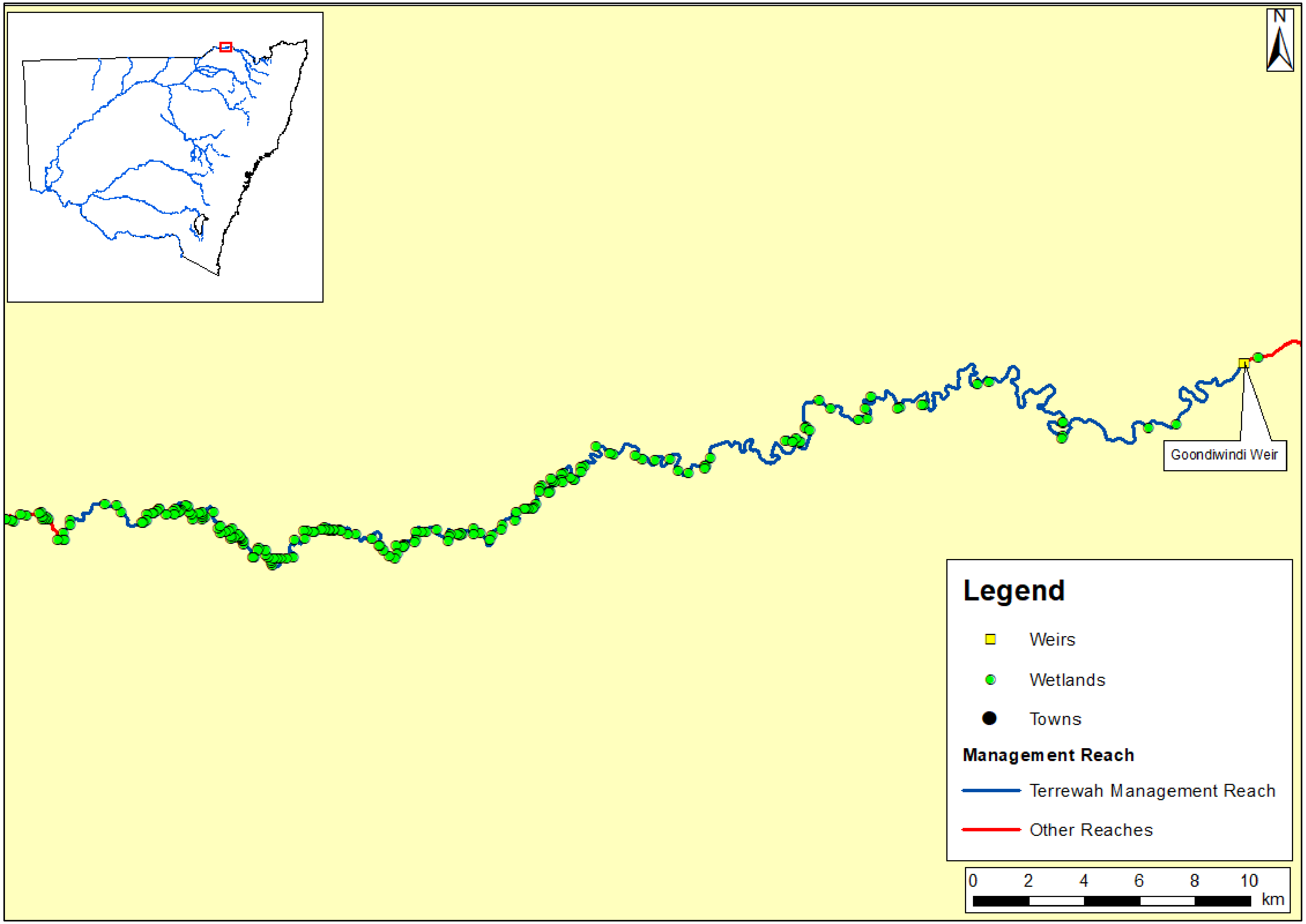


Figure 43. Location of wetland entry points recorded within the Terrewah Management Reach

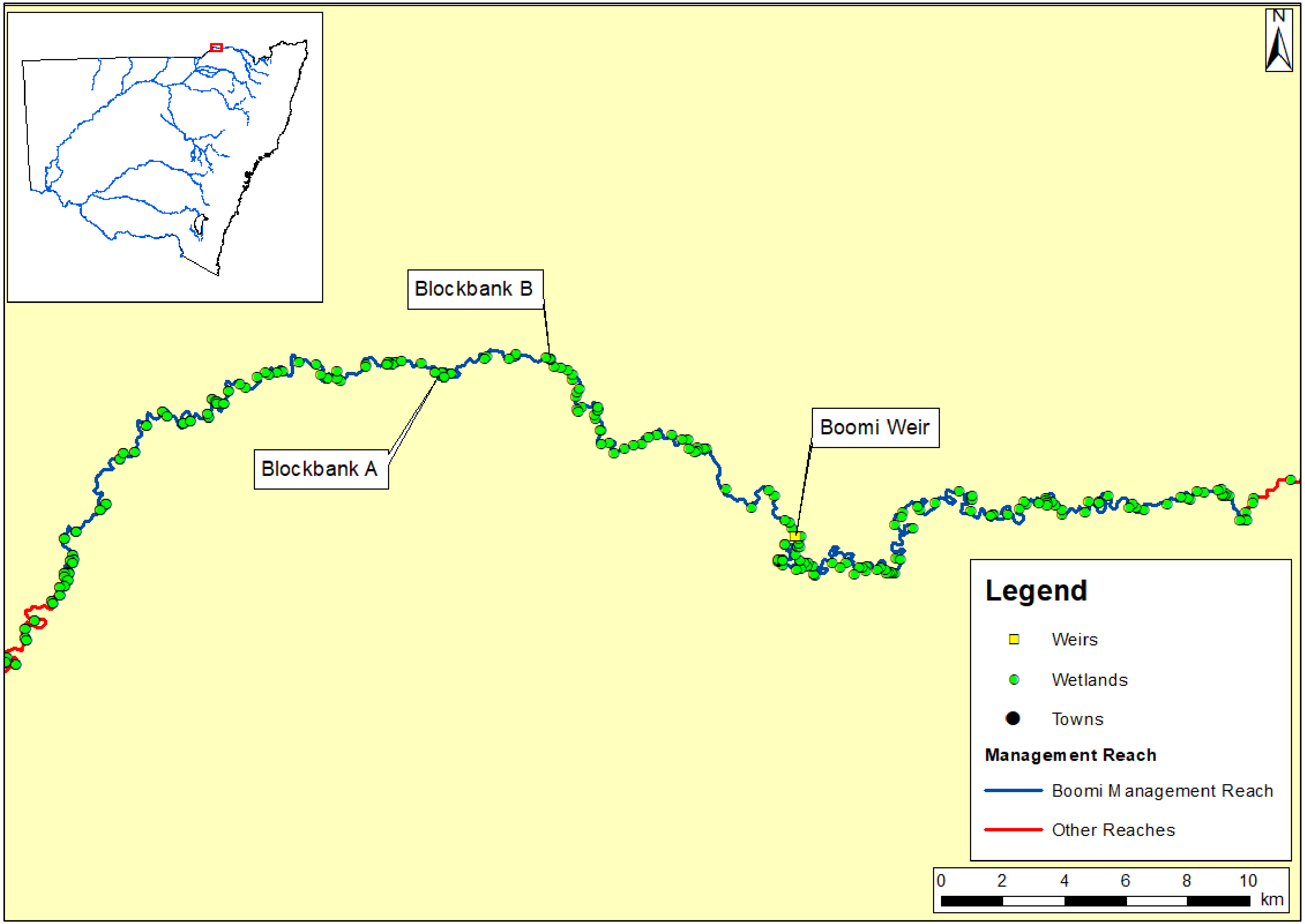


Figure 44. Location of wetland entry points recorded within the Boomi Management Reach.

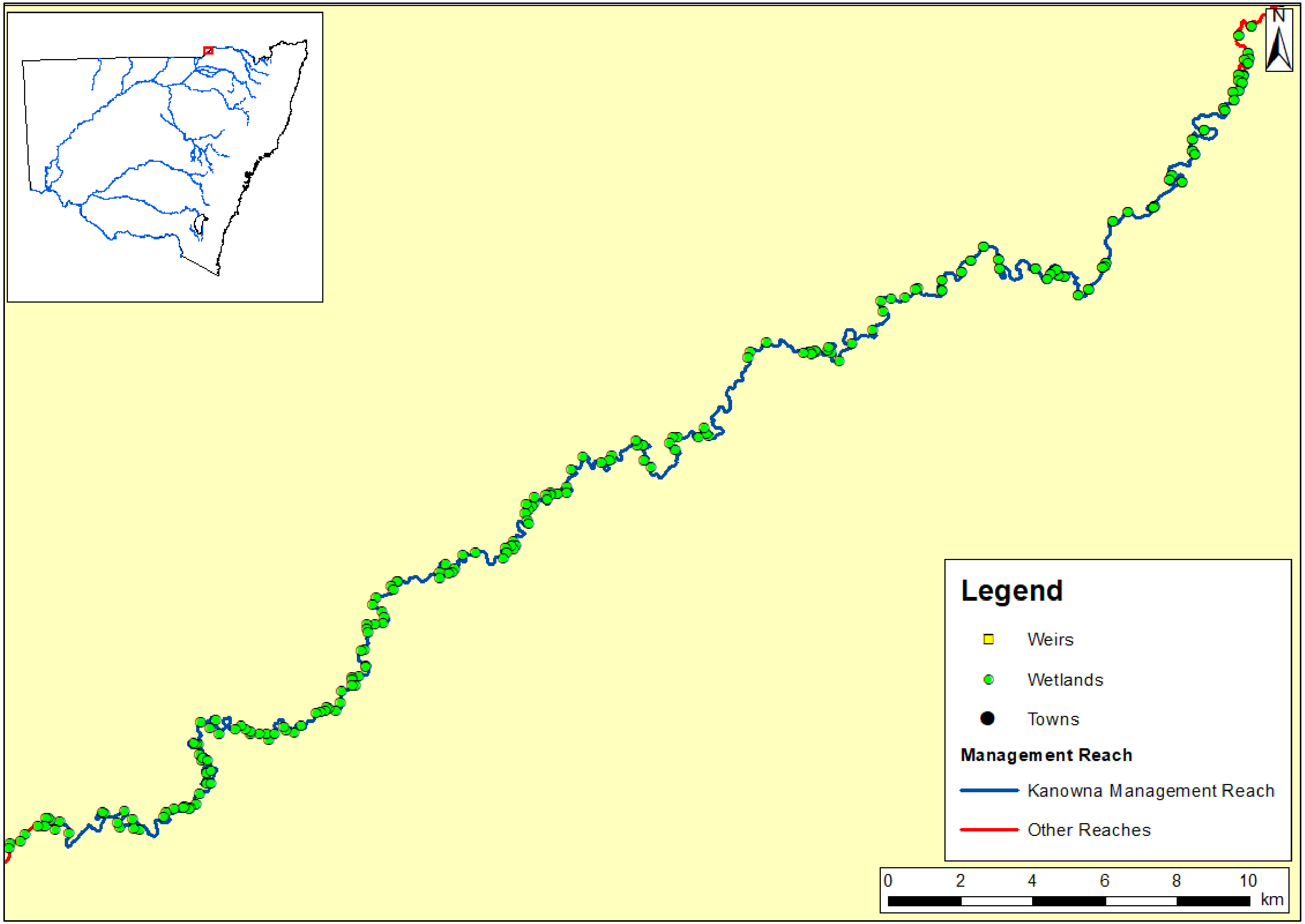


Figure 45. Location of wetland entry points recorded within the Kanowna Management Reach.

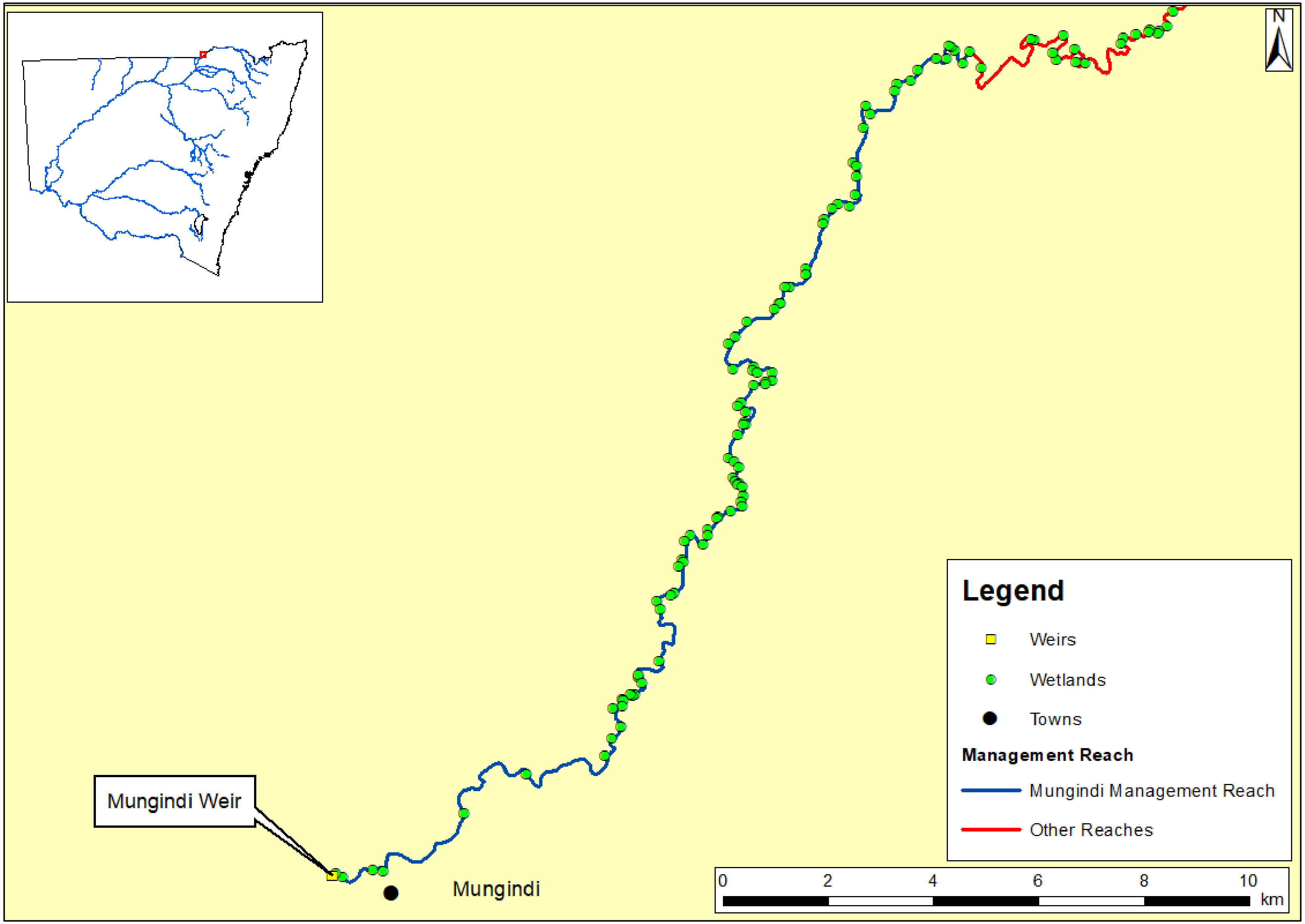


Figure 46. Location of wetland entry points recorded within the Mungindi Management Reach.

Aquatic macrophytes

Macrophytes provide physical structure used by freshwater fish for shelter, refuge and as nesting and spawning sites (Petr, 2000; Thomaz and Cunha, 2010). Macrophytes also provide a direct and indirect food source, such as rich foraging microhabitats, as they are inhabited by numerous species of macro-invertebrates (Delariva *et al*. 1994; Petr, 2000; Casatti *et al*. 2003). One threatened species, olive perchlet, is commonly associated with submerged macrophytes and the loss of these habitats is believed to be a contributing factor to the decline of the species in NSW (NSW DPI, 2014a).

Aquatic macrophytes were observed throughout the project area, covering a total area of 21.5 ha (Table 18). The distribution of species recorded varied between reaches (Figure 47 - Figure 51), most likely due to varied hydrology. The Boggabilla Management Reach had the largest extent of aquatic macrophytes (8.2 ha), due largely to the amount of phragmites (*Phragmites australis*) present (7.7 ha), followed by the Terrewah Management Reach (7.4 ha), due largely to 5.0 ha of lignum (*Duma florulenta)* and 1.8 ha of knotweed (*Polygonum spp.)* present (Figure 52; Figure 53. Lignum growing in a floodrunner 13.2 km downstream of Terrewah gauge, in the Boomi Management Reach, 25/6/2020. Flow rate was 83 ML/day.; Figure 54).

Phragmites and lignum were the two most abundant aquatic macrophyte species recorded, covering 9.0 and 8.7 ha respectively. At least 90% of the lignum observed was growing on the flood plain and in flood runners, not in the main channel, therefore it is only available as fish habitat at high flows or during floods. Some aquatic macrophyte species were recorded in billabongs or depressions on the floodplain only- not in the main channel; these were swamp lily (*Ottelia ovalifolia*), common nardoo (*Marsilea drummondii*), water milfoil (*Myriophyllum* sp.) and duckweed (*Lemnaceae*). Water primrose and cumbungi were predominantly found in weir pools, particularly upstream of Mungindi Weir and Goondiwindi Weir where stable water levels provide ideal growing conditions. Slender knotweed was most common downstream of Goondiwindi Weir within the Terrewah Management Reach.

The following macrophyte species were observed in the project area:

- Azolla (*Azolla* sp.*)*
- Cumbungi (*Typha* sp.)
- Duckweed (*Lemnaceae*)*
- Juncus/sedge (*Juncus* spp.*, Bolboshoenus* spp.)
- Knotweeds (Polygonum spp.)
- Lignum (*Duma florulenta)*
- Common nardoo (*Marsilea drummondii*)*
- Phragmites/Common reed (*Phragmites australis*)
- Swamp lily (*Ottelia ovalifolia*)*
- Water couch (*Paspalum* sp.)
- Water primrose (*Ludwigia* ssp.)
- Water milfoil (*Myriophyllum* sp.)*

*Observed in billabongs only.

Table 18: Extent (m^2) of aquatic macrophyte species identified in each Management Reach

Species	Boggabilla	Terrewah	Boomi	Kanowna	Mungindi	Total area (m^2)
Azolla	0	163	1,121	0	55	**1,339**
Cumbungi	225	0	62	29	1,434	**1,750**
Juncus/sedge	2,768	243	1,881	796	1,499	**7,187**
Knotweed	2,362	18,496	601	0	173	**21,632**
Lignum	0	50,384	18,322	17,388	690	**86,784**
Phragmites	76,529	4,546	551	6,797	1,139	**89,562**
Water primrose	487	0	940	0	5,563	**6,990**
Total Area (m^2) #	**82,371**	**73,901**	**23,481**	**25,010**	**10,553**	

1 Ha. = 10,000 m^2

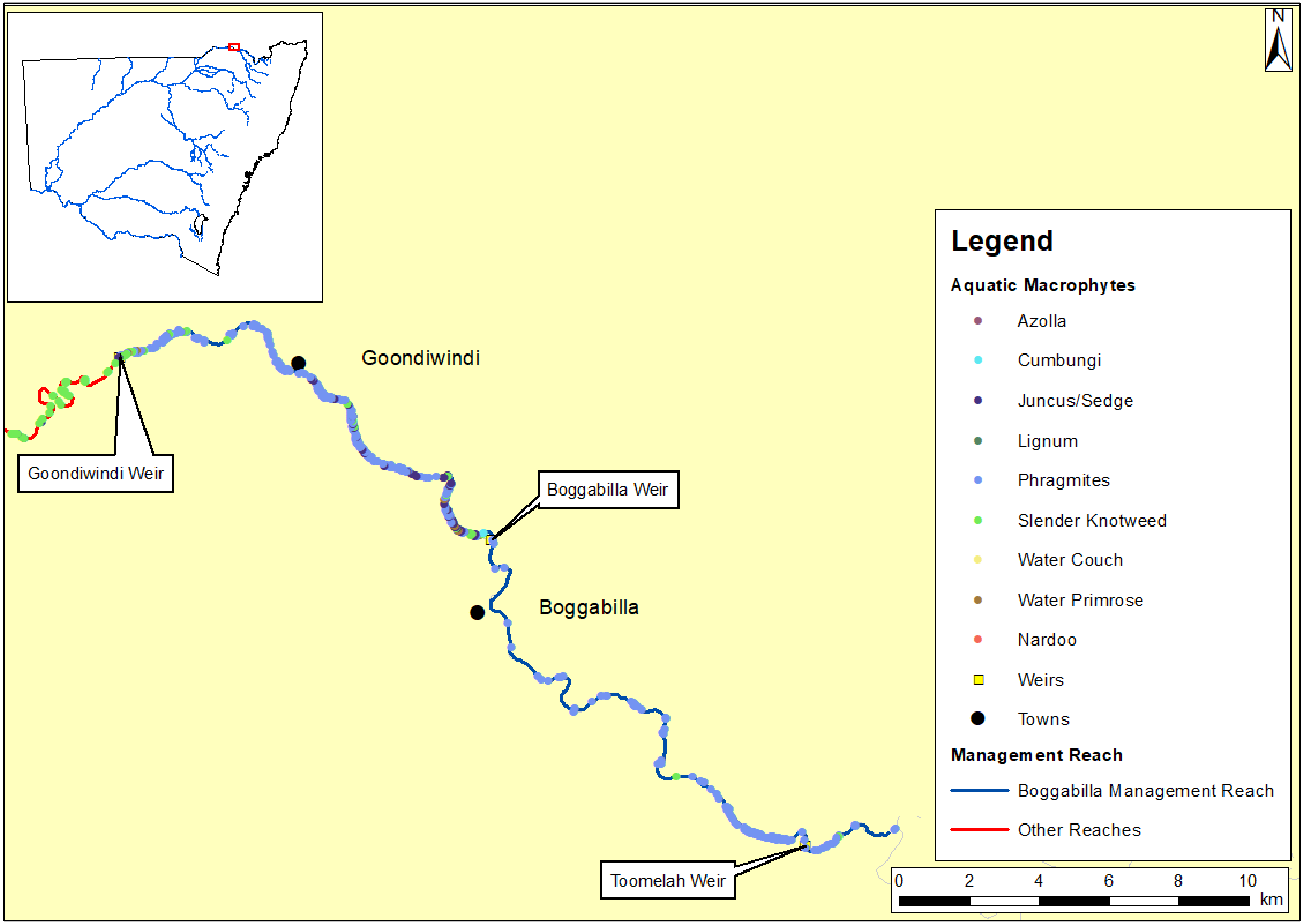


Figure 47. Location of aquatic macrophytes recorded within Boggabilla Management Reach.

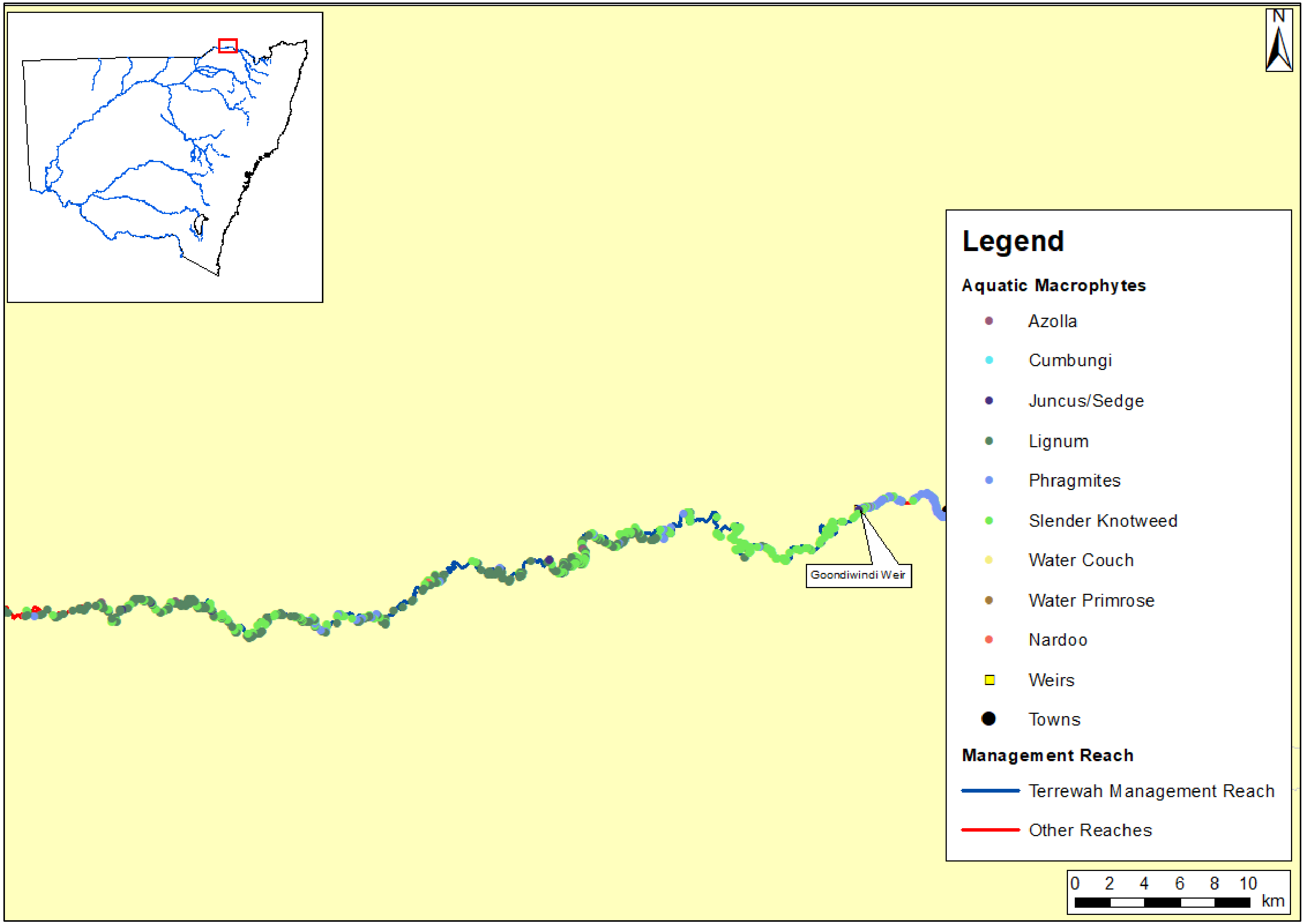


Figure 48. Location of aquatic macrophytes recorded within the Terrewah Management Reach.

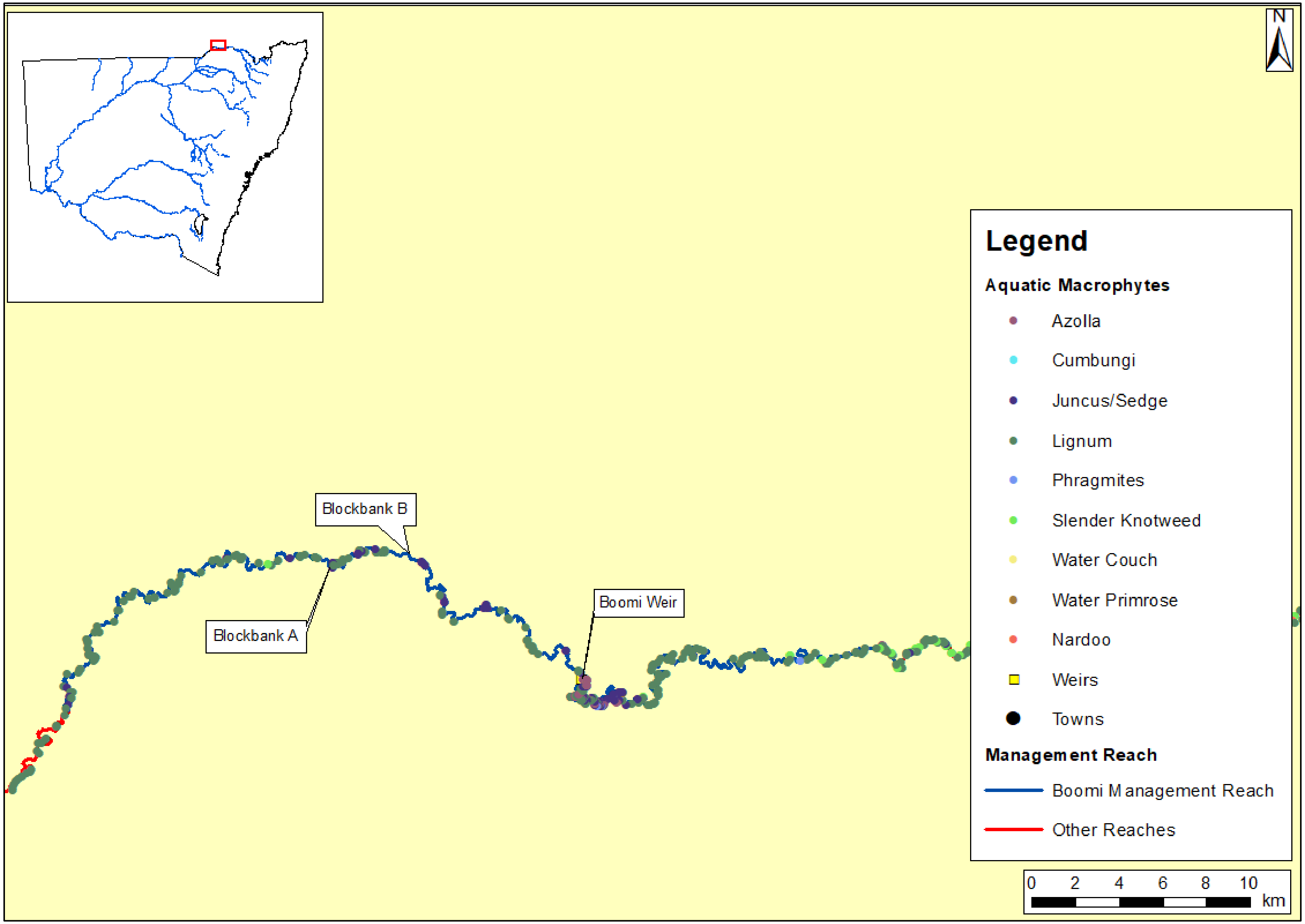


Figure 49. Location of aquatic macrophytes recorded within the Boomi Management Reach.

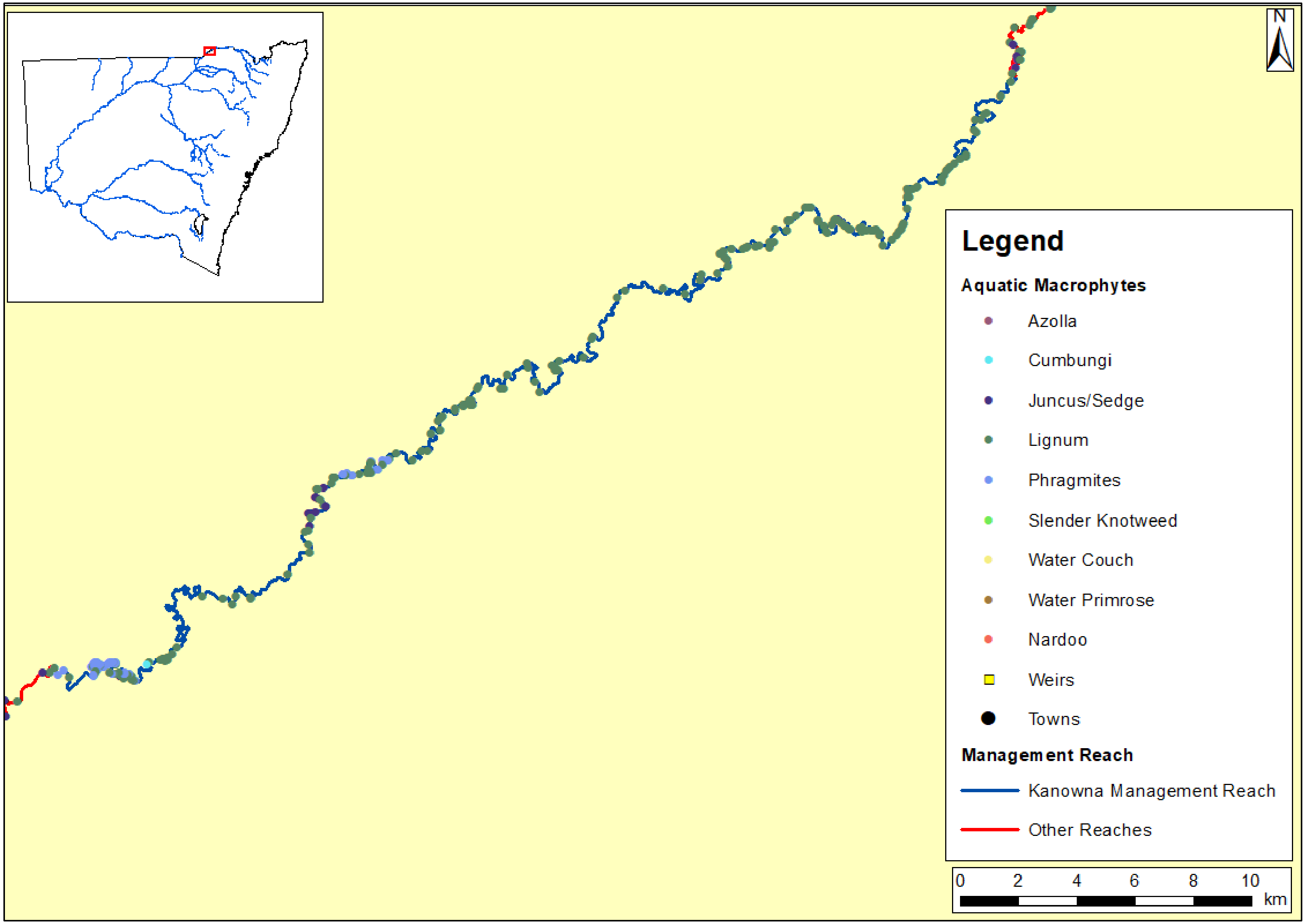


Figure 50. Location of aquatic macrophytes recorded within the Kanowna Management Reach.

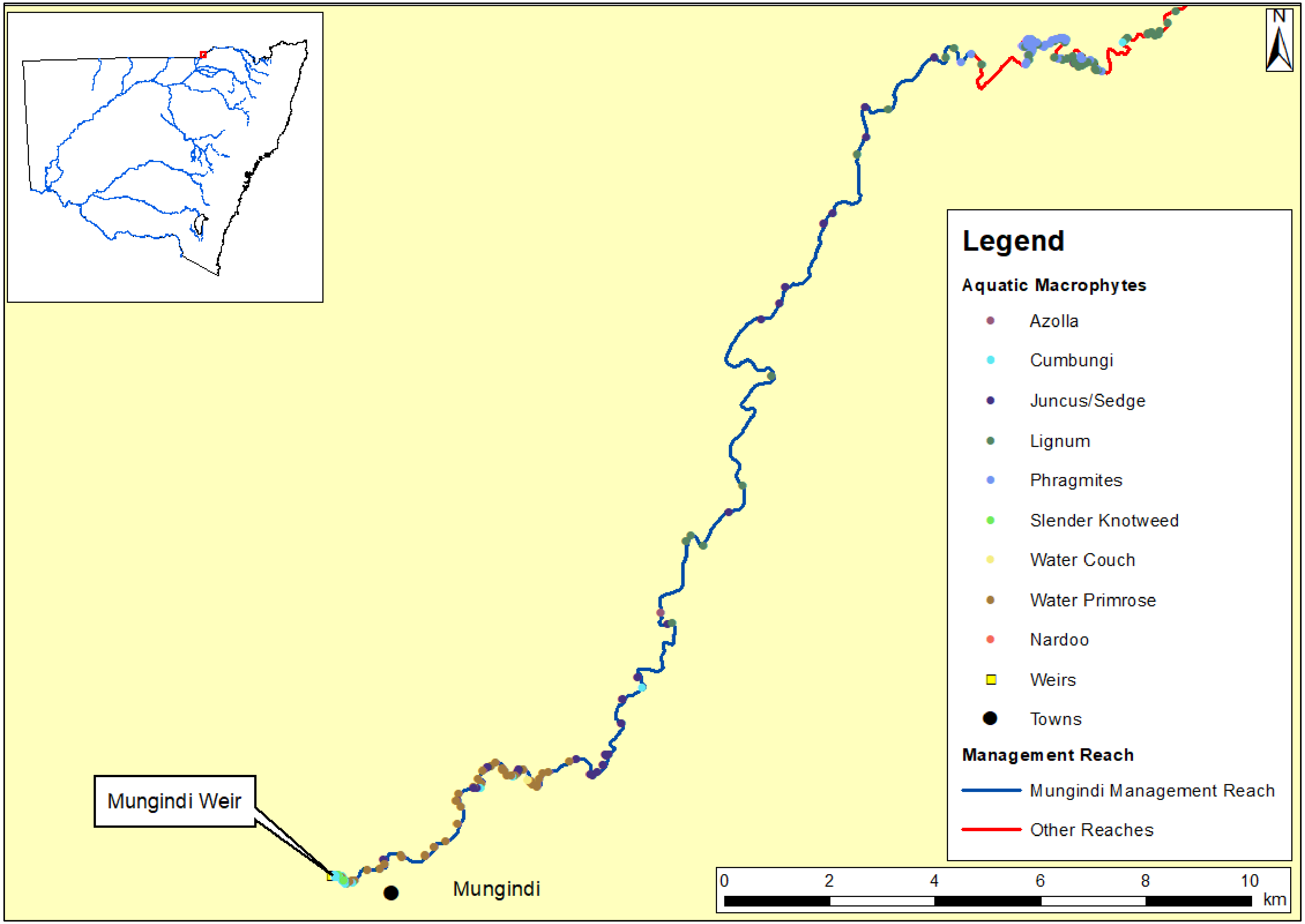


Figure 51. Location of aquatic macrophytes recorded within the Mungindi Management Reach.

Figure 52. Phragmites lining the river channel 5.7 km upstream of the Macintyre-Weir River junction, in the Kanowna Management Reach, 8/5/2020. Flow rate was 91 ML/day.

Figure 53. Lignum growing in a floodrunner 13.2 km downstream of Terrewah gauge, in the Boomi Management Reach, 25/6/2020. Flow rate was 83 ML/day.

Figure 54. Slender knotweed growing on the edge of the river 4.4 km upstream of Terrewah gauge, in the Terrewah Management Reach, 23/6/2020. Flow rate was 64 ML/day.

Pumpsites

The project area supports major agriculture industries including grazing and irrigated crops (particularly cotton) (MDBA, 2019). Currently, potentially millions of native fish are lost from rivers every year, being extracted by pumps and diverted into channels, significantly compromising native fish communities (Boys and Rayner, 2017). Pumps have the potential to draw fish during water abstraction and can physically harm or kill them (Baumgartner *et al.* 2009). Studies in the Condamine catchment in Queensland have recorded over 12,000 native fish being removed from two 300 mm pumps over a 9-hour period (Norris, 2015).

There was a total of 316 pumps were recorded in the project area (Table 19). Pumpsites were categorised into three size categories <100 mm, 100 mm to 250 mm and >250 mm. 103 large scale irrigation pumps (>250mm) were recorded throughout the project area and were relatively evenly distributed (Figure 55). 139 smaller pumps (<100 mm) were observed within the project area and 74 pumps of 100-250 mm diameter. Pumps <100 mm in diameter are generally used for stock and domestic purposes and were most concentrated around the township of Goondiwindi (Figure 55). Stock and domestic extraction for grazing properties is less exhaustive on flows but can impact on refuge pools during critical cease-to-flow periods. Pumps in the100-250 mm range are commonly associated with pivot irrigation.

Table 19: Number of identified pumpsites within each Management Reach

Reach	Reach length (km)	Pumpsite count	Average per km
Boggabilla	35.54	194	5.46
Terrewah	88.71	35	0.39
Boomi	90.98	37	0.41
Kanowna	81.92	31	0.38
Mungindi	29.84	19	0.64

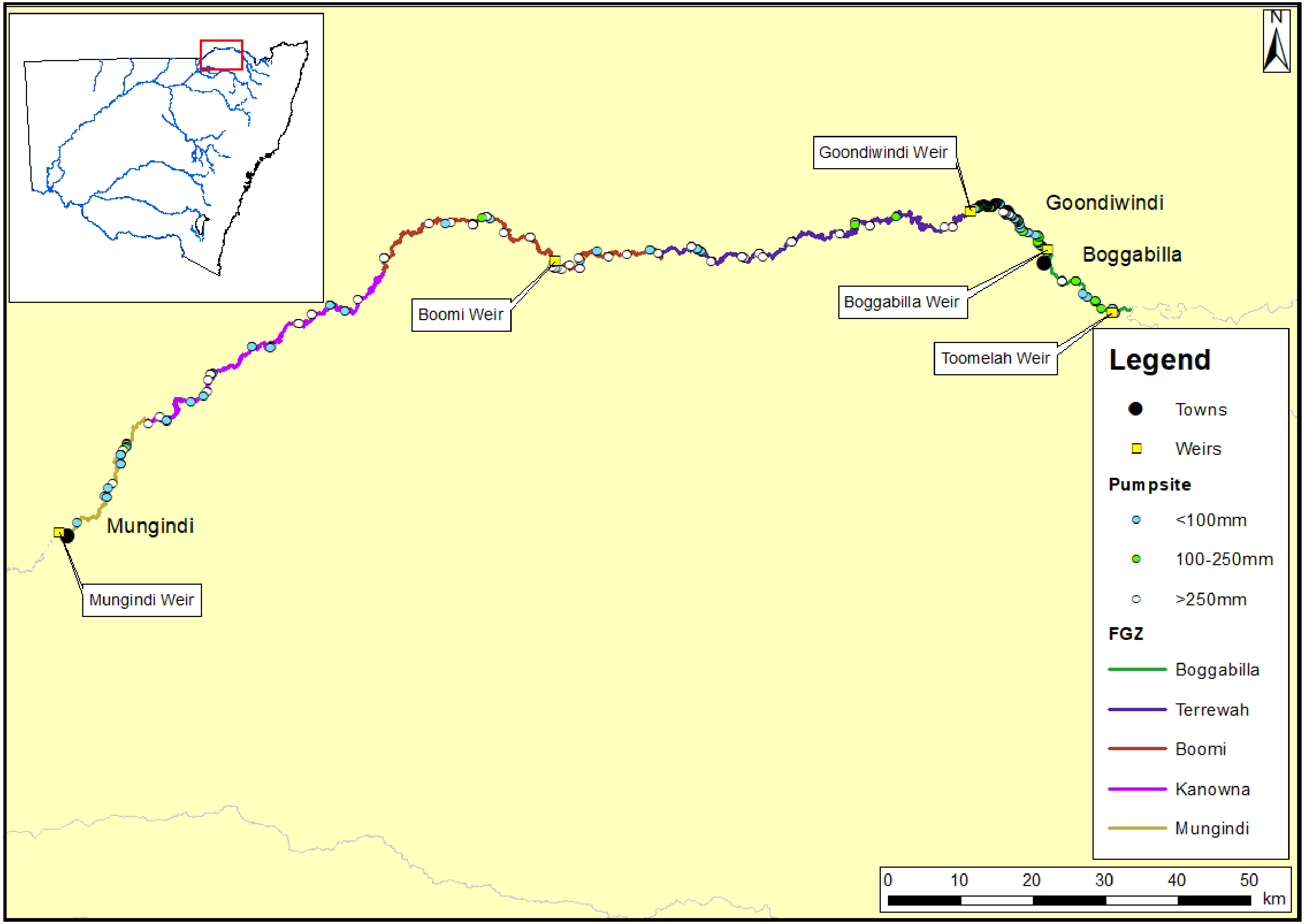


Figure 55. Location and size of pumpsites in the project area

Fish passage

Australian native fish have evolved to rely on a variety of habitat types to complete their life cycle. One of these habitat requirements is the need to move both short and long distances between varying aquatic environments (Thorncraft and Harris, 2000; Fairfull and Witheridge, 2003; Barrett, 2008). While fish migrations are commonly associated with breeding events, other reasons for native fish species needing to disperse include the search for food, shelter, avoidance of predation and competition pressures (Humphries and Walker, 2013). Unfortunately, riverine connectivity has been severely disrupted within Australia by the creation of in-stream barriers to fish that limit habitat and resource availability and diminish the opportunities for species to adapt to changing environmental conditions (Pethebridge *et al.* 1998).

The installation and operation of in-stream structures and the alteration of natural flow regimes have been recognised as a *Key Threatening Process* under the FM Act 1994 and the NSW *Biodiversity Conservation Act 2016*. One threatened species in the project area, silver perch, can undergo significant migrations and the presence of barriers has been listed as a cause of their decline (Fisheries Scientific Committee, 2000). Another factor associated with such structures is the presence of weir pools, which has been suggested by the Fisheries Scientific Committee (2000) to contribute to egg mortality for the species with the reduction of water movement.

Weirs can also be a barrier to the downstream passage of fish. Overshot weirs can injure fish if there is a big drop into a shallow pool. Undershot weirs are more typically detrimental to the downstream movement of fish, through pressure changes, shear forces, and physical strike. In a study by Lee Baumgartner et al (2013b), > 90% of golden perch larvae, > 90% of silver perch larvae and > 50% of Murray cod larvae died during undershot weir passage. Small bodied native fish also had extremely high mortality rates: >90% for Australian smelt and unspecked hardyhead. The hydraulics of undershot weirs can be remediated to lessen the impact on native fish. (Baumgartner, 2013b).

Nine artificial barriers were identified in the project area isolating fish populations between them (Table 20; Figure 56; Figure 57). Seven of these barriers were recorded in the field, with the other two being inaccessible during field work (Toomelah Weir was fully inundated and Blockbank B1 inaccessible on foot). Data for the inaccessible barriers was extracted from the NSW DPI – Fisheries Fish Passage Database. In some cases, it may be possible for held environmental water to supplement or protect natural events to 'drown out' barriers and provide passage, however held environmental water will only provide small contributions to these events. The remediation of these barriers is proposed in the Northern Basin Toolkit measures and would provide access to 445 km of habitat, not including increased access to major tributaries. Boggabilla Weir is an undershot regulator and its remediation includes downstream fish passage.

Seven natural barriers were identified in the project area (Figure 58). Six of these were clay or indurated sediment benches on the riverbed and are barriers to fish passage under very low flow conditions only. One natural barrier was a log jam and it is uncertain at what height fish passage would become attainable.

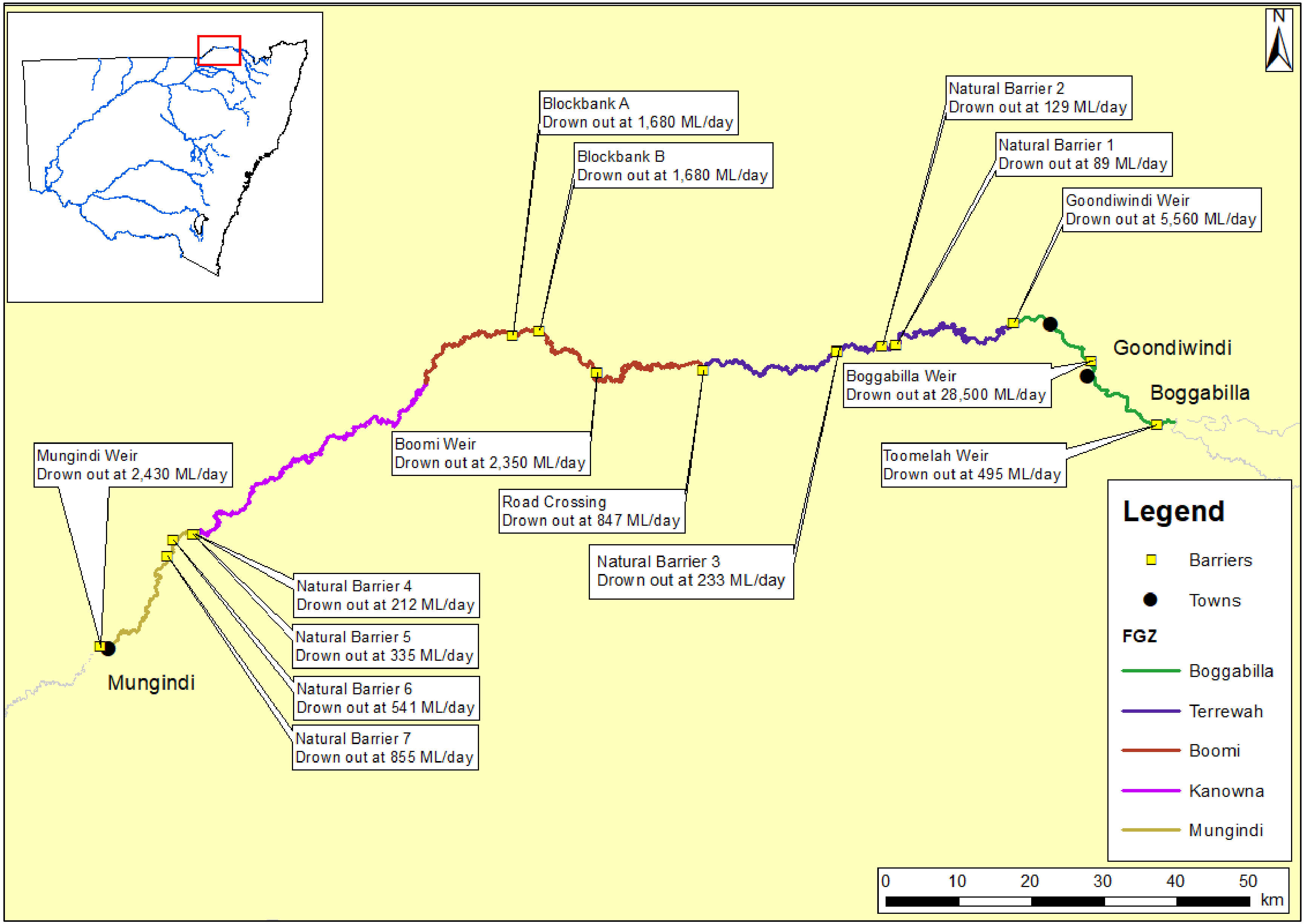


Figure 56. Fish passage barriers recorded in the project area.

Table 20: Manmade barriers to fish passage within the project area.

Structure name	Structure type	Height (m)	Ownership	Remediation type	Upstream habitat (km)
Toomelah Weir	Rock weir	0.5 *	Private	Removal	106
Boggabilla Weir	Undershot regulator	6	WaterNSW	Vertical slot	18
Goondiwindi Weir	Fixed crest with rock ramp fishway	2	WaterNSW	Vertical slot	15
Road crossing	Rock road crossing	0.4	Private	Not listed for remediation	88
Boomi Weir*	Fixed crest weir	4	WaterNSW	Vertical slot	39
Blockbank B1 and B2 (Two river channels, each has a blockbank)	Blockbank	0.6*	Private	Full width rock ramp	18
Blockbank A	Blockbank	0.6	Private	Full width rock ramp	6
Mungindi Weir	Fixed crest weir	4	WaterNSW		140

* Heights taken from the NSW DPI - Fisheries Fish Barrier database, due to structures being inaccessible during fieldwork

The drown out flows for structures were determined using the nearest gauging stations ratings table to find the flow rate that exceeds structure height (Figure 57, Figure 58). This analysis does not include detailed investigation of flow velocity and tail water dynamics, as such these values should be treated as indicative only and not a replacement for a formal drown out appraisal.

Toomelah Weir is a rock weir structure 0.5 m high. The weir is a barrier to fish passage at flows less than 495 ML/day or 56% of the time (over the past 30 years). There is approximately 106 km of unimpeded fish habitat upstream.

Boggabilla Weir is a large adjustable release structure approximately six metres high, with five vertical lift steel gates. The structure is 73 meters wide across the crest. Analysis of the existing vertical slot fish way observed excessive turbulence when the weir is at full supply level, resulting in inadequate fish passage (NSW DPI, 2012). Further analysis found that passage is still limited to most native fish even under low-turbulence conditions i.e. low head difference (NSW DPI, 2006). As such, Boggabilla Weir remains a high priority structure for remediation. Based on a drown out height of 6 metres, Boggabilla Weir is a barrier to fish at flows less than 28,500 ML/day or 99% of the time. The remediation of Boggabilla Weir fishway would provide access to 18 km of unimpeded fish habitat upstream.

Goondiwindi Weir is a concrete crib-work weir approximately two metres in height. It has an existing rock-ramp fishway located in the centre of the weir. Fish passage has been observed although it has been noted that moderate flows (900 ML/day) cause the weir wall to spill, attracting fish away from the fishway entry (Thorncraft and Harris, 1996). Two stone guiding walls were added, with the aim to guide fish into the fishway entry, although further analysis is required to confirm their effectiveness. Goondiwindi is estimated to drown out at flows exceeding 5,560 ML/day, estimated to occur 6% of the time (based on the past 30 years). There is approximately 15 km of unimpeded fish habitat upstream.

A small rock road crossing located approximately 39 km upstream of Boomi Weir. The structure stands at 0.4 meters and impedes upstream fish passage. The road crossing is a barrier to fish passage at flows below 847 ML/day or 80% of the time (over the past 30 years). There is approximately 94 km of unimpeded fish habitat upstream.

Boomi Weir is a four metre high concrete and sheet piling, fixed crest weir located approximately 20 km north of Boomi Township. The structure stands create a weir pool approximately 12 km long. The weir is a barrier to fish at flows below 2,350 ML/day or 94% of the time (over the past 30 years). This figure is consistent with previously calculated values, which placed drown out flows at 2000 ML/day (NSW DPI, 2006). Boomi Weir is categorised as a high priority for remediation within DPIE Fisheries fish passage database. If remediated, fish passage at Boomi Weir would increase access to approximately 39 km of upstream habitat.

Blockbank A is a rock bank located 23 km downstream of Boomi weir. The structure is 0.6 m in height and drowns out at 1,680 ML/day. As such the blockbank prevents fish passage 90% of the time (based on the past 30 years). There is approximately six km of unimpeded fish habitat upstream.

Blockbank B is composed of two separate rock blockbanks blocking two channels where the Macintyre river has split into two channels, located 18 km downstream of Boomi weir. Both structures stand at 0.6 metres in height and drown out at 1,680ML/day. Based on the past 30 years of flow, this structure remains a barrier to fish passage 90% of the time. There is approximately 17 km of unimpeded fish habitat upstream.

Mungindi Weir is a fixed crest sheet pile rock faced fill weir. The structure is six metres high. The weir is a barrier to fish passage at flows less than 2,430 ML/day or 92% of the time (over the past 30 years). There is approximately 148 km of unimpeded fish habitat upstream.

Natural barrier 1 is an indurated silt bench at a height of 0.4 metres, impeding passage at flows less than 89 ML/day. Based on the past 30 years of flow, this feature remains a barrier to fish passage 34% of the time.

Natural barrier 2 is an indurated silt bench at height of 0.5 metres, impeding passage at flows less than 129 ML/day. Based on the past 30 years of flow, this feature remains a barrier to fish passage 41% of the time.

Natural barrier 3 is was a log jam extending across the entire river channel at a height of 0.7 metres, impeding fish passage at flows less than 233 ML/day. Based on the past 30 years of flow, this feature remains a barrier to fish passage 51% of the time.

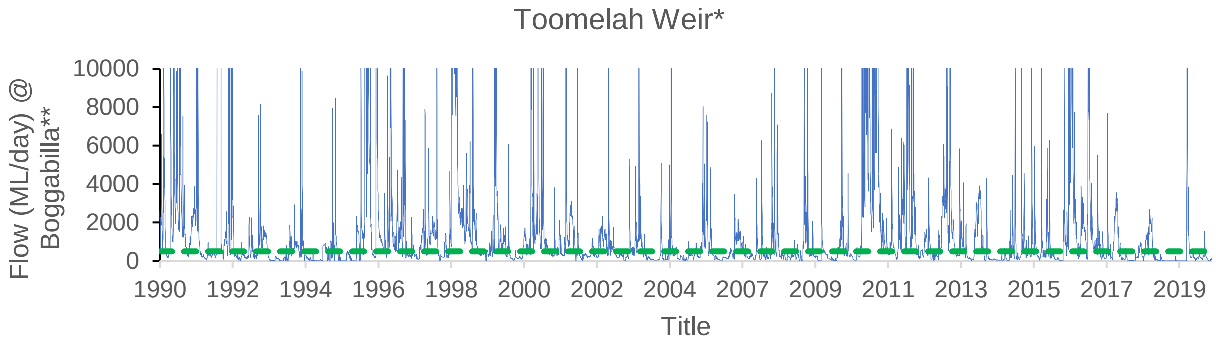
Natural barrier 4 is a clay bench at a height of 0.8 metres, impeding fish passage at flows less than 212 ML/day. Based on the past 30 years of flow, this feature remains a barrier to fish passage 59% of the time.

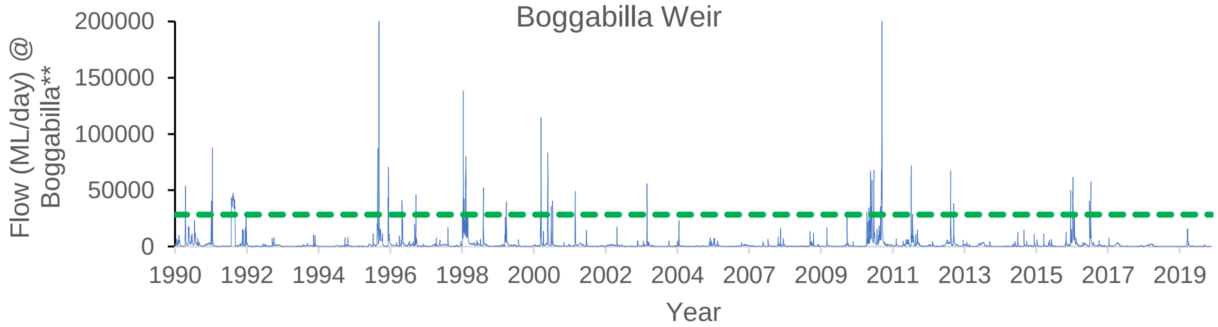
Natural barrier 5 is an indurated silt bench at a height of 1.1 metres, impeding fish passage at flows less than 335 ML/day. Based on the past 30 years of flow this feature remains a barrier to fish passage 68% of the time.

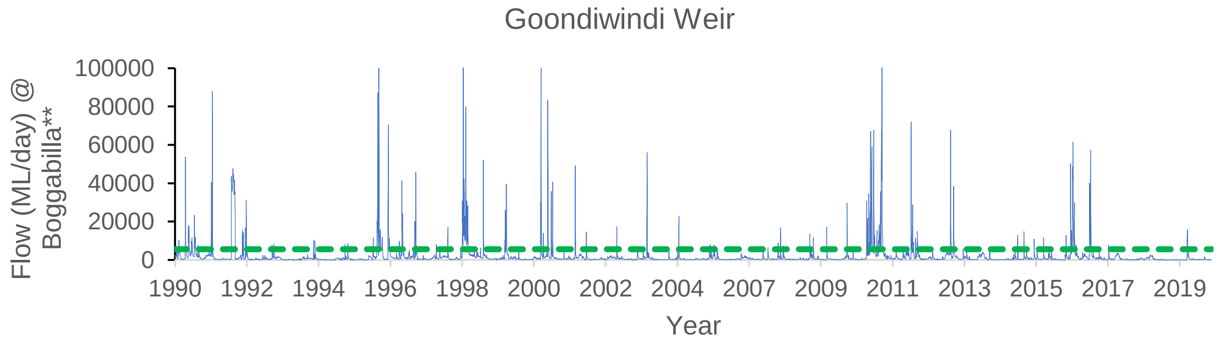
Natural barrier 6 is an indurated silt bench at a height of 0.3metres, impeding fish passage at flows less than 541 ML/day. Based on the past 30 years of flow, this feature remains a barrier to fish passage 79% of the time.

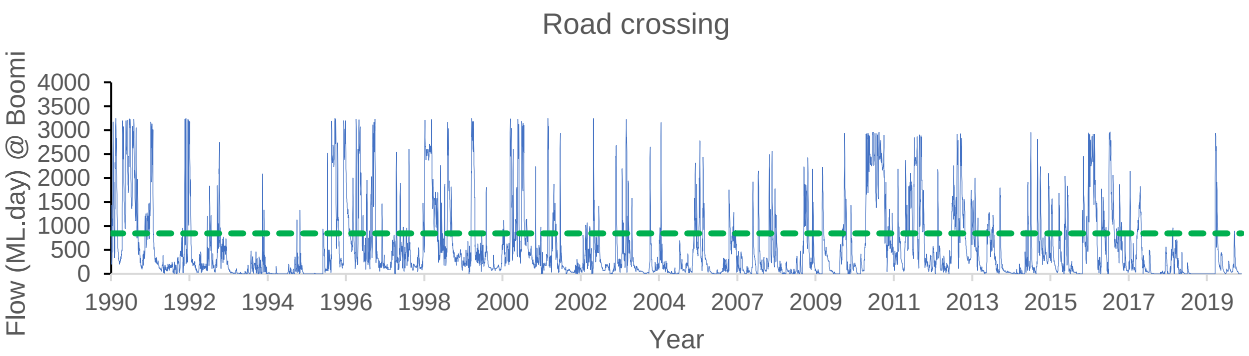
Natural barrier 7 is clay bench at a height of 0.4 metres, impeding fish passage at flows less than 855 ML/day. Based on the past 30 years of flow, this feature remains a barrier to fish passage 84% of the time.

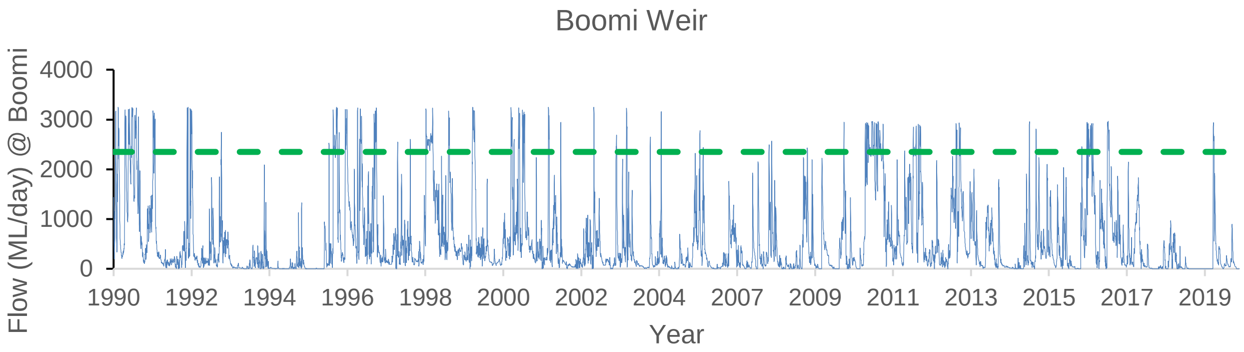
*Image not available

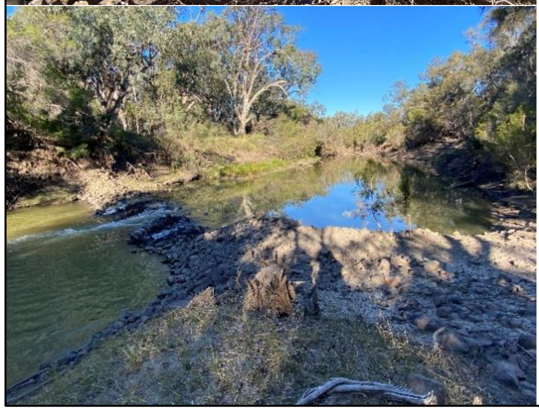


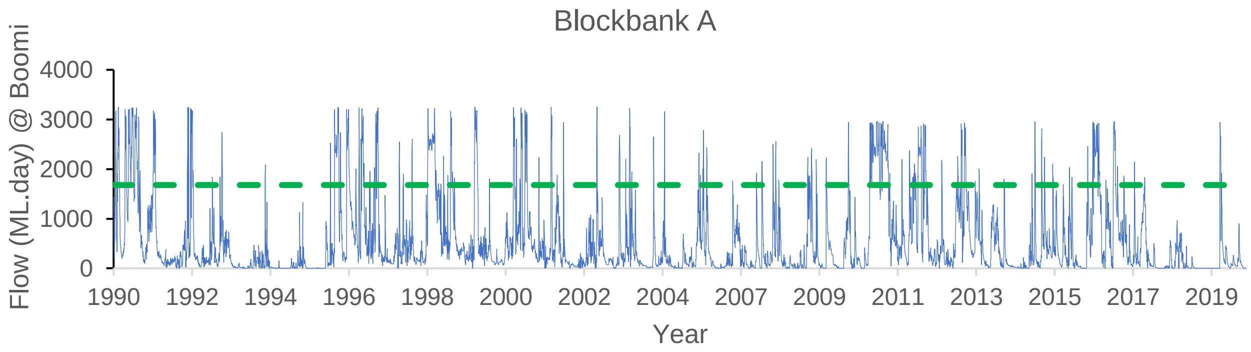





Road crossing
Flow (ML.day) @ Boomi
4000
3500
3000
2500
2000
1500
1000
500
0
1990 1992 1994 1996 1998 2000 2002 2004 2007 2009 2011 2013 2015 2017 2019
Year


Boomi Weir
Flow (ML/day) @ Boomi
4000
3000
2000
1000
0
1990 1992 1994 1996 1998 2000 2002 2004 2007 2009 2011 2013 2015 2017 2019
Year




Blockbank A
Flow (ML.day) @ Boomi
4000
3000
2000
1000
0
1990 1992 1994 1996 1998 2000 2002 2004 2007 2009 2011 2013 2015 2017 2019
Year

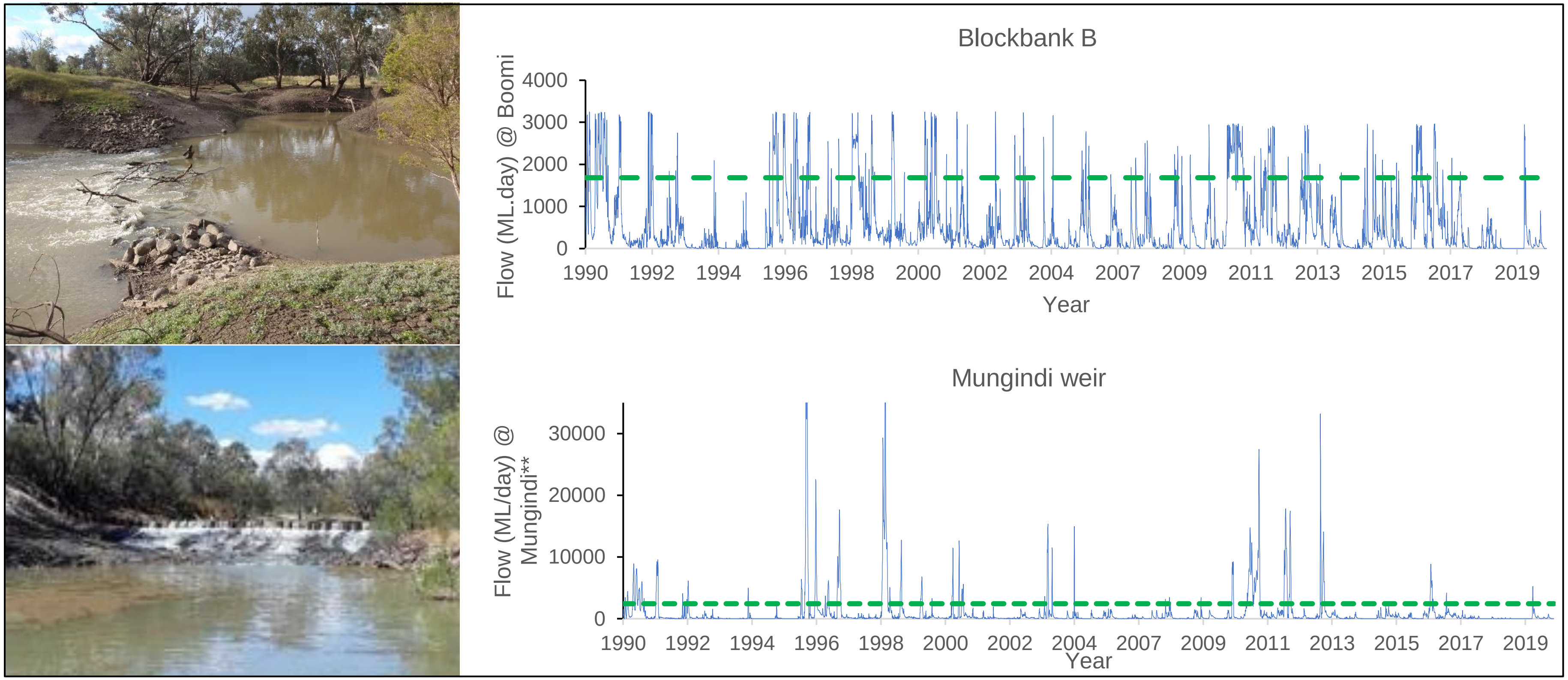
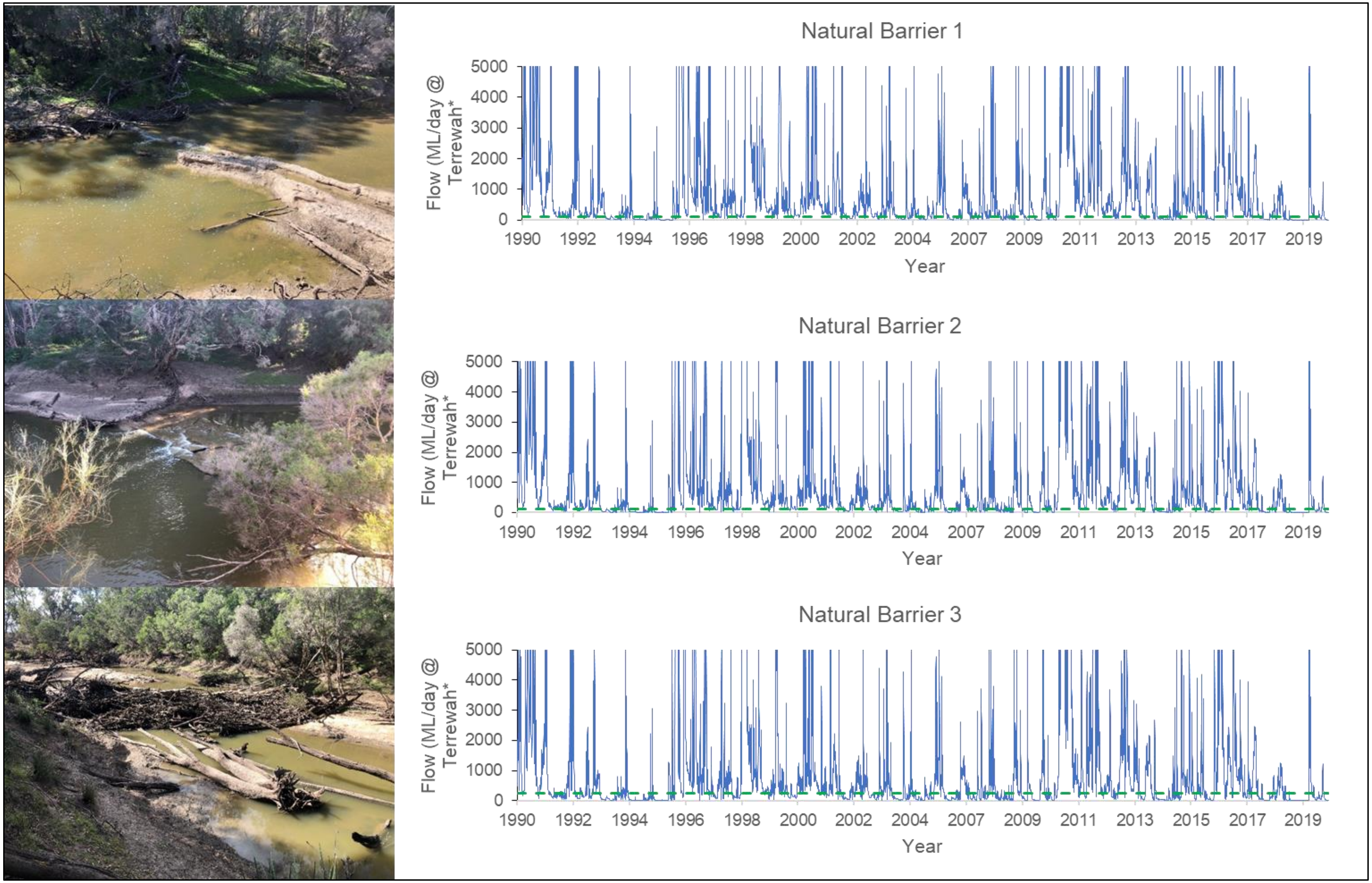
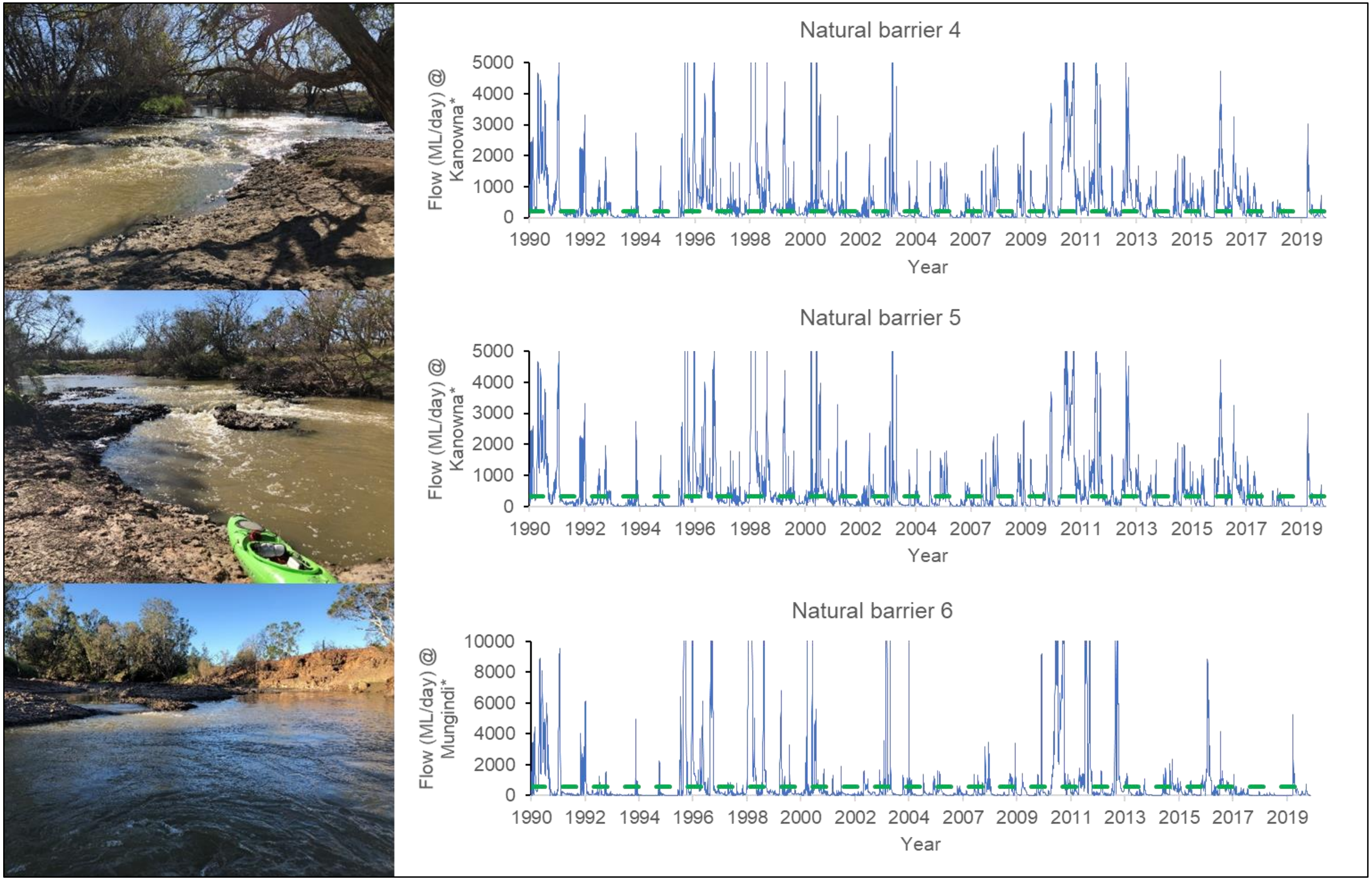


Figure 57. Fish passage barriers in the project area and flows in the Macintyre River during the last 30 years. The green dotted line highlights the drown out value for each weir, indicating when fish passage would have been available. Note that Blockbank B is comprised of two separate rock walls equal in height, an image of the second wall could not be obtained due to flows impeding access during fieldwork. *Toomelah weir was inundated during fieldwork, hence no image could be produced. ** maximum axis value reduced to increase resolution of flow axis therefore flow peaks are not necessarily shown


Natural Barrier 1
Flow (ML/day @ Terrewah*
0
1000
2000
3000
4000
5000
1990 1992 1994 1996 1998 2000 2002 2004 2007 2009 2011 2013 2015 2017 2019
Year
Natural Barrier 2
Flow (ML/day @ Terrewah*
0
1000
2000
3000
4000
5000
1990 1992 1994 1996 1998 2000 2002 2004 2007 2009 2011 2013 2015 2017 2019
Year
Natural Barrier 3
Flow (ML/day @ Terrewah*
0
1000
2000
3000
4000
5000
1990 1992 1994 1996 1998 2000 2002 2004 2007 2009 2011 2013 2015 2017 2019
Year


Natural barrier 4
Flow (ML/day) @ Kanowna*
5000
4000
3000
2000
1000
0
1990 1992 1994 1996 1998 2000 2002 2004 2007 2009 2011 2013 2015 2017 2019
Year
Natural barrier 5
Flow (ML/day) @ Kanowna*
5000
4000
3000
2000
1000
0
1990 1992 1994 1996 1998 2000 2002 2004 2007 2009 2011 2013 2015 2017 2019
Year
Natural barrier 6
Flow (ML/day) @ Mungindi*
10000
8000
6000
4000
2000
0
1990 1992 1994 1996 1998 2000 2002 2004 2007 2009 2011 2013 2015 2017 2019
Year

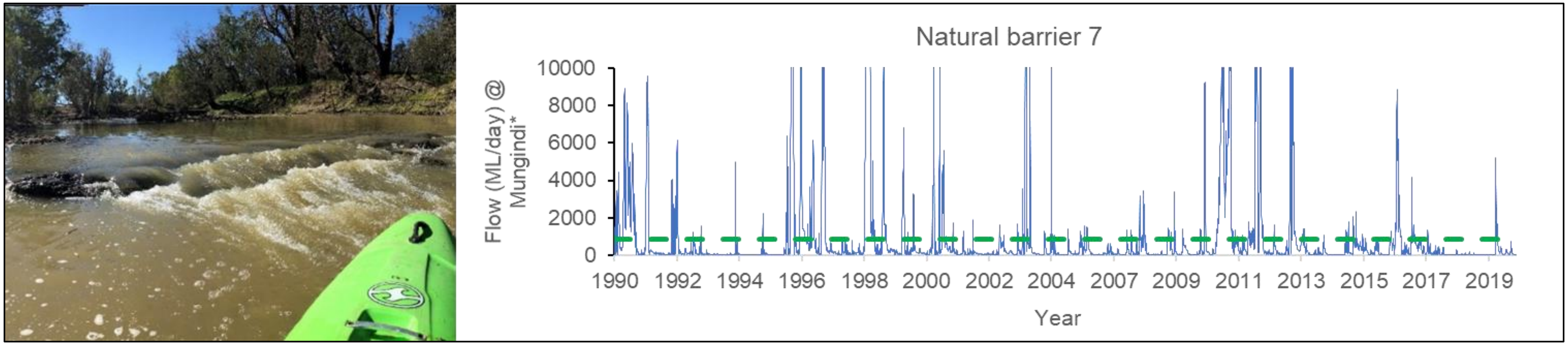


Figure 58. Natural barriers to fish passage barriers in the project area and flows in the Macintyre River during the last 30 years. The green dotted line highlights the drown out value for each weir, indicating when fish passage would have been available. * maximum axis value reduced to increase resolution of flow axis therefore flow peaks are not necessarily shown.

Flow relationship results

The use of functional groups of freshwater fish in the Murray-Darling Basin and detailed habitat mapping information can assist with managing water for the environment to deliver native fish benefits and develop specific EWRs. When developing EWRs there are several basic principles that need to be considered:

- Natural flow regimes - one of the important principles considered in the development of conceptual flow models for fish in the Murray-Darling Basin is that the natural flow regimes provide a strong foundation for the rehabilitation of flows; however the impacts of river regulation, including connectivity, access to habitat, and changes to geomorphology, need to be considered and incorporated into specific planning objectives (Mallen-Cooper and Zampatti, 2015).
- Water quality parameters - the importance of water quality, not just water quantity, also needs to be considered when developing and delivering water requirements, with water temperature driving life history responses from the majority of native species, whilst turbidity, dissolved oxygen and productivity (related to chemical, nutrient and plankton composition) also play an important role in maximising benefits to species (Jenkins and Boulton, 2003; Górski *et al*. 2013; Zampatti and Leigh, 2013; Mallen-Cooper and Zampatti, 2015). The influence of water quality parameters on guiding flows for fish will result in management actions primarily occurring in the warmer spring and summer months; however the importance of replenishing critical refugia, supporting baseflows all year round and late-winter high flow events still need to be considered given their benefits to water quality maintenance and productivity (Robertson *et al*. 2001).
- Fundamental riverine elements – the influence of flow, habitat and connectivity on the dynamics and response of fish populations are inseparable and need to be intimately considered in flow management decisions and actions (Mallen-Cooper and Zampatti, 2015). These three key factors will influence the need for still water or flowing environments, the spatial scale that connectivity and hydraulic complexity needs to be maintained, and the variation in flow needed for habitat access and completion of life history aspects (Mallen-Cooper and Zampatti, 2015). Consideration has been given to determining appropriate flow-height and flow-velocity relationships in the Macintyre River that account for connectivity and hydraulic requirements of native fish using the overarching principles below to guide the identification of flow rates:
    - Minimum depth for small bodied and moderate bodied fish movement is 0.3 metres above cease to flow (Gippel 2013; O'Connor *et al.* 2015)
    - Minimum depth for large bodied fish movement is 0.5 metres above cease to flow (Fairfull and Witheridge 2003; Gippel 2013; O'Connor *et al*. 2015)
    - Optimal transition of small pulse to large pulse events for the flow specialist spawning and movement response is 2 metres above cease to flow and/or velocity greater than or equal to 0.3-0.4m/s (Mallen-Cooper and Zampatti 2015; Marshall *et al.* 2016).

Thresholds for each flow component (very low flow, baseflow, small pulse, large pulse, bankfull and overbank) were determined using data from WaterNSW gauges. It should be noted that the thresholds developed for flow components using these guiding principles may be further refined as part of future hydrological analysis; however, for the purpose of this project they have been adopted to investigate the habitat inundation relationships for each flow component. Using this information, flow relationships were assessed for LWH, benches and entry points to connected wetlands. The height recorded for each feature was used to calculate the inundation level in ML/day. Cumulative frequency was calculated for each feature type for each Management Reach.

Summary of project area flow components

Differing flow events may be separated into several ecologically significant components, with each of these providing a diverse range of ecosystem services (Figure 59 and Table 21). To provide water managers with a greater understanding of what specific flows may achieve in the project area, detailed flow/height relationships were determined (Figure 60 and Table 21). Cross-sections and flow data for each gauge were used to approximate flow regime components in conjunction with bank heights that were recorded in the field using the hypsometer. These were used to assist in identifying hydrological components for each Management Reach.

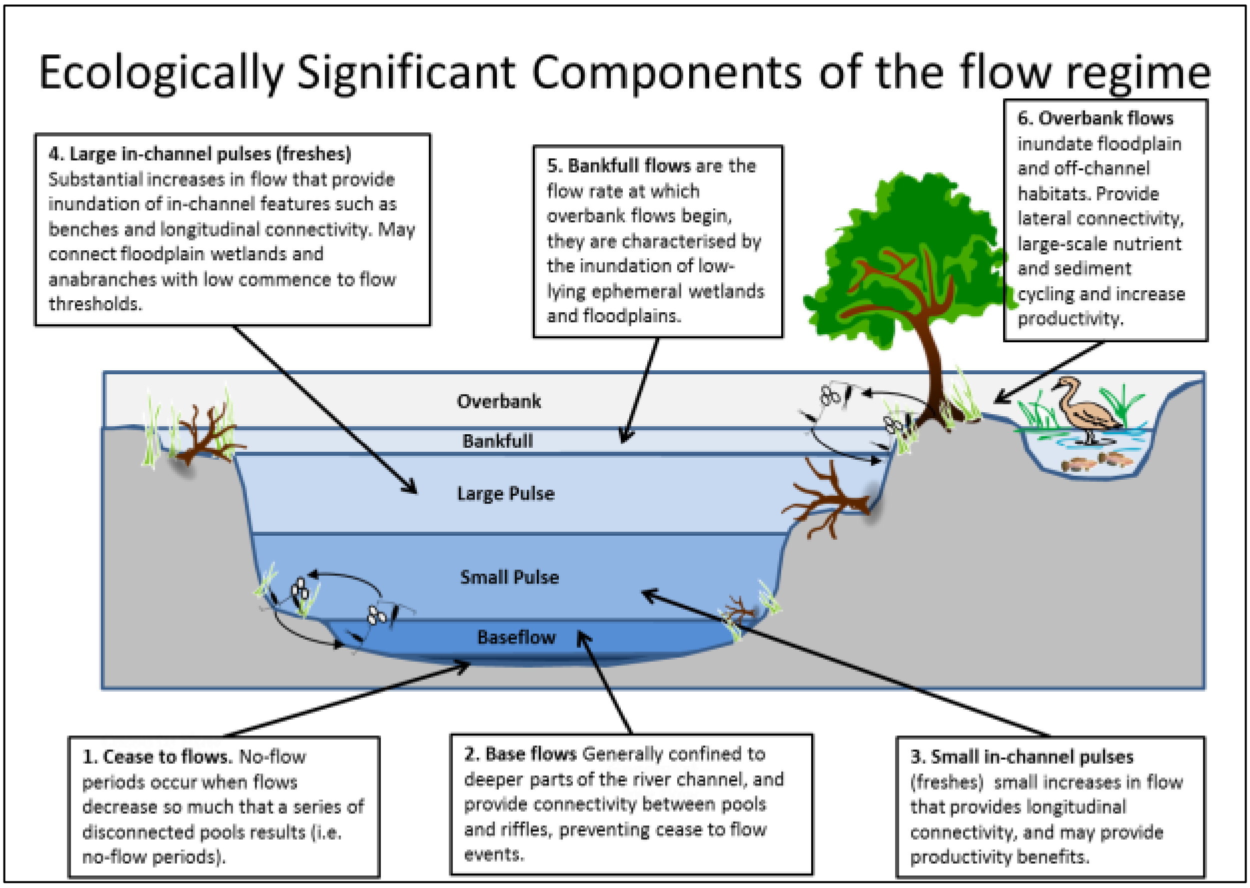


Figure 59: Components of the in channel flow regime (adapted from Ellis *et al.* 2016).

Table 21: Definition of the six flow regime components identified for this study (adapted from Ellis *et al.* 2016; NSW DPI, 2017a).

Flow regime component	Definition
Very low flow and cease to flow	No-flow periods occasionally occur in intermittent streams where flows decrease so much that a series of disconnected pools eventuates. High food availability for predatory species at higher trophic levels may occur initially during cease to flow periods and very low flows, with limited refuge habitat for prey. Ultimately, however, food supply and water quality would be expected to decrease in isolated pools as water levels contract. No-flow periods have been associated with poor body condition; particularly for species at lower trophic levels (Balcombe *et. al*. 2012). Cease to flow and very low flow periods can play an important role in these streams by promoting growth of biofilms and productivity. Rates of wetting and drying are important. Cease to flow can also be useful in controlling carp populations and would generally occur annually in highly intermittent systems.
Baseflow	Confined to deeper low-lying part of the channel and would typically inundate geomorphic units such as pools and riffle areas between pools. Baseflows (and cease to flows) also allow for the accumulation of allochthonous carbon and vegetation on benches and dry river channel sediments, which then contribute to ecosystem productivity during subsequent flow events. They would generally occur on an ongoing basis in perennial systems. They may be important in maintaining aquatic habitat for fish, plants and invertebrates when low inflow conditions prevail; retain longitudinal connectivity for small-bodied fish and maintain reasonable water quality. Baseflows maintain drought refuges during dry periods and contribute to nutrient dilution during wet periods or after a flood event. Baseflows may also support winter conditioning and oxygenation through riffle habitats, and historically may have benefited small-bodied native species in terminal wetlands. Stable Low Flow Spawning Fish as described by Kerr *et al.* 2017 rely on stable baseflows for completing important life-cycle stages, they even thrive in some cases from very low and flows as described above. Baseflows are commonly maintained by seepage from groundwater and low surface flows (MDBA, 2014).
Small pulse	Generally short increases in flow that provide longitudinal connectivity and may provide productivity benefits by replenishing soil water for riparian vegetation, inundating low-lying benches and cycling nutrients between different parts of the river channel. Small pulses would generally be considered to be relatively slow flowing (e.g. less than 0.3m/s). They can contribute to the maintenance of refugia and key aquatic habitat such as snags and aquatic vegetation, which supports diverse heterotrophic biofilm generation, with high nutritional value to higher organisms (Wallace *et al.* 2014). Small within channel pulses would have generally occurred annually throughout the majority of the Basin, and potentially two to three times in a year for perennial systems.
Large pulse	More substantial increases in flow that provide greater inundation of in channel features such as benches and longitudinal connectivity and may connect floodplain wetlands and anabranches with low commence to flow thresholds. Large within channel pulse are distinct from small pulses in that they provide fast flowing in channel habitats (e.g. velocity greater than 0.3m/s). Large in channel pulses enhance productivity and nutrient exchange, promote dispersal and recruitment for all species and can trigger spawning in flow dependent species (i.e. golden perch and silver perch). These flow events are also important for maintaining refuges and minimising geomorphological impacts of regulation (e.g. sedimentation). The shape of these events should reflect the natural rates of flow increase or decrease corresponding to position in the catchment. Maintaining natural rates of change in water level may be important for nesting species such as Murray cod and freshwater catfish, as water level fluctuations that are out of sync with natural patterns and climatic cues can have adverse impacts (e.g. rapid decreases in water levels over short time periods leading to nest abandonment). Large in channel pulses would have generally occurred annually across most of the Basin, and up to two to three times a year in some systems.
Bankfull flow	The flow rate at which overbank flows begin, or maximum regulated flow releases. Bankfull flows generate similar ecological benefits to large in channel pulses, potentially at a greater magnitude depending on

	channel geomorphology. They are characterised by the inundation of low-lying ephemeral wetlands and floodplains. As with large in channel pulses, the shape of these events should reflect the natural rates of flow increase or decrease corresponding to position in the catchment.
Overbank event	Inundate floodplain and off-channel habitats and are important in providing lateral connectivity, large-scale nutrient and sediment cycling and an increase in productivity. Overbank events can enhance breeding opportunities for many species by creating additional spawning habitat and floodplain productivity benefits which contribute to increased condition and recruitment. Overbank events generally would have occurred between 1 - 25 years (depending on the magnitude of the event) for both intermittent and perennial systems. These events are generally unregulated, although there may be scenarios where water for the environment management activities could augment in channel flows to create overbank events in which case the shape of these events should reflect the natural rates of flow increase or decrease corresponding to position in the catchment.

Inundation by Management Reach

Boggabilla Management Reach

A total of 707 LWH were observed within the Boggabilla Management Reach. During cease-to flow and very low flow conditions 52% of LWH remains inundated (Table 22). 54% of LWH are inundated under baseflows (840 ML/day), increasing to 68% under small pulse flows (3,100 ML/day). Large pulse flows result in 91% inundation and overbank flows >10,900 ML/day are required to achieve 100% inundation of observed LWH.

A total of 94 rootballs were observed within the Boggabilla Management Reach. No rootballs are inundated under cease to flow, very low flow and baseflow conditions. A small pulse of 3,100 ML/day results in 11% rootball inundation. Inundation increases with flow, reaching 46% under large pulse, 48% at bankfull and 100% under overbank flows.

A total of 31 wetlands entry/exits were observed within the Boggabilla Management Reach, with 94% connected under baseflow conditions. Wetland connection increases to 97% under small pulse flows, large pulse flows and bankfull flows. Overbank flows exceeding 10,900 ML/day are required to achieve 100% inundation. All wetland entries disconnect under very low flows, indicating the ability to implement a wetting and drying regime in adjacent wetlands utilising only in-stream flow, a significant opportunity to generate habitats ideal for floodplain specialist fish species

A total of 167 benches were recorded within the Boggabilla Management Reach, covering a total area of 34.6 ha. None of the observed benches are inundated under cease to flow or very low flow conditions. 6% of bench area is inundated under baseflow conditions, increasing to 10 % under small pulse conditions, 52% under large pulse conditions, 64% at bankfull and 100% under overbank flow conditions.

Table 22: Inundation of habitat features by flow component for the Boggabilla Management Reach

Component of flow regime	Stage Height (m)	Flow (ML/day)	LWH	LWH (%)	Rootballs	Rootballs (%)	Wetland Entry/Exits	Wetland Entry/Exits (%)	Benches (n)	Benches Count (%)	Benches Area (ha)	Bench Area (%)
Cease to flow	0	<20	370	52.3	0	0	0	0	0	0	0	0
Very low flow	0.1 - 0.2	20 - 230	370	52.3	0	0	0	0	0	0	0	0
Baseflow	0.3 - 0.5	230 - 840	381	53.9	0	0	29	93.5	2	1.2	0.2	0.6
Small pulse	0.6 - 1.0	840 - 3,100	481	68.0	11	11.7	30	96.8	40	24	3.3	9.6
Large pulse	1.1 - 2.6	3,100 - 10,900	640	90.5	46	48.9	30	96.8	110	65.9	17.8	51.5
Bankfull	2.7	10,900	642	90.8	48	51.1	30	96.8	113	67.7	18.8	54.3
Overbank	>2.8	>10,900	707	100	94	100	31	100	167	100	34.6	100

Terrewah Management Reach

A total of 5,505 LWH were recorded within the Terrewah Management Reach (Table 23). Modest amounts of LWH are inundated under cease to flow (14%) or very low flow (15%) conditions. 29% of LWH are inundated under baseflows of 110 ML/day, increasing to 70% under small pulses of 1,300 ML/day, 92% under large pulses of 3,300 ML/day and bankfull flows of 3,300 ML/day. Overbank flows exceeding 7,900 ML/day are required to inundate 100% of LWH.

A total of 456 rootballs were recorded within the Terrewah Management Reach. Rootballs were at a high elevation within the river channel, a result consistent in other habitat mapping reports, and is reflected in the high flow requirement to achieve inundation. No rootballs are inundated under cease to flow or very low flow (444 ML/day) conditions. Only one rootball is inundated under baseflows, increasing to 5% under small pulses, 22% under large pulses, 24% at bankfull flows and 100% under overbank flows.

A total of 180 wetlands entry/exit points were recorded with the Terrewah Management Reach. Like rootballs, wetland connection points were typically elevated within the river channel. Zero wetlands are connected under cease to flow conditions, increasing to 1% inundation under very low flow conditions (40 ML/day). 2% of wetlands connections are connected under baseflow conditions, increasing to 14% under small pulse, 34% under large pulse, and 38% at bankfull. Overbank flows exceeding 7,900 ML/day are required to achieve 100% wetland inundation within the Management Reach. A total of 26 wetlands (14%) can be connected using small pulses of 1,300 ML/day, presenting the opportunity to implement a wetting and drying regime within these wetlands utilising in channel flows. A total of 112 wetlands (62%) are only inundated by overbank flows. Infrastructure works, manual pumping and constraint mitigation should be used where feasible to maintain healthy wetting and drying regimes.

A total of 1,272 benches were recorded within the Terrewah Management Reach, covering a total area of 27.5 ha. No observed benches are inundated under cease to flow conditions, increasing to 0.4% inundation under very low flows. There is a significant opportunity to increase system productivity by inundating low-lying benches using relatively small volumes of environmental water, as bench area inundation increases from 13% under baseflow (110 ML/day) to 68% under small pulse flows (1,300 ML/day). Large pulse flows increase bench area inundation to 86% and overbank flows exceeding 7,900 ML/day are required to achieve 100% inundation.

Table 23: Inundation of habitat features by flow component for the Terrewah Management Reach

Component of flow regime	Stage Height (m)	Flow (ML/day)	LWH	LWH (%)	Rootballs	Rootballs (%)	Wetland Entry/Exits	Wetland Entry/Exits (%)	Benches (n)	Benches Count (%)	Benches Area (ha)	Bench Area (%)
Cease to flow	0	<5	793	14.4	0	0	0	0	0	0	0	0
Very low flow	0.1 - 0.2	5 - 40	849	15.4	0	0	2	1.1	11	0.9	0.1	0.4
Baseflow	0.3 - 0.5	40 - 110	1,636	29.7	1	0.2	3	1.7	255	20	4.1	13
Small pulse	0.6 - 2.0	110 - 1,300	3,878	70.4	24	5.3	26	14.4	1,029	80.9	21.2	68.1
Large pulse	2.1 - 3.2	1,300 - 3,300	5,047	91.7	100	21.9	62	34.4	1,220	95.9	26.9	86.4
Bankfull	3.3	3,300	5,083	92.3	108	23.7	68	37.8	1,223	96.1	27	86.9
Overbank	>3.4	>7,900	5,505	100	456	100	180	100	1,272	100	27.5	100

Boomi Management Reach

A total of 5,347 LWH were recorded within the Boomi Management Reach (Table 24). 42% of LWH are inundated under cease to flow and very low flow conditions (60 ML/day). The rate of LWH inundation is relatively gradual within the Boomi Management Reach, reaching 47% under baseflow (100 ML/day), 48% under small pulse (650 ML/day), 50% under large pulse (1,200 ML/day) and 52% at bankfull (1,200 ML/day). Overbank flows exceeding 1,200 ML/day are required to achieve 100% LWH inundation.

Rootballs are relatively elevated within the river channel throughout the Boomi Management Reach. 17% of rootballs are inundated under baseflow conditions and only increases to 19% at bankfull flows (1,200 ML/day). Overbank flows exceeding 1,200 ML/day are required to achieve 100% inundation.

231 Wetland entry/exit points were recorded within the Boomi Management Reach, the majority of which were highly elevated within the river channel. 4% of wetlands commence to inundate under very low flows (60 ML/day); and no additional wetlands connect as flows increase to baseflow (60 ML/day) and small pulse conditions (100 ML/day). 5% wetlands are connected under large pulse and bankfull flows (1,200 ML/day).

Very few low-lying benches were observed within the Boomi Management Reach. 0.2 ha of bench area is inundated under baseflow conditions, an equivalent of 2.1% of total bench area. Bench area inundation increases gradually with flow to 5.2% under small pulse flows, 11.9% under large pulse flows and 15.9% at bankfull. 50% bench inundation occurs at overbank flows exceeding 2,900 ML/day, with no height data being available for flows exceeding 2,900 ML/day at the Boomi gauge.

Table 24: Inundation of habitat features by flow component for the Boomi Management Reach

Component of flow regime	Stage Height (m)	Flow (ML/day)	LWH	LWH (%)	Rootballs	Rootballs (%)	Wetland Entry/Exits	Wetland Entry/Exits (%)	Benches (n)	Benches Count (%)	Benches Area (ha)	Bench Area (%)
Cease to flow	0	<5	2,253	42.1	0	0	0	0	0	0	0	0
Very low flow	0.1	5 - 60	2,253	42.1	61	17.1	8	3.5	1	0.2	0	0.2
Baseflow	0.2	60 - 100	2,439	45.6	62	17.4	8	3.5	15	3	0.2	2.1
Small pulse	0.3	100 - 650	2,562	47.9	62	17.4	8	3.5	38	7.6	0.6	5.2
Large pulse	0.4	650 - 1,200	2,677	50.1	66	18.5	10	4.3	87	17.5	1.3	11.9
Bankfull	0.5	1,200	2,752	51.5	68	19.1	12	5.2	114	22.9	1.7	15.1
Overbank	>0.6	>1,200	5,347	100	356	100	231	100	498	100	11.0	100

Kanowna Management Reach

LWH were available at relatively low flow rates within the Kanowna Management Reach (Table 25), with 37.9% of LWH inundated under cease to flow and very low flow conditions (40 ML/day) and 43% inundated under baseflows (90 ML/day). Small pulse flows (900 ML/day) result in 72% LWH inundation and large pulse flows (2,500 ML/day) result in 95% inundation. Overbank flows exceeding 4,700 ML/day are required to inundate 100% of observed LWH. The significant increase in LWH from baseflow (43%) to small pulse flows (72%) presents a significant opportunity to increase LWH availability with relatively low volumes of water.

Rootballs were highly elevated within the river channel for the Kanowna Management Reach, with only 1% of rootballs inundated under baseflow conditions. Significant inundation begins to occur under large pulse flows, with 62% inundation occurring at 2,500 ML/day. Overbank flows of 5,170 ML/day are required to inundate 100 % of observed rootballs.

Wetland entry/exits points were likewise elevated within the river channel for the Kanowna Management Reach. 2 % of wetlands are connected under very low flows, increasing to 4% under baseflow conditions. A small pulse inundates a total of 37 wetland entry/exit points, the equivalent of 17% of wetlands within the Management Reach. Large pulse flows of 2,500 ML/day results in 67% wetland connection, increasing to 71% at bankfull. An overbank flow of 4,700 ML/day is required to inundate 100% of wetlands.

Very few low-lying benches were observed within the Kanowna Management Reach, with only 8% of bench area inundated under baseflow conditions. Small pulse flows significantly increased bench area inundation to 38% and further gains of 78% inundation occurs under large pulse flows. A total bench area of 16.4 ha is inundated under overbank flows exceeding 5,103 ML/day.

Table 25: Inundation of habitat features by flow component for the Kanowna Management Reach

Component of flow regime	Stage Height (m)	Flow (ML/day)	LWH	LWH (%)	Rootballs	Rootballs (%)	Wetland Entry/Exits	Wetland Entry/Exits (%)	Benches (n)	Benches Count (%)	Benches Area (ha)	Bench Area (%)
Cease to flow	0	<5	1,940	37.9	0	0	0	0	0	0	0	0
Very low flow	0.1 - 0.2	5 - 40	1,940	37.9	3	0.5	5	2.3	0	0	0	0
Baseflow -max	0.3 - 0.5	40 - 90	2,209	43.1	3	0.5	8	3.6	76	18	1.3	7.6
Small pulse	0.6 - 2.0	90 - 900	3,679	71.8	67	10.2	37	16.8	288	68.1	6.3	38.4
Large pulse	2.1 - 3.5	900 - 2,500	4,879	95.2	405	61.9	148	67.3	395	93.4	12.7	77.5
Bankfull	3.6	2,500	4,903	95.7	424	64.8	155	70.5	404	95.5	13.7	83.1
Overbank	>3.7	>2,500	5,124	100	654	100	220	100	423	100	16.4	100

Mungindi Management Reach

A total of 1,154 LWH were recorded within the Mungindi Management Reach (Table 26). 17% of LWH remain inundated under cease to flow and very low flow conditions (300 ML/day). 52% of LWH are inundated under baseflow conditions, indicating good habitat availability within the Management Reach. LHW inundation increases to 84% under small pulse flows (5,400 ML/day) and to 93% inundation under large pulse flows (7,400 ML/day).

107 LWH were observed within the Mungindi Management Reach. No rootballs are inundated under cease to flow, very low flow or baseflow conditions. 43% of rootballs become inundated under small pulse flows, 58% under large pulse flows and 59% at bankfull. An overbank flow exceeding 7,750 ML/day is required to inundate 100% of rootballs.

A total of 95 wetlands entry/exits were recorded within the Mungindi Management Reach. Zero wetlands are connected under cease to flow conditions, increasing to 12% under baseflows. Small pulse flows increase wetland inundation to 71%, indicating that a significant proportion of adjacent wetlands could have flow regimes implemented utilising in channel flows. Large pulse flows of 7,400 ML/day increase wetland connection to 87% and bankfull flows to 88% inundation.

397 benches were recorded within the Mungindi Management Reach, covering a total area of 23.7 ha. There were relatively few low-lying benches observed, with only 1% of bench area is inundated under baseflows, however inundation increases to 76% under small pulse flows of 5,400 ML/day. This presents an opportunity to dramatically increase in-stream productivity utilising small pulse flows to inundate dry benches. 88% of bench area is inundated under large pulse conditions and 89% at bankfull. Overbank flows of 11,200 ML/day are required to inundate 100% of observed benches.

Table 26: Inundation of habitat features by flow component for the Mungindi Management Reach

Component of flow regime	Stage Height (m)	Flow (ML/day)	LWH	LWH (%)	Rootballs	Rootballs (%)	Wetland Entry/Exits	Wetland Entry/Exits (%)	Benches (n)	Benches Count (%)	Benches Area (ha)	Bench Area (%)
Cease to flow	0	<30	198	17.2	0	0	0	0	0	0	0	0
Very low flow	0.1	30 - 300	198	17.2	0	0	10	10.5	1	0.3	0	0.1
Baseflow -max	0.2 - 0.3	300 -550	596	51.6	0	0	11	11.6	6	1.5	0.1	0.6
Small pulse	0.4 - 2.3	550 - 5,400	969	84	46	43	67	70.5	332	83.6	18	75.8
Large pulse	2.4 - 2.8	5,400 - 7,400	1,071	92.8	62	57.9	83	87.4	380	95.7	21.8	91.9
Bankfull	2.9	7,400	1,093	94.7	63	58.9	84	88.4	385	97	22.1	93.4
Overbank	>2.9	>7,400	1,154	100	107	100	95	100	397	100	23.7	100

Recommendations for future management in the Macintyre River

Flows for native fish

The analysis conducted on the Macintyre River as part of the *Mapping the Macintyre* project, focuses on the flow relationships of in channel habitat features and the fish communities of the reach, including the most abundant native species and modelled threatened species distribution for the reach. This analysis allows the knowledge of key native fish species in the Macintyre river, including their flow requirements during critical life history stages. This information builds upon existing knowledge and recommendation within existing strategies, such as Long-Term Water Plans and the Basin Wide Environmental Watering Strategy and should be incorporated into further developing EWRs for fish in the Macintyre River.

The proposed fish specific EWRs focus on in channel flow requirements based on an understanding of flow-ecology relationships for fish and habitat inundation in the Macintyre River to provide greater opportunity for spawning, recruitment, maintenance and condition outcomes for native fish. The implementation of these EWRs would achieve significant native fish outcomes, especially for target species and fish with specific life-cycle requirements for flow events, including in channel specialists, by providing improved spawning and recruitment opportunities. The EWRs would also enhance the maintenance and condition of all native fish functional groups.

Several flow targets have been described for EWRs that will achieve beneficial outcomes for native fish. It is hoped that this will help guide management actions in the project area by recognising the potential value of all water in the system that will contribute to the ecological objectives, including planned environmental water, Commonwealth environmental water holdings and natural flows, which could be supplemented to contribute to greater inundation of key habitat features.

The recommended EWRs are targeted at various levels of longitudinal and lateral connection (see Figure 60). Longitudinal connectivity can be achieved or enhanced by in-channel flows including baseflows but may require high flow levels where barriers exists. Lateral connection generally requires bankfull and overbank flows which inundate off stream wetlands and distributary streams. Minor increases in lateral connection can be achieved with smaller flows that inundate connected wetlands, benches and low-lying floodplains, however ecologically significant lateral connection requires higher flows especially overbank events. The Basin Plan attempts to achieve improvements in longitudinal and lateral connectivity.

Stable low flow specialist species as described by Kerr *et al.* (2017) do not require pulse events, rather require flow to be sustained at a level that does not significantly fluctuate (>5cm) during the spawning and development phase (~3 weeks). There is no proposed flow for these species however flow may be targeted at maintaining stable river levels under baseflows for these species by filling ‘gaps in the hydrograph from water extraction. Stable low flow specialists include the threatened purple spotted gudgeon and olive perchlet, both priority species within the project area.

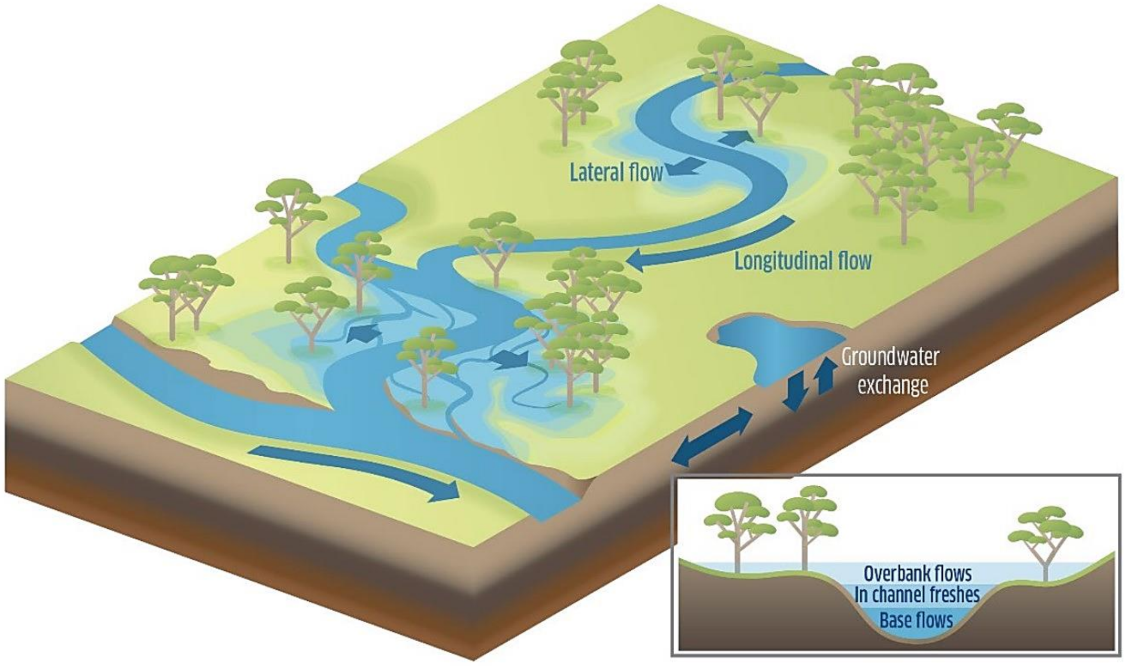


Figure 60. Hydrological connectivity and flows (MDBA, 2014).

As part of these management activities, consideration should also be given to the requirements for timing of flow events. With many native fish species currently understood to have temperature cues for spawning, the impacts of cold-water pollution should be considered when delivering flows as releases may interrupt natural temperature cues for movement and spawning. Within the project area, cold-water pollution only affects the reaches upstream of Boggabilla Weir. However, the impacts on upstream populations should be considered, including the Dumaresq, Macintyre Brook and the upper Macintyre River (Lugg and Copeland 2014). Where possible, supplementing natural flows can increase inundation of habitat features and mitigate impacts of cold-water pollution by dissipating the temperature variation of the water being released.

The existing Long-Term Watering Plan has a process outlined for reviewing and updating flow values, the EWRs outlined below are guidelines only and further review including local expertise should be considered before implementing any changes to flow values.

Enhanced in channel specialists spawning

Ecological objective

Provide flow regimes that enhance spawning opportunities for in channel specialist native fish species, focussing on Murray cod and freshwater catfish.

Improve the inundation and availability of key habitat features along the Macintyre River for in channel specialists (flow dependent – Murray cod), particularly LWH and rootballs.

Improve the inundation and availability of key habitat features along the Macintyre River for in channel specialists (flow independent – freshwater catfish), particularly gravel/cobble benches, and wetland entry points.

Improve the longitudinal connectivity along the Barwon River, enhancing localised movement opportunities for native fish.

Environmental water requirement

A small pulse event across the project area for a minimum of 14 days from September to April, every second year (ideally annually) with a maximum inter- event period of two years will provide significant outcomes for in channel species. Benefits would include increased spawning substrate, increased productivity and dispersion opportunities. A slow recession should be maintained to avoid stranding nests and nest abandonment.

Site specific flow indicators

The magnitude of flow required to achieve small pulse conditions varies between Management Reaches within the project area. Boggabilla Management Reach requires 3,100 ML/day to reach small pulse conditions, Terrewah requires 1,300 ML/day, Boomi requires 650 ML/day, Kanowna requires 900 ML/day and Mungindi requires 5,400 ML/day.

All inundation values below are be discussed in terms of flow component condition i.e. small pulse, rather than numeric flow values.

Rationale

Small in channel pulse events across Management Reaches within the project area would provide benefits for all functional groups of fish through improved habitat availability. Increasing flows from baseflow to small pulse conditions increases LWH inundation from 41% to 65 % and bench area inundation from 5% to 44%, and wetland connection from 8% to 22%; indicating that the current flow thresholds are adequately increasing habitat availability throughout the project area.

Research throughout parts of the Murray cod's range has suggested a strong association between the species and complex woody habitat (Koehn and Nicol, 2014). With the increase in availability of these habitats from this higher flow target there would be more opportunities for spawning.

This flow target would also have significant benefits for freshwater catfish with over 65% of benches becoming inundated, which could result increased availability of breeding sites and nesting materials (gravel and cobbles).

The availability of these key habitat features provided by the small pulse events would allow regular maintenance and condition opportunities for all fish communities, as well as opportunities for short to moderate movements in the system through improved longitudinal connectivity. The proposed frequency of the events is especially important for short-lived fish, including those described as stable low flow spawning fish by Kerr *et al*. (2017), as they need regular flow events to complete important life-cycle stages.

The minimum duration of 14 days is linked to pre-development natural hydrological patterns and the hatch time for eggs of the target species to ensure a stable flow when eggs are on the nest, with rapid changes in height and flow rate, either up or down, to be avoided to maximise spawning outcomes. The minimum of 14 days allows for sufficient time for in channel specialists (Murray cod) to select a nest, spawn, allow time for the eggs to develop and larvae to disperse (NSW DPI, 2015).The ideal length of this event is >20 days with the main outcome for the event being regular access to spawning habitat and movement opportunities for spawning outcomes, and it is therefore considered appropriate for the event to occur during the prescribed spawning window for target species.

Held environmental water delivered from Glenlyon and/or Pindari Dams could be used to shape the hydrograph adding to natural flow to reach the threshold or providing a stable recession while not impacting on water temperature. To maximise environmental outcomes, the held environmental water component of these types of flows would have to be actively managed once it leaves the regulated water sharing plan area from which it was delivered. Active management allows protection of held environmental water from extraction after it leaves the regulated system where it was delivered (DPIE, 2019b).

Small pulse flows utilising held environmental water should be coordinated and aligned with downstream valley outcomes, to leverage the increased productivity, habitat availability and recruitment generated with the Macintyre project area. This has been successfully implemented in the past, where held environmental water was actively managed in 2019 for the Northern Fish Flow, which consisted of held environmental water being delivered from the Border Rivers out of Glenlyon Dam and the Gwydir system out of Copeton Dam, the flows travelled down these systems before connecting with the Barwon River (CEWO, 2019b).

Large pulse events for flow dependent specialists

Ecological objective

Maintain large pulse events for spawning and recruitment of flow dependent specialists.

Large pulse flows provide significant longitudinal connection and provide an increased level of lateral connection inundating some wetland entry points and low-level floodplains providing spawning and recruitment opportunities for some floodplain specialists.

Flow connectivity with downstream reaches is also critical to the dispersal pelagic larvae of golden perch and silver perch into nursery habitats (Stuart and Sharpe 2020).

Environmental water requirement

This flow would generally not require delivery but protection of the integrity of natural events within the flow class. Natural flow events could be supplemented with held environmental water from tributaries. This is particularly important after long periods of no flow or extended period with no large pulses.

A large pulse event 10,900 ML at Boggabilla for a minimum of 20 consecutive days from September to March, preferably every year but can be every second year, with a maximum inter-flow period of two years to enhance migration, spawning and recruitment outcomes for flow specialists and floodplain specialists.

The flow target could be adjusted to a small pulse flow rate of 840 ML at Boggabilla weir while still achieving some of the objectives, although the effectiveness of outcomes may be compromised, with a timing shift from September to March enhancing spawning outcomes for in channel specialists (flow independent – freshwater catfish) species. Reducing flow rates may also not drown out barriers to fish passage and reduce the distance that pelagic larvae can disperse, both key ecological requirements of the threatened silver perch. The duration and frequency of flows should still be maintained.

Supplementing natural flows to reach heights of a sufficient magnitude is problematic as infrastructure becomes inundated and other third-party impacts become apparent. Complementary water delivery actions for floodplain specialists may be needed in some situations. In the absence of overbank flows, delivery of water to replenish floodplain wetlands may be required via pumping from the main channel do avoid drying of these habitats and subsequent localised extinctions; as is common within the Southern Murray-Darling Basin. The floodplain specialist species, olive perchlet, has been found in the project area, and is of conservation significance, with protection of their population a priority.

Site specific flow indicators

The magnitude of flow required to achieve large pulse conditions varies between Management Reaches within the project area. Boggabilla Management Reach requires 10,900 ML/day to reach large pulse conditions, Terrewah requires 3,300 ML/day, Boomi requires 2,500 ML/day, Kanowna requires 2,500 ML/day and Mungindi requires 7,400 ML/day.

The flow rates required to achieve large pulse flows within each management drowns out all manmade and natural fish barriers across the project area except for Boggabilla Weir, which remains a barrier until flows of 28,500 ML/day. This indicates that fish passage can occur across the project area under large pulse conditions, apart from Boggabilla Weir preventing movement into upstream reaches and tributaries such as the Dumaresq and Severn Rivers.

Rationale

Large in channel pulse events would provide benefits for all functional groups of fish through improved habitat availability and system productivity. LWH availability across the entire project area increases from 41% inundation under baseflow to 80% inundation under large pulse conditions. Likewise, bench area inundated increases from 5% at baseflow to 71% under large pulse conditions. Wetland connections also increases from 8% at to 44% inundation, connecting a total of 274 adjacent wetlands.

The availability of these core habitat features provided by the large pulse event would also improve the condition of emergent aquatic macrophytes such as cumbungi, phragmites and juncus/sedge, helping contribute to regular maintenance and condition opportunities for all fish communities, as well as opportunities for short to moderate movements in the system through improved longitudinal connectivity. The proposed frequency of the events is especially important for short-lived fish, including those described as stable flow spawning species by Kerr *et al*. (2017), as they need regular flow events into connected wetlands and anabranches to complete important life-cycle stages.

A large portion of the in channel food resources in lowland river systems comes from organic material on the floodplain (Vannote *et al.* 1980; Oliver and Merrick, 2006). Inundating areas out of the main channel increases availability of these resources and increases in channel productivity while increasing the condition and growing area for macrophytes. Inundation of benches mobilises carbon which stimulates river productivity. Wetland inundation provides a stimulus for plant germination and the emergence of invertebrates from resting life stages, many of which can become abundant within days of inundation (Kerr *et al*. 2017).

Although not the primary environmental objective, these flows may also provide some opportunities for spawning and recruitment outcomes for generalists, flow dependent specialists, in channel specialists and floodplain specialists that are more opportunistic and quicker to respond to the shorter duration event. Species that may respond include bony bream, golden perch, spangled perch and the threatened silver perch and olive perchlet.

The proposed duration of five days can be adjusted as needed, depending on hydrological and antecedent conditions. Flow duration is directly linked to productivity with diversity of in-stream communities decreasing with decreased floodplain inundation (Zeiringer *et al.* 2018). Due to the lowland nature of the project area flows generally consist of a more gradual rise and fall than systems in the slopes upland areas, as a result fish species in this area are adapted to these types of events. Events of a shorter duration provide limited time for fish to move but may provide a window of time when passing a barrier is possible or provide an opportunity to move to a more substantial refuge pool. Ideally this flow would occur leading up to and following the in-stream specialist spawning flow. Very low flow and cease to flow events should be avoided between these events where possible to maintain connection through the system and support native fish recruitment.

This flow can be used to prime the system for spawning events when delivered in late winter to early spring or can be used to increase food availability and connectivity for larval and juvenile fish in mid-summer to mid-autumn. Late winter/early spring flows are intended primarily to support pre-spawning conditioning for all functional groups through inundation of in channel benches and aquatic habitat. Mid-summer to autumn peaks are intended to provide inundation of in channel benches and habitat to increase productivity and support larval and juvenile drift.

The main outcomes for this EWR are recruitment and dispersal of juveniles, increased in-stream productivity via bench inundation and increasing movement opportunities via barrier inundation. It is therefore considered appropriate for the timing of the event to occur during the spawning timeframes for the targeted freshwater species, taking into consideration any water quality issues such as destratification, cold-water pollution and downstream algae seeding.

Refuge replenishment and connection

Ecological objective

The ecological objective of this flow is to maintain critical water quality and quantity in refuge pools to avoid fish kills during sustained dry periods. This will also provide intermittent connection between refuge habitats. Maintaining refugia allows key ecosystem functions including cycling of nutrients and provision of carbon for productive food webs (MDBA, 2018).

Environmental water requirement

There is no recommended flow for this EWR as it varies depending on the specific conditions of downstream reaches during a prolonged cease to flow event. The persistence of refuge pools is estimated to be approximately 170 days per meter in depth (DSITI, 2015). Based on this analysis, three refuge pools of depths exceeding two meters will persist within the project area for 340 days, noting that water quality will deteriorate rapidly as pools reduce in depth. This ‘river restart’ event is delivered during critical dry periods to replenish refuge pools and provide a short period of connectivity between habitats. Natural flows can be supplemented to more efficiently achieve lateral connection.

In the absence of natural events, this flow can be delivered from regulated tributaries or releases from Boggabilla Weir. Events like this have been delivered in 2018 and 2019. The longer the period of zero flow the greater the reduction in flow between gauges, meaning earlier delivery would be more efficient. Magnitude will depend on the amount of time and length of channel that has been dry. Extended dry periods will require more water to ‘restart’ the river with water infiltrating into the soil and ground water aquifers.

River restarts also need to be responsibly managed, as there are considerable risks to water quality of refuge pools. Deep water storages are prone to developing thermal stratification during warmer months, especially under lotic conditions. Stratification results in increased algae activity in surface water layers and anoxic conditions in deeper water layers (Vertessy, 2019), as such there may be significant risks of releasing poor quality water into downstream reaches, particularly for undershot weirs such as Boggabilla. Released water can collect large quantities of sediment, organic matter and latent heat from dry riverbeds, typically forming a low-quality slug of hot water at the front of the flow. When connecting multiple refuge pools, particularly during summer, this restart flow can lead to fish kills as seen in the lower Darling River and Gwydir Rivers in 2019/20 (Charlie Caruthers pers. Comms; Iain Ellis pers. comms). This risk can be mitigated in a number of ways, such as pre-emptively topping up refuge pools during cooler weather in preparation for an anticipated summer cease to flow event, delaying river restarts until cooler months and making the initial restart at a flow rate sufficient in magnitude to allow fish trapped in refugia to swim upstream past the low dissolved oxygen flow front. Considerable data and knowledge were gained in 2019/20 cease to flow events across the Northern Murray-Darling Basin and this information should be made available to all technical advisory groups and river operators (Iain Ellis pers. comms).

Site specific flow indicators

Replenishment and connection of refuge pools

Distance of river to be reconnected will depend on the nature of the drying event and in flows, or lack of, from tributaries. The lower Darling restart flow in March 2020 started at 3,000 ML/day release for seven days, before being reduced to 400 ML/day, the equivalent of starting at small pulse flows and reducing to baseflow. The equivalent flow regime for a restart for the Macintyre project area would be a seven-day release from Boggabilla at 1,300 ML/day being reduced to 250 ML/day, noting that these values are indicative only and future planning should incorporate local technical and ecological expertise.

Maintain stable water levels during low-flow specialist nesting periods

The ecological objective of this EWR is to maintain stable water levels during the critical nesting period of short-lived fish that spawn during low-flow events. Two threatened species within the project area (purple spotted gudgeon and olive perchlet) spawn during stable low-flow events, attaching eggs to undercut banks, LWH and aquatic macrophytes. Rapid changes in water level due to water extraction or supplemented flows may threaten the viability of these populations by stranding spawning habitat and drying our eggs and larvae.

At present, there is no recommended EWR to address the needs of the stable low-flow guild within the Long-Term Water Plan, as they are currently included within the floodplain specialist functional group, which focusses on lateral connection with floodplain habitats.

Environmental water may be utilised opportunistically to fill in gaps operational water orders or smooth supplementary flows during spawning season, ensuring that water heights remain relatively stable and preventing the desiccation of eggs and larvae. Additional research has found that submerged aquatic macrophytes such as *Vallisneria spp* provide valuable spawning sites for stable low-flow specialists, as macrophytes will bend and remain underwater if flow recedes post-spawning (Kerr *et al* 2017). Therefore, it is critical that aquatic macrophytes are also protected and maintained within the project area.

Existing research indicates that olive perchlet breed from September to December and purple spotted gudgeon in December to February (Kerr *et al*. 2017). Further research is required to determine site-specific spawning period and detection methods for the Macintyre river project area. This research should be further developed into a strategic framework to assist environmental water planners in delivering outcomes for stable low-flow spawning fish.

Maintain integrity of bankfull and overbank flows for flow dependent specialist and floodplain specialists

There is minimal potential for the CEWO to impact on this flow class, due to upstream holdings being too small to feasibly deliver the flow rates required to achieve bankfull flows within the project area e.g. 10,000 ML/day at Boggabilla. However, protection should be advocated with other water management agencies to maintain its integrity in areas with connection points to significant wetland areas. Establishing the height at which significant wetland areas become inundated would be very valuable. This would require further analysis of where the connection points lead too, potential methods are discussed in the following section. The protection, monitoring and management of these events is not considered to be the responsibility of the CEWO, however it is a responsibility of other agencies. Relevant stakeholders include NSW Department of Planning, Industry and Environment – Environment, Energy and Science; WaterNSW; Border Rivers Commission; Queensland Department of Regional Development, Manufacturing and Water; and Queensland Department of Environment and Science.

An Environmental Watering Advisory Group (EWAG) is currently being developed for the Border Rivers Valley and will include representatives from relevant community stakeholders. Stake holders will include the local Aboriginal community, farming sector and relevant government departments, alongside ecological experts.

The occurrence interval for these events varies significantly between target species, longer lived flow dependent specialist species such as golden perch and silver perch do not require as frequent recurrence intervals as short-lived floodplain specialist species such as olive perchlet that can suffer localised extinctions if these events do not occur for an extended period of time.

Activities to address the lack of natural inundation of off stream wetlands may need to be considered in some areas. This could be done by pumping water from the main channel, a method which has been used in areas of the Southern Murray-Darling Basin at several scales with varying levels of success (see NSW DPIE-EES, 2019).

Recommendations for future management in the Macintyre River

The Macintyre habitat mapping project has considerably advanced the available information and understanding for water management in the Macintyre River related to fish and river outcomes; and enhanced the existing information for the already mapped stretch of the Barwon Darling from Mungindi to Wilcannia. However, knowledge gaps still exist that require attention to enhance the development of future environmental water requirements.

The outcomes of water management in the Macintyre River would be greatly enhanced through development and implementation of complementary aquatic habitat rehabilitation and adaptive monitoring programs. The recommendations outlined in the section below are the views of NSW DPI - Fisheries and are not considered to be the sole responsibility of the CEWO but may be supported or progressed with other state and federal government agencies.

Management Actions

To improve native fish populations and river health in the Macintyre River and throughout the Border Rivers, future management of water for the environment should consider management actions including:

2. Align complementary actions with the Northern Basin Toolkit recommendations

The Northern Basin Review (2016) established a framework for a series of ‘toolkit measures’ that are intended to meet environmental outcomes of the Murray-Darling Basin Plan, using complementary measures outside of water recovery. Measures included remediation of barriers to fish passages, cold-water pollution, pump-screening, threatened species recovery and improved management and coordination of existing environmental water (MDBA, 2020b).

The remediation of barriers to fish passage are a key measure recommended by the Northern Basin Toolkit. Seven in-stream barriers were observed within the project area, ranging in drown out flows from 495 ML/day (Toomelah Weir) to 28,500 ML/day (Boggabilla Weir). Remediation of fish passage at these barriers would increase fish movement through 455 km of aquatic habitat.

Cold-water pollution only effects the upper reaches of the project area, where Pindari Dam releases reduce temperatures to Boggabilla Weir. Tributaries immediately upstream of the project area are also impacted by cold-water pollution including the Dumaresq River (Glenlyon Dam) and Macintyre Brook (Coolmunda Dam). The combined influence of cold-water releases from tributaries may have negative effects on in-stream productivity, growth rates and recruitment (Lugg and Copeland 2014; Michie *et al*. 2020).

The project area contained 316 pumpsites including 103 pumps exceeding 250 mm in diameter. Fine mesh screens installed on pump intakes have been demonstrated to reduce the loss of fish larvae and juveniles via irrigations diversions (Boys et *al.* 2012) and benefit irrigators via reduced maintenance costs.

Threatened species recovery is a key component of the Northern Basin Toolkit. The data gathered in this report should be utilised to inform water management, optimise flow regime, guide protection and translocation of existing threaten populations and to prioritise complementary works such as barrier remediation and stock exclusion (Koehn *et al.* 2020).

The habitat mapping data can be used to provide direction on how to proceed with aquatic habitat restoration and protection initiatives. This information can be used by natural resource managers to prioritise areas for action increasing the benefits of environmental flow deliveries in the project area. For example, habitat mapping data could be used to improve the condition of riparian vegetation by showing where there are significant weed issues and where there is revegetation of native riparian species, allowing natural resource managers to make more informed decision when directing their resources. Furthermore, this data should inform the protection and translocation of existing threatened fish species i.e. aquatic macrophyte presence or locations of refuge pools during prolonged cease to flow events.

A recent proposal from NSW DPI – Fisheries titled “Fish for the Future” intends to include the above complementary actions including:

- Reconnecting the Northern basin – improved fish passage at 22 priority structures within the Barwon-Darling and Border Rivers.
- Addressing cold-water pollution – mitigation of cold-water pollution downstream below Pindari Dam.
- Fish friendly water extraction – targeted diversion screening program within the Border Rivers, Gwydir and Barwon Darling valleys.
- Threatened species recovery – reestablishment of populations of four key threatened fish species in the northern Basin.

3. Continued and sustained cross-disciplinary and inter-jurisdictional collaboration on information and knowledge of ecological relationships in the Barwon River and adjoining catchments

Current activities across the Murray-Darling Basin related to water management provide opportunities to effectively establish and foster linkages between relevant community, academic and government experts. The *Mapping the Macintyre river* project gathered a range of relevant knowledge, expertise and information related to fish and flow relationships in the Macintyre River. While much of this information is readily accessible, other material occurs in variable formats and is held by several different institutions and agencies.

To support the proposed long-term adaptive management plan and Macintyre River fish management strategy, it would also be useful to review existing management and research needs, including data sharing arrangements and management actions relating to fish and flow information in the Macintyre River.

This compiled information could be provided to the Environmental Water Advisory Group currently in development for the Border Rivers; promoting a collaborative and open approach to management of existing and future watering activities, including a shared commitment to identifying and addressing knowledge gaps.

Research and Monitoring

To improve native fish populations and river health in the Macintyre River and throughout the Border Rivers, future management of water for the environment should consider research and monitoring options such as:

1. Undertaking further habitat mapping to connect mapped areas in the Border Rivers, Gwydir and Barwon Darling River and secure additional data source

This habitat mapping project has connected a 1,916 km continuous reach of habitat inundation data from the Roseneath gauge on the Dumaresq River to Wilcannia on the Darling River. However, significant gaps still exist in our understanding of habitat features and their relationship to river flow across the Northern Murray-Darling Basin, particularly regarding inter-valley flow connectivity. The Barwon-Darling River downstream of the project area is highly dependent on regulated and protected unregulated releases from upstream tributaries, as demonstrated during the drought conditions of the 2019/20 drought (NSW DPIE, 2020). As such, further mapping should be undertaken in the Macintyre and Gwydir valleys and this data utilised to inform flow management at an inter-valley scale.

Priority mapping should include the Severn River downstream of Pindari Dam (~200 km) and the remainder of the upstream sections of the Macintyre River (~300km). This information, coupled with fish community details and water management activities, would allow critical flow thresholds to be identified in relation to inundation values, structure drown out requirements, and bankfull capacity volumes, helping to develop specific water requirements and strengthen water management actions at an inter-valley scale.

To complement habitat mapping data, LiDAR could be used to assess wetland area associated with entry points. This would allow a wetland area to be attached to each entry/exit point recorded during on ground mapping. Further analysis could also be complete of these wetlands using satellite imagery to map vegetation extent.

3. Committing to a long-term, adaptive management plan driven by monitoring and evaluation

The hydrological and hydraulic variation required to restore key elements for fish in the Macintyre River will differ across functional groups, and whilst some benefits will be experienced across groups from different flow regimes, a long-term commitment to adaptive management to flow and aquatic habitat management is required to maximise outcomes. Management plans that consider flow, habitat and connectivity need to include objectives for each functional group to ensure benefits are experienced across all native fish communities over relevant spatial and temporal scales. The development and implementation of a rigorous monitoring program is essential to help validate program assumptions and measure the success of flow delivery/protection and water requirements against the program objectives.

Information about the use of habitat by fish and their response to certain flow delivery scenarios will allow management plans to be evaluated and flow hydrographs to be adapted to ensure that outcomes are optimised, whilst providing confidence in stakeholders that decision making is being informed by biological information.

This has already been demonstrated in downstream reaches, where a refined hydrograph has delivered significant golden perch and Murray cod spawning in the lower Darling river (Stuart and Sharpe; Iain Ellis pers. comms.). It is important to establish long-term monitoring in project area that can supplement other monitoring programs in tributaries and downstream in the Barwon-Darling River. This will ensure that outcomes from managing water for the environment across a range of different valley types are captured and used to guide management decisions. In addition to this, it is essential that monitoring information and research outcomes are communicated and readily accessible to advance knowledge and management actions across related systems where applicable.

Conclusion

The Mapping the Macintyre River project has improved the understanding of the spatial distribution and inundation dynamics of fish habitat within the 327 km project area. Prioritised reach scale assessment has helped describe flow related attributes of the area, including hydrological conditions, fish barriers and connectivity issues, aquatic habitat condition and improving the understanding of hydrological and ecological information for the system.

The degradation of key habitat features on the Macintyre River has been exacerbated by the modification of natural inflows, having a significant effect on the status of native fish populations in the system. Smaller weirs within the main channel itself have significantly altered the local hydrology, with evident ecological differences observed between weir pool and free-flowing reaches within the project area. Fish condition within the project varied from moderate to good, highlighting the importance of remediating barriers to fish passage and enabling this strong population to replenish more depleted reaches.

Information from the Fish and Flows in the Northern Basin project (NSW DPI, 2015) and review of the most current literature has helped to refine fish functional groups specific to conditions of the Macintyre River based on biological, hydrological and hydraulic similarities related to spawning, recruitment and movement. The formation of fish functional groups for the Macintyre River has enabled overarching conceptual flow models to be developed that identify the importance of certain flow characteristics and hydrological variability for groups of species. This information can be used to guide the development of the EWRs that can be used by water managers to improve outcomes for certain species in certain functional groups. The information will also guide management of water for the environment for a system over long-term planning frameworks to maximise water use and environmental benefits.

The habitat data recorded during habitat mapping can be used by natural resource managers and landholders to direct resources for protection and rehabilitation of riparian and in-stream habitats. These actions can complement the benefits from the management of water for the environment, providing a greater benefit to the fish communities in the project area.

References

Australian Government. (2020). Environmental Water Holdings: Border Rivers https://www.environment.gov.au/water/cewo/about/water-holdings and Portfolio and Planning – Border Rivers https://www.environment.gov.au/water/cewo/catchment/border-rivers/portfolio-planning Last accessed 6/11/2020.

Barrett, J. (Ed.). (2008). *The Sea to Hume Dam: Restoring Fish Passage in the Murray River*. Murray-Darling Basin Commission, Canberra.

Baumgartner, L., Conallin, J., Campbell, B., Gee, R., Robinson, W. and Mallen-Cooper, M. (2013a). Using Flow Guilds of Freshwater Fish in an Adaptive Management Framework to Simplify Environmental Flow Delivery for Semi-Arid Riverine Systems. *Fish and Fisheries.* 15: 410-427.

Baumgartner, L., McPherson, B., Doyle, J., Cory, F., Cinotti, N. and Hutchison, J. (2013b). Quantifying and Mitigating the Impacts of Weirs on Downstream Passage of Native Fish in the Murray-Darling Basin. NSW Department of Primary Industries Fisheries Final Report Series no.136. Department of Industry and Investment NSW, Narrandera, NSW, Australia.

Beesley, L., King, A., Amstaetter, F., Koehn, J., Gawne, B., Price, A., Nielson, D., Vilizzi, D. and Meredith, S. (2012). Does Flooding affect Spatiotemporal Variation of Fish Assemblages in Temperate Floodplain Wetlands? *Freshwater Biology*. 57, 2230-2246.

Bioregional Assessments. (2019). Surface Waters Systems: Condamine-Balonne River Basin. https://www.bioregionalassessments.gov.au/assessments/11-context-statement-maranoa-balonne-condamine-subregion/1151-surface-water-systems

Bureau of Meteorology. (2018). Climate Statistics for Australia: Summary Statistics Mungindi Post Office. http://www.bom.gov.au/climate/averages/tables/cw_052020.shtml

Boys, C. (2007). *Fish-habitat Associations in a Large Dryland River of the Murray-Darling Basin, Australia*. PhD Thesis, University of Canberra, Canberra. 320 pp

Boys, C., L. Baumgartner, B. Rampano, W. Robinson, T. Alexander, G. Reilly, M. Roswell, T. Fowler, and M. Lowry. (2012)."*Development of fish screening criteria for water diversions in the Murray-Darling Basin*. "Fisheries Final Report Series-NSW Department of Primary Industries 134

Boys, C. and Rayner, T. (2017). *Pump and Diversion Screening: The Sleeping Giant of Australian River Restoration*. Proceedings of the Murray Darling Basin Native Fish Forum 2017.

Brooks, A., Gehrke, P., Jansen, J. and Abbe, T. (2004). Experimental Reintroduction of Woody Debris on the Williams River, NSW: Geomorphic and Ecological Responses. *River Research and Applications*. 20, 513-536.

Bunn, S. and Arthington, A. (2002). Basic Principles and Ecological Consequences of Altered Flow Regimes for Aquatic Biodiversity. *Environmental Management*. 30: 492- 507.

Butcher, A. (2007). Characteristics of Fish Fauna of the Macintyre and Dumaresq Rivers and Macintyre Brook. A Report to the Queensland Murray-Darling Committee.

Casatti, L., Mendes, H. and Ferreira, K. (2003). Aquatic Macrophytes as Feeding Sites for Small Fishes in the Rosana Reservoir, Paranapanema River, South-eastern Brazil. *Brazilian Journal of Biology*. 63, 213- 222.

Crown Lands and Water Division. (2017). Barwon-Darling Water Resource Plan: Surface Water Resource Description. https://www.industry.nsw.gov.au/__data/assets/pdf_file/0010/152938/Barwon-Darling.pdf

Commonwealth Environmental Water Office. (2016). Restoring and Protecting the Unregulated Rivers of the Northern Basin 2016-17. https://www.environment.gov.au/water/cewo/publications/restoring-protecting-northern-basin-2016-17

Commonwealth Environmental Water Office. (2019a). Environmental Water Holdings. http://www.environment.gov.au/water/cewo/about/water-holdings

Commonwealth Environmental Water Office. (2019b). Northern Fish Flow – Factsheet. https://www.environment.gov.au/water/cewo/publications/northern-fish-flow-fact-sheet

Crook, D. and Robertson, A. (1999). Relationships Between Riverine Fish and Woody Debris: Implications for Lowland Rivers. *Marine and Freshwater Research.* 50, 941-953.

Davies, P.E., Stewardson, M.J., Hillman, T.J., Roberts, J.R. and Thoms, M.C. (2012). *Sustainable Rivers Audit 2: The Ecological Health of the Rivers in the Murray-Darling Basin at the end of the Millennium Drought (2008–10)*. Prepared by the Independent Sustainable Rivers Audit Group for the Murray-Darling Basin (ISRAG). MDBA Publication No. 72/12. Murray Darling Basin Authority, Canberra.

Department of Environment, Climate Change and Water. (2011). Gwydir Wetlands Adaptive Environmental Management Plan: Synthesis of Information Projects and Actions. Department of Environment, Climate Change and Water NSW. DECCW 2011/0027.

Department of Science, Information Technology and Innovation (2015). Waterhole refuge mapping and persistence analysis in the Lower Balonne and Barwon–Darling rivers. Department of Science, Information Technology and Innovation, Canberra

Department of Natural Resource, Mines and Energy. (2018). Stable Low-flow Spawning Fish: Phase II: Assessment of spawning habitat and establishment of lower threshold for stable low-flows in the Condamine-Balonne and Border Rivers WP areas. State of Queensland, Toowoomba.

Delariva, R., Agostinho, A., Nakatani, K. and Baumgartner, G. (1994). Ichthyofauna Associated to Aquatic Macrophytes in the Upper Paraná River Floodplain. Rev. *Unimar*, 16, 41-60.

Dyer, F., Thoms, M. and Olley, J. (2002). The Structure, Function and Management Implications of Fluvial Sedimentary Systems. International Association Hydrological Sciences Press. Centre for Ecology and Hydrology, Wallingford, Oxfordshire, UK.

Ebner, B., Scholz, O. and Gawne, B. (2009). Golden Perch *Macquaria ambigua* are Flexible Spawners in the Darling River, Australia. *New Zealand Journal of Marine and Freshwater Research*. 43, 571-578.

Ellis, I., Cheshire, K., Townsend, A., Copeland, C. Danaher, K. and Webb, L. (2016). *Fish and Flows in the Murray River Catchment - A Review of Environmental Water Requirements for Native Fish in the Murray River Catchment.* NSW Department of Primary Industries, Queanbeyan.

Fairfull S. and Witheridge, G. (2003). *Why do Fish Need to Cross the Road? Fish Passage Requirements for Waterway Crossings*. NSW Fisheries, Cronulla, 16pp.

Fisheries Scientific Committee. (2000). *Fisheries Scientific Committee Final Determination: Silver Perch*. NSW Fisheries, Pyrmont.

Foster, N. and Cooke, R. (2011). *Barwon-Darling IQQM Analysis – Critical Flow Thresholds for Environmental Values Identified within the Barwon-Darling Water Sharing Plan.* NSW Department of Primary Industries, Tamworth.

Gaillard, J., Coulson, T. and Festa-Bianchet, M. (2008). Recruitment. In Encyclopedia of Ecology. Elsevier, Amsterdam, The Netherlands.

Gippel, C. (1995). Environmental Hydraulics of Large Woody Debris in Streams and Rivers. *Journal of Environmental Engineering.* 121, 388-395.

Gippel, C.J. (2013). Assessment of the hydraulics of the Little Murray River Weir Pool under alternative operating scenarios. Fluvial Systems Pty Ltd, Stockton. Goulburn-Murray Water, Shepparton, January.

Gorski, K., Buijse, A., Winter, H. and Nagelkerke, L. (2013). Geomorphology and Flooding Shape Fish Distribution in a Large- Scale Temperate Floodplain. River Research and Applications. 29. 1226-1236

Humphries, P., King, A. and Koehn, J. (1999). Fish, Flows and Floodplains: Links between Freshwater Fishes and Their Environment in the Murray-Darling River System, Australia. *Environmental Biology of Fishes*. 56, 129-151.

Humphries, P. and Walker, K. (2013). *Ecology of Australian Freshwater Fish*. CSIRO Publishing, Collingwood, Victoria, Australia.

Industry and Investment NSW. (2010). *Road Crossing Barrier Summaries, Little River Sub Catchment*. Prepared for the Central West Catchment Management Authority. Industry and Investment NSW, Dubbo, NSW.

Jenkins, K. and Boulton, A. (2003) Connectivity in a Dryland River: Short-term Aquatic Macroinvertebrate Recruitment Following Floodplain Inundation. *Ecology*. 84. 27m08-2723.

Jones, H. (2007). The Influence of Hydrology on Freshwater Mussel (Bivalvia: Hyriidae) Distributions in a Semi-Arid River System, the Barwon-Darling River and Intersecting Streams. In Dickman, C., Lunney, D. and Burgin, S. (eds). (2007). *Animals of Arid Australia – Out on Their Own?* Royal Zoological Society of New South Wales, Mosman, New South Wales.

Kerr, J., Prior, A. and Fawcett, J. (2017). *Stable Low-flow Spawning Fish – Assessment of Generic Model Parameters used to Assess Risk to Stable Low-flow Spawning Fish Species in Condamine-Balonne, Border Rivers and Moonie Water Resource Plans*. Department of Natural Resources and Mines, Toowoomba.

Koehn, J. (2009). Multi-scale Habitat Selection by Murray Cod *Maccullochella Peelii Peelii* in Two Lowland Rivers. Journal of Fish Biology. 75, 113-129.

Koehn, J. and Nichol, S. (2014). Comparative Habitat use by Large Riverine Fishes. *Marine and Freshwater Research*. 65, 164-174.

Koehn, J., Raymond, S.,Stuart, I., Todd, C., Balcombe, S., Zampatti, B., Bamford, H., Ingram, B., Bice, C., Burnfred, K., Butler, G., Baumgartner, L., Clunie, P., Ellis, I., Forbes, J., Hutchison, M., Koster, W., Lintermans, M., Lyon, J., Mallen-Cooper, M., McLellan, M., Pearce, L., Ryall, J., Sharpe, C., Stoessel, D., Thiem, J., Tonkin, Z., Townsend, A. and Qifeng, Y. (2020). A Compendium of Ecological Knowledge for Restoration of Freshwater Fishes in Australia's Murray-Darling Basin. *Marine and Freshwater Research*. 71, 1391-1463.

Koehn, J., Balcombe, S., Baumgartner, L., Bice, C., Burndred, K., Ellis, I., Koster, W., Lintermans, M., Pearce, L., Sharpe, C., Stuart, I. and Todd, C. (2020). What is Needed to Restore Native Fishes in Australia's Murray-Darling Basin? *Marine and Freshwater Research*. 71, 1464-1468

Lake, P. (1995). *Of Floods and Droughts: River and Stream Ecosystems of Australia*. In Cushing, E., Cummins, K. and Minshall, G. E. (eds). River and Stream Ecosystems. p. 659-94. Elsevier, New York.

Lintermans, M. (2009). *Fishes of the Murray-Darling Basin: An Introductory Guide*. Murray Darling Basin Authority, Canberra.

Lucas, M. and Baras, E. (2000). Methods for Studying Spatial Behaviour of Freshwater Fishes in the Natural Environment. *Fish and Fisheries*. 1, 283-316.

Lugg, A. and Copeland, C. (2014). *Review of Cold Water Pollution in the Murray–Darling Basin and the Impacts on Fish Communities*. Ecological Management & Restoration. Vol. 15 No. 1 January 2014.

Mallen-Cooper M. (2000) Review of Fish Passage in New South Wales - Public Distribution Copy. Fishway Consulting Services, St Ives 123 pp.

Mallen-Cooper, M. and Zampatti, B. (2015). *Background Paper: Use of Life History Conceptual Models of Fish in Flow Management in the Murray-Darling Basin*. Murray-Darling Basin Authority, Canberra.

Marshall, J., Menke, N., Crook, D., Lobegeiger, J., Balcombe, S., Huey, J., Fawcett, J., Bond, N., Starkey, A., Sternberg, D., Linke, S., and Arthington, A. (2016). *Go with the flow: the movement behaviour of fish from isolated waterhole refugia during connection flow events in an intermittent dryland river*. Freshwater Biology.

Michie LE, Thiem JD, Boys CA, Mitrovic SM (2020) *The effects of cold shock on freshwater fish larvae and early-stage juveniles: implications for river management*. Conservation Physiology, 8(1)

Moffat, D. and Voller, J. (2002). *Fish and Fish Habitat of the Queensland Murray-Darling Basin*. Department of Primary Industries, 98pp.

Murray-Darling Basin Authority (2012). *Assessment of Environmental Water Requirements for the proposed Basin Plan: Barwon-Darling River upstream of Menindee Lakes*. Murray-Darling Basin Authority, Canberra.

Murray-Darling Basin Authority. (2014). Basin-wide Environmental Watering Strategy. Murray–Darling Basin Authority, Canberra.

Murray-Darling Basin Authority. (2015). *Barwon-Darling*. Murray-Darling Basin Authority, Canberra. http://www.mdba.gov.au/about-basin/how-river-runs/barwon-darling-catchment

Murray-Darling Basin Authority. (2016). Northern Basin Review: Understanding the Economic, Social and Environmental Outcomes from Water Recovery in the Northern Basin. https://www.mdba.gov.au/sites/default/files/pubs/Northern-basin-review-report-FINAL.pdf

Murray-Darling Basin Authority. (2018). Ecological Needs of Low Flows in the Baron-Darling. Technical Report. Murray-Darling Basin Authority, Canberra. https://www.mdba.gov.au/sites/default/files/pubs/ecological-needs-low-flows-barwon-darling.pdf

Murray-Darling Basin Authority (2019). Geographic profile maps for basin catchments: Barwon-Darling. Murray-Darling Basin Authority, Canberra. https://www.mdba.gov.au/publications/mdba-reports/geographic-profile-maps-basin-catchments

Murray Darling Basin Authority (2020a). *Barwon Darling Profile.* *https://www.mdba.gov.au/sites/default/files/pubs/Barwon_geographic-profile.pdf* Last accessed 22/11/2020. Last accessed 6/11/2020.

Murray Darling Basin Authority (2020b). *Northern Basin projects.* *https://www.mdba.gov.au/basin-plan/northern-basin-projects.* Last accessed 23/11/2020.

Norris, A. (2015). *Fish loss via irrigation offtake in the Condamine Catchment*. Department of Agriculture and Fisheries.

NSW Department of Primary Industries-Fisheries. (2015). NSW Fish Community Status. Available at https://data.gov.au/dataset/ds-dga-5a33f53c-c1d9-4b55-915e-5d86d0c2bd18/details Last accessed 6/11/2020.

NSW Department of Planning, Industry and Environment. (2017). NSW Border Rivers Surface Water Resource Plan. https://www.mdba.gov.au/sites/default/files/pubs/nsw-border-rivers-surface-water-resource-plan.pdf NSW Department of Planning, Industry and Environment, Sydney.

NSW Department of Planning, Industry and Environment. (2019a). Barwon-Darling Long-Term Watering Plan Part A. https://www.environment.nsw.gov.au/-/media/OEH/Corporate-Site/Documents/Water/Water-for-the-environment/barwon-darling-long-term-water-plan-part-a-190478.pdf . NSW Department of Planning, Industry and Environment, Sydney.

NSW Department of Planning, Industry and Environment. (2019b). Barwon-Darling Watercourse Water Resource Plan. INT19/141942

NSW Department of Planning, Industry and Environment – Environment, Energy and Science (2019). *Private Wetland Watering in the Murray Valley*. https://www.environment.nsw.gov.au/topics/water/water-for-the-environment/murray-and-lower-darling/private-wetland-watering

NSW Department of Planning Industry and Environment – Water. (2020). Environmental Water Register. https://ewp.water.dpi.nsw.gov.au/ewr/main/erShSearchEWL

NSW Department of Primary Industries (2006). *Reducing the Impact of Weirs on Aquatic Habitat - New South Wales Detailed Weir Review. Border Rivers / Gwydir CMA region*. Report to the New South Wales Environmental Trust. NSW Department of Primary Industries, Flemington, NSW.

NSW Department of Primary Industries. (2007). *Endangered Ecological Communities in NSW – Lowland Darling River Aquatic Ecological Community*. Primefact 173.NSW DPI. https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/634557/Lowland-Darling-River-aquatic-ecological-community.pdf

NSW Department of Primary Industries (2012) *Fishway options for weirs of the Northern Murray Darling Basin.* Report prepared for the Murray-Darling Basin Authority. NSW Department of Primary Industries, Sydney.

NSW Department of Primary Industries. (2013a). *'Flow for Fish Recruitment in the Barwon-Darling River'*. Unpublished Final Report prepared for the Murray-Darling Basin Authority, NSW Department of Primary Industries, Armidale.

NSW Department of Primary Industries (2013b). Bringing Back the Fish on the Horton. Final Report prepared for the Border Rivers Gwydir Catchment Management Authority. NSW Department of Primary Industries, Dubbo.

NSW Department of Primary Industries. (2014a) Prime Fact: Olive Perchlet (Western Population) – *Ambassis agassizii*.

http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/426594/PUB12-10-Primefact-176-Western-Olive-Perchlet-Ambassis-agassizii.pdf

NSW Department of Primary Industries. (2014b). Protecting the Purple Patch - Investment Recommendations for Buckinbah and Hanover Creeks. Habitat mapping and prioritisation report prepared for Little River Landcare Group Inc. NSW Department of Primary Industries, Dubbo.

NSW Department of Primary Industries. (2015). *Fish and Flows in the Northern Basin: Responses of Fish to Changes in Flow in the Northern Murray-Darling Basin – Reach Scale Report*. Final report prepared for the Murray-Darling Basin Authority. NSW Department of Primary Industries, Tamworth.

NSW Department of Primary Industries. (2016). *NSW Fish Community Status – final report*. NSW Department of Primary Industries. In press Fisheries Final Report Series.

NSW Department of Primary Industries. (2017a). Barwon-Darling Watercourse Water Resource Plan (Surface Water SW12), Status and Issues Paper

NSW Department of Primary Industries. (2017b). *Improving Fish Habita*ts. Accessed at http://www.dpi.nsw.gov.au/fishing/habitat/rehabilitating/habitats#Restoring-riparian-vegetation

NSW Department of Primary Industries. (2018a). *Mapping the Dumaresq Aquatic Habitat Mapping to Inform Water Management*. Report prepared for the Commonwealth Environmental Water Office. NSW Department of Primary Industries, Dubbo.

NSW Department of Primary Industries. (2018b). *Inundation Heights for Key Habitat Features and Management Recommendations for Cudgegong River Between Windamere Dam and Burrendong Dam Habitat Mapping and Prioritisation.* Report prepared for Central Tablelands Local Land Service. NSW Department of Primary Industries, Dubbo

NSW Department of Primary Industries (2019). NSW Native Fish Drought Response 2019/20. https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/1188348/NSW-native-fish-drought-response.pdf

O'Connor, J. (1992). Quantification of Submerged Wood in a Lowland Australian Stream System. *Freshwater Biology*. 27. 387-395.

O'Connor, J., O'Mahony, D. and O'Mahony, J. (2005) Movement of *Macquaria ambigua*, in the Murray River, South Eastern Australia. *Ecology of Freshwater Fish*. 15, 419-427.

O'Connor, J., Mallen-Cooper, M. and Stuart, I. (2015). Performance, Operation and Maintenance Guidelines for Fishways and Fish Passage Works. Arthur Rylah Institute for Environmental Research Technical Report No. 262 for the Water and Catchments Group, Department of Environment, Land, Water and Planning. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Oliver, R. and Merrick, C. (2006). Partitioning of River Metabolism Identifies Phytoplankton as a Major Contributor in the Regulated Murray River (Australia). *Freshwater Biology*. 51: 1131-1148.

Pethebridge, R., Lugg, A. and Harris, J. (1998). *Obstructions to Fish Passage in NSW South Coast Streams*. NSW Fisheries, Final Report Series No. 4 for CRC for Freshwater Ecology, NSW Fisheries Research Institute, Cronulla.

Petr, T. (2000). *Interactions between Fish and Aquatic Macrophytes in Inland Waters: A Review*. FAO Fisheries Technical Paper. Toowoomba Queensland.

Ponder, W., Hallan, A., Shea, M. and Clarke, S. (2016). Australian Freshwater Molluscs. http://keys.lucidcentral.org/keys/v3/freshwater_molluscs/

Queensland Department of Environment and Resource Management. (2013). Conceptual Model Case Study Series - Aquatic Connectivity: Macintyre River. State of Queensland. Accessed at https://wetlandinfo.des.qld.gov.au/resources/static/pdf/resources/tools/conceptual-model-case-studies/cs-connectivity-macintyre-12-04-13.pdf ; last accessed 6/11/2020.

Reynolds, L. (1983). Migration Patterns of Five Fish Species in the Murray-Darling River System. *Australian Journal of Marine and Freshwater Research*. 34, 857-871.

Robertson, A.I., Bacon, P. and Heagney, G. (2001) *The response of floodplain primary production to flood frequency and timing*. Journal of Applied Ecology 38: 126-136

Rogers, K. and Ralph, T. (2010) *Floodplain Wetland Biota in the Murray Darling Basin Water and Habitat Requirements*. CSIRO Publishing, Collingwood, Victoria, Australia.

Rolls, R. and Wilson, G. (2010). Spatial and Temporal Patterns in Fish Assemblages Following an Artificially Extended Floodplain Inundation Event, Northern Murray-Darling Basin, Australia. *Environmental Management*. 45, 867-880

Rutherford, I., Jerie, K. and Marsh, N. (2000). *A Process for Rehabilitating Australian Streams.* CD ROM. Cooperative Research Centre for Catchment Hydrology, Land and Water Australia 2000.

Saintilan, N. and Overton, I. (2010). *Ecosystem Response Modelling in the Murray Darling Basin*. CSIRO Publishing, Collingwood, Victoria, Australia

Sheldon, F. (2017). Characterising the Ecological Effects of Changes in the ‘Low-Flow Hydrology’ of the Barwon-Darling River. Advice to the Commonwealth Environmental Water Office. Griffith University and Commonwealth Environmental Water Office. https://www.environment.gov.au/system/files/resources/bb774e1f-d7fa-4825-8851-cb5e5f1b3f51/files/characterising-eco-effects-changes-low-flow-barwon-darling.pdf

Stuart, I and Sharpe, C (2020). *Riverine spawning, long distance larval drift and floodplain recruitment of a pelagophilic fish: A case study of golden perch (Macquaria ambigua) in the* *arid Darling River, Australia.* Aquatic Conservation: Marine and Freshwater Ecosystems, 30 (4), 675 - 690

Southwell, M. (2008). Floodplains as Dynamic Mosaics: Sediment and Nutrient Patches in a Large Lowland Riverine Landscape. PhD Thesis, University of Canberra, Canberra, Australia.

Thomaz, S. and Cunha, E. (2010). The Role of Macrophytes in Habitat Structuring in Aquatic Ecosystems: Methods of Measurement, causes and Consequences on Animal Assemblages' Composition and Biodiversity. *Acta Limnologica Brasiliensia*. 22 (2).

Thoms, M.C., Southwell, M., McGinness, H. (2005). Floodplain-River Ecosystems: Fragmentation and Water Resources Development. Co-operative Research Centre for Freshwater Ecology, University of Canberra, ACT, Australia. *Geomorphology 71 (2005) 126-138*.

Thorncraft, Garry, and John Hamlyn Harris (1996). *"Assessment of rock-ramp fishways."* Report for Environmental Trusts, NSW Environmental Protection Agency, Border Rivers Commission, NSW Department of Land and Water Conservation and Wyong Shire Council.

Thorncraft, G. and Harris, J. (2000). *Fish Passage and Fishways in NSW: A Status Report*. Cooperative Research Centre for Freshwater Ecology Technical Report 1/2000, Canberra, ACT.

Treadwell, S. (1999). Managing Snags and Large Woody Debris. In Lovett, S. and Price, P. (eds). *Riparian Land Management Guidelines: Volume Two: On-ground Management Tools and Techniques*. P.15-22. Land and Water Resources Research and Development Corporation, Canberra.

Vannote, R., Minshall, G., Cummins, K., Sedell, J. and Cushing, C. (1980). *The River Continuum Concept. Canadian* Journal of Fisheries and Aquatic Sciences. 37, 130-137.

Vertessy, R. (2019) *Final report of the Independent Assessment of the 2018-19 fish deaths in the lower Darling.* Independent panel for the Australian Government.

Vietz, G., Rutherford, I., Stewardson, M. and Finlayson, B. (2007). Managing River Flow for Geomorphic Form: Erosion and Accretion of River Benches. *5th Australian Stream Management Conference; Australian rivers: Making a difference*. Charles Sturt University.

Wallace, T., Daly, R., Aldridge, K., Cox, J., Gibbs, M., Nicol, J., Oliver, R., Walker, K., Ye, Q, and Zampatti, B. (2014). River Murray Channel: Environmental Water Requirements: Ecological Objectives and Targets. Adelaide, South Australia, Goyder Institute for Water Research.

WaterNSW. (2019). Annual Operations Plan: Barwon-Darling 2019-20. https://www.waternsw.com.au/__data/assets/pdf_file/0010/150013/Barwon-Darling-Annual-Operations-Plan-Water-Year-2019-20.pdf

WaterNSW. (2020). Real-time water data website. https://realtimedata.waternsw.com.au/ Last accessed 6/11/2020.

Western Catchment Management Authority (2009). The Barwon-Darling River Aboriginal life along the River. State of New South Wales through the Western Catchment Management Authority, New South Wales. http://archive.lls.nsw.gov.au/__data/assets/pdf_file/0003/496704/archive-barwon-darling-river-aboriginal-life-along-the-river.pdf

Wrathall, M. (2019). Barwon-Darling and Lower Darling Drought Update. https://www.industry.nsw.gov.au/__data/assets/pdf_file/0007/283273/Barwon-Darling-and-Lower-Darling-Drought-Overview.pdf

Zalewski, M., Thorpe, J. and Naiman, R. (2001). Fish and Riparian Ecotones – A Hypothesis. *Ecohydrology and Hydrobiology*. 1, 11-24.

Zeiringer, B., Seliger, C., Greimel, F. and Stefan S. (2018). River Hydrology, Flow Alteration, and Environmental Flow. Riverine Ecosystems Management. 8 , 67-89

Appendix

Appendix A: Stream cross sections for the five gauges in the project area

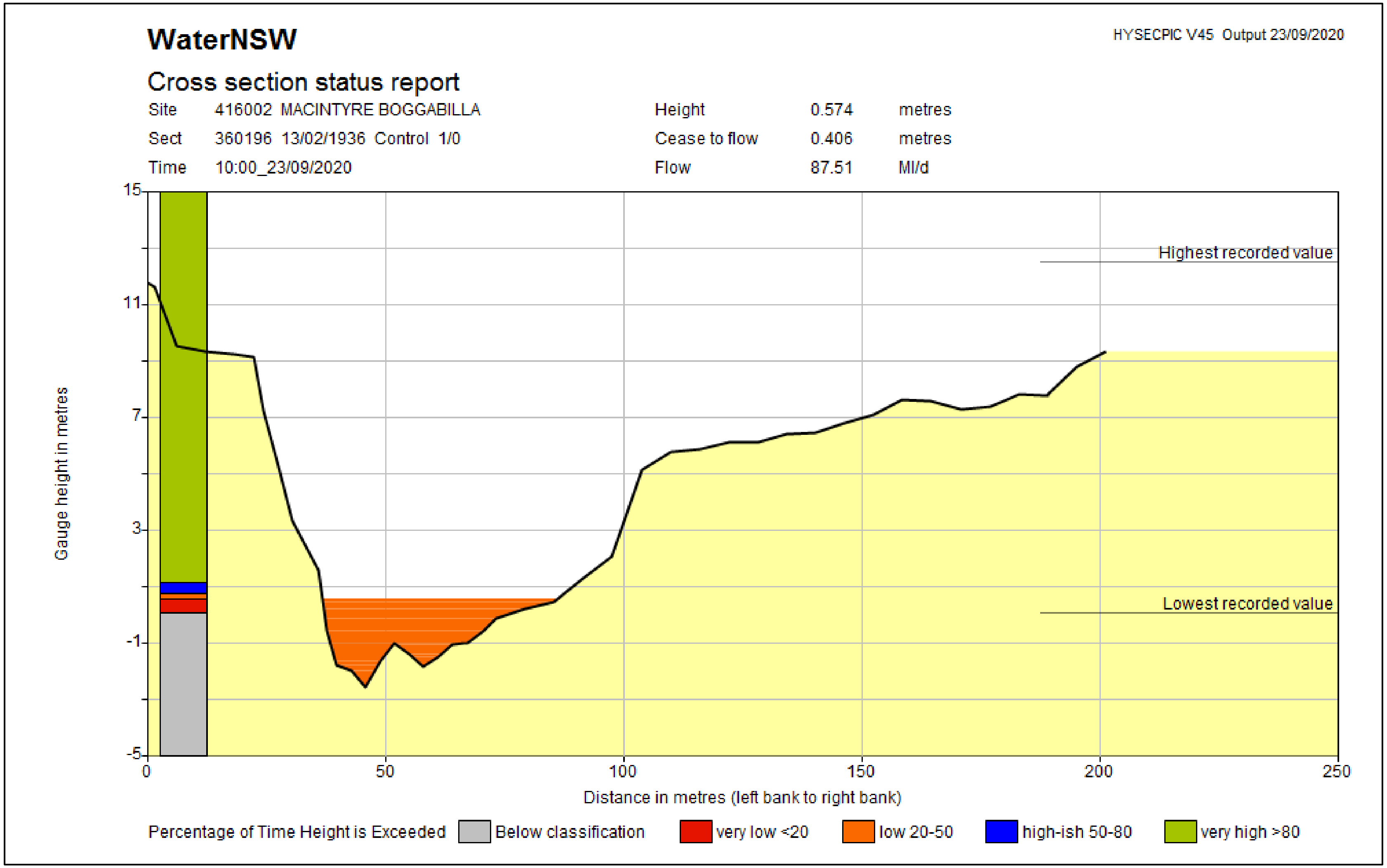


Figure 61: Cross section for Macintyre @ Boggabilla gauge.

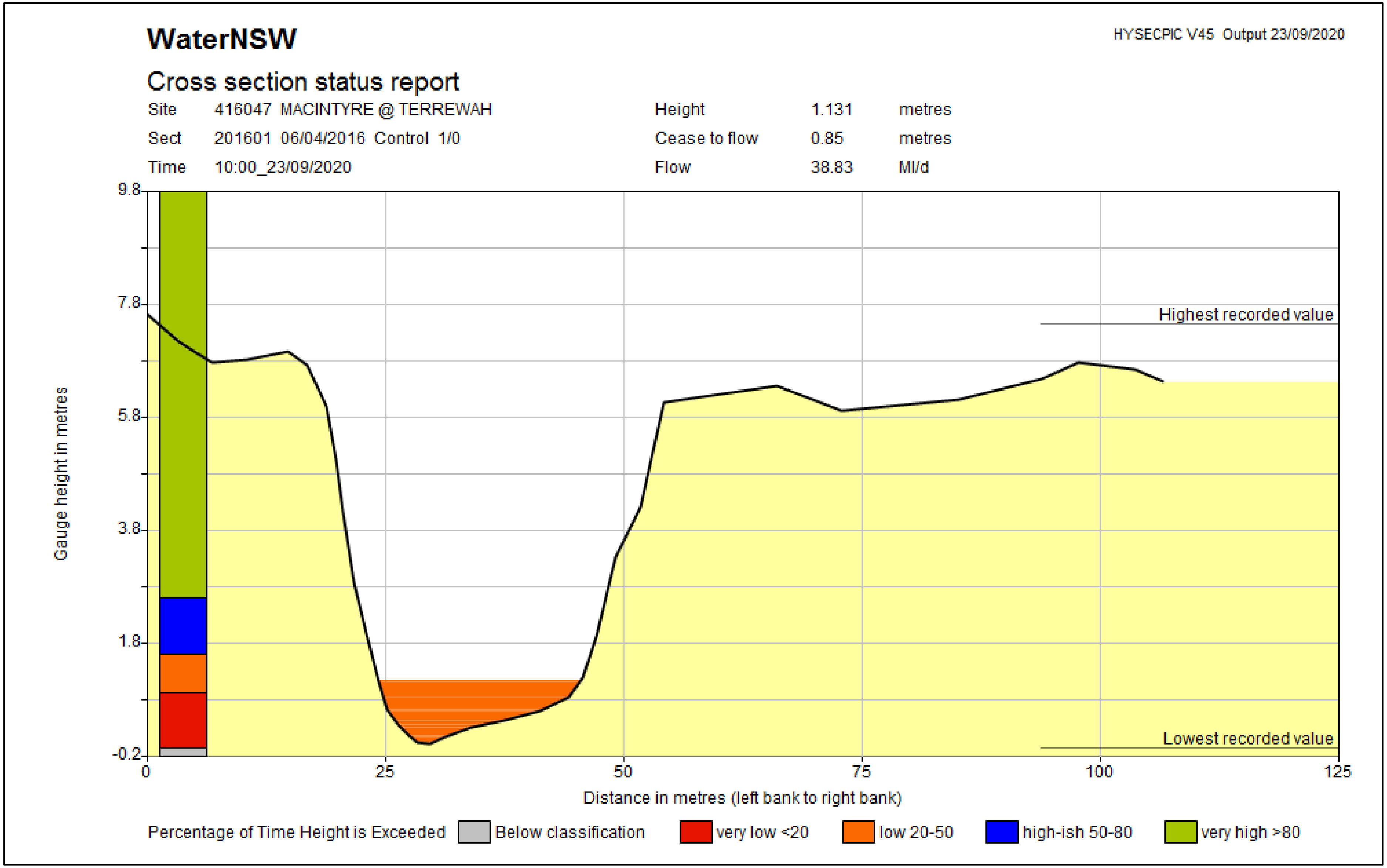


Figure 62: Cross section for Macintyre @ Terrewah gauge.

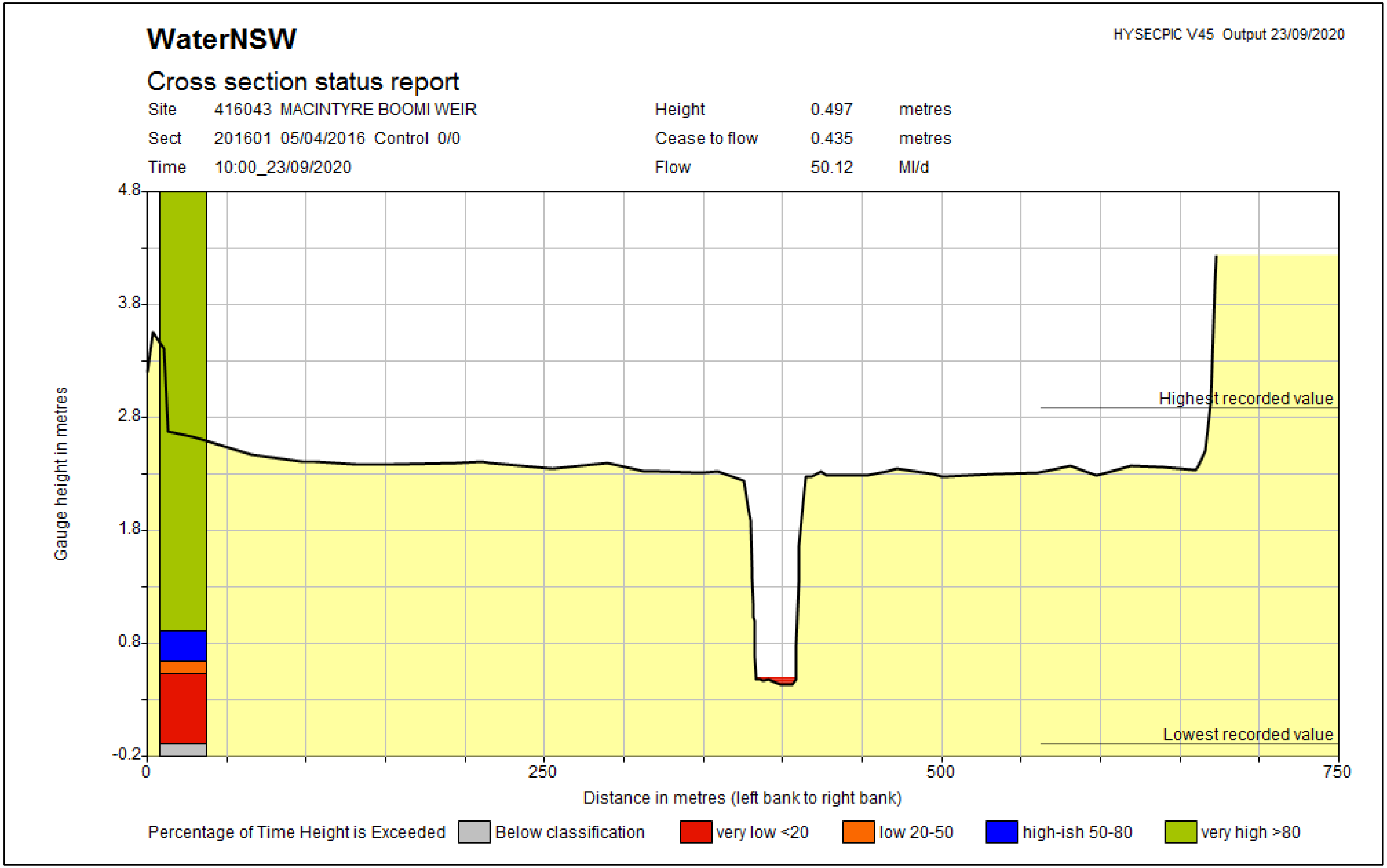


Figure 63: Cross section for Macintyre @ Boomi weir

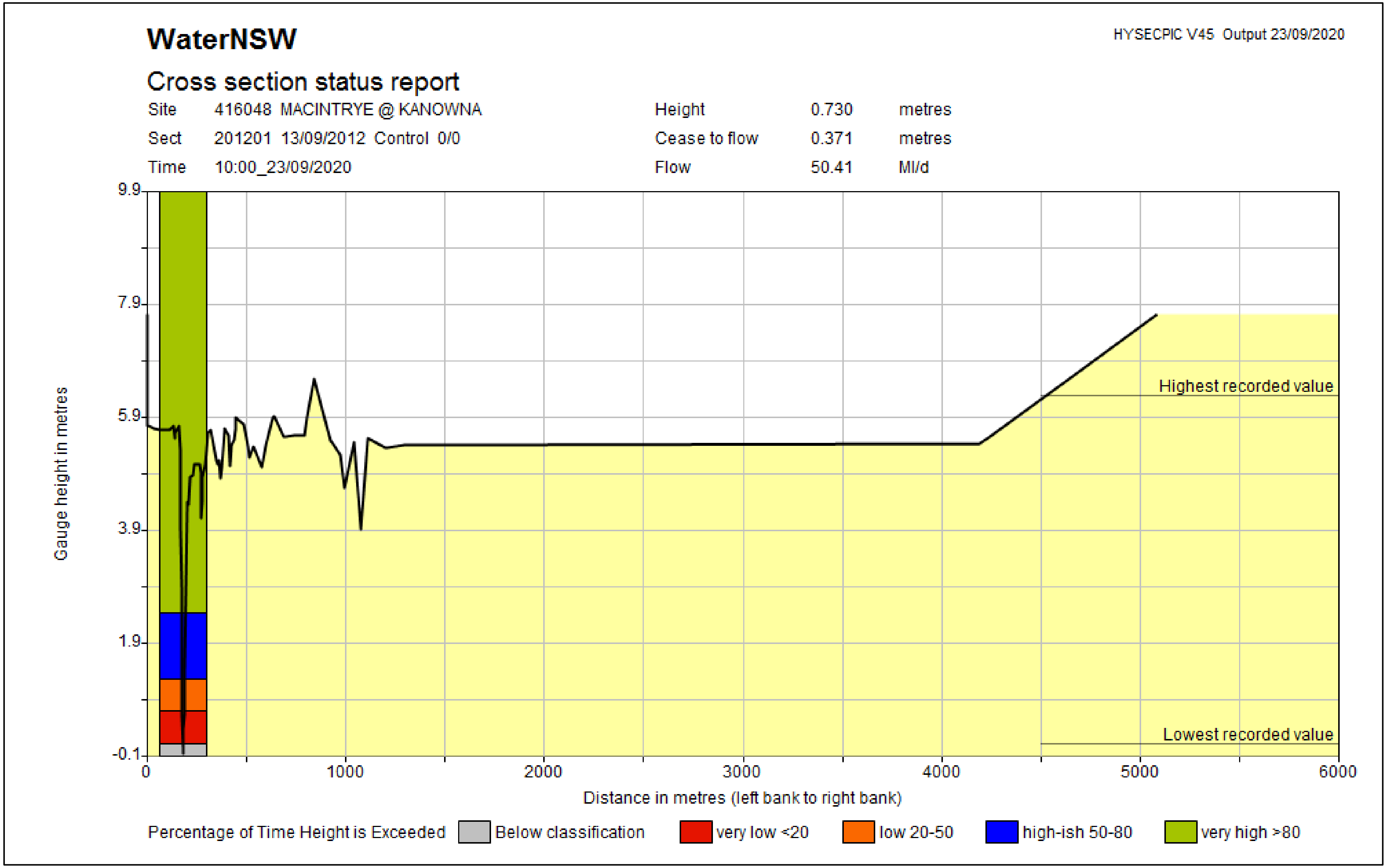


Figure 64: Cross section for Macintyre @ Kanowna.

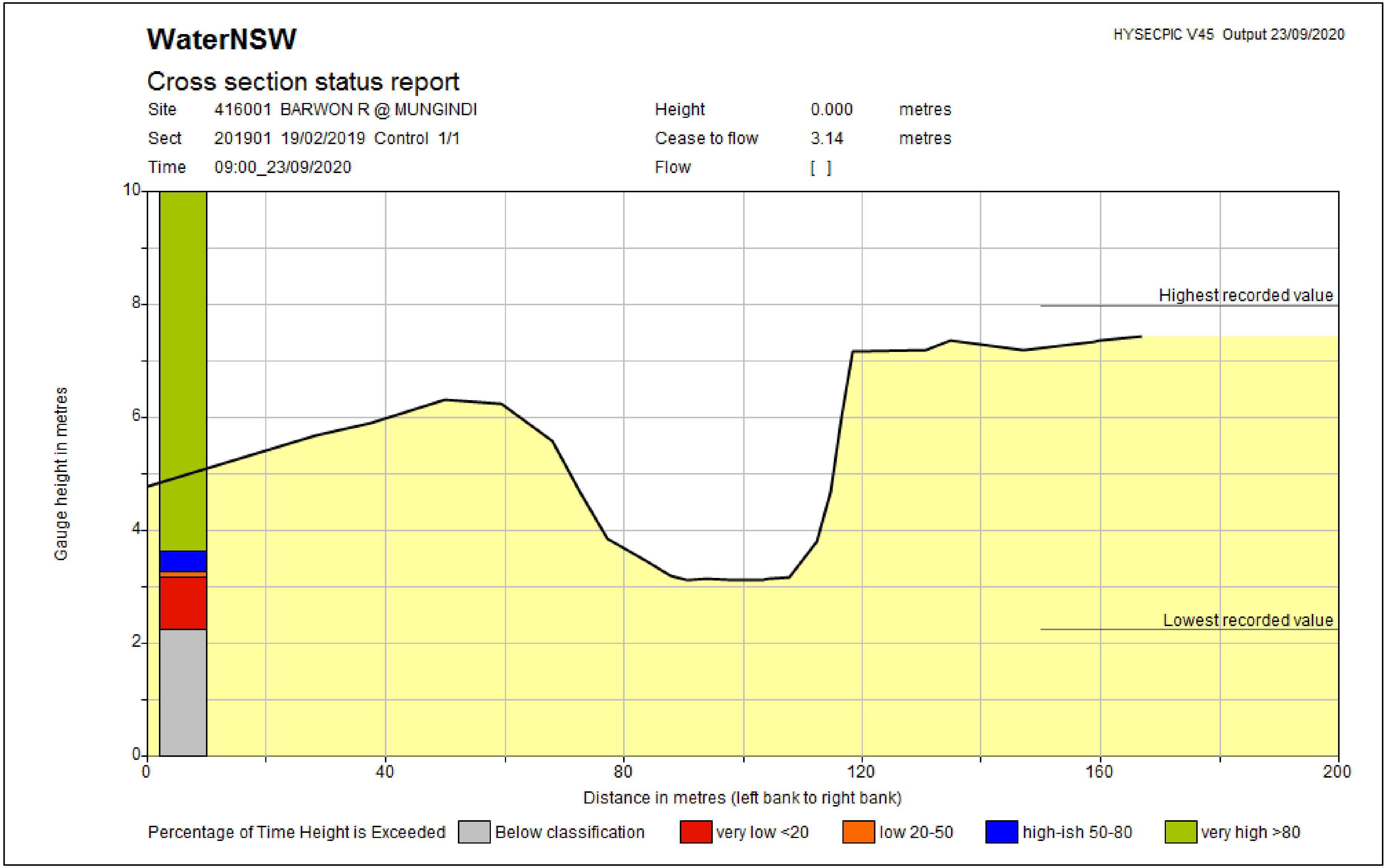


Figure 65: Cross section for Macintyre @ Mungindi.

Appendix B: Commence to Inundate Tables

Boggabilla Management Reach

Table 27: Summary of habitat feature inundation of stage height and mean daily flow rates for the Boggabilla Management Reach.

Flow component	Gauge height (m)	Flow (ML/day)	Large Woody Habitat		Rootballs		Wetland Entry/Exits		Benches			
			Cumulative Frequency (n)	Cumulative Frequency (%)	Cumulative Frequency (n)	Cumulative Frequency (%)	Cumulative Frequency (n)	Cumulative Frequency (%)	Cumulative Frequency (n)	Cumulative Frequency (%)	Cumulative Area (ha)	Cumulative Area (%)
Cease to flow	0.4	0	370	52.3	0	0.0	0	0.0	0	0.0	0.0	0.0
Very Low Flow	0.5	29.8	370	52.3	0	0.0	0	0.0	0	0.0	0.0	0.0
Very Low Flow	0.6	114	370	52.3	0	0.0	0	0.0	0	0.0	0.0	0.0
Baseflow	0.7	247	370	52.3	0	0.0	0	0.0	0	0.0	0.0	0.0
Baseflow	0.8	495	370	52.3	0	0.0	26	83.9	0	0.0	0.0	0.0
Baseflow	0.9	846	381	53.9	0	0.0	29	93.5	2	1.2	0.2	0.6
Small Pulse	1	1310	411	58.1	1	1.1	29	93.5	5	3.0	0.3	1.0
Small Pulse	1.1	1680	429	60.7	3	3.2	29	93.5	13	7.8	0.7	2.1
Small Pulse	1.2	2080	452	63.9	3	3.2	29	93.5	19	11.4	1.2	3.4
Small Pulse	1.3	2510	465	65.8	6	6.4	29	93.5	32	19.2	2.5	7.2
Small Pulse	1.4	2980	481	68.0	11	11.7	30	96.8	40	24.0	3.3	9.6
Large Pulse	1.5	3470	498	70.4	12	12.8	30	96.8	48	28.7	4.3	12.5
Large Pulse	1.6	3870	511	72.3	15	16.0	30	96.8	55	32.9	5.0	14.6
Large Pulse	1.7	4280	525	74.3	18	19.1	30	96.8	59	35.3	5.5	15.9
Large Pulse	1.8	4700	530	75.0	19	20.2	30	96.8	65	38.9	6.6	18.9
Large Pulse	1.9	5130	534	75.5	20	21.3	30	96.8	68	40.7	7.5	21.6
Large Pulse	2	5560	535	75.7	20	21.3	30	96.8	74	44.3	8.4	24.4
Large Pulse	2.1	6000	544	76.9	22	23.4	30	96.8	75	44.9	8.5	24.7
Large Pulse	2.2	6450	553	78.2	24	25.5	30	96.8	75	44.9	8.5	24.7
Large Pulse	2.3	6900	567	80.2	28	29.8	30	96.8	79	47.3	9.0	25.9
Large Pulse	2.4	7360	579	81.9	34	36.2	30	96.8	83	49.7	9.6	27.9
Large Pulse	2.5	7830	595	84.2	41	43.6	30	96.8	94	56.3	12.3	35.4
Large Pulse	2.6	8300	605	85.6	42	44.7	30	96.8	96	57.5	12.9	37.4
Large Pulse	2.7	8770	621	87.8	44	46.8	30	96.8	98	58.7	13.9	40.3
Large Pulse	2.8	9260	631	89.3	44	46.8	30	96.8	101	60.5	15.6	45.2
Large Pulse	2.9	9740	636	90.0	45	47.9	30	96.8	107	64.1	17.3	50.0
Large Pulse	3	10200	640	90.5	46	48.9	30	96.8	110	65.9	17.8	51.5

Bankfull	3.1	10700	642	90.8	48	51.1	30	96.8	113	67.7	18.8	54.3
Overbank	3.2	11200	647	91.5	50	53.2	30	96.8	115	68.9	19.2	55.4
Overbank	3.3	11700	652	92.2	52	55.3	31	100.0	119	71.3	20.7	59.7
Overbank	3.4	12200	659	93.2	57	60.6	31	100.0	126	75.4	21.8	62.9
Overbank	3.5	12800	666	94.2	61	64.9	31	100.0	129	77.2	22.4	64.7
Overbank	3.6	13300	675	95.5	63	67.0	31	100.0	130	77.8	22.5	65.1
Overbank	3.7	13800	682	96.5	67	71.3	31	100.0	130	77.8	22.5	65.1
Overbank	3.8	14300	683	96.6	70	74.5	31	100.0	135	80.8	24.4	70.6
Overbank	3.9	14900	686	97.0	72	76.6	31	100.0	138	82.6	25.3	73.2
Overbank	4	15400	687	97.2	74	78.7	31	100.0	141	84.4	26.1	75.5
Overbank	4.1	16000	687	97.2	76	80.9	31	100.0	147	88.0	27.5	79.6
Overbank	4.2	16600	689	97.5	76	80.9	31	100.0	147	88.0	27.5	79.6
Overbank	4.3	17200	689	97.5	77	81.9	31	100.0	149	89.2	28.0	80.8
Overbank	4.4	17800	690	97.6	80	85.1	31	100.0	152	91.0	28.7	82.8
Overbank	4.5	18500	693	98.0	84	89.4	31	100.0	153	91.6	28.7	83.0
Overbank	4.6	19100	697	98.6	85	90.4	31	100.0	157	94.0	29.2	84.5
Overbank	4.7	19700	701	99.2	88	93.6	31	100.0	158	94.6	29.4	84.9
Overbank	4.8	20400	701	99.2	90	95.7	31	100.0	160	95.8	31.0	89.7
Overbank	4.9	21000	702	99.3	90	95.7	31	100.0	161	96.4	31.8	91.9
Overbank	5	21700	703	99.4	90	95.7	31	100.0	163	97.6	33.1	95.7
Overbank	5.1	22300	703	99.4	90	95.7	31	100.0	163	97.6	33.1	95.7
Overbank	5.2	23000	703	99.4	90	95.7	31	100.0	164	98.2	33.5	96.7
Overbank	5.3	23700	703	99.4	91	96.8	31	100.0	164	98.2	33.5	96.7
Overbank	5.4	24400	704	99.6	92	97.9	31	100.0	166	99.4	34.4	99.3
Overbank	5.5	25000	706	99.9	93	98.9	31	100.0	166	99.4	34.4	99.3
Overbank	5.6	25700	706	99.9	93	98.9	31	100.0	167	100.0	34.6	100.0
Overbank	5.7	26400	707	100.0	93	98.9	31	100.0	167	100.0	34.6	100.0
Overbank	5.8	27100	707	100.0	94	100.0	31	100.0	167	100.0	34.6	100.0
Overbank	5.9	27800	707	100.0	94	100.0	31	100.0	167	100.0	34.6	100.0
Overbank	6	28500	707	100.0	94	100.0	31	100.0	167	100.0	34.6	100.0
Overbank	6.1	29400	707	100.0	94	100.0	31	100.0	167	100.0	34.6	100.0
Overbank	6.2	30300	707	100.0	94	100.0	31	100.0	167	100.0	34.6	100.0
Overbank	6.3	31200	707	100.0	94	100.0	31	100.0	167	100.0	34.6	100.0
Overbank	6.4	32100	707	100.0	94	100.0	31	100.0	167	100.0	34.6	100.0
Overbank	6.5	33000	707	100.0	94	100.0	31	100.0	167	100.0	34.6	100.0
Overbank	6.6	33900	707	100.0	94	100.0	31	100.0	167	100.0	34.6	100.0

Overbank	6.7	34800	707	100.0	94	100.0	0	0.0	167	100.0	34.6	100.0
Overbank	6.8	35800	707	100.0	94	100.0	0	0.0	167	100.0	34.6	100.0
Overbank	6.9	36700	707	100.0	94	100.0	0	0.0	167	100.0	34.6	100.0
Overbank	7	37700	707	100.0	94	100.0	0	0.0	167	100.0	34.6	100.0
Overbank	7.1	38700	707	100.0	94	100.0	0	0.0	167	100.0	34.6	100.0
Overbank	7.2	39600	707	100.0	94	100.0	0	0.0	167	100.0	34.6	100.0
Overbank	7.3	40600	707	100.0	94	100.0	0	0.0	167	100.0	34.6	100.0
Overbank	7.4	41600	707	100.0	94	100.0	0	0.0	167	100.0	34.6	100.0
Overbank	7.5	42600	707	100.0	94	100.0	0	0.0	167	100.0	34.6	100.0
Overbank	7.6	43700	707	100.0	94	100.0	0	0.0	167	100.0	34.6	100.0
Overbank	7.7	44700	707	100.0	94	100.0	0	0.0	167	100.0	34.6	100.0
Overbank	7.8	45700	707	100.0	94	100.0	0	0.0	167	100.0	34.6	100.0
Overbank	7.9	46800	707	100.0	94	100.0	0	0.0	167	100.0	34.6	100.0
Overbank	8	47900	707	100.0	94	100.0	0	0.0	167	100.0	34.6	100.0
Overbank	8.1	48900	707	100.0	94	100.0	0	0.0	167	100.0	34.6	100.0

Terrewah Management Reach

Table 28: Summary of habitat feature inundation of stage height and mean daily flow rates for the Terrewah Management Reach.

Flow component	Gauge height (m)	Flow (ML/day)	Large Woody Habitat		Rootballs		Wetland Entry/Exits		Benches			
			Cumulative Frequency (n)	Cumulative Frequency (%)	Cumulative Frequency (n)	Cumulative Frequency (%)	Cumulative Frequency (n)	Cumulative Frequency (%)	Cumulative Frequency (n)	Cumulative Frequency (n)	Cumulative Frequency (%)	Cumulative Frequency (n)
Cease to flow	0.9	2.83	793	14.4	0	0.0	0	0.0	0	0.0	0.0	0.0
Very low flow	1	14	793	14.4	0	0.0	0	0.0	0	0.0	0.0	0.0
Very low flow	1.1	31.7	849	15.4	0	0.0	2	1.1	11	0.9	0.1	0.4
Baseflow	1.2	57	1153	20.9	0	0.0	2	1.1	72	5.7	1.0	3.3
Baseflow	1.3	88.6	1336	24.3	1	0.2	3	1.7	151	11.9	2.3	7.4
Baseflow	1.4	129	1636	29.7	1	0.2	3	1.7	255	20.0	4.1	13.0
Small Pulse	1.5	178	1886	34.3	1	0.2	4	2.2	375	29.5	6.4	20.6
Small Pulse	1.6	233	2118	38.5	3	0.7	5	2.8	458	36.0	8.1	26.0
Small Pulse	1.7	291	2270	41.2	3	0.7	7	3.9	526	41.4	10.0	32.3
Small Pulse	1.8	350	2413	43.8	4	0.9	7	3.9	588	46.2	11.5	36.8

Small Pulse	1.9	416	2531	46	5	1.1	7	3.9	651	51.2	12.9	41.4
Small Pulse	2	488	2629	47.8	6	1.3	8	4.4	695	54.6	14.0	45.0
Small Pulse	2.1	560	2725	49.5	8	1.8	11	6.1	750	59.0	15.3	49.3
Small Pulse	2.2	639	2813	51.1	8	1.8	12	6.7	793	62.3	16.4	52.6
Small Pulse	2.3	724	2918	53	10	2.2	16	8.9	840	66.0	17.4	55.9
Small Pulse	2.4	816	3080	55.9	12	2.6	18	10.0	879	69.1	18.0	58.0
Small Pulse	2.5	915	3236	58.8	14	3.1	21	11.7	916	72.0	18.8	60.3
Small Pulse	2.6	1020	3437	62.4	16	3.5	21	11.7	953	74.9	19.6	63.0
Small Pulse	2.7	1130	3601	65.4	18	3.9	22	12.2	978	76.9	20.2	64.8
Small Pulse	2.8	1250	3748	68.1	23	5.0	23	12.8	1005	79.0	20.6	66.3
Small Pulse	2.9	1360	3878	70.4	24	5.3	26	14.4	1029	80.9	21.2	68.1
Large Pulse	3	1480	3972	72.2	28	6.1	28	15.6	1050	82.5	21.7	69.7
Large Pulse	3.1	1610	4066	73.9	34	7.5	30	16.7	1070	84.1	22.3	71.8
Large Pulse	3.2	1740	4110	74.7	37	8.1	30	16.7	1092	85.8	22.7	72.8
Large Pulse	3.3	1880	4179	75.9	43	9.4	33	18.3	1123	88.3	23.5	75.6
Large Pulse	3.4	2020	4241	77.0	50	11.0	35	19.4	1142	89.8	24.2	77.9
Large Pulse	3.5	2160	4322	78.5	61	13.4	37	20.6	1162	91.4	25.1	80.5
Large Pulse	3.6	2310	4474	81.3	64	14.0	40	22.2	1171	92.1	25.3	81.3
Large Pulse	3.7	2480	4613	83.8	66	14.5	48	26.7	1183	93.0	25.7	82.5
Large Pulse	3.8	2640	4748	86.2	77	16.9	49	27.2	1195	93.9	26.0	83.6
Large Pulse	3.9	2810	4865	88.4	84	18.4	50	27.8	1202	94.5	26.3	84.4
Large Pulse	4	2990	4953	90.0	91	20.0	56	31.1	1211	95.2	26.6	85.5
Large Pulse	4.1	3170	5047	91.7	100	21.9	62	34.4	1220	95.9	26.9	86.4
Bankfull	4.2	3350	5083	92.3	108	23.7	68	37.8	1223	96.1	27.0	86.9
Overbank	4.3	3550	5119	93.0	116	25.4	69	38.3	1230	96.7	27.5	88.4
Overbank	4.4	3750	5137	93.3	121	26.5	75	41.7	1237	97.2	27.9	89.8
Overbank	4.5	3960	5163	93.8	128	28.1	78	43.3	1240	97.5	28.1	90.2

Overbank	4.6	4170	5199	94.4	131	28.7	88	48.9	1245	97.9	28.4	91.2
Overbank	4.7	4390	5219	94.8	141	30.9	92	51.1	1247	98.0	28.4	91.3
Overbank	4.8	4620	5245	95.3	149	32.7	99	55.0	1249	98.2	28.5	91.5
Overbank	4.9	4850	5271	95.7	159	34.9	105	58.3	1252	98.4	28.6	91.9
Overbank	5	5090	5301	96.3	172	37.7	114	63.3	1256	98.7	28.8	92.5
Overbank	5.1	5330	5345	97.1	184	40.4	121	67.2	1256	98.7	28.8	92.5
Overbank	5.2	5570	5351	97.2	190	41.7	126	70.0	1257	98.8	28.9	93.0
Overbank	5.3	5840	5376	97.7	200	43.9	133	73.9	1259	99.0	29.2	93.8
Overbank	5.4	6110	5380	97.7	207	45.4	136	75.6	1259	99.0	29.2	93.8
Overbank	5.5	6390	5394	98.0	215	47.1	144	80.0	1260	99.1	29.2	93.9
Overbank	5.6	6680	5406	98.2	233	51.1	150	83.3	1261	99.1	29.2	94.0
Overbank	5.7	6970	5412	98.3	245	53.7	153	85.0	1261	99.1	29.2	94.0
Overbank	5.8	7270	5432	98.7	276	60.5	158	87.8	1268	99.7	29.9	96.1
Overbank	5.9	7580	5441	98.8	293	64.3	164	91.1	1268	99.7	29.9	96.1
Overbank	6	7890	5451	99.0	310	68.0	167	92.8	1269	99.8	30.4	97.7
Overbank	6.1	8210	5478	99.5	349	76.5	170	94.4	1269	99.8	30.4	97.7
Overbank	6.2	8530	5481	99.6	370	81.1	177	98.3	1270	99.8	30.5	98.2
Overbank	6.3	8860	5488	99.7	384	84.2	179	99.4	1270	99.8	30.5	98.2
Overbank	6.4	9190	5488	99.7	395	86.6	179	99.4	1270	99.8	30.5	98.2
Overbank	6.5	9530	5498	99.9	406	89.0	179	99.4	1270	99.8	30.5	98.2
Overbank	6.6	9880	5498	99.9	411	90.1	179	99.4	1270	99.8	30.5	98.2
Overbank	6.7	10200	5499	99.9	414	90.8	179	99.4	1270	99.8	30.5	98.2
Overbank	6.8	10600	5499	99.9	416	91.2	179	99.4	1272	100.0	31.1	100.0
Overbank	6.9	11000	5499	99.9	420	92.1	179	99.4	1272	100.0	31.1	100.0
Overbank	7	11400	5500	99.9	426	93.4	179	99.4	1272	100.0	31.1	100.0
Overbank	7.1	11700	5503	100.0	439	96.3	179	99.4	1272	100.0	31.1	100.0
Overbank	7.2	12100	5503	100.0	445	97.6	179	99.4	1272	100.0	31.1	100.0
Overbank	7.3	12500	5503	100.0	450	98.7	180	100.0	1272	100.0	31.1	100.0
Overbank	7.4	12900	5503	100.0	451	98.9	180	100.0	1272	100.0	31.1	100.0
Overbank	7.5	13400	5503	100.0	452	99.1	180	100.0	1272	100.0	31.1	100.0
Overbank	7.6	13800	5503	100.0	453	99.3	180	100.0	1272	100.0	31.1	100.0
Overbank	7.7	14200	5503	100.0	453	99.3	180	100.0	1272	100.0	31.1	100.0
Overbank	7.8	14700	5503	100.0	453	99.3	180	100.0	1272	100.0	31.1	100.0
Overbank	7.9	15100	5503	100.0	453	99.3	180	100.0	1272	100.0	31.1	100.0
Overbank	8	15500	5504	100.0	454	99.6	180	100.0	1272	100.0	31.1	100.0
Overbank	8.1	16000	5504	100.0	455	99.8	180	100.0	1272	100.0	31.1	100.0

Overbank	8.2	Estimated	5504	100.0	455	99.8	180	100.0	1272	100.0	31.1	100.0
Overbank	8.3	Estimated	5504	100.0	455	99.8	180	100.0	1272	100.0	31.1	100.0
Overbank	8.4	Estimated	5504	100.0	455	99.8	180	100.0	1272	100.0	31.1	100.0
Overbank	8.5	Estimated	5504	100.0	455	99.8	180	100.0	1272	100.0	31.1	100.0
Overbank	8.6	Estimated	5505	100.0	456	100.0	180	100.0	1272	100.0	31.1	100.0

Boomi Management Reach

Table 29: Summary of habitat feature inundation of stage height and mean daily flow rates for the Boomi Management Reach.

			Large Woody Habitat		Rootballs		Wetland Entry/Exits		Benches			
Flow component	Gauge height (m)	Flow (ML/day)	Cumulative Frequency (n)	Cumulative Frequency (%)	Cumulative Frequency (n)	Cumulative Frequency (%)	Cumulative Frequency (n)	Cumulative Frequency (%)	Cumulative Frequency (n)	Cumulative Frequency (n)	Cumulative Frequency (%)	Cumulative Frequency (n)
Cease to flow	0.4	0	2253	42.1	0	0.0	0	0.0	0	0.0	0.0	0.0
Very low flow	0.5	53.8	2253	42.1	61	17.1	8	3.5	1	0.2	0.0	0.2
Baseflow - min	0.6	240	2439	45.6	62	17.4	8	3.5	15	3.0	0.2	2.1
Small pulse	0.7	508	2562	47.9	62	17.4	8	3.5	38	7.6	0.6	5.2
Large pulse	0.8	847	2677	50.1	66	18.5	10	4.3	87	17.5	1.3	11.9
Bankfull	0.9	1240	2752	51.5	68	19.1	12	5.2	114	22.9	1.7	15.1
Overbank	1	1680	2831	52.9	75	21.1	19	8.2	156	31.3	2.4	22.3
Overbank	1.1	2050	2877	53.8	77	21.6	20	8.7	184	36.9	2.9	26.3
Overbank	1.2	2300	2915	54.5	77	21.6	22	9.5	205	41.2	3.3	29.7
Overbank	1.3	2510	2983	55.8	77	21.6	24	10.4	227	45.6	3.6	32.8
Overbank	1.4	2690	3041	56.9	78	21.9	31	13.4	257	51.6	4.6	42.2
Overbank	1.5	2820	3137	58.7	80	22.5	38	16.5	277	55.6	5.2	47.0
Overbank	1.6	2910	3205	59.9	83	23.3	42	18.2	301	60.4	5.8	52.4
Overbank	1.7	Estimated	3255	60.9	88	24.7	49	21.2	323	64.9	6.2	56.5
Overbank	1.8	Estimated	3354	62.7	94	26.4	60	26.0	345	69.3	6.7	60.9
Overbank	1.9	Estimated	3458	64.7	100	28.1	66	28.6	357	71.7	7.0	64.0
Overbank	2	Estimated	3590	67.1	102	28.7	70	30.3	375	75.3	7.7	70.4
Overbank	2.1	Estimated	3682	68.9	106	29.8	71	30.7	391	78.5	8.1	73.7
Overbank	2.2	Estimated	3732	69.8	110	30.9	76	32.9	412	82.7	8.7	78.8
Overbank	2.3	Estimated	3790	70.9	116	32.6	81	35.1	425	85.3	9.0	82.3

Overbank	2.4	Estimated	3841	71.8	117	32.9	85	36.8	436	87.6	9.3	84.9
Overbank	2.5	Estimated	3938	73.6	123	34.6	86	37.2	447	89.8	9.6	87.9
Overbank	2.6	Estimated	4001	74.8	134	37.6	91	39.4	453	91.0	9.8	89.3
Overbank	2.7	Estimated	4075	76.2	141	39.6	94	40.7	462	92.8	10.1	91.9
Overbank	2.8	Estimated	4161	77.8	142	39.9	97	42.0	469	94.2	10.3	94.0
Overbank	2.9	Estimated	4245	79.4	151	42.4	103	44.6	472	94.8	10.4	94.5
Overbank	3	Estimated	4399	82.3	168	47.2	107	46.3	475	95.4	10.4	94.9
Overbank	3.1	Estimated	4511	84.4	181	50.8	113	48.9	483	97.0	10.6	96.3
Overbank	3.2	Estimated	4631	86.6	193	54.2	116	50.2	488	98.0	10.7	97.7
Overbank	3.3	Estimated	4726	88.4	204	57.3	123	53.2	488	98.0	10.7	97.7
Overbank	3.4	Estimated	4773	89.3	213	59.8	129	55.8	491	98.6	10.8	98.1
Overbank	3.5	Estimated	4896	91.6	225	63.2	133	57.6	493	99.0	10.9	98.9
Overbank	3.6	Estimated	4937	92.3	234	65.7	142	61.5	493	99.0	10.9	98.9
Overbank	3.7	Estimated	4976	93.1	239	67.1	149	64.5	495	99.4	10.9	99.6
Overbank	3.8	Estimated	5025	94.0	242	68.0	164	71.0	497	99.8	11.0	99.8
Overbank	3.9	Estimated	5058	94.6	248	69.7	171	74.0	497	99.8	11.0	99.8
Overbank	4	Estimated	5130	95.9	263	73.9	174	75.3	498	100.0	11.0	100.0
Overbank	4.1	Estimated	5162	96.5	268	75.3	181	78.4	498	100.0	11.0	100.0
Overbank	4.2	Estimated	5193	97.1	269	75.6	187	81.0	498	100.0	11.0	100.0
Overbank	4.3	Estimated	5239	98.0	280	78.7	195	84.4	498	100.0	11.0	100.0
Overbank	4.4	Estimated	5248	98.1	283	79.5	199	86.1	498	100.0	11.0	100.0
Overbank	4.5	Estimated	5299	99.1	293	82.3	206	89.2	498	100.0	11.0	100.0
Overbank	4.6	Estimated	5304	99.2	298	83.7	211	91.3	498	100.0	11.0	100.0
Overbank	4.7	Estimated	5320	99.5	302	84.8	215	93.1	498	100.0	11.0	100.0
Overbank	4.8	Estimated	5329	99.7	307	86.2	220	95.2	498	100.0	11.0	100.0
Overbank	4.9	Estimated	5331	99.7	320	89.9	223	96.5	498	100.0	11.0	100.0
Overbank	5	Estimated	5341	99.9	333	93.5	224	97.0	498	100.0	11.0	100.0
Overbank	5.1	Estimated	5342	99.9	340	95.5	227	98.3	498	100.0	11.0	100.0
Overbank	5.2	Estimated	5345	100.0	341	95.8	230	99.6	498	100.0	11.0	100.0
Overbank	5.3	Estimated	5346	100.0	348	97.8	231	100.0	498	100.0	11.0	100.0
Overbank	5.4	Estimated	5346	100.0	350	98.3	231	100.0	498	100.0	11.0	100.0
Overbank	5.5	Estimated	5347	100.0	354	99.4	231	100.0	498	100.0	11.0	100.0
Overbank	5.6	Estimated	5347	100.0	354	99.4	231	100.0	498	100.0	11.0	100.0
Overbank	5.7	Estimated	0	0.0	356	100.0	231	100.0	498	100.0	11.0	100.0
Overbank	5.8	Estimated	0	0.0	356	100.0	231	100.0	498	100.0	11.0	100.0
Overbank	5.9	Estimated	0	0.0	356	100.0	231	100.0	498	100.0	11.0	100.0

Overbank	6	Estimated	0	0.0	356	100.0	231	100.0	498	100.0	11.0	100.0
Overbank	6.1	Estimated	0	0.0	356	100.0	231	100.0	498	100.0	11.0	100.0
Overbank	6.2	Estimated	0	0.0	356	100.0	231	100.0	498	100.0	11.0	100.0
Overbank	6.3	Estimated	0	0.0	356	100.0	231	100.0	498	100.0	11.0	100.0
Overbank	6.4	Estimated	0	0.0	356	100.0	231	100.0	498	100.0	11.0	100.0
Overbank	6.5	Estimated	0	0.0	356	100.0	231	100.0	498	100.0	11.0	100.0
Overbank	6.6	Estimated	0	0.0	356	100.0	231	100.0	498	100.0	11.0	100.0
Overbank	6.7	Estimated	0	0.0	356	100.0	231	100.0	498	100.0	11.0	100.0
Overbank	6.8	Estimated	0	0.0	356	100.0	231	100.0	498	100.0	11.0	100.0
Overbank	6.9	Estimated	0	0.0	356	100.0	231	100.0	498	100.0	11.0	100.0
Overbank	7	Estimated	0	0.0	356	100.0	231	100.0	498	100.0	11.0	100.0
Overbank	7.1	Estimated	0	0.0	356	100.0	231	100.0	498	100.0	11.0	100.0

Kanowna Management Reach

Table 30:Summary of habitat feature inundation of stage height and mean daily flow rates for the Kanowna Management Reach.

Flow component	Gauge height (m)	Flow (ML/day)	Large Woody Habitat		Rootballs		Wetland Entry/Exits		Benches			
			Cumulative Frequency (n)	Cumulative Frequency (%)	Cumulative Frequency (n)	Cumulative Frequency (%)	CFRE	CFRE %	CF RE	Cumulative Frequency (n)	Cumulative Frequency (%)	Cumulative Frequency (n)
Cease to flow	0.40	0.99	1940	37.9	0	0.0	0	0.0	0	0.0	0.0	0.0
Very low flow	0.50	9.96	1940	37.9	0	0.0	0	0.0	0	0.0	0.0	0.0
Very low flow	0.60	25.8	1940	37.9	3	0.5	5	2.3	0	0.0	0.0	0.0
Baseflow	0.70	44.3	2018	39.4	3	0.5	5	2.3	13	3.1	0.2	1.2
Baseflow	0.80	67.9	2124	41.5	3	0.5	5	2.3	39	9.2	0.6	3.4
Baseflow	0.90	96.5	2209	43.1	3	0.5	8	3.6	76	18.0	1.3	7.6
Small pulse	1.00	130	2480	48.4	4	0.6	9	4.1	97	22.9	1.5	9.4
Small pulse	1.10	170	2800	54.6	7	1.1	9	4.1	116	27.4	2.0	11.9
Small pulse	1.20	212	2878	56.2	8	1.2	9	4.1	142	33.6	2.4	14.8
Small pulse	1.30	257	2952	57.6	9	1.4	11	5.0	159	37.6	2.7	16.6
Small pulse	1.40	304	3012	58.8	11	1.7	14	6.4	172	40.7	3.1	18.8
Small pulse	1.50	355	3054	59.6	14	2.1	14	6.4	183	43.3	3.3	20.1
Small pulse	1.60	405	3100	60.5	19	2.9	17	7.7	196	46.3	3.7	22.6
Small pulse	1.70	456	3168	61.8	22	3.4	17	7.7	208	49.2	4.1	24.9
Small pulse	1.80	510	3238	63.2	26	4.0	19	8.6	214	50.6	4.2	25.8
Small pulse	1.90	566	3306	64.5	28	4.3	23	10.5	226	53.4	4.5	27.3
Small pulse	2.00	625	3373	65.8	31	4.7	27	12.3	240	56.7	4.8	29.4
Small pulse	2.10	687	3461	67.5	43	6.6	28	12.7	247	58.4	5.0	30.1
Small pulse	2.20	753	3540	69.1	54	8.3	29	13.2	266	62.9	5.3	32.3
Small pulse	2.30	822	3599	70.2	62	9.5	33	15.0	278	65.7	6.0	36.6
Small pulse	2.40	893	3679	71.8	67	10.2	37	16.8	288	68.1	6.3	38.4
Large pulse	2.50	970	3736	72.9	78	11.9	41	18.6	297	70.2	6.6	39.8

Large pulse	2.60	1050	3807	74.3	95	14.5	45	20.5	304	71.9	6.7	40.6
Large pulse	2.70	1130	3857	75.3	112	17.1	51	23.2	308	72.8	6.8	41.2
Large pulse	2.80	1230	3931	76.7	131	20.0	60	27.3	319	75.4	7.0	42.8
Large pulse	2.90	1320	4005	78.2	147	22.5	71	32.3	325	76.8	7.2	43.8
Large pulse	3.00	1420	4066	79.4	168	25.7	83	37.7	330	78.0	7.3	44.5
Large pulse	3.10	1520	4222	82.4	183	28.0	86	39.1	338	79.9	7.7	47.0
Large pulse	3.20	1630	4360	85.1	211	32.3	95	43.2	341	80.6	7.9	48.1
Large pulse	3.30	1730	4505	87.9	242	37.0	100	45.5	349	82.5	8.4	50.8
Large pulse	3.40	1830	4642	90.6	271	41.4	111	50.5	357	84.4	9.0	55.0
Large pulse	3.50	1930	4690	91.5	307	46.9	118	53.6	366	86.5	10.2	62.1
Large pulse	3.60	2030	4764	93.0	339	51.8	126	57.3	377	89.1	11.2	68.3
Large pulse	3.70	2140	4806	93.8	360	55.0	131	59.5	384	90.8	11.8	71.5
Large pulse	3.80	2260	4851	94.7	386	59.0	142	64.5	390	92.2	12.4	75.5
Large pulse	3.90	2370	4879	95.2	405	61.9	148	67.3	395	93.4	12.7	77.5
Bankfull	4.00	2480	4903	95.7	424	64.8	155	70.5	404	95.5	13.7	83.1
Overbank	4.10	2590	4934	96.3	454	69.4	163	74.1	413	97.6	14.9	90.5
Overbank	4.20	2700	4960	96.8	483	73.9	169	76.8	415	98.1	15.5	94.0
Overbank	4.30	2820	4992	97.4	516	78.9	175	79.5	418	98.8	16.1	98.1
Overbank	4.40	2950	5015	97.9	549	83.9	185	84.1	419	99.1	16.2	98.4
Overbank	4.50	3070	5031	98.2	588	89.9	197	89.5	420	99.3	16.3	98.9
Overbank	4.60	3190	5064	98.8	597	91.3	205	93.2	421	99.5	16.3	99.1
Overbank	4.70	3310	5069	98.9	602	92.0	205	93.2	421	99.5	16.3	99.1
Overbank	4.80	3430	5088	99.3	610	93.3	212	96.4	422	99.8	16.3	99.4
Overbank	4.90	3560	5093	99.4	624	95.4	215	97.7	422	99.8	16.3	99.4
Overbank	5.00	3690	5103	99.6	626	95.7	216	98.2	423	100.0	16.4	100.0
Overbank	5.10	3840	5107	99.7	632	96.6	216	98.2	423	100.0	16.4	100.0

Overbank	5.20	4000	5109	99.7	637	97.4	217	98.6	423	100.0	16.4	100.0
Overbank	5.30	4170	5111	99.7	644	98.5	217	98.6	423	100.0	16.4	100.0
Overbank	5.40	4340	5114	99.8	648	99.1	217	98.6	423	100.0	16.4	100.0
Overbank	5.50	4520	5118	99.9	648	99.1	217	98.6	423	100.0	16.4	100.0
Overbank	5.60	4700	5122	100.0	650	99.4	217	98.6	423	100.0	16.4	100.0
Overbank	5.70	4920	5122	100.0	650	99.4	218	99.1	423	100.0	16.4	100.0
Overbank	5.80	5170	5124	100.0	654	100.0	219	99.5	423	100.0	16.4	100.0
Overbank	5.90	5430	5124	100.0	654	100.0	220	100.0	423	100.0	16.4	100.0
Overbank	6.00	5700	5124	100.0	654	100.0	220	100.0	423	100.0	16.4	100.0
Overbank	6.10	5980	5124	100.0	654	100.0	220	100.0	423	100.0	16.4	100.0
Overbank	6.20	6290	5124	100.0	654	100.0	220	100.0	423	100.0	16.4	100.0
Overbank	6.30	6600	5124	100.0	654	100.0	220	100.0	423	100.0	16.4	100.0
Overbank	6.40	6930	5124	100.0	654	100.0	220	100.0	423	100.0	16.4	100.0
Overbank	6.50	7280	5124	100.0	654	100.0	220	100.0	423	100.0	16.4	100.0
Overbank	6.60	7640	5124	100.0	654	100.0	220	100.0	423	100.0	16.4	100.0
Overbank	6.70	8020	5124	100.0	654	100.0	220	100.0	423	100.0	16.4	100.0
Overbank	6.80	8420	5124	100.0	654	100.0	220	100.0	423	100.0	16.4	100.0
Overbank	6.90	8830	5124	100.0	654	100.0	220	100.0	423	100.0	16.4	100.0

Mungindi Management Reach

Table 31: Summary of habitat feature inundation of stage height and mean daily flow rates for the Mungindi Management Reach.

			Large woody habitat		Rootballs		Wetland Entry/Exits		Benches			
Component function	Gauge Height (m)	Flow (ML/day)	CFRE	CFRE%	CFRE	CFRE%	CFRE	CFRE%	CFRE	CFRE%	CFRE Area (ha)	CFRE Area%
Cease to flow	3.1	0.0	198	17.2	0	0.0	0	0.0	0	0.0	0.0	0.0
Very low flow	3.2	69.6	198	17.2	0	0.0	10	10.5	1	0.3	0.0	0.1
Baseflow	3.3	282	552	47.8	0	0.0	10	10.5	1	0.3	0.0	0.1

Baseflow	3.4	541	596	51.6	0	0.0	11	11.6	6	1.5	0.1	0.6
Small pulse	3.5	855	631	54.7	0	0.0	11	11.6	11	2.8	0.3	1.2
Small pulse	3.6	1210	655	56.8	0	0.0	11	11.6	15	3.8	0.5	2.1
Small pulse	3.7	1590	677	58.7	0	0.0	13	13.7	36	9.1	0.8	3.6
Small pulse	3.8	1880	701	60.7	0	0.0	15	15.8	49	12.3	1.1	4.7
Small pulse	3.9	2170	716	62.0	4	3.7	18	18.9	64	16.1	1.6	6.7
Small pulse	4	2430	732	63.4	6	5.6	19	20.0	82	20.7	2.3	9.5
Small pulse	4.1	2660	744	64.5	10	9.3	20	21.1	104	26.2	3.2	13.5
Small pulse	4.2	2880	770	66.7	15	14.0	26	27.4	125	31.5	4.0	17.1
Small pulse	4.3	3100	779	67.5	17	15.9	27	28.4	144	36.3	4.7	19.9
Small pulse	4.4	3310	792	68.6	18	16.8	30	31.6	163	41.1	5.7	23.9
Small pulse	4.5	3530	813	70.5	20	18.7	30	31.6	182	45.8	6.6	28.1
Small pulse	4.6	3740	830	71.9	21	19.6	34	35.8	202	50.9	7.7	32.4
Small pulse	4.7	3960	867	75.1	27	25.2	39	41.1	235	59.2	9.6	40.7
Small pulse	4.8	4170	893	77.4	27	25.2	41	43.2	250	63.0	10.9	46.2
Small pulse	4.9	4390	912	79.0	27	25.2	45	47.4	266	67.0	12.3	52.0
Small pulse	5	4610	927	80.3	34	31.8	48	50.5	285	71.8	14.1	59.4
Small pulse	5.1	4830	935	81.0	37	34.6	54	56.8	294	74.1	14.8	62.6
Small pulse	5.2	5040	962	83.4	44	41.1	61	64.2	310	78.1	16.1	67.8
Small pulse	5.3	5280	964	83.5	44	41.1	64	67.4	322	81.1	16.9	71.6
Small pulse	5.4	5570	969	84.0	46	43.0	67	70.5	332	83.6	18.0	75.8
Large pulse	5.5	5870	980	84.9	47	43.9	69	72.6	339	85.4	18.7	79.0
Large pulse	5.6	6170	993	86.0	50	46.7	73	76.8	350	88.2	19.7	83.1
Large pulse	5.7	6480	1026	88.9	59	55.1	81	85.3	367	92.4	20.6	87.1
Large pulse	5.8	6800	1054	91.3	60	56.1	82	86.3	375	94.5	21.2	89.6
Large pulse	5.9	7110	1071	92.8	62	57.9	83	87.4	380	95.7	21.8	91.9
Bankfull	6	7430	1093	94.7	63	58.9	84	88.4	385	97.0	22.1	93.4
Overbank	6.1	7750	1100	95.3	66	61.7	86	90.5	386	97.2	22.1	93.5
Overbank	6.2	8080	1116	96.7	77	72.0	89	93.7	393	99.0	23.0	97.2
Overbank	6.3	8630	1117	96.8	78	72.9	89	93.7	393	99.0	23.0	97.2
Overbank	6.4	9240	1123	97.3	78	72.9	90	94.7	394	99.2	23.2	98.2
Overbank	6.5	9860	1131	98.0	78	72.9	90	94.7	395	99.5	23.3	98.2
Overbank	6.6	10500	1135	98.4	78	72.9	91	95.8	395	99.5	23.3	98.2
Overbank	6.7	11200	1144	99.1	80	74.8	93	97.9	397	100.0	23.7	100.0
Overbank	6.8	11900	1147	99.4	80	74.8	94	98.9	397	100.0	23.7	100.0
Overbank	6.9	12600	1148	99.5	80	74.8	94	98.9	397	100.0	23.7	100.0

Overbank	7	13300	1148	99.5	83	77.6	94	98.9	397	100.0	23.7	100.0
Overbank	7.1	14100	1148	99.5	83	77.6	95	100.0	397	100.0	23.7	100.0
Overbank	7.2	15000	1152	99.8	93	86.9	95	100.0	397	100.0	23.7	100.0
Overbank	7.3	16500	1152	99.8	93	86.9	95	100.0	397	100.0	23.7	100.0
Overbank	7.4	18200	1152	99.8	94	87.9	95	100.0	397	100.0	23.7	100.0
Overbank	7.5	19900	1153	99.9	94	87.9	95	100.0	397	100.0	23.7	100.0
Overbank	7.6	23800	1153	99.9	94	87.9	95	100.0	397	100.0	23.7	100.0
Overbank	7.7	29100	1153	99.9	96	89.7	95	100.0	397	100.0	23.7	100.0
Overbank	7.8	38300	1153	99.9	99	92.5	95	100.0	397	100.0	23.7	100.0
Overbank	7.9	59800	1153	99.9	99	92.5	95	100.0	397	100.0	23.7	100.0
Overbank	8	100000	1153	99.9	100	93.5	95	100.0	397	100.0	23.7	100.0
Overbank	8.1	Estimated	1154	100.0	100	93.5	95	100.0	397	100.0	23.7	100.0
Overbank	8.2	Estimated	1154	100.0	105	98.1	95	100.0	397	100.0	23.7	100.0
Overbank	8.3	Estimated	1154	100.0	105	98.1	95	100.0	397	100.0	23.7	100.0
Overbank	8.4	Estimated	1154	100.0	105	98.1	95	100.0	397	100.0	23.7	100.0
Overbank	8.5	Estimated	1154	100.0	105	98.1	95	100.0	397	100.0	23.7	100.0
Overbank	8.6	Estimated	1154	100.0	105	98.1	95	100.0	397	100.0	23.7	100.0
Overbank	8.7	Estimated	1154	100.0	106	99.1	95	100.0	397	100.0	23.7	100.0
Overbank	8.8	Estimated	1154	100.0	106	99.1	95	100.0	397	100.0	23.7	100.0
Overbank	8.9	Estimated	1154	100.0	106	99.1	95	100.0	397	100.0	23.7	100.0
Overbank	9	Estimated	1154	100.0	106	99.1	95	100.0	397	100.0	23.7	100.0
Overbank	9.1	Estimated	1154	100.0	106	99.1	95	100.0	397	100.0	23.7	100.0
Overbank	9.2	Estimated	1154	100.0	106	99.1	95	100.0	397	100.0	23.7	100.0
Overbank	9.3	Estimated	1154	100.0	106	99.1	95	100.0	397	100.0	23.7	100.0
Overbank	9.4	Estimated	1154	100.0	106	99.1	95	100.0	397	100.0	23.7	100.0
Overbank	9.5	Estimated	1154	100.0	106	99.1	95	100.0	397	100.0	23.7	100.0
Overbank	9.6	Estimated	1154	100.0	106	99.1	95	100.0	397	100.0	23.7	100.0
Overbank	9.7	Estimated	1154	100.0	106	99.1	95	100.0	397	100.0	23.7	100.0
Overbank	9.8	Estimated	1154	100.0	106	99.1	95	100.0	397	100.0	23.7	100.0
Overbank	9.9	Estimated	1154	100.0	106	99.1	95	100.0	397	100.0	23.7	100.0
Overbank	10	Estimated	1154	100.0	107	100.0	95	100.0	397	100.0	23.7	100.0