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Submission to Review of the *Water Sharing Plan for the Lachlan Unregulated Water Sources 2012*

The Inland Rivers Network (IRN) is a coalition of environment groups and individuals concerned about the degradation of the rivers, wetlands and ground waters of the Murray-Darling Basin. It has been advocating for the conservation of rivers, wetlands and groundwater in the Murray-Darling Basin since 1991.

Member groups include the Australian Conservation Foundation; the Nature Conservation Council of NSW; the National Parks Association of NSW; Friends of the Earth; Central West Environment Council; Wilderness Australia and Healthy Rivers Dubbo.

Introduction

IRN welcomes the opportunity to participate in the Natural Resources Commission (NRC) review of the *Water Sharing Plan for the Lachlan Unregulated Water Sources 2012* (the WSP).

We note that the version of the WSP being reviewed was amended on 1 July 2016. We also note that the WSP was amended in 2020 partly to meet NSW's commitments under the Murray-Darling Basin Plan to develop water resource plans (WRP) consistent with the Basin Plan. [1]

IRN would appreciate an understanding of how this review process will inform the final version of the WSP to be included in the Lachlan Surface Water WRP. We understand that this WRP was returned to the NSW Government by the Murray-Darling Basin Authority for improvement before final accreditation and has since been resubmitted. There has been no transparency around this process.

[1] DPIE Water, 2020. Final Draft WSP Lachlan Unregulated p 7

IRN has also participated in the development of the Lachlan Regional Water Strategy. This process has identified that rule changes in the region's water sharing plans may be needed to improve water security. This indicates that clear opportunities for amendment are needed in a new plan.

New climate modelling for the Lachlan region demonstrates an increasing challenge in the future to share water between extractive users and the needs of healthy river ecology.

IRN notes that an audit of the WSP conducted in 2018 found that the following provisions were not being given effect to:

- Part 2 Vision, objectives, strategies and performance indicators, cl. 12 Performance indicators
- Part 6 Limits to the availability of water, cl. 31 Compliance with the long-term average annual extraction limit for the EMU.

And that a number of provisions were only partially given effect to. [2]

It is significant that the audit found that the likelihood of compliance with the long-term average annual extraction limit not being met was very high. Also, that the lack of monitoring and metering led to a high likelihood of the intended objectives of the WSP not being met.

Context to the water plan's area

The Lachlan River and its tributaries, including the Abercrombie, Boorowa, Belubula and Crookwell Rivers are located in the Southern Tablelands, Central West, and Riverina regions. The Lachlan catchment covers an area of approximately 84,700 km2. The Lachlan River rises near Gunning and terminates in the Great Cumbung Swamp near Oxley, 1450 river kilometres to the west.[3]

The Lachlan River system is a very long catchment with delivery problems from major storages. Tributary inflows from unregulated streams form an important role in rules for meeting environmental flow triggers and for providing inflows to downstream storages at Lake Cargelligo and Lake Brewster.

There are only 11 flow gauges across the WSP area and an MDBA hydrological indicator site at Wylandra Weir used for generating flow sequences in the unregulated Lachlan rivers.

There is high connectivity between surface water and groundwater sources in the Lachlan Valley, particularly in the Belubula sub-catchment. While there are objectives in the WSP relating to connectivity between water sources specific rules are needed to better protect longitudinal, lateral and groundwater recharge connectivity.

[2] Alluvium, October 2019. *Audit of the Water Sharing Plan for the Lachlan Unregulated Water Source 2012*

[3] MDBA June 2020. NSW Lachlan surface water fact sheet

The Basin-wide Watering Strategy has an expectation that connectivity between the Lachlan River and its floodplains is improved by 10-20% in the Lachlan WRPA.[4] This has implications on rules in the WSP.

The review of the WSP also needs to consider its context within the implementation of the Murray Darling Basin Plan and how the rules for management and access of water in the WSP contribute to keeping water take within the constraints of the Basin Plan.

There are only 3 water quality sampling sites in the WSP area. These demonstrate some high risk of poor water quality. Consideration of flows and management actions to improve water quality for ecological benefits is also needed.

Environmental Health

Key environmental assets and ecosystem functions [5]

The Lachlan catchment has significant aquatic ecological value, including:

• 471,011 ha of wetlands in the lower floodplain

• nine wetlands with particular values for water bird and migratory bird habitat, listed in the Directory of Important Wetlands in Australia (Environment Australia 2001)

• native fish species including the Australian smelt, freshwater catfish, silver perch, golden perch, big-headed gudgeon and western carp gudgeon

• habitat for threatened species, such as Sloane's froglet, Australian painted snipe, osprey, blue-billed duck and the fishing bat

• areas of river red gum forest and woodland, black box woodland and lignum (Commonwealth Environmental Water Office 2012).

The nine nationally important wetlands include the Booligal Wetlands, Murrumbidgil Swamp/Lake Merrimajeel, Cuba Dam, Merrowie Creek, Great Cumbung Swamp, Lachlan Swamp, Lake Brewster, Lower Mirrool Creek Floodplain, and Lake Cowal/Wilbertroy wetlands (Commonwealth Environmental Water Office 2012).

The Booligal Wetlands and the Great Cumbung Swamp are notable sites as both wetlands are well known for providing habitat for both large numbers and species of waterbirds, particularly straw-necked, white and glossy ibis when the area is flooded. The catchment has been recorded to support 80,000 breeding pairs of ibis. The Great Cumbung Swamp also contains one of the largest stands of river red gums in NSW (Commonwealth Environmental Water Office 2012).

The Lachlan riverine system supports a diverse assemblage of species, including over 23 native freshwater fish species. Of the species recorded in the Lachlan seven are listed as threatened in NSW waters.

[4] Risk assessment p 67

[5] DPI -Water 2016. Background document for Lachlan Unregulated and Alluvial Water Source

Over 40 species of water birds including some that are listed under international conservation agreements are found in the lower catchment. This area is also important refuge for waterbirds listed as vulnerable including the freckled and blue-billed duck.

In recognition of this the aquatic ecological community in the lowland catchment of the Lachlan River has been listed as an Endangered Ecological Community (EEC) under the *Fisheries Management Act 1994* (Lachlan CMA, 2012).

Sixteen of the 23 unregulated surface water sources within the WSP area are identified as having high instream values. This includes Mandagery Creek where the instream value assessment was updated in 2015 with new data.

In the upland and midland zones, the Abercrombie River above Wyangala Dam, the Crookwell River, the Lachlan River above Reids Flat and Mandagery Creek have high ecological values due to the occurrence of threatened fish and frog species, including Macquarie perch, silver perch, Murray crayfish and the southern bell frog.

In the lowland and terminal zones, the mid-Lachlan unregulated water source and the unregulated effluent creeks water source have high and medium consequence scores due to the presence of Murray cod, Menindee nightshade and the southern bell frog.[6]

Rules to protect and improve environmental health, such as cease to pump rules, must be more specific and regularly monitored for compliance.

Current river health

High evaporation rates and seepage to groundwater mean that large volumes of water are needed to provide benefits to environmental assets that rely on surface water. In addition, the region's main storages cause cold water pollution which poses risks to native and threatened fish species. Floods and droughts can also increase the risk of blackwater events or localised algae blooms. At present, despite a number of measures, the fish community of the Lachlan valley is in poor health and some species are under serious threat. [7]

Stressed River Assessments show consistent scores of 'high' stress across the inland unregulated streams

Unregulated rivers in the Lachlan WRPA have medium or high risk of not meeting environmental flow requirements in the following water sources[8]:

Belubulah tributaries, Bogandillon and Manna Creeks, Boorowa River and Hovells Creek, Burrangong Creek, Crookwell River, Crowther Creek, Goobang and Billabong Creeks, Goonigal and Kanga Rooby Creeks, Lachlan River, Mandagery Creek, Mid Lachlan unregulated, Ooma Creek and tributaries, Tyagong Creek, Unregulated effluent Creeks, Waugoola Creek, Western Bland Creek.

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[6] Risk assessment p 75
[7] DPIE -Water, September 202o. Draft Lachlan Regional Water Strategy
[8] Ibid (Table 4-3) p 12

These unregulated water sources have highly altered low flows of >50% compared to natural flows. Rules in the WSP must be updated to improve the risk to river ecology and environmental assets.

Lachlan Long Term Water Plan (LTWP)
The LTWP identifies management strategies for each unregulated stream that must inform the remake of the WSP. These include raising cease to pump and commence to pump triggers.

The objectives and outcomes in the WSP must have improved alignment with the LTWP management strategies for access to all water sources.

Fish Research in the Lachlan:
Attached is a report on fish monitoring conducted in the Lachlan catchment between 2017 and 2020.

Groundwater extraction
The irrigation industry in the Lachlan Valley does not rely on on-farm storage to improve water access and security. There is total reliance on surface water flows and public storages with the main irrigation districts relying on groundwater licences in prolonged dry periods.

This has placed significant pressure on both surface and groundwater sources. The volume of water needed to recharge overdrawn aquifers must be better understood in relation to connectivity to surface hydrology and impacts on ecological values. Some areas of the Lachlan aquifers have suffered permanent drawdown through over extraction during recent intense droughts. This level of stress impacts the entire system including connected unregulated water sources.

Raising of Wyangala Dam Wall
IRN has major concerns about the proposal to raise Wyangala Dam wall to increase the storage level by 10m. This will result in further inundation of the unregulated Lachlan above Reid's Flat and the Abercrombie River. These water sources have been recognised as having high ecological values.

The impact of the proposal on river health and water licences in the inundation area is an issue that has not yet been publicly discussed. Changes to WALs in these river reaches need to be better understood in relation to the WSP and LTAAEL.

Cease to pump rules (CtP)
The Lachlan Unregulated Water Sources rules summary[9] describes the mostly generic CtP rules across all unregulated streams with a few exceptions.

The unregulated water sources with specific CtP rules protecting some low flows include Abercrombie River, Boorowa River, Crookwell Creek and Lachlan above Reid's Flat

[9] DPIE -Water, 2020

Mandagery Creek is the only water source with management zones. This is because a specific plan was developed for this water source with community consultation. This process needs to be developed for other water sources with high use in the WSP area.

Booberai and Effluent Creeks have specific rules carried over from the *Water Act 1912* relating to rules in the Lachlan Regulated WSP.

Lake Waljeers can be pumped down to 80% of full capacity and Lake Forbes can be pumped to 50%.

It is noted that many CtP rules commence at year 5 of the WSP commencement (July 2016 to June 2017). The Alluvium audit of the WSP was conducted in 2018. There is no clear discussion around the implementation of the year 5 rules.

The generic CtP rules across most water sources do not protect very low flows and include:

Access rules for rivers and creeks:
Pumping is not permitted from natural pools when the water level in the pool is lower than its full capacity.
Notes:

- Full capacity can be approximated by the pool level at the point where there is no visible flow into and out of that pool
- Natural pools include in-river pools found within the channels of rivers and creeks and off-river pools located on floodplains and effluents eg lakes, lagoons and billabongs
- For pumps not within a natural pool, the cease to pump rule is when there is no visible flow at the pump site.

Access rules for natural off-river pools:
Pumping is not permitted when the water level in that natural off-river pool is lower than its full capacity.
Notes:

- 'Full capacity" can be approximated by the pool water level at the point when there is no visible flow into or out of that pool
- Off-river pools include those natural pools located on flood runners or floodplains, or an effluent that only commences during high flow

These access rules do not apply:

- If the existing *Water Act 1912* entitlement had more stringent access licence conditions. These existing conditions will be carried forward under the plan and are included in schedule 1.
- To major water utility, local water utility or unregulated river (town water supply) access licences.
- To water taken for domestic consumption by stock and domestic access licences.
- For the first 5 years of the plan to water taken for stock watering by stock and domestic access licences.

- To water taken from existing dams. Any existing licence conditions associated with a dam will be carried forward under the plan.

IRN has major concerns that the range of CtP rules and the various exemptions are not adequate to protect the ecological values in the Lachlan unregulated streams. These streams experience prolonged drought conditions and all need a first flush CtP rule. The protection of very low flows is needed in all water sources.

The genuine protection of environmental water from consumptive take across all connected water sources is fundamental to the WSP making its contribution to NSW's commitment to the Basin Plan. Strong CtP rules are part of a suite of rules that protect environmental water, and these should be well co-ordinated within and across a water source to properly achieve the purpose of environmental water to meet well-defined environmental watering requirements.

CtP rules need to take full account of identified risks to all environmental assets especially future risks associated with a changing climate.

Aquifer Interference from Mining and CtP rules:
IRN notes that there are significant mining operations in the Lachlan unregulated streams catchment. Conditions of approval often require the purchase of surface water licences to mitigate volumes of groundwater and surface water intercepted through mining operations.

The exemption to the mining industry from CtP rules in unregulated water licences purchased to mitigate mining interception is a key issue for the long-term management of riverine ecology in these areas. (Cl 47 (1)). This clause should be removed or modified so that replacement flows are a provision.

Replacement flows should be a recommended requirement in the conditions of approval for all mining operations.

IRN understands that this aquifer interference exemption has been removed from the new draft Hunter Unregulated WSP.

Response to Review Questions

1. **To what extent do you feel the plan has contributed to environmental outcomes?**

The implementation of CtP and trading rules in Lachlan unregulated streams has commenced the process of recognising the need to protect river health. However, the current ecosystem health of water sources in the region needs to be better protected or improved. More targeted rules are needed to achieve enhanced environmental outcomes and to meet the WSP environmental objectives.

The definition of Planned Environmental Water (WSP Part 4 cl 16 (c))'*by reference to the water that is not committed after the commitments to basic landholder rights and for* *sharing and extraction under any other rights have been met'* demonstrates that water for environmental health of the river system has the lowest priority in the WSP.

The lack of protection for very low flows in the majority of the WSP area and the range of exemptions from CtP rules fails to provide important environmental outcomes.

The risk assessment for the Lachlan WRP SW 10 identified medium to high risk of elevated phosphorus and nitrogen and decreased dissolved oxygen. The WSP does not have clear rules to manage for improved water quality.

Many of the important environmental assets in the Lachlan are floodplain dependent species. There is currently no rule to stimulate breeding opportunities such as an aligned 'first flush no take' rule.

2. To what extent do you feel the plan has contributed to social outcomes?

The WSP has failed to meet the vision to provide for *the spiritual, social, customary and economic benefits of surface water to Aboriginal communities.*

No native title determinations have been achieved, no cultural water licences have been allocated and fish populations are in very poor health.

It is unclear how First Nation peoples' views about cultural flows have been incorporated into the WSP and where this has been defined in the WSP. Cultural objectives should not be conflated with environmental objectives. There is need for greater regard of the views of First Nations in the management of cultural flows within all the Lachlan waters. Better management of unregulated waters is important to protect and maintain cultural flows for the social benefit of First Nation peoples.

Lagoons, billabongs and off-river natural pools have significant Aboriginal cultural value. These provide important drought refuge for many native species and are not fully protected from water extraction in dry times.

The protection of basic landholder rights requires more recognition. The lack of protection of flows for downstream use has caused a failure to achieve social outcomes.

The ongoing risk of poor water quality also impacts social outcomes.

3. To what extent do you feel the plan has contributed to economic outcomes?

The WSP has clear trading rules and aims to provide certainty for all water users. Most of the WSP rules are tailored to large extractions for the agricultural industry.

This is mainly at the expense of secure town water supply, stock & domestic access, and basic rights access.

The economic value of irrigated agriculture must be assessed against the environmental and social costs associated with unhealthy rivers. The long-term sustainability of water extraction under newly modelled climate change scenarios must be a key consideration for the WSP review. Current Long-term annual average diversions limits were not set with climate change impacts under consideration. The environmental health of the river is likely to be the key victim of unchanged water sharing arrangements in a drying climate.

The economic value of town water supply, water-related tourism and recreational fishing and community well-being must be included in consideration of economic outcomes.

4. **To what extent do you feel the plan has contributed to meeting its objectives?**

The lack of clear monitoring and reporting requirements to demonstrate the meeting of objectives and performance indicators is a failure of the plan.

The ongoing high risks to ecosystem health and water quality, the lack of allocation of Aboriginal cultural water licences, and the failure to protect very low flows demonstrates that the WSP is not able to meet its objectives.

The lack of rules to stimulate breeding opportunities for important floodplain dependent species is a failure to meet the targeted environmental objectives of the WSP.

5. **What changes do you feel are needed to the water sharing plan to improve outcomes?**

- Specific rules to improve connectivity between water sources to better protect longitudinal, lateral and groundwater recharge connectivity. The rule changes outlined in the Lachlan LTWP must be considered in the new WSP.

- The establishment of management zones with gauges in all water sources with high water entitlement. More than half of the water sources in the WSP area have entitlements over 1,000 ML.

- Rules to protect and improve environmental health, such as CtP rules, must be more specific and regularly monitored:
    - For extraction from instream flows, all reaches must have a very low flow class attached to a gauge and, as an interim measure until very low flow classes are established, standard conditions should not permit pumping unless there has been visible flow past the pump for at least the previous 24 hours. The current rule for CtP when there is no visible flow at the pump site does not protect downstream connectivity.
    - For extraction from in-river and off-river pools, pumping should be prohibited unless there has been visible outflow from the pool for at least 24 hours and unless there is both visible inflow **and** visible outflow from the pool.
    - Extraction from Waljeers Lake and Lake Forbes must have the same CtP rule as all other natural pools

- All sub-catchments must have a CtP rule that protects the first flows after prolonged drought and active management to protect these flows for environmental, social and cultural benefits of instream flow as far downstream as possible.

- The exemption from CtP rules in unregulated water access licences owned by mining companies must be mitigated through a requirement in conditions of approval to provide replacement flows into the associated unregulated streams of water with high quality and the timing needed to maintain and restore the aquatic ecosystems. This must also be a rule in the WSP.

- Volumes for some classes of water licences permitted under the WSP need to be checked for consistency with the requirements of the Basin Plan to reduce over-extraction of basin waters.

- No new or enlarged in-river dams on stream orders 3 or higher should be permitted without public exhibition of an environmental impact statement.

Conclusion

IRN looks forward to recommendations from the NRC that will inform the making of new WSPs for the Lachlan Unregulated Water Sources. Improved water sharing rules will help ecosystem function and health to improve in this stressed and poor condition catchment.

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The Benefits of Community and Stakeholder Driven Fish Monitoring Projects in a Murray-Darling Basin River

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Abstract

River and catchment management in Australia's Murray-Darling Basin underwent a transformation in the latter part of the twentieth century, from being focused on delivering water predominantly for human and agricultural needs to also considering environmental considerations. The main driver of this change was the realisation that a comparatively long period of river regulation and associated alterations to natural systems had resulted in negative consequences. Native fish communities, in particular, have been considered to be in a poor or degraded condition. The centrally located Lachlan River, in New South Wales (NSW), is a poignant example, as the fish community has been rated as 'extremely poor' in both of the basin-scale Sustainable Rivers Audit reports in 2008 and 2012. River management can generally be regarded as a top-down process, with the Murray-Darling Basin Authority and state-based agencies simultaneously relied on and looked to for advice, but also blamed for any perceived problems and inequities. However, neither the federal nor state governments and their agencies have the capacity to undertake accurate monitoring of individual catchments at localised scales. In order to achieve this, local communities and stakeholders can make a difference to the management of their catchments by actively sponsoring and participating in sampling and monitoring projects that can then inform broader catchment management. This process has begun with positive results within the Lachlan catchment, and offers a representative case study that can be applied to other areas within the Murray-Darling Basin.

Keywords: Lachlan River, off-river areas, Lake Cargelligo, Booberoi Creek, community involvement, fish surveys, endangered species

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Introduction

In Australia's heavily modified Murray-Darling Basin (M-DB) in the nation's south-east, rivers were historically managed (from the mid-1800s) in order to ameliorate the effects of Australia's unpredictable weather systems and ensure that water could be supplied for towns and agriculture and – somewhat later – for the establishment and sustenance of irrigation districts and the generation of hydroelectricity.

Due to Australia's dry climate, the principal tools for controlling flows in the M-DB were (and remain) large headwater dams that enabled flows from the highest-rainfall areas to be harvested and stored, and a series of smaller weirs or other structures situated at various points downstream that similarly enabled water to be prevented from following riverine channels until it was required (Water Conservation and Irrigation Commission, 1971). Today, there are very few rivers in the M-DB that are unaffected by such regulation (a notable exception is the Paroo River in far western Queensland and New South Wales; Kingsford & Thompson, 2006).

By the latter part of the twentieth century, and facilitated by evolving areas of study within applied science and ecology, it became obvious that the regulated rivers of the M-DB were affected by a range of negative issues, including damming of rivers preventing natural flows, the introduction and spread of alien species, over-allocation of water, riparian denudation, pollution, and the decline of native fish species and stocks (Arthington, 1991; Walker et al., 1995; Humphries et al., 1999; King et al., 2003; Koehn, 2004). However, these issues were also complicated by geographic location, for the basin occupies four Australian states and one territory: Queensland, New South Wales, Victoria, South Australia and the Australian Capital Territory. Within each jurisdiction, agencies with associated responsibilities (water, planning, natural resources and fisheries) worked autonomously to develop 'their' rivers and associated infrastructure. However, within 100 years it became necessary to create an over-arching organisation, first called the Murray-Darling Basin Commission (MDBC) and then the Murray-Darling Basin Authority (MDBA), as it became obvious that addressing basin issues at basin scale was essential.

The observed problems were also confounded by a general absence of historical records that documented these perturbations in a quantitative manner (the survey work of J. O. Langtry, in Cadwallader, 1977, being a notable exception). Given that fish are the ecological focus of this paper, a dataset that illustrates native fish decline in the M-DB is the commercial catch data from New South Wales (Reid et al., 1997). From 1947 (when records commenced) the catch records for three of the four native species targeted by commercial fishers (Murray cod, *Maccullochella peelii*; silver perch, *Bidyanus bidyanus*; and freshwater catfish, *Tandanus tandanus*) plummeted by the 1970s (Reid et al., 1997). Following a peak in 1960 (80 tonnes), Murray cod capture fell rapidly and stabilised to less than 10 tonnes per year within seven years. Silver perch peaked in 1958–1959 with a catch of 44 tonnes, but the fishery was exhausted by 1984–1985. Catfish were similar: 43 tonnes in 1974–1975 and complete decline by 1990. This compelling evidence led to the closure of the inland riverine commercial fishery for native species in September 2001 and is indicative of the wider problems within the basin by that time (Lintermans, 2007).

The imposition of a top-down framework to manage the M-DB (including the MDBA and state government agencies, supported by research by universities and other groups) has often led to friction between jurisdictions and – most noticeably – anger within local riverine communities who sometimes feel affronted by this approach. Graphic examples include irrigators in Griffith, New South Wales publicly burning copies of the draft Murray-Darling Basin Plan in 2010 (Australian Broadcasting Commission, 2010), and the world-wide media reaction to fish kills in the Darling River near Menindee in the summer of 2018–2019 (*The Guardian*, 2019). A more consultative approach to managing these rivers is therefore clearly desirable.

The Lachlan catchment is the geographic focus of this paper and is centrally located in the basin within NSW (Figure 1). It is the northernmost catchment in the southern M-DB, the fourth-longest river in Australia, and somewhat unique within the M-DB as it most usually reaches a terminus in the Great Cumbung Swamp (near Oxley), so is essentially an isolated catchment. The Lachlan rises in the Great Dividing Range west of Sydney, and the headwater reservoir – Wyangala Dam – harvests water from both the upper Lachlan and Abercrombie Rivers.

With the exception of the native species caught by commercial fishers and targeted by recreational and illegal fishing (those mentioned above and golden perch or yellowbelly, *Macquaria ambigua*), there is limited historical knowledge of the fish communities within the Lachlan catchment (Roberts & Sainty, 1996; Trueman, 2011). Indeed, the first published record of species within the Lachlan did not occur until Llewellyn's survey (1983), where nine native and four alien species were detected.

In response to the realisation that fish communities within the M-DB (in particular) were declining, NSW Fisheries and the Cooperative Centre for Freshwater Ecology conducted the NSW Rivers Survey (Harris & Gehrke, 1997) in an effort to generate baseline river health data across the state. The Lachlan delivered poor results, with only six native fish species present.

The urgency of the M-DB problems prompted the MDBC/MDBA to initiate a large-scale and ambitious project – the Sustainable Rivers Audit (SRA) – in an effort to measure several indicators (fish, macroinvertebrates, vegetation and hydrology) in all major M-DB catchments. However, against the SRA criteria, the fish theme presents sobering reading, as the Lachlan fish community consistently rates as 'extremely poor' (Davies et al., 2008; Davies et al., 2012).

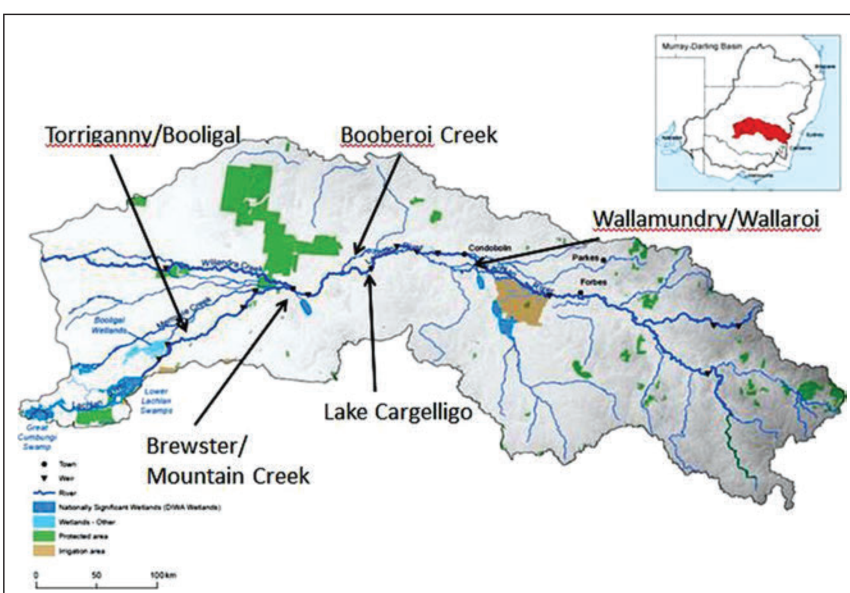
The data presented in this paper relate to fish from multiple surveys at multiple locations in the mid-Lachlan (i.e. roughly between Condobolin and Booligal; Figure 1), conducted at various times and for many different reasons between 2017 and 2020. These data have not been collected as part of a large-scale study, but instead have been sponsored and supported by local and/or regional groups – both government and not-for-profit – with an interest in auditing and then contributing to improvement of the riverine environment at local scales. The data are presented and then discussed under five headings that highlight the benefits of this 'bottom-up' approach to river management: the involvement, interest and education of local participants; the delivery of records for unknown or poorly known areas that can inform riverine management; the ecological relevance of sampling off-river areas away from the main stem of M-DB rivers; the longevity and flexibility afforded by localised monitoring; and the creation of new projects that can ensue following initial engagement. The results and discussion may, therefore, be relevant to other systems throughout the M-DB and are intended to inform future monitoring programs and management strategies.

Materials and Methods

Study Area

All fish sampling described in this paper was undertaken in what could be termed the 'mid-Lachlan' between 2017 and 2020. The sampling area stretches from Condobolin (elevation 220 m) in the east to Booligal (elevation 83 m) in the south-west, across a distance of approximately 253 km (Figure 1). As such, the mid-Lachlan represents a typical meandering, low-gradient river valley that is similar to many of the longer M-DB rivers such as the Murrumbidgee, Darling and Macquarie. The principal land use within this stretch of the Lachlan is dryland agriculture (cereal cropping combined with livestock production); however, irrigated systems are also common, with concentrations around Hillston and Condobolin producing cotton and tree crops (nuts and citrus). The climate of the mid-Lachlan is mediterranean, with long, hot summers (temperatures frequently exceed 40°C between November and March) and short, cold winters with multiple frosts.

Figure 1. Map of the Lachlan catchment. Arrows indicate areas where the fish sampling described herein has occurred between 2017 and 2020.



The mid-Lachlan is characterised by a deep (frequently deeper than 10 m) and incised main channel, and several creeks and off-river areas that are generally regulated by weirs and lock gates managed by WaterNSW. The majority of sampling was undertaken in these off-channel areas, such as the Wallamundry Creek complex close to Condobolin, Booberoi Creek between Condobolin and Lake Cargelligo, Torriganny Creek between Hillston and Booligal, and within the Lake Cargelligo system (Figures 1 & 2). Constructed from 1902–1904 by excavating channels to link low-lying areas, the Lake Cargelligo storage comprises three connected lakes that hold 36,000 ML when full. The Lake Cargelligo storage is used in conjunction with Wyangala Dam and the Lake Brewster storage to supply water to the lower sections of the Lachlan. Sampling was also undertaken at main channel sites close to the Booberoi Creek offtake and re-entry points; in the Brewster weir pool; and in Mountain Creek, which drains Lake Brewster back to the main channel of the Lachlan (Figure 1).

Sampling Rationale and Timing

The data presented do not derive from a discrete project but are the cumulative data collected from several projects that have occurred within the mid-Lachlan since 2017. As such, some sites have been sampled on multiple occasions, whereas others have been sampled only once or twice. Nevertheless, the same sampling methodology (described below) has been used during all sampling events, thus allowing the data to be used to infer general trends regarding the fish communities in this section of the Lachlan catchment.

Booberoi Creek was sampled on eight occasions between November 2017 and January 2020. The purpose of this sampling was to monitor the short- and long-term changes in the fish community following environmental flow releases by state and/or national water holders, who also enabled/sponsored the monitoring (NSW Department of Primary Industries and Environment (DPIE) and Commonwealth Environmental Water Office (CEWO)). Main channel sites in the vicinity of Booberoi Creek were sampled as an addition to Booberoi Creek sites in September–October 2019.

The Lake Cargelligo system was sampled on seven occasions between December 2017 and January 2020. The purpose of this sampling was to provide basic inventory information to a local not-for-profit group, the Cargelligo Wetlands and Lakes Council, in order to inform their management of an island (Robinson Crusoe Island) which they lease and manage for conservation.

The weir pool above Brewster Weir was sampled in both February and March 2019 and also in February 2020 in order to monitor the population of the endangered olive perchlet (*Ambassis agassizii*) that is known to inhabit this area. This work was undertaken in conjunction with volunteers from NSW ANGFA (Australia and New Guinea Fishes Association). Mountain Creek, which drains Lake Brewster back to the main channel of the Lachlan River, was also sampled in February 2019 in order to monitor the population of olive perchlet.

Yarrabandai Creek and Wallamundry Creek (both close to Condobolin) were sampled in October 2019 in order to provide basic inventory information and monitor an environmental flow (NSW DPIE/CEWO), and Torriganny Creek (close to Booligal) was also monitored in October 2019 for the same reasons.

In all areas, a minimum of three sites were sampled on each sampling occasion.

Fish Sampling Methods

Fish populations were sampled at all sites and on all sampling occasions using a combination of large and small fyke nets. These methods successfully capture fish of all body sizes and life stages in Australian inland waterways (Arthington et al., 2005; Balcombe et al., 2007). Large double-winged fyke nets with a 13 mm stretched mesh and 8 m wings (1 m deep) were set parallel to the bank with their openings facing in opposite directions upstream and downstream from a central post. Cod-ends were secured above the water surface in order to allow air-breathing vertebrates to survive if they became entrapped. Small double-winged fyke nets with a stretched mesh of 2 mm and a wing width of 3 m (1 m deep) were set in an identical manner. All fyke nets were set in the afternoon (as close as possible to 4.00 pm) and retrieved the following morning (as close as possible to 9.00 am). Following the clearing of fyke nets, all fish were held in shaded water-filled buckets prior to processing.

Figure 2. Habitats sampled between 2017 and 2020 ranged from areas of open water in the Lake Cargelligo system (top) to channelised riverine environments such as Booberoi Creek (bottom) (Photos: Adam Kerezsy).

Fish species were identified using a combination of published literature relating to fishes of the Murray-Darling Basin (Allen et al., 2002; Lintermans, 2007). All sampled fish were measured from the tip of the snout to the caudal peduncle to obtain a standard length (SL) measurement in millimetres. Following identification and measurement for standard length, all native fish were returned to the water alive and alien species were euthanised using a dilute solution of Aqui-S (as per OEH Animal Research Authority AEC Approval No. 171017/01).

Data Presentation and Comparison with Previous Studies

Owing to the large number of sites and the fact that some sites were sampled on multiple occasions whereas others were only sampled once over the extended seasonal sampling timeframe, analysis of the entire dataset was neither envisaged nor attempted.

Overall total catches were calculated and tabulated for each site and species. Totals were calculated by adding all results from all sampling events in a particular area, with the number of sampling occasions also noted.

Totals were used in areas sampled multiple times (Lake Cargelligo and Booberoi Creek) in order to graph and compare fish community composition and provide a visual representation of the contribution of common and alien species in such areas.

Fish species' presence/absence was compared to previous sampling data within the Lachlan catchment (Llewellyn, 1983; Harris & Gehrke, 1997; Growns, 2001; Kerezsy, 2005; MDBC, 2004a; Davies et al., 2008; Price, 2009; Davies et al., 2012) in order to permit discussion of the current state of fish communities within the mid-Lachlan catchment.

Results

Total Fish Results, 2017–2020

Close to 30,000 individual fish were sampled at all sites in the mid-Lachlan between 2017 and 2020, with the vast majority (84%) being native species (Table 1). Small gudgeons of the genus *Hypseleotris* were the most commonly sampled species and were found at all sites except in the main channel of the Lachlan (Table 1). Bony herring (*Nematolosa erebi*) were also sampled in large numbers (>10,000; Table 1); however, their range was generally concentrated in the open water habitats (such as Lake Cargelligo and the Brewster Weir pool; Table 1).

Small-bodied native species such as un-specked hardyhead (*Craterocephalus stercusmuscarum fulvus*), Australian smelt (*Retropinna semoni*) and flathead gudgeon (*Philypnodon grandiceps*) were sampled in reasonable numbers; however, they were generally detected more often in Lake Cargelligo and Booberoi Creek, the two areas that were sampled on multiple occasions.

Large-bodied native species such as yellowbelly and Murray cod were sampled in small numbers, and only from Lake Cargelligo, and the endangered population of olive perchlet was detected within its known range in the Brewster Weir pool (Figure 1; Table 1).

Freshwater catfish – classified as a listed endangered population within the M-DB – was found at four locations, including Booberoi Creek, Mountain Creek, Wallamundry Creek and Lake Cargelligo. At each location, one adult catfish was sampled (Figure 1; Table 1).

The most commonly sampled alien species was gambusia (*Gambusia holbrooki*), which was present at all sites except the main channel of the Lachlan River and Yarrabandai Creek (Figure 1; Table 1). Carp were similarly distributed, occurring at all sites except Wallamundry Creek. Goldfish and redfin were sampled in far lower numbers and at a more limited number of sites (Table 1).

Fish Communities in Different Areas

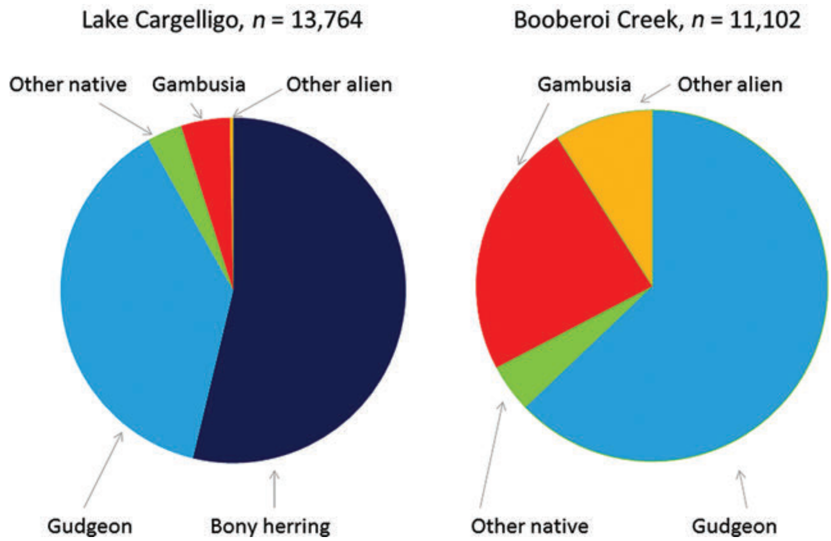
The fish community in the meandering and riverine Booberoi Creek (summed from eight sampling occasions) was dominated by small species such as gudgeons and gambusia, whereas the open-water habitat of Lake Cargelligo was dominated by bony herring (Figure 3).

In Booberoi Creek, gudgeons and gambusia were sampled during all surveys (eight) and carp were sampled during seven. Goldfish were sampled during five surveys, and un-specked hardyhead and flathead gudgeon during four. All other species in Booberoi Creek (bony herring, freshwater catfish, Australian smelt and redfin) were sampled during one survey.

Table 1. Total numbers of fish sampled at sites throughout the mid-Lachlan catchment from 2017–2020, including number of times each site was sampled.

Scientific name	**Common name**	**Booberoi Creek** (sampled eight times)	**Lake Cargelligo** (sampled seven times)	**Brewster Weir Pool** (sampled three times)	**Mountain Creek** (sampled once)	**Wallamundry Creek** (sampled once)	**Yarrabandai Creek** (sampled once)	**Torriganny Creek** (sampled once)	**Lachlan main channel** (sampled once)	**Totals**
Native species										
Nematolosa erebi	Bony herring	7	7400	1690	1569	—	—	—	—	**10666**
Retropinna semoni	Australian smelt	79	131	—	—	3	—	—	—	**213**
Tandanus tandanus	Freshwater catfish	1	1	—	1	1	—	—	—	**4**
Craterocephalus stercusmuscarum fulvus	Un-specked hardyhead	140	52	1	—	—	—	—	—	**193**
Ambassis agassizii	Olive perchlet	—	—	11	—	—	—	—	—	**11**
Macquaria ambigua	Yellowbelly	—	18	—	—	—	—	—	1	**19**
Maccullochella peelii peelii	Murray cod	—	3	—	—	—	—	—	—	**3**
Philypnodon grandiceps	Flathead gudgeon	269	245	12	—	—	—	—	—	**526**
Hypseleotris spp.	Carp gudgeons	6981	5242	712	97	25	149	25	—	**13231**
Alien species										
Cyprinus carpio	Carp	976	22	6	73	—	17	13	3	**1110**
Carassius auratus	Goldfish	28	1	—	—	—	1	2	5	**37**
Gambusia holbrooki	Gambusia	2620	631	259	89	6	—	125	—	**3730**
Perca fluviatilis	Redfin	1	18	—	—	—	—	—	—	**19**

Figure 3. Proportional representation of summed totals of all fish sampled in Lake Cargelligo (left) and Booberoi Creek (right) between 2017 and 2020.



In Lake Cargelligo, gudgeons and bony herring were sampled during all surveys (seven), carp and gambusia during six, flathead gudgeon during five, and yellowbelly, redfin and Australian smelt during four. Un-specked hardyhead were sampled during three surveys, Murray cod during two, and both freshwater catfish and goldfish were sampled during one survey.

The population of native fish sampled in Booberoi Creek represented 67% of the total, whereas in Lake Cargelligo native fish comprised 95% of the total.

Comparison with Existing Surveys in the Lachlan Catchment

Two native species (yellowbelly and *Hypseleotris* gudgeons) and three alien species (carp, goldfish and gambusia) have been detected during nine surveys in the mid-Lachlan since 1983 (Tables 1 & 2).

Two native species (bony herring and flathead gudgeon) have been detected during eight of the nine surveys, and two native species (Murray cod and Australian smelt) and one alien species (redfin) have been detected during seven (Tables 1 & 2). Native species detected in fewer surveys include un-specked hardyhead (five surveys), freshwater catfish (four surveys), silver perch (three surveys) and olive perchlet (two surveys; Tables 1 & 2). Southern pygmy perch, flathead galaxias, Murray-Darling rainbowfish, southern purple-spotted gudgeon and trout cod have not been detected by any of the surveys of freshwater fish in the mid-Lachlan (Tables 1 & 2).

Discussion

Fish Records for Unknown or Poorly Known Areas Can Inform Management

River and catchment management relies on accurate records such that decisions can be made in relation to restoration works or the provision of flows that may have ecological benefit. During the monitoring studies presented here, both NSW DPIE and CEWO have used the fish survey results from specific areas to inform the timing and volume of environmental flows (J. Lenehan, DPIE, pers. comm.).

Following the detection of endangered freshwater catfish in Booberoi Creek, environmental flows were directed down this off-river system, and during subsequent sampling events populations of small native species such as un-specked hardyhead and flathead gudgeon were also recorded (Table 1). Subsequent sampling of other off-river creeks such as Wallamundry and Mountain Creeks also found catfish present and may become target areas for future environmental flows (J. Lenehan, NSW DPIE, pers. comm.).

TTable 2. Records of fish species in the mid-Lachlan catchment during surveys undertaken since 1983. Empty squares indicate absence.

Family	Scientific name	Common name	Llewellyn	Harris & Gehrke	Growns	MDBC SRA Pilot Study	Kerezsy	SRA 1 Davies et al.	MDFRC Price	SRA 2 Davies et al.	Recent surveys
			1983	**1997**	**2001**	**2004**	**2005**	**2008**	**2009**	**2012**	**2017–1920**
Native species											
Clupeidae	*Nematolosa erebi*	Bony herring		*	*	*	*	*	*	*	*
Retropinnidae	*Retropinna semoni*	Australian smelt	*	*	*	*	*	*			*
Plotosidae	*Tandanus tandanus*	Freshwater catfish	*		*		*				*
Atherinidae	*Craterocephalus stercusmuscarum fulvus*	Un-specked hardyhead	*				*	*	*		*
Ambassidae	*Ambassis agassizii*	Olive perchlet	*								*
Percichthyidae	*Macquaria ambigua*	Yellowbelly	*	*	*	*	*	*	*	*	*
Percichthyidae	*Maccullochella peelii peelii*	Murray cod	*		*	*		*	*	*	*
Terapontidae	*Bidyanus bidyanus*	Silver perch	*	*			*				
Eleotridae	*Philypnodon grandiceps*	Flathead gudgeon	*	*	*	*	*		*	*	*
Eleotridae	*Hypseleotris* spp.	Carp gudgeons	*	*	*	*	*	*	*	*	*
Alien species											
Cyprinidae	*Cyprinus carpio*	Carp	*	*	*	*	*	*	*	*	*
Cyprinidae	*Carassius auratus*	Goldfish	*	*	*	*	*	*	*	*	*
Poecilidae	*Gambusia holbrooki*	Gambusia	*	*	*	*	*	*	*	*	*
Percidae	*Perca fluviatilis*	Redfin	*	*	*	*	*			*	*

In Lake Cargelligo, the presence of most expected species in the Robinson Crusoe Island area similarly prompted the managers of this reserve (Cargelligo Wetlands and Lakes Council) to ask the water provider (WaterNSW) to consider altering their traditional management of the lake as a storage to also factor in the ecological and social benefits of more regular water delivery (P. Skipworth, CWLC, pers. comm.). The result has been that some water that normally would have flowed down the Lachlan has been diverted through the Lake Cargelligo system, and this appears to have had a positive effect on aquatic fauna (Tables 1 & 2).

In both of these cases, locally sponsored monitoring provided survey results that have then been used by managers to make informed decisions regarding catchment management.

The Biological Relevance of Repeated Sampling in Off-river Habitats

Broad-scale river surveys provide a snapshot of fish community composition in a catchment but are generally restricted to main channel sites, as opposed to lotic or lentic sites that are situated in creeks, lakes and floodplains (Davies et al., 2008; Davies et al., 2012; Price, 2009). Localised sampling has the potential to fill knowledge gaps with regard to catchment fish communities by augmenting broad-scale surveys with monitoring in a wider range of off-river habitat types. Furthermore, the repeated nature of some of this sampling (for example in Booberoi Creek and Lake Cargelligo) may deliver more informative and useful fish community data from which to inform river and water management.

Results from the mid-Lachlan between 2017 and 2020 compare favourably with all previous surveys with regard to species present (Table 2) and suggest that these off-river areas may provide valuable habitat and ecosystem services, particularly as potential refuge or nursery areas (Datry et al., 2017).

The Lake Cargelligo system (Figures 1 & 2) was essentially altered from an ephemeral wetland to a permanent storage from the early 1900s (Kerezsy, 2005). This has created large areas of shallow, open water and provided ideal habitat for pelagic schooling species such as bony herring, Australian smelt and un-specked hardyhead. The numerical dominance of bony herring in this habitat is exemplified by the survey results from 2017 onwards (Table 1), and unsurprisingly, the species also favours the similar lacustrine environment created by the Brewster Weir (Table 1).

In contrast, in the channelised and riverine habitat that occurs in Booberoi Creek (Figure 2), bony herring are uncommon and the community is dominated by small generalists such as gudgeons (*Hypseleotris* spp.) and alien gambusia (Table 1).

Carp are generally present in off-river habitats of the mid-Lachlan. However, it is notable that commercial carp fishers have been operating in Lake Cargelligo since 1 May 2018 and estimate they have removed approximately 180 tonnes of carp from the system in the intervening period (Steve Hounsell, pers. comm). It is therefore possible that sustained carp removal may be contributing to the positive results for all native species recorded from Lake Cargelligo since mid-2018 (Table 1).

Monitoring undertaken in the mid-Lachlan between 2017 and 2020 has confirmed the presence of endangered species such as freshwater catfish in four areas (Table 1) and has similarly confirmed the presence of olive perchlet within the Lake Brewster weir pool (Table 1) following the discovery of this isolated population approximately 10 years earlier (McNeill et al., 2008).

However, five species remain elusive in the mid-Lachlan, despite predictions that they were historically present and may still occur (Davies et al., 2008; Davies et al., 2012). Flathead galaxias (*Galaxias rostratus*), Murray-Darling rainbowfish (*Melanotaenia fluviatilis*), trout cod (*Maccullochella macquariensis*), southern pygmy perch (*Nannoperca australis*) and southern purple-spotted gudgeon (*Mogurnda adspersa*) have not been recorded in mid-Lachlan surveys since 1983 (Table 2), and museum records do not exist for any of these species except for a single record of a rainbowfish from Hillston in 1950 (Amanda Hay, Australian Museum, pers. comm.).

The Longevity and Flexibility Associated with Localised Monitoring Projects

Localised and locally supported fish sampling can be timed to coincide with and/or inform environmental watering events, and can be tailored and expanded to meet desired project management goals where necessary. For example, all of the sampling that has occurred in Booberoi Creek has been targeted with a view to obtaining before, during and after samples of fish populations relative to the timing and volume of environmental water deliveries (J. Lenehan, DPIE, pers. comm.), and the sampling in Wallamundry Creek was initiated for the same reason. It is envisaged that long-term monitoring of Booberoi Creek is likely to continue (J. Lenehan, NSW DPIE, pers. comm.), and commencing in late 2020, another project aimed at mid-Lachlan creeks in the Forbes/Condobolin area is also planned (Mary Ewing, Lachlan Valley Water, pers. comm.).

In Lake Cargelligo, the local not-for-profit Cargelligo Wetlands and Lakes Council made a decision to continue fish monitoring in the Robinson Crusoe Island reserve area on a regular basis from 2019–2020 onwards. This decision was based on the early fish survey results and the need to create a longer-term dataset upon which to base environmental watering management plans (P. Skipworth, CWLC, pers. comm.).

This flexible approach to sampling and monitoring can have unintended benefits, with a good example being the detection of freshwater catfish in Mountain Creek (Table 1), which was initially sampled (along with the Brewster weir pool) for the purposes of auditing the Lachlan population of the endangered olive perchlet.

Locally sponsored sampling can complement established long-term monitoring projects (Dyer et al., 2019) by expanding the overall sampling area within a catchment and focusing on specific habitats or areas that are beyond the scope of larger projects.

Involvement, Interest and Education of Local Participants

Monitoring that is sponsored and supported by community and/or stakeholder groups – by its very nature – encourages the participation of local communities, and in the mid-Lachlan numerous examples relating to the work that has been carried out between 2017 and 2020 suggest that the flow-on effects regarding community engagement are beneficial.

During two of the Booberoi Creek monitoring events (spring 2018 and spring 2019), fish sampling took place as part of stakeholder engagement weekends/overnight trips that included local landholders, representatives from the local Aboriginal community and government agents (from NSW DPIE and CEWO). The majority of participants – but most notably the landowners – expressed interest (and surprise) at both the variety and abundance of small-bodied native fish, and most commented that although they had lived adjacent to the creek for extended periods, they were somewhat ignorant of (but keen to learn about) the local biodiversity (landowners D. Stewart, J. Ireland, pers. comms).

In April 2019, as part of routine sampling of the Robinson Crusoe Island area sponsored by Cargelligo Wetlands and Lakes Council, two coordinators and six Aboriginal teenagers from the Down The Track youth-at-risk program attended and assisted with both fish sampling and bird counts, as well as staying overnight and helping with general chores associated with bush camping (Figure 4). Coordinator Lana Masterson commented that the participants were all completely engaged with the activities, and – as soon as they were heading back to the ‘mainland’ by boat – enquired as to when they would be repeating the exercise (L. Masterson, Down The Track, pers. comm.).

Similarly, interest in ecological projects and associated work has become an accepted and possible career/occupation pathway for school-aged students, with one Year 10 student working on fish sampling within Lake Cargelligo as part of the local ‘School to Work’ work experience program (T. Kendall, careers advisor, Lake Cargelligo Central School, pers. comm.).

The Creation of New Projects Following Initial Engagement

Fish monitoring work undertaken in the mid-Lachlan from 2017 onwards has yielded some encouraging results regarding native fish, particularly for the areas that have been sampled on multiple occasions (Table 1; Figure 3). The communication of results from this work – mainly through informal networks and word of mouth – appears to have had a positive influence within the catchment, and as a consequence, monitoring of other areas, sponsored by different stakeholders, has commenced or will be commencing from 2020.

Figure 4. Members of the Down The Track program for at-risk youth participating in fish sampling at Robinson Crusoe Island, Lake Cargelligo, in March 2020 (Photo: Mal Carnegie).

From mid-2020, the ongoing monitoring of the Robinson Crusoe Island area within Lake Cargelligo will be funded and supported by a partnership between Cargelligo Lakes and Wetlands Council (a local not-for-profit group) and Lachlan Shire Council (P. Skipworth, CWLC, pers. comm.). This is an important development as it indicates that local governments have the ability to contribute positively to community-based projects that have a broad utilitarian goal (i.e. better management of the catchment for the benefit of all parties).

Commencing in spring 2020, a three-year project will commence in the Belubula catchment, and this work will be supported by Newcrest Mining (T. Thornberry, Newcrest, pers. comm.). The Belubula, which rises in high country between Bathurst and Orange and joins the Lachlan close to Gooloogong, can be considered an upstream tributary of the Lachlan, as opposed to the majority of sites discussed and sampled to date (Table 2). However, the Belubula is also poorly known regarding fish communities; thus, there is demonstrated interest from local landholders and government agencies (G. Fitzhardinge, M. Martin, C. Dunhill, J. Sanders, M. Payten, C. Proctor, pers. comms), and the results from these surveys are also likely to contribute to management of both the Belubula and Lachlan Rivers.

In a similar fashion, Lachlan Valley Water – a water users group with a focus on irrigation – will sponsor the aforementioned fish monitoring in another poorly known area of the Lachlan (from Jemalong, downstream of Forbes, to Wallamundry, in the vicinity of Condobolin) commencing in spring 2020.

Lastly, based on the success of the community-based monitoring workshops held at Booberoi Creek (spring 2018 and spring 2019), NSW DPIE is planning to repeat this model (incorporating fish sampling, bird sampling and other ecological information) in the lowland section of the Lachlan in the area close to Booligal, again commencing in spring 2020 (J. Lenehan, NSW DPIE, pers. comm.).

Conclusions

Monitoring specific or targeted areas within a catchment is beset by the same problems that apply to broad-scale monitoring, because not all areas are likely to be sampled, and some important areas will inevitably be missed. However, if this monitoring is supported by a broad range of local and regional groups – as the surveys presented and discussed here have been – the chances of obtaining accurate information that can guide catchment management can certainly be improved.

Contrary to the results from broad-scale riverine surveys (Davies et al., 2008; Price, 2009; Davies et al., 2012), the results from specific areas within the mid-Lachlan (for example Booberoi Creek and Lake Cargelligo) indicate that off-river areas are likely to provide habitat for the majority of extant native species. The importance of these habitats can be confirmed by targeted fish surveys, especially if sampling is carried out on multiple occasions. Replicating surveys such as those documented herein, both within individual catchments and across the M-DB, would undoubtedly provide enhanced records and reliable information upon which fishery and catchment managers can base decisions.

Though desirable, monitoring at these scales is beyond the capacity of state agencies and the MDBA. However, the work cited demonstrates that there is both capacity and intent within local riverine communities to learn about and improve river management with a view to enhancing biodiversity and overall catchment health. The diversity of interested community and stakeholder groups – encompassing a local not-for-profit, a local council, a mining company, an irrigation group, Indigenous owners, and state and federal agencies charged with delivering environmental flows – is indicative, perhaps, of a changing mood within riverine communities in the M-DB, and bodes well for the future.

A bottom-up approach to catchment management, where local and regional people can invest in monitoring programs that seek to document the biota and health of their rivers and waterways, could be an extremely effective way of sharing the considerable load associated with making informed management decisions. The template that has evolved – and is evolving – in the Lachlan catchment in New South Wales could easily be adapted and replicated in other catchments across the M-DB and elsewhere.

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Literature Cited

Allen, G. R., Midgley, S. H., & Allen, M. (2002). *Field Guide to the Freshwater Fishes of Australia*. Western Australian Museum.

Arthington, A. H. (1991). Ecological and Genetic Impacts of Introduced and Translocated Freshwater Fishes in Australia. *Canadian Journal of Fisheries and Aquatic Sciences, 48*(Suppl. 1), 33–43.

Arthington, A. H., Balcombe, S. R., Wilson, G. A., Thoms, M. C., & Marshall, J. (2005). Spatial and temporal variation in fish assemblage structure in isolated waterholes during the 2001 dry season of an arid-zone river, Cooper Creek, Australia. *Australian Journal of Marine and Freshwater Research*, *56*, 25–35.

Australian Broadcasting Commission. (2010). Copies of guide to Murray-Darling Basin plan burnt. *ABC News*. https://www.abc.net.au/news/2010-10-14/young-men-burn-copies-of-the-guide-to-the-murray/2298002?nw=0

Balcombe, S. R., Bunn, S. E., Arthington, A. H., Fawcett, J. H., McKenzie-Smith, F. J., & Wright, A. (2007). Fish larvae, growth and biomass relationships in an Australian arid zone river: links between floodplains and waterholes. *Freshwater Biology*, *52*, 2385–2398.

Cadwallader, P. (1977). *J.O. Langtry's 1949-50 Murray River Investigations* (Fisheries and Wildlife paper, Victoria, No. 13). Fisheries and Wildlife Division, Victoria.

Datry, T., Bonada, N., & Boulton, A. (Eds.). (2017). *Intermittent Rivers and Ephemeral Streams: Ecology and Management*. Academic Press/Elsevier.

Davies, P., Harris, J., Hillman, T., & Walker, K. (2008). *SRA Report 1: Report on the Ecological Health of Rivers in the Murray-Darling Basin, 2004–2007.* Prepared by the Independent Sustainable Rivers Audit Group for the Murray-Darling Basin Ministerial Council.

Davies, P., Stewardson, M., Hillman, T., Roberts, J., & Thoms, M. (2012). *Sustainable Rivers Audit 2: The ecological health of rivers in the Murray-Darling Basin at the end of the Millenium Drought (2008–2010)*. Prepared by the Independent Sustainable Rivers Audit Group for the Murray-Darling Basin Ministerial Council.

Dyer, F., Broadhurst, B., Tschierschke, A., Higgisson, W., Allan, H., Thiem, J., Wright, D., & Thompson, R. (2019). *Commonwealth Environmental Water Office Long Term Intervention Monitoring Project: Lower Lachlan River System 2018–2019 Annual Report*. https://www.environment.gov.au/water/cewo/publications/ltim-lachlan-annual-report-2018-19

Growns, I. (2001). *An Assessment of the status of Native Fish and Fish Habitats in the Lachlan River*. NSW Fisheries Office of Conservation.

Harris, J., & Gehrke, P. (1997). *Fish and Rivers in Stress – the NSW Rivers Survey*. NSW Fisheries Office of Conservation; Cooperative Research Centre for Freshwater Ecology, Canberra.

Humphries, P., King, A. J., & Koehn, J. D. (1999). Fish, flows and flood plains: Links between freshwater fishes and their environment in the Murray-Darling River system, Australia. *Environmental Biology of Fishes*, *56*, 129–151.

Kerezsy, A. (2005). *The distribution and abundance of fish in the Lake Cargelligo system, New South Wales* [Honours thesis]. Charles Sturt University, North Wagga, New South Wales.

King, A. J., Humphries, P., & Lake, P. S., (2003). Fish recruitment on floodplains: the roles of patterns of flooding and life history characteristics. *Canadian Journal of Fisheries and Aquatic Sciences*, *60*, 773–786.

Kingsford, R., & Thompson, J. (2006). Desert or dryland rivers of the world: an introduction. In R. T. Kingsford (Ed.), *Ecology of Desert Rivers* (pp. 3–10). Cambridge University Press.

Koehn, J. D. (2004). Carp (*Cyprinus carpio*) as a powerful invader in Australian waterways. *Freshwater Biology*, *49*, 882–894.

Lintermans, M. (2007). *Fishes of the Murray-Darling Basin: An introductory guide* (MDBC Publication No. 10/07). Murray-Darling Basin Authority.

Llewellyn, L. C. (1983). *The distribution of fish in New South Wales* (Australian Society for Limnology Special Publication No. 7). Australian Society for Limnology.

McNeill, D., Wilson, P., Hartwell, D., & Pellizarre, M. (2008). *Olive perchlet (*Ambassis agassizii*) in the Lachlan River: Population Status and Sustainability in the Lake Brewster Region* (SARDI Research Report Series No. 309; F2008/000846-1). South Australian Research and Development Institute (Aquatic Sciences).

Murray-Darling Basin Commission. (2004). *Fish Theme Pilot Audit Technical Report – Sustainable Rivers Audit* (MDBC Publication No. 06/04). Murray-Darling Basin Authority.

Price, A. (2009). *Distribution and Recruitment Patterns of Fish in the Lower Lachlan River* (Final Report prepared for the Lachlan Catchment Management Authority by The Murray-Darling Freshwater Research Centre; MDFRC Publication 17/2010). Murray-Darling Freshwater Research Centre.

Reid, D., Harris, J., & Chapman, D. (1997). *NSW inland commercial fishery data analysis* (Fisheries Research and Development Corporation Project No. 94/027 Report). Fisheries Research and Development Corporation.

Roberts, J., & Sainty, G. (1996). *Listening to the Lachlan*. Sainty and Associates.

The Guardian. (2019, 28 January). Menindee fish kill: another mass death on Darling River 'worse than last time'. *The Guardian*. https://www.theguardian.com/australia-news/2019/jan/28/menindee-fish-kill-another-mass-death-on-darling-river-worse-than-last-time/

Trueman, W. (2011). *True Tales of the Trout Cod: River Histories of the Murray-Darling Basin*. Murray-Darling Basin Authority.

Walker, K., Sheldon, F., & Puckridge, J. (1995). A Perspective on Dryland River Ecosystems. *Regulated Rivers: Research and Management*, *11*, 85–104.

Water Conservation and Irrigation Commission. (1971). *Water Resources of New South Wales*. Government Printer, Sydney.

Author Profile

Adam Kerezsy completed his PhD at Griffith University (Brisbane) on the distribution and recruitment of fish in far western Queensland, and then worked for the not-for-profit Bush Heritage Australia, principally on the conservation of endangered fish at Edgbaston Reserve in central western Queensland. He is the author of many scientific papers and the natural history book *Desert Fishing Lessons: Adventures in Australia's Rivers*. In 2016 he returned to his home in western New South Wales, and now works as a consultant on the ecology of inland rivers and springs in New South Wales and Queensland.

Lachlan River habitat mapping

Inundation heights for key habitat features and management recommendations
for
Wyangala Dam to Cottons Weir reach of the Lachlan River

Habitat mapping and prioritisation report prepared for Central Tablelands Local Land Services

Title: Lachlan River habitat mapping – inundation heights for key habitat features and management recommendations for Wyangala Dam to Cottons Weir reach of the Lachlan River.

Front Cover: Lachlan River downstream of Wyangala Dam 16/11/2015

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Executive Summary

Extensive habitat mapping was completed along a 210 km reach of the Lachlan River between Wyangala Dam and Cottons Weir, Forbes. The mapping focused on physical features specific to river health and management, developing a comprehensive dataset to support management decisions. Information from habitat mapping was used to identify relationships between river flow height and habitat availability.

Flow relationships were assessed for Large Woody Habitat (LWH), in-channel benches and entry points to connected wetlands. Features were separated into Flow Gauging Zones (FGZ) according to the nearest NSW DPI Water gauging station. The height recorded for each feature was used to calculate the inundation level in megalitres per day (ML/day). Flow analysis revealed that bankfull and overbank flows, greater than 50,000 ML/day were required to inundate all LWH in the project area, except those in the Cottons Weir FGZ which were above the range of the gauge. Most of the bench area and connected wetland entry points could be inundated by large pulse and bankfull flows. This relationship information can be used to prioritise future water management actions that deliver effective and efficient ecological outcomes.

The Central Tablelands LLS area was divided into 14 reaches with a Decision Support System (DSS) applied to determine aquatic habitat condition rankings. The DSS analysed selected geomorphological (e.g. erosion and refugia), vegetation (e.g. exotic plant species) and structural (e.g. LWH) features. The DSS further provided a prioritisation matrix to guide rehabilitation activities and revealed that no Management Reaches in Central Tablelands LLS are currently considered to be in better ecological health. Four reaches (1, 12, 13 and 14) were identified as being in moderate health, with the remainder considered to be in poor health.

Priority actions for on-ground investment in the project area include the remediation of erosion sites in the Boorowa River catchment to reduce sediment inputs that are causing a 150 km long sediment slug in the Lachlan River. This has caused the infilling of all refuges and burying of LWH from Reach 2 to 11, most of the benthic habitat from Reach 12 to16, and is spreading downstream. Both of these habitat features are critical to native fish survival and their restoration is recommended. Stock fencing was recorded along 48.4 km of the study area, leaving the remaining 373 km of riverbank (both left and right banks) susceptible to impacts from unmanaged stock access. Therefore, the protection of riparian zones through stock fencing, along with a revegetation program in these locations will improve water quality and assist in restoring ecosystem processes.

Other issues that were identified that should be considered include addressing fish passage at weirs, installing infrastructure to prevent thermal pollution below Wyangala Dam and implementation of management plans to control emerging weed threats and Weeds of National Significance / Class 4 noxious weeds in Local Government Areas under the *Noxious Weeds Act 1993*, in particular ossage orange (*Maclura pomifera*) and crack willow (*Salix fragilis*).

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1. Introduction

Native freshwater fish stocks have suffered alarming declines since European settlement. Many of the freshwater habitats for juvenile and adult fish have been degraded or lost through urban, industrial and agricultural development. Habitat deterioration is now widely accepted as having a major influence on the decline in diversity and abundance of native fish. As such, aquatic habitat rehabilitation has become progressively more important in NSW as the community recognises the benefits of natural, healthy systems. The Aquatic Habitat Rehabilitation Unit is at the forefront of aquatic habitat repair and has a lead role in rehabilitating fish habitat and native fish populations in NSW.

Aquatic habitat is an important element of the riverine environment and consists of stream features such as bed substrates, hydrology, pools, riffles, floodplains, instream and bank vegetation (macrophytes and riparian vegetation), Large Woody Habitat (LWH), undercut banks 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 fauna such as native fish.

As part of this project, habitat features were recorded, digitised and then analysed to benchmark aquatic habitat condition and provide natural resource managers with a guide for rehabilitation measures along the river. This approach provides a reach based assessment score that may be used as a guide for investment in river protection and rehabilitation activities that focus on protecting and linking areas with the highest habitat value. The assessment is based on the concept that it is usually more cost-effective to protect reaches of stream that are in good condition (or the best first) than to rehabilitate severely degraded areas (Rutherford *et al*. 2000; Lovett and Edgar, 2002) and expand restoration outward from protected sites (Beechie *et al*. 2008; Frissell and Bayles, 1996; Ziemer, 1997).

Additionally, commence to inundate heights were calculated for key habitat features, including benches, LWH, billabongs, paleo-channels and off-stream wetlands, related to the nearest gauging station. Accurate estimates of likely inundation of aquatic habitat from planned and natural flows can be extracted from this information, providing an understanding of when the ecological benefits that these features offer become available in the system. This relationship information can be used to prioritise future water management actions.

2. Project scope and objectives

2.1. Project objectives

This project identified riparian, in channel and aquatic habitat features along the Lachlan River between Wyangala Dam and Cottons Weir, Forbes. The main objectives of this project included:

- Documenting and assessing river bed morphology, including the location, size and maximum depth of pools that may act as drought refugia, in-stream habitat features such as aquatic vegetation, benches and LWH (snag) loading
- Recording, digitising and analysing habitat features to benchmark aquatic habitat condition and provide natural resource managers with a guide for rehabilitation, protection and enhancement measures along the river and inform water managers of potential flow targets
- Determining commence to inundate heights for key habitat features, including benches and LWH, related to the nearest gauging station
- Conduct analysis of habitat mapping data to determine a reach condition ranking based on overall reach condition score (standardised and weighted to account for variables measured in the study area).

2.2. Study area

The Lachlan River rises on the western slopes of the Great Dividing Range in the Southern Tablelands area of New South Wales (NSW DPI, 2006c; Green *et al*. 2011). The catchment is made up of 37 tributaries including the Abercrombie, Boorowa, Belubula, Crookwell, Goobang, Bland and Mirool (NSW DPI, 2006c; Green *et al.* 2011). The Lachlan generally terminates near Oxley in the Great Cumbung Swamp, however it can flow into the Murrumbidgee when both systems are in flood (Department of the Environment, 2013). The project area is situated in the mid Lachlan and takes in the area from Wyangala Dam to Cottons Weir, Forbes (see Figure 1). Wyangala Dam was built at the confluence of the Lachlan and Abercrombie rivers between 1928 and 1935 (LRWG, 2015).

The study area is a part of the Aquatic Ecological Community in the Natural Drainage System of the Lowland Catchment of the Lachlan River which has been listed as an Endangered Ecological Community under the *Fisheries Management Act (1994)* (NSW DPI, 2006a). The study area has been greatly modified since European settlement and is affected by degradation of the riparian zone, decreased water quality, loss of macrophytes and modification of natural flows (NSW DPI, 2006a).

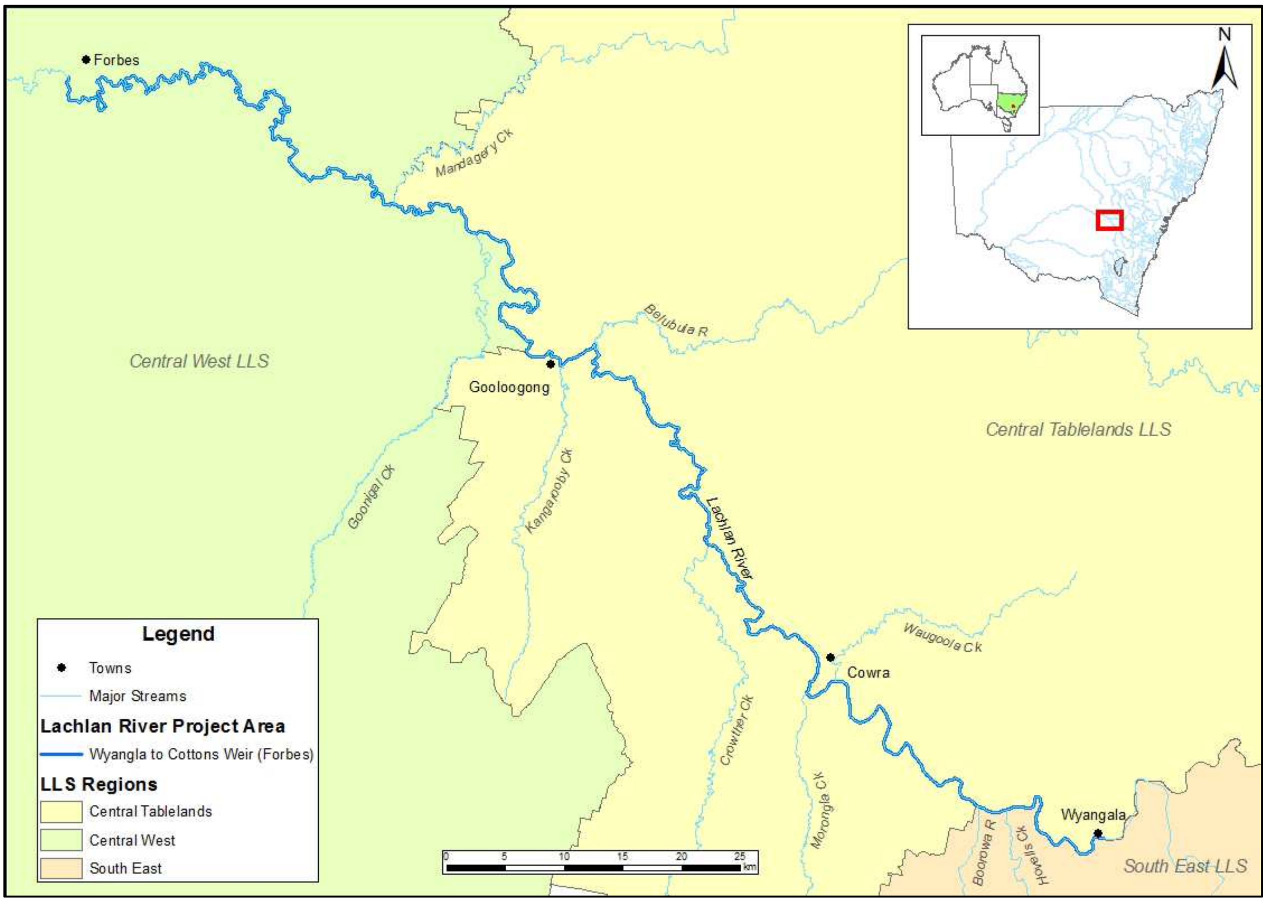


Figure 1. Lachlan River Habitat Mapping Wyangala to Cottons Weir, Forbes project area.

The project area sees the river change substantially from a slopes form in the upper reaches to a lowland floodplain system in the lower reaches (Figure 2 & Figure 3). The section of the project area from Wyangala to Gooloogong is located on the slopes with the river flowing gently and substrate made up of sand and rock (NSW DPI, 2006b). The section downstream of Gooloogong represents the beginning of the floodplains where the river channel is no longer confined and substrate is primarily silt and sand (NSW DPI, 2006b).

Figure 2. Example of a slopes section of an upper reach of the study area.

Figure 3. Example of lowland section of lower reach of the study area.

2.3. Hydrology

The Lachlan River is a highly regulated river of the Murray-Darling Basin, with flow managed under the *Water Sharing Plan for the Lachlan Regulated River Water Source 2016* under the *Water Management Act 2000*. The maximum capacity of the River is reached at Forbes, where flows greater than 15,000 ML/day start to break out of the river channel (Barma Water Resources 2011, Green *et al*. 2011). The flows in the catchment are manipulated by four large storages and 323 weirs, including nine major weirs on the main stem (Armstrong *et al.* 2009).

The four large storages, Carcoar Dam on the Belubula River, Lake Brewster and Lake Cargelligo re-regulating storages and Wyangala Dam on the main stem, are used to provide measured flows to water users in the Lower Lachlan (NSW Department of Infrastructure, Planning and Natural Resources, 2004; NSW DPI, 2006c). Carcoar and Wyangala Dams regulate approximately 70% of runoff, while Lake Brewster and Cargelligo regulate approximately 30% of flows (Armstrong *et al.* 2009).

The impacts of thermal pollution from Wyangala Dam have been investigated by NSW DPI – Fisheries. The maximum known distance that thermal pollution has an impact in the Lachlan River is 210 km, which is approximately where the town of Forbes is located (Lugg, pers. comm., 2016). This has an impact on the entire project area and the effects of it have been considered in the prioritisation.

2.4. Fish Species in the Lachlan River

The Lachlan River provides habitat to a variety of native freshwater fish, some of which are listed as threatened (Figure 4 & Figure 5). The size of these species at adult phase varies from 50 mm to over 1000 mm in length.

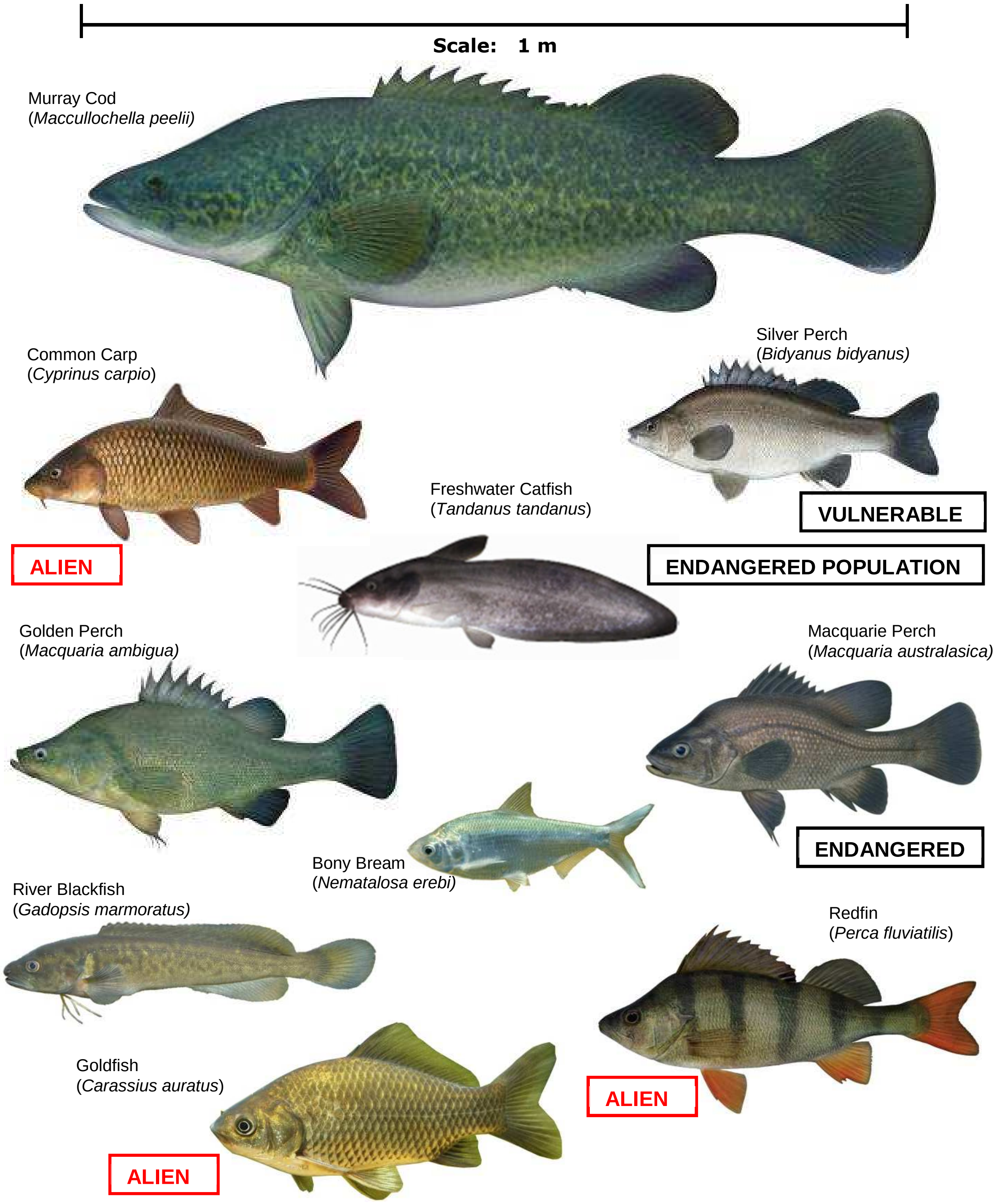


*Figure 4. Large bodied fish found or expected in the Lachlan River (adapted from McDowell, 1996 and from NSW DPI*http://www.nsw.dpi.gov.au/*, 2015).*

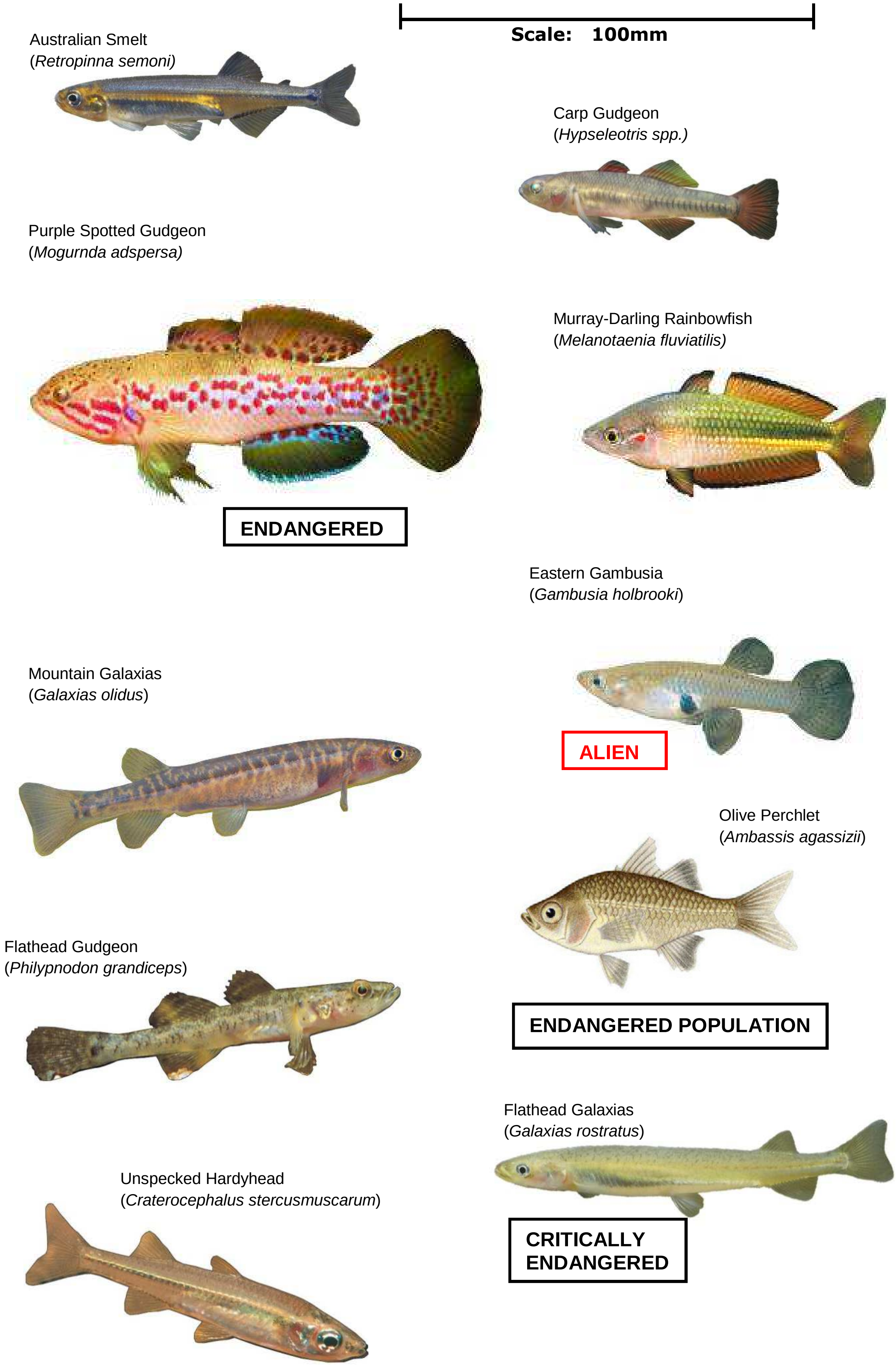


Figure 5. Small bodied fish found or expected in the Lachlan River (adapted from McDowell, 1996 and Lintermans, 2007).

3. Methodology

3.1. Habitat Mapping

Habitat mapping was undertaken by NSW DPI staff and used methods developed and implemented for similar projects in the Barwon-Darling Rivers (NSW DPI, 2015), Macquarie River (Industry and Investment, 2010), Horton River (NSW DPI, 2013) and Little River systems (NSW DPI, 2014).

Project staff completed two field trips to collect the project data between Wyangala Dam and Cottons Weir on 16–20/11/2015 and 18–21/01/2016. There are five NSW DPI Water gauges in the project area. Over this period flow in the Lachlan River was influenced by regulated flows released from Wyangala Dam. Flow range varied between 911 and 2,065 ML/day.

Two methods of field data collection were used:

- GPS equipped GIS interface for features above the water surface.
- GPS equipped side-scanning sonar for submerged features (i.e. LWH and refuge pools).

These two 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 Lachlan River corridor in the project area. A ‘Trimble Nomad’ PDA and a ‘Trimble Yuma 2’, both 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 1). A section approximately 1 km long, upstream of Wyangala Road Bridge was not navigable by boat due to a 3 m waterfall and large rocky outcrops. This area was mapped on foot using two handheld PDAs.

To improve data collection efficiencies and standards, unique scripting codes were written by NSW DPI technicians to provide prescribed data entry dropdown 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 1. Typical features recorded on PDAs during habitat mapping of the Lachlan River.

Point Features	**Line Features**	**Polygon Features**
LWH – Alignment, Complexity, Width, Length, Height	Fencelines	Exotic Riparian Vegetation – type & extent
Pumpsites: Pipe Diameter		Aquatic Vegetation – type & extent
Wetland/ Anabranch: Height of entry/exit point and Changes in Substrate		Erosion
Fish Barriers – Barrier type, headloss		Stock Management
General Points of Interest (e.g. boat launch sites, recreation).		Instream features– benches with height; Refuge Habitat with extent and depth, Riffle

The data was georectified for analysis, with associated metadata providing the information necessary to perform the reach assessments and scoring (Figure 6).

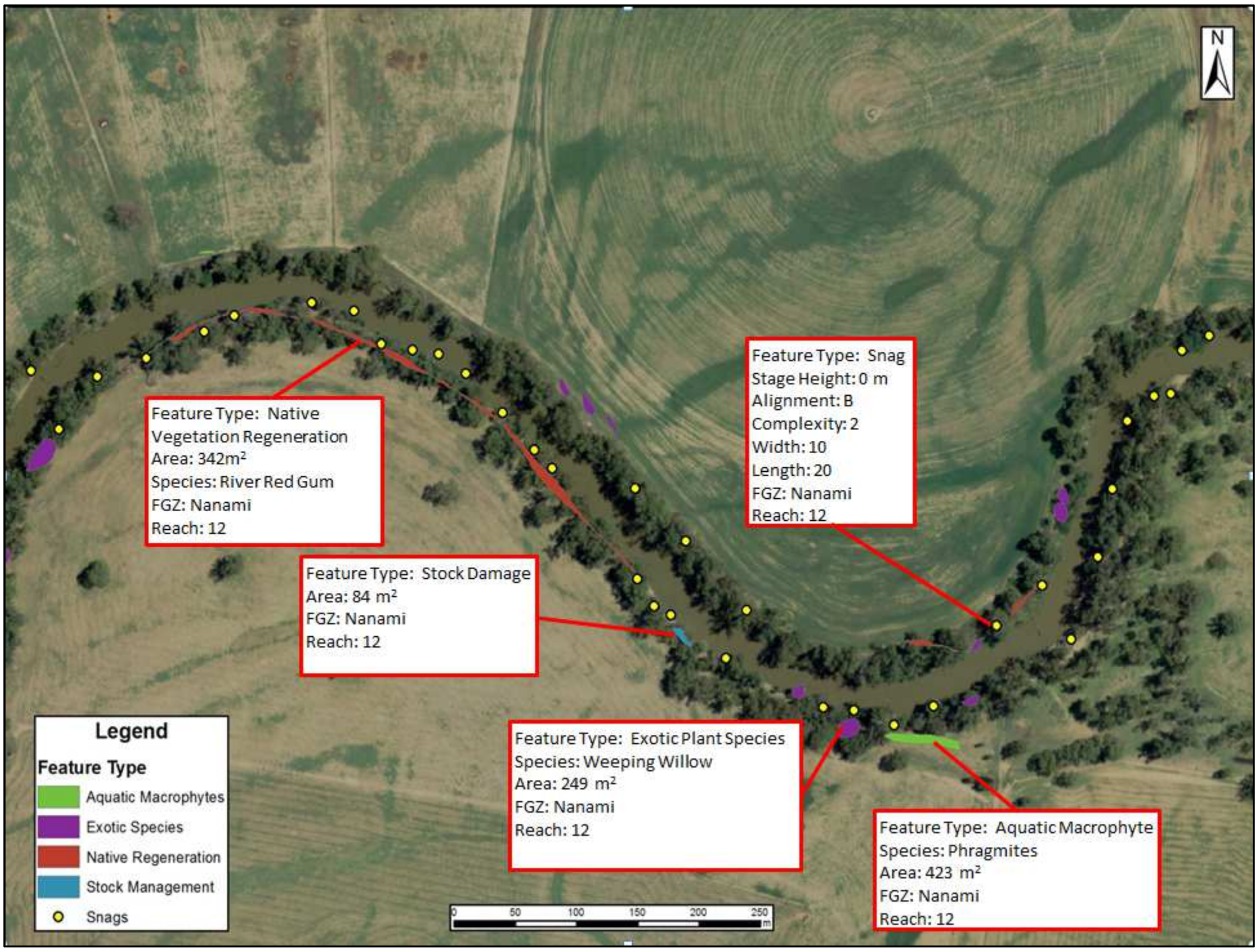


Figure 6. Feature types with key attributes used in reach assessment and prioritisation.

Data collected using the side-scanning sonar was converted into georectified imagery and imported into ArcMap to identify additional submerged LWH (Figure 7). This data also includes water depth & temperature, boat speed and direction.

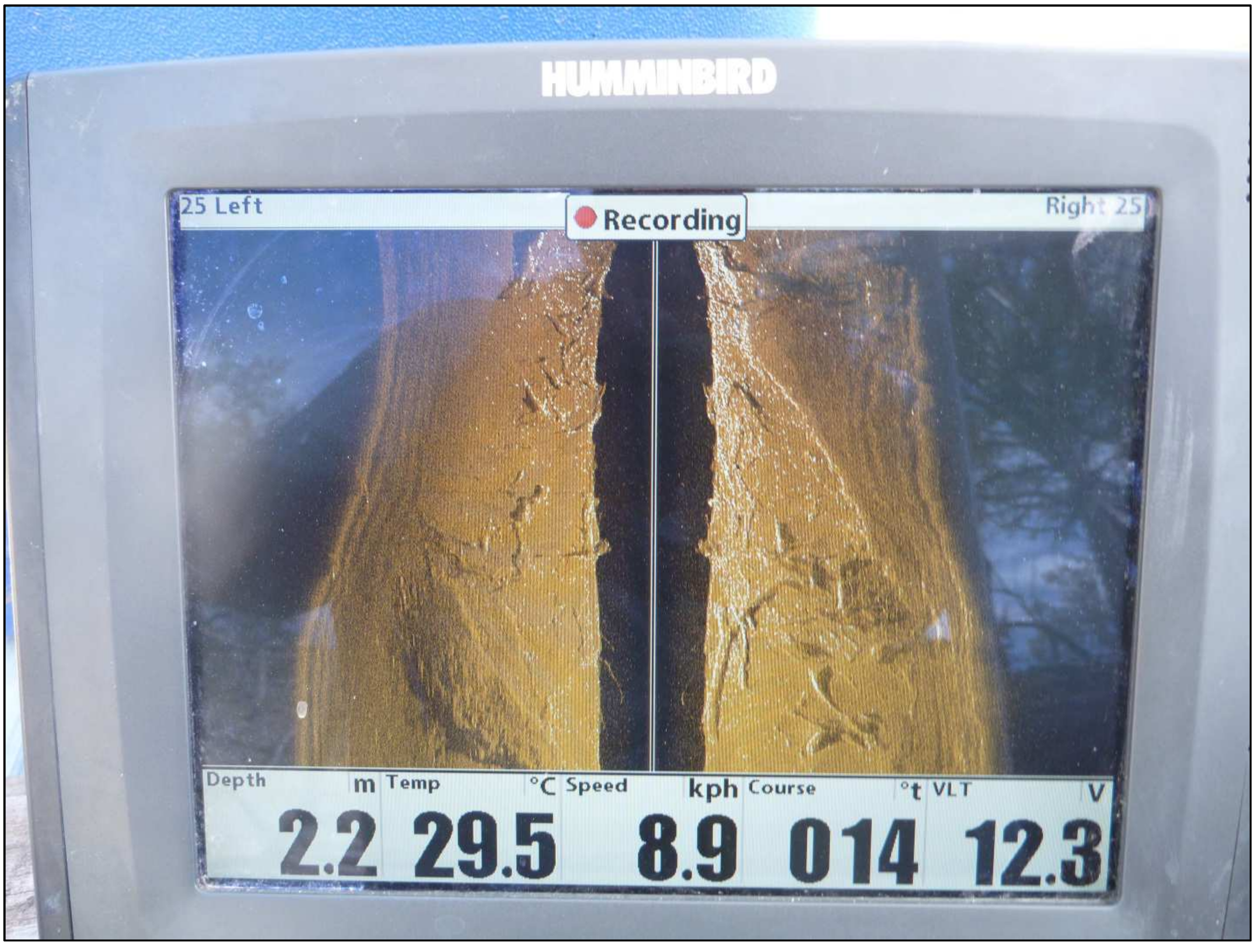


Figure 7. Side-scanning sonar recording instream habitat features.

The converted data was overlayed in the project GIS and used to identify the presence and alignment of LWH as well as determine complexity, width and length (Figure 8). Red points in Figure 8 indicate a LWH that has been recorded and assessed.

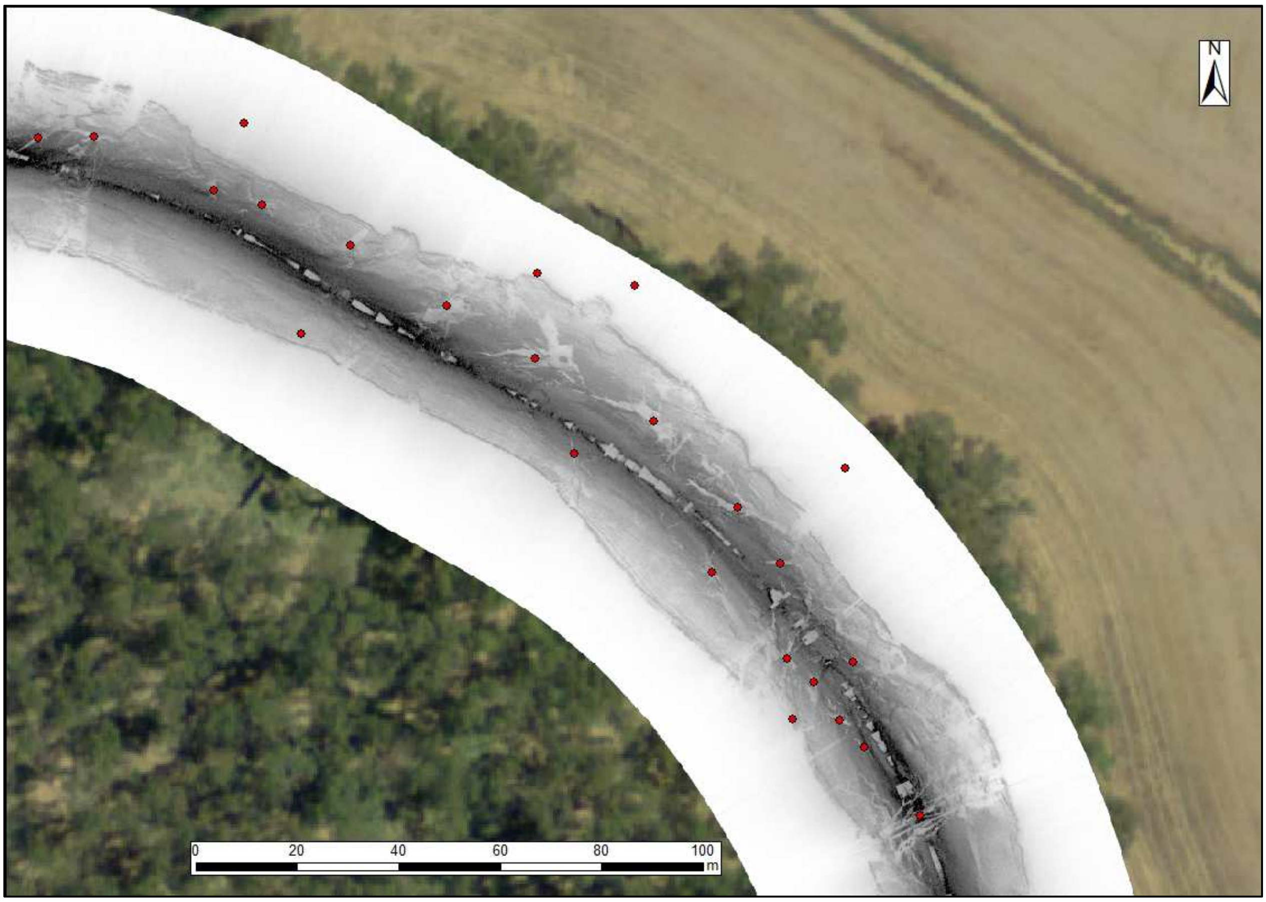


Figure 8. Example of georeferenced data in the Lachlan River superimposed on aerial photography.

3.1.1. 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 9).

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 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 9).

LWH were recorded at the discretion of the staff member, taking into account the geomorphology and knowledge of flow levels through the section of river; if a LWH was deemed too high to inundate it was not recorded. The stage height (sh) of the river on the day of mapping was obtained from the relevant gauging stations (Wyangala, Cowra, Nanami and Cottons Weir). The inundation height was then turned into an inundation level by using the known height/discharge curve for the nearest gauging station (Southwell, 2008).

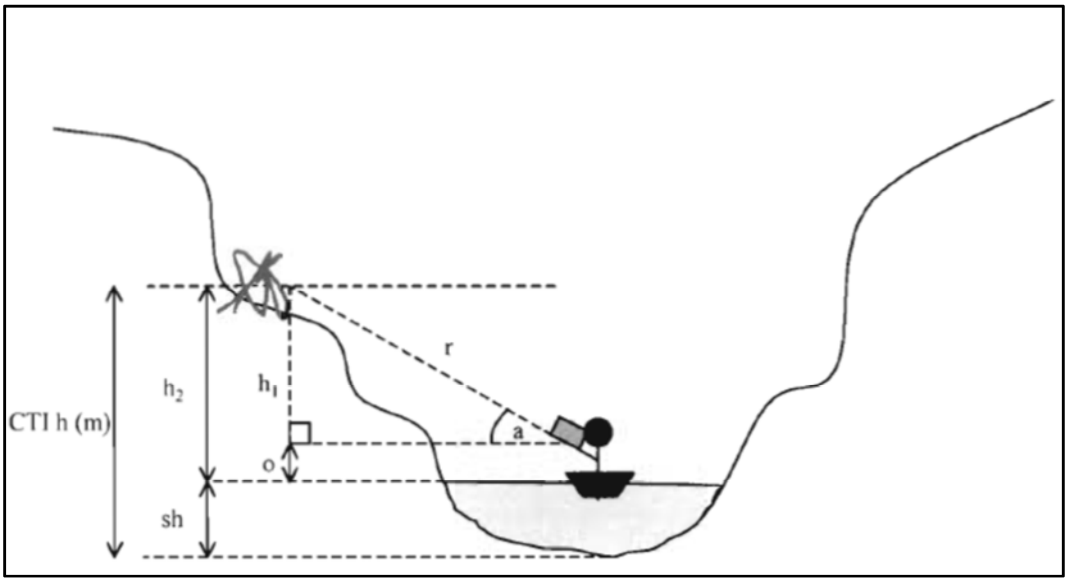


Figure 9: Schematic of methods used to calculate CTIh of key habitat features along the Lachlan River (see text for explanation of values: Boys, 2007).

Interference and/or poor GPS signal had a minor impact on the data collected, with a small number (5) of the 194 files suffering from corruption that rendered the data partly unusable (Figure 10). This affected approximately 500 m (0.23% of the project extent), with minimal impact on the results for LWH data.

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

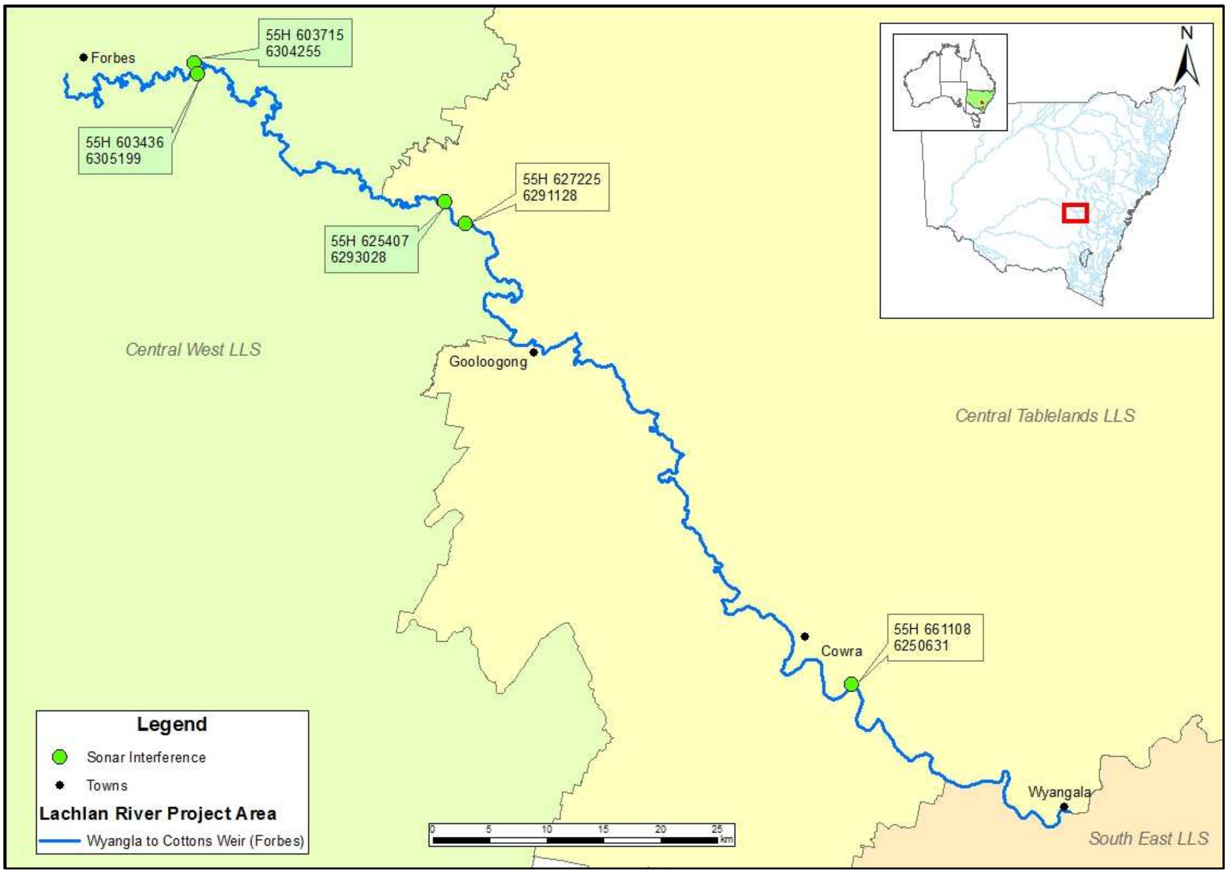


Figure 10. Sites where sonar interference occurred.

3.1.2. Refuge Pools

Aquatic refugia (refuge pools) were recorded in the field by observing the outputs on the sonar unit and recording the location and depth. This was then verified using GIS, flow data and sonar records to check the bed depth up- and downstream of a potential refuge pool site. This process removed any errors that were encountered from the increased depth during high flow periods, allowing the variable flow conditions encountered during assessment to be considered in the refuge identification process.

3.2. Decision Support System

A Decision Support System (DSS), developed by NSW DPI to determine reach scale conservation management priorities, was employed to assess individual habitat features on an individual management reach basis and scored based on overall health.

3.2.1. Reach grouping and ArcMap Toolbox

The first stage of the DSS involved dividing the study area into management reaches (each 10 km in length) in ArcMap by grouping the attributes and splitting the relevant segments of the river line feature class (Figure 11). This management reach scale limits the potential for introducing masking issues that may influence a reach condition score and allows effective, targeted threat management and habitat protection activities.

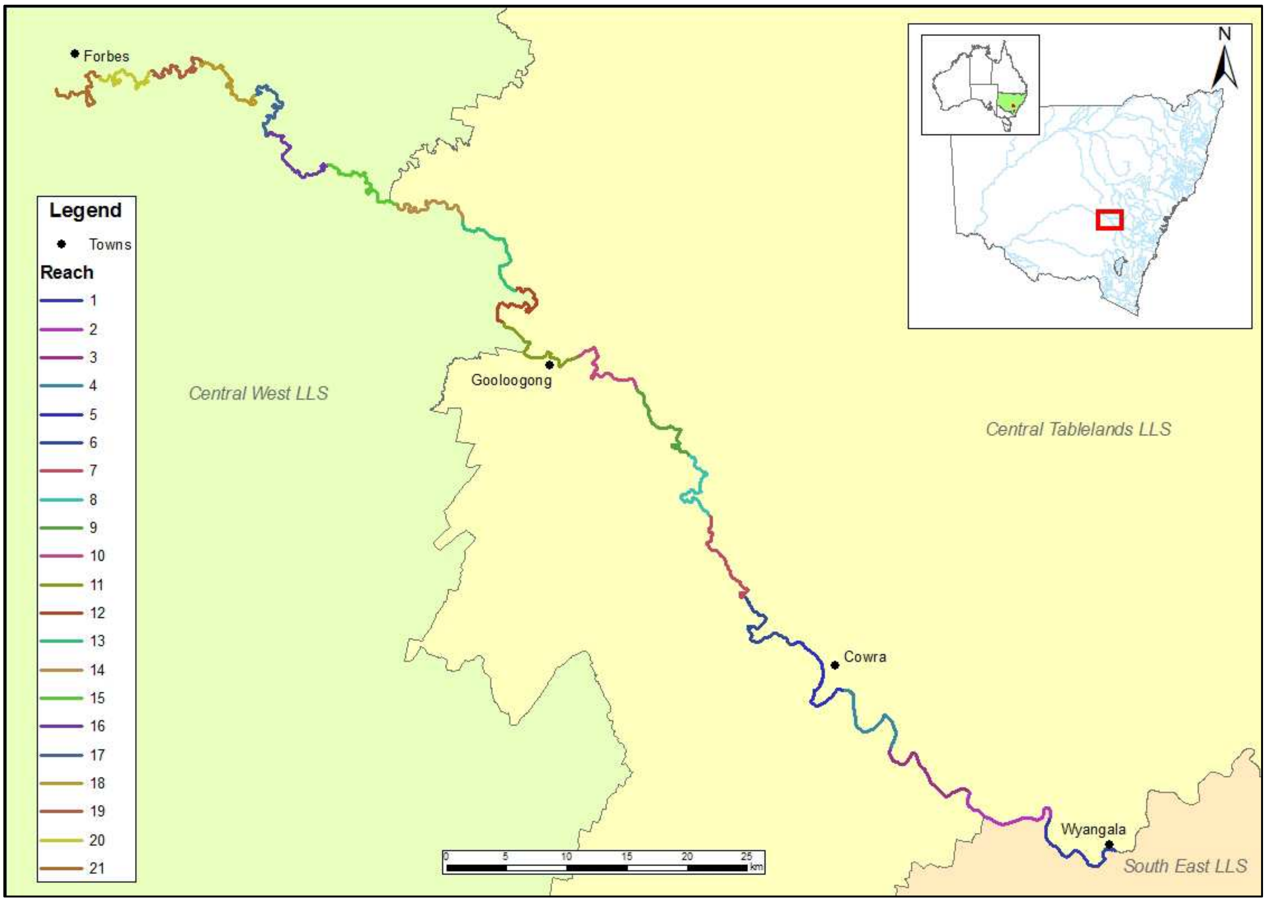


Figure 11. Management reaches for Wyangala to Cottons Weir, Forbes project area.

The second stage of the DSS involves a suite of tools in the ArcMap Toolbox, developed by NSW DPI, containing a series of comprehensive scripts (six in total). These tools use Python programming language to automate the interrogation of ESRI feature classes and identify and summarise individual habitat features by management reach. Some data could not be interrogated using the tool, such as barriers to fish passage, in which case manual collation was necessary.

The tool firstly ran through the river line feature class in ArcMap and consecutively numbers the management reaches, prompting manual correction in the event of gaps in the spatial data. All data points in each habitat feature class being interrogated (Appendix A lists the GIS data that was used in the assessment) are assigned the relevant reach number (involving conversion to point feature classes and/or snapping to the river line feature class), then summarised by reach and tabulated. This tabulation is then exported into a series of tab delimited text files, which in turn are manually imported into the Microsoft Excel® based Prioritisation Module. The format of data output for each habitat feature class is shown in

Table 2.

Table 2. Format of data output from the ArcMap Toolbox

Habitat Feature Class	Output Format
LWH	Number, Width, Length, Complexity
Instream Refugia (refuge holes)	Number, Depth, Surface Area
Exotic Plant Species	Number, Area
Erosion	Number, Area
Stock Damage	Number, Area

3.2.2. Prioritisation Module

The final stage of the DSS involved the development of a Microsoft Excel® based Prioritisation Module to determine conservation and management priorities. Outputs from the ArcMap tool and manual data collation were imported into the Prioritisation Module for individual habitat features for each 10 km management reach. The total bank area within each management reach was calculated to be 40 hectares, based on a 20 m corridor along both banks of the river.

A prioritisation scheme was then developed to assist in ranking both individual habitat features and overall reach condition. The scheme helps determine priorities by ranking reaches based on the following categories:

- LWH – total number of LWH
- Instream refugia – total refuge depth (sum of the deepest point of each refuge pool[1])
- Regeneration of native canopy species - total extent within the reach (ha)
- Exotic plant species – total extent within the reach (ha)
- Erosion – total extent within the reach (ha)
- Stock damage – total extent within the reach (ha)
- Barriers to fish passage – taking into account barrier type, headloss, distance and quality of upstream and downstream habitat, the number of downstream barriers and ancillary uses of the structures (see Section 5.6.3).

[1] This method determines the total availability of native fish refuge by taking into account the number of refuge holes and the depth of each, adjusted for flow levels at the time of data collection.

3.2.3. Treatment of habitat features for prioritisation

Data for habitat features differ in terms of type and scale (that is, unit and magnitude) and it is important to note that variables measured at different scales will not contribute equally to the analysis (http://www.biomedware.com). For example, LWH data collected as individual points with the count per management reach ranging from 23 to 894, will outweigh native regeneration, exotic plant species, erosion and stock damage that was collected in area units, typically ranging in magnitude from 0 to 2 ha.

Transforming the data to comparable scales can alleviate this issue by equalising the range of the data. Data were standardised in the prioritisation module to have a mean of 0 and standard deviation of 1 by the function: (value – mean)/standard deviation so that comparison of spatial trends in the parameters could be made on the same scale, then weighted according to relative influence of the habitat feature on protection and rehabilitation priorities as follows:

$$HabitatFeatureScore_{Weighted} = \frac{(habitatfeaturetotal - mean)}{StDev} \times Weight$$

where habitat feature total is the sum of habitat features within each management reach.

The habitat feature scores (weighted) were then combined to generate reach condition scores in terms of overall health and condition. Reach condition scores were subsequently ranked and coded into three groups - better health, moderate health and poorer health - based on the reach condition score and the number or extent of various habitat features. There is not an even split into these groups; a highly degraded project area may have no reaches coded as being in better health.

4. Landholder liaison

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

Landholders were curious about the habitat mapping and why it was undertaken and were generally supportive of the activity.

5. Results and discussion

The habitat feature dataset developed through the fieldwork was processed to identify priority reaches to assist natural resource managers and landholders to make strategic decisions about investment in on-ground works. The DSS provides a ranking of reaches based on overall reach condition score. The main drivers for setting priorities include available instream habitat for native fish, such as refugia and LWH, and to a lesser extent impacting habitat features such as the presence of exotic plants, erosion, stock access and damage.

The measures necessary to protect and rehabilitate aquatic habitat condition can be determined by interrogating the relative impact of individual habitat feature scores. These can provide natural resource managers with a clear direction on how to proceed with aquatic and riparian habitat restoration and protection initiatives. Additionally, the *NSW Biosecurity Strategy 2013-2021*(2013) may assist with weed management.

Additionally, the flow relationship data can be used to infer the amount of aquatic habitat that will be inundated at different flows. This provides water managers the opportunity to set targets for the inundation of specific levels of habitat with appropriate water management. This could be used to specifically target critical breeding habitat and associated ecological functions for identified native fish species and river health.

NB. The results and discussion includes all the data from Wyangala Dam to Cottons Weir, Forbes, that was collect as part of this project. The Lachlan River leaves Central Tablelands LLS Region at its confluence with Mandagery Creek therefore reaches 1 – 14 were used for the prioritisation and Management Reach recommendations.

5.1. Riparian native vegetation condition

The riparian area was varied in its condition from sections that were well intact with a range of vegetation age cohorts across species, including numerous areas of regeneration to heavily grazed sites with senescing or old monocultures of canopy species.

Typical canopy species in the slopes reaches were high densities of river oak (*Casuarina cunninghamiana*) along the toe of the bank with river bottlebrush (*Callistemon sieberi*) and various acacias (*Acacia spp.*) occasionally found under them (Figure 12 & Figure 13). River red gum (*Eucalyptus camaldulensis*) was present but always higher on the bank and was not common in Reaches 1, 2 and 3. Rocky outcrops found in the channel usually had lomandra (*Lomandra spp.*) growing in between them while other areas contained a mix of native and exotic grasses.

Lowland reaches of the project area (as shown in Figure 14) were dominated by river red gum (*E. camaldulensis*) in the overstorey vegetation layer. River cooba was infrequently seen. The understorey layer was sparse, however there were occasionally areas where lignum (*Muehlenbeckia florulenta*) was prevalent. Ground covers included juncus (*Juncus spp.*) and a mix of unidentified native and exotic grasses.

Several cleared sections of riverbank were protected from constant stock grazing pressure and appeared to be managed effectively to maintain groundcover. However, most of the river was not protected and unmanaged grazing pressure was having an obvious impact on riparian and aquatic health as seen in Figure 15.

Unprotected areas of riverbank were observed to be in a relatively poor condition with stock damage creating areas devoid of vegetation and susceptible to, or already impacted by erosion. The examples shown in Figure 15 allow for rapid erosion of soil by wind, rain or high flow and cause turbidity and eutrophication of waterways.

Figure 12. Example of typical vegetation layers in slopes reaches of the project area.

Figure 13. River bottlebrush growing midstream in Reach 1.

Figure 14. Typical native vegetation layers in the lowland reaches of the project area.

Figure 15. Damaged sites in the Lachlan River resulting from uncontrolled stock access.

There was a clear difference during field work with regard to how livestock are managed on different properties. Boundary fences provided a point of contrast and there were many occasions where dense grass cover was found on one side, while bare eroded ground was on the other.

Some of the recommendations outlined in the report, especially those that relate to managing livestock access to the riparian zones, will provide the opportunity for native vegetation to regenerate naturally once grazing and trampling pressure is reduced in these areas.

5.2. Exotic plant species

A wide variety of exotic plant species were identified throughout the study area as a result of the habitat mapping. Table 3 lists the main species of exotic plants identified and their declaration status for the relevant Local Government Area (Boorowa, Cabonne, Cowra and Forbes) and/or Weed of National Significance.

Table 3. Exotic Plant Species recorded in the study area

Common Name	Scientific Name	Shire	Status under *Noxious Weeds Act 1993*
Apple	*Malus spp.*		Not declared
Asparagus	*Asparagus spp.*	Boorowa, Cabonne, Cowra and Forbes	Class 4 Noxious
Bathurst burr	*Xanthium spinosum*	Boorowa, Cabonne, Cowra and Forbes	Class 4 Noxious
Blackberry	*Rubus fruticosus*	Boorowa, Cabonne, Cowra and Forbes	Class 4 Noxious Weed Of National Significance
African boxthorn	*Lycium ferocissimum*	Boorowa, Cabonne, Cowra and Forbes	Class 4 Noxious Weed Of National Significance
Black/ Crack willow	*Salix fragilis or Salix nigra*	Boorowa, Cabonne, Cowra and Forbes	Class 2 Noxious Weed Of National Significance
Box elder	*Acer negundo*		Not declared
Canary Islands date palm	*Phoeix canariensis*		Not declared
Dodder	*Cuscuta spp.*	Boorowa, Cabonne, Cowra and Forbes	Class 3 Noxious
Elm	*Ulmus spp.*		Not declared
Fierce thornapple	*Datura ferox*		Not declared
Fig	*Ficus carica*		Not declared
Firethorn	*Pyracantha*		Not declared
Honey locust	*Gleditsia triacanthos*	Cabonne and Cowra	Class 3 Noxious
Lippia	*Phyla canescens*	Boorowa, Cabonne, Cowra and Forbes	Class 4 *The plant must not be sold, propagated or knowingly distributed* ***except incidentally in hay or lucerne***
Madeira vine	*Anredera cordifolia*	Boorowa, Cabonne, Cowra and Forbes	**WEED ALERT: REGIONALLY PROHIBITED WEED** If you see this plant contact your council weeds officer, the NSW

		Invasive Plants & Animals Enquiry Line 1800 680 244 or emailweeds@dpi.nsw.gov.au Weed Of National Significance
Mulberry	*Morus nigra*	Not declared
Noogoora burr	*Xanthium occidentale*	Not declared
Orange trumpet creeper	*Pyrostegia venusta*	Not declared
Ossage orange	*Maclura pomifera*	Not declared
Pecan	*Carya illinoinensis*	Not declared
Pepper tree	*Schinus molle*	Not declared
Prickly pear	*Optuntia spp.*	Class 4 Noxious Weed Of National Significance
Privet	*Ligustrum spp.*	Not declared
Poplar	*Populus spp.*	Not declared
Robinia/ False locust	*Robinia pseudoacacia.*	Not declared
Silky oak	*Grevillea robusta*	Not declared
Sweet briar	*Rosa rubiginosa*	Class 4 Noxious
Tree of heaven	*Ailanthus altissima*	Class 4 Noxious
Tree tobacco	*Nicotiana glauca*	Not declared
Weeping willow	*Salix babylonica*	Class 4 Noxious
White cedar	*Melia azedarach*	Not declared

Class 1 Noxious – State Prohibited Weed *The plant must be eradicated from the land and that land must be kept free of the plant*

Class 2 Noxious – Regionally Prohibited Weed *The plant must be eradicated from the land and that land must be kept free of the plant*

Class 3 Noxious – Regionally Controlled Weed *The plant must be fully and continuously suppressed and destroyed and the plant must not be sold, propagated or knowingly distributed*

Class 4 Noxious – Locally Controlled Weed – *The plant must not be sold, propagated or knowingly distributed*

Class 5 Noxious – Restricted Plant *The requirements in the Noxious Weeds Act 1993 for a notifiable weed must be complied with*

NB. Weed declarations are accurate for the LGAs listed at the time of writing. A ‘Not declared’ status above does not reflect the status of these weeds in other LGAs.

Weed Of National Significance are a list of 32 weeds that have been agreed by Australian governments based on an assessment process that prioritised these weeds based on their invasiveness, potential for spread and environmental, social and economic impacts.

The cumulative total coverage of exotic plant species was 103.32 ha or 12.3% of the study area. There was a large increase in the occurrence of exotic plant species extent and diversity around townships, especially Cowra (Reach 5 & 6) and Forbes (Reach 20 & 21).

The highest densities of exotic plant species infestation were found in Reaches 5 (11.52 ha or 28.79% of the riparian area) and 20 (11 ha or 27.49%). The lowest density of exotic species was Reach 14 (0.39 ha or 0.97%).

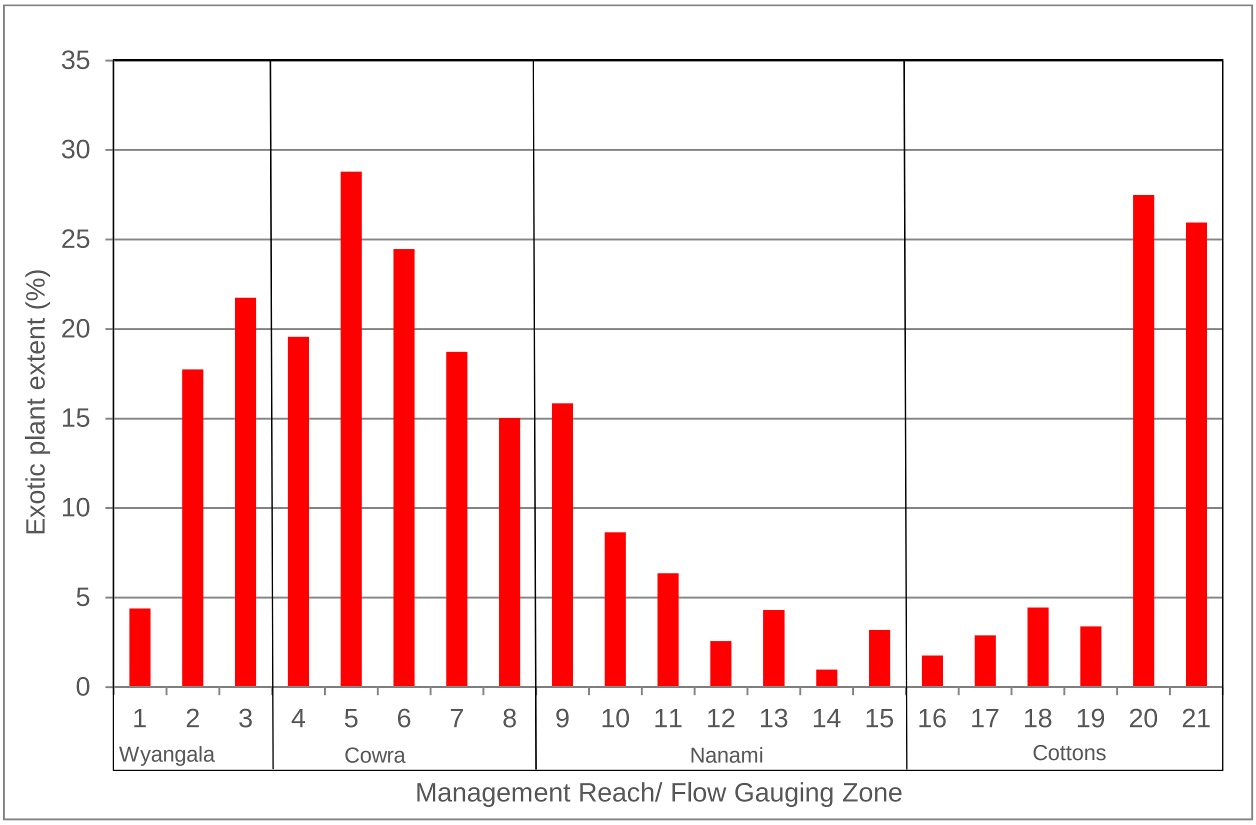


Figure 16. Extent of Exotic Plant Species in Lachlan River between Wyangala Dam and Cottons Weir.

By species, willow had the highest extent at 54.53 ha or 6.5%. This was, to some degree, expected as willow is commonly understood to be an invasive species along waterways in NSW. Ossage orange (*Maclura pomifera*) has become well established, covering 16.64 ha and is the dominant species in many areas, being found in small outbreaks in Reaches 8, 9, 10, 14, 17, 18 and 19, then dominating Reaches 20 and 21 where it covers 16.11 ha and makes up 20.3% of the riparian area. Downstream of the project area, in the Central West LLS area, the infestation continues along the Lachlan River for a further 110 km, presenting a major issue for management.

While not a declared weed, ossage orange has become a significant threat to the ecology of the riparian areas of the Lachlan River where it is found. The large fruit is presumed to be spread by floodwaters. Control by stem injection has proven successful at eradicating all trees of this species from the Little River, in Central West NSW. Similarly, box elder (*Acer negundo*) was found to be spreading rapidly in many locations, particularly downstream of Cowra. Plants found in this genus are prolific seeders with the riparian area appearing to provide ideal conditions for germination.

5.3. Aquatic habitat

5.3.1. Large Woody Habitat

Large Woody Habitat is a major ecological and structural element of many Australian waterways and provides valuable habitat for aquatic and terrestrial species. Instream LWH provides spawning sites, shelter, resting places and territorial markers for several species of native fish. In many cases, LWH assists in developing scour pools and preventing erosion through bank stabilisation.

Availability

Large Woody Habitat loading was recorded throughout the study area to identify the availability of instream woody habitat to aquatic fauna. Details recorded included the number, complexity, orientation and commence to inundate height (CTIh) of each LWH. The LWH loading observed along the study area was low in the upper reaches (Management Reaches 1-9) and became very high in the middle to lower reaches (Management Reach 12-21).

In the 210 km of river channel that was surveyed, a total of 8,936 LWH were recorded, with the average loading increasing in the downstream direction as shown in Figure 17. The low density in the upper reaches was influenced by:

- the higher flow velocity due to Reaches 1 and 2 being in the slopes region of the catchment
- the high density of exotic riparian species
- the influence of vegetation assemblages- river red gum was not common in upper reaches and would not contribute to LWH loading
- the high level of sediment originating from the Boorowa River, in the lower section of Reach 2 and extending to Reach 12, burying many LWH that were there (Figure 18)

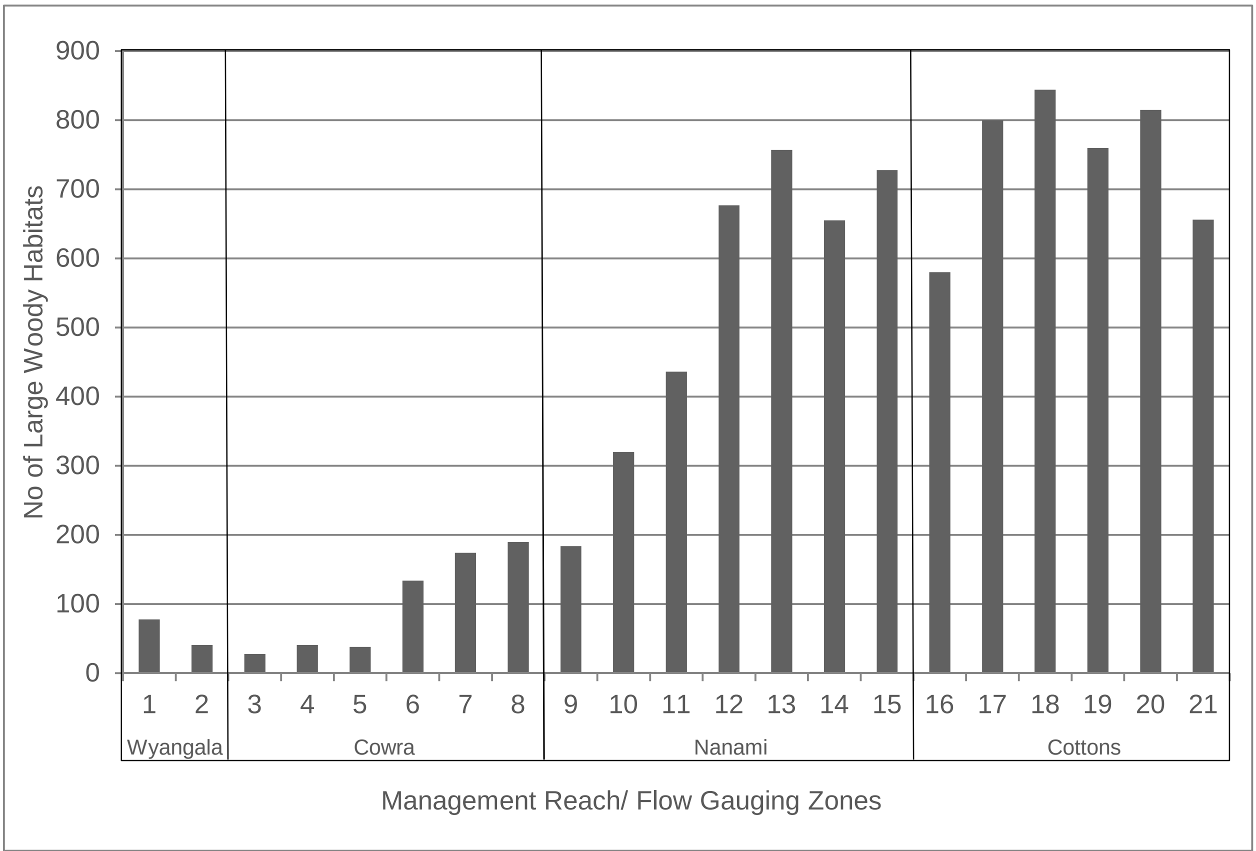


Figure 17. Distribution of LWH in the Lachlan River between Wyangala and Cottons Weir.

Figure 18. Exotic species lining the toe of the bank in Reach 3. Note the shallow water due to the presence of a sand slug.

Complexity

There is an ecological basis for differentiating LWH based on size and complexity (Boys, 2011). More complex LWH provide 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 (Figure 19).

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 19. Structural complexity classes used to describe LWH during field work.

The majority of LWH throughout the study area was simple, Class 1 and Class 2 complexity LWH (80.24% and 18.16%, respectively), while more complex class 3 and 4 LWH make up the remaining 1.6% (Table 4). A trend was evident of more complex and higher numbers of LWH in general in the lower Reaches (Management Reaches 12-21) which exhibited the greatest number of complexity Class 4 LWH and high levels of Class 3 LWH (Figure 20).

Table 4. Number and percentage of LWH by complexity in project area.

Complexity	Number	Percentage (%)
1	7,170	80.24
2	1,623	18.16
3	125	1.40
4	18	0.20

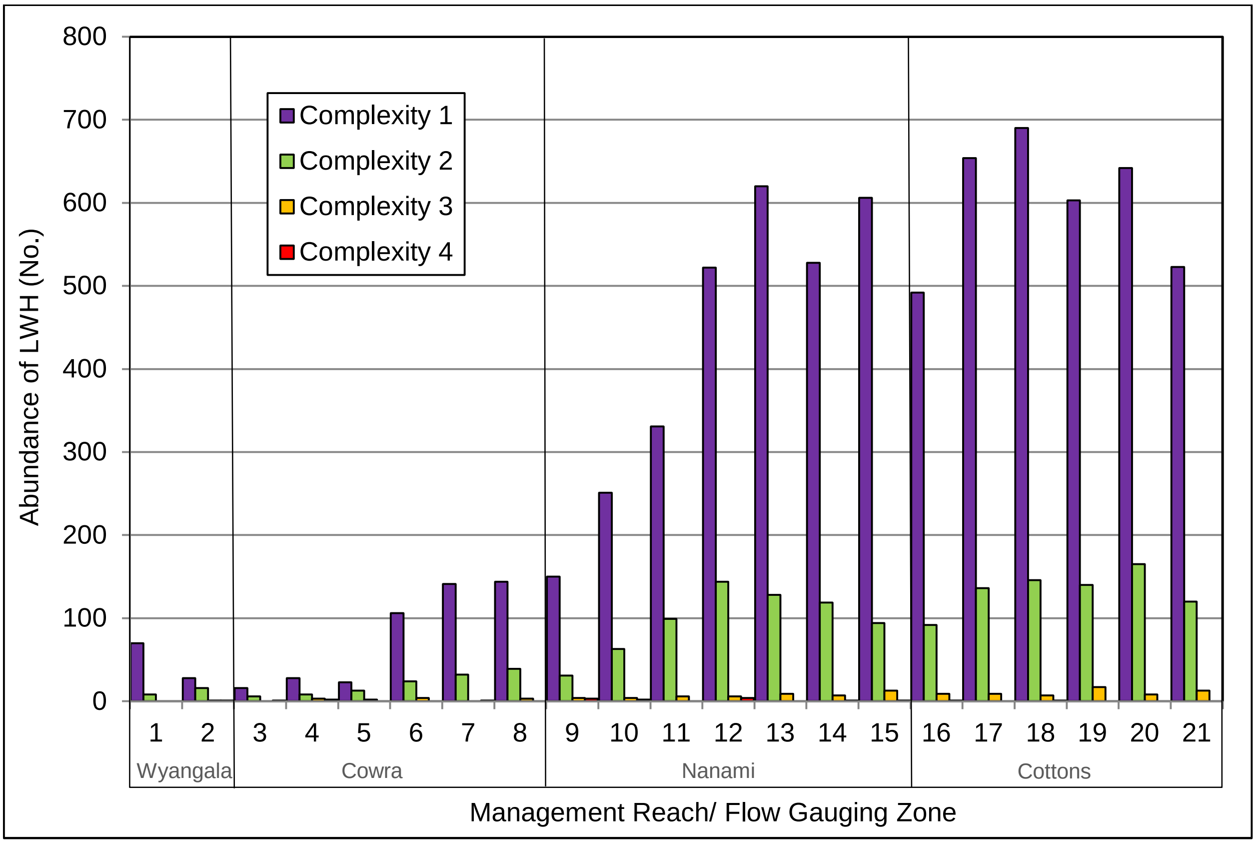


Figure 20. Abundance and complexity of LWH by Management Reach.

5.3.2. Sediment slug

A large sediment slug was detected in the Lachlan River extending from the downstream end of Reach 2 and ending in Reach 16. The entire 150 km long slug consisted of small fines (class grading – silt/sand/gravel) that is dispersing from the Boorowa River. Benthic habitats are being smothered by the sand slug. Anthropogenic influences have increased sediment supply from agricultural areas to Australian waterways (Prosser et al, 2001); including the Lachlan, particularly from gully erosion and stream banks as a result of broadscale landclearing.

No correlation was found in the GIS data between willow density and the sediment slug. From mapping conducted in similar locations (eg. Macquarie River), the presence and density of willows appears to be related to location rather than channel depth.

The observations of the sediment slug recorded during fieldwork are supported in the Lachlan River Styles Map Report, maps and GIS data (Outhet, 2001) (Figure 21).The report indicates that the recovery potential for the Lachlan River is listed as low to moderate in the area of the sand slug where no refuge habitat was recorded and high in the reaches downstream.

As indicated in section 5.3.1, the high sediment loading is potentially one of the reasons that LWH loading is comparatively low in many reaches in the project area. Sediment slugs such as the one found in the Lachlan River have other significant impacts to aquatic habitat; they reduce the geomorphic complexity of streams as fine sediment fills in undercuts, backwater zones, edgewater habitats and pools and riffles (Bartley & Rutherford, 1999). This may lead to a reduction or local extinction of flora and fauna that require such habitats as part of their life cycle.

The results in 5.3.3 highlight the effect that the sediment infilling is having on refugia distribution.

Brierley & Fryirs (2005) state:

> ‘Oversupply of materials may generate a sand slug. Downstream migration of the slug is marked by a cycle of aggradation and degradation, with accompanying changes to channel planform and cross-sectional geometry. Initially, aggradation promotes the development of a multichannel configuration and channel widening, decreasing channel heterogeneity and smothering habitat.’

Based on this statement and the River Styles framework, without a reduction in sediment inputs, the disturbance to the Lachlan River from the sediment slug is will continue to expand downstream. Only with a reduction in erosion from the headwaters and foothills of the Boorowa River catchment will a turning point be reached and restoration of in-channel heterogeneity be possible.

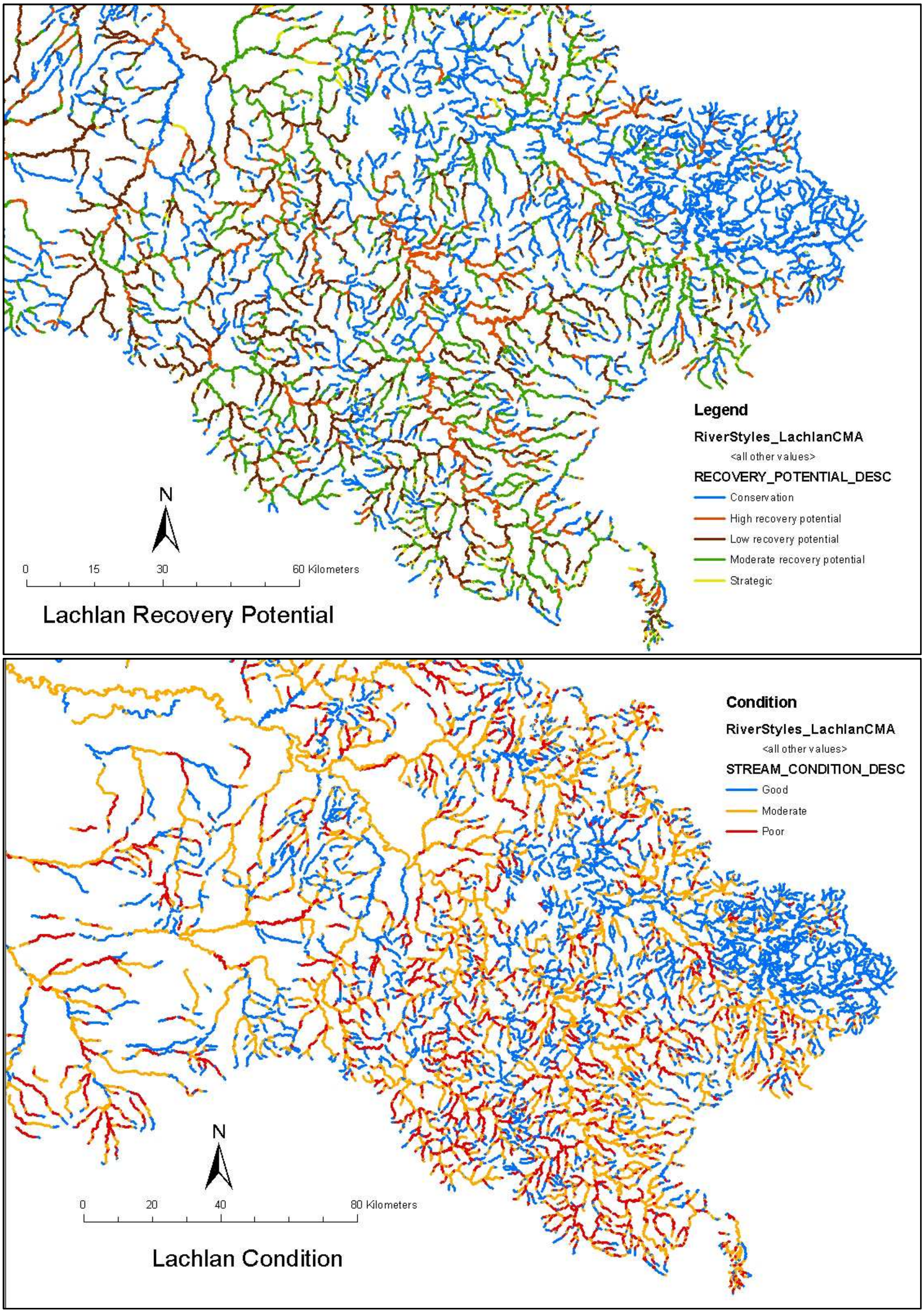


Figure 21. Recovery potential and condition of the upper Lachlan River catchment. Adapted from Outhet (2001).

5.3.3. Drought refugia

Drought refuge is an essential habitat feature in determining protection and rehabilitation priorities and was weighted accordingly. Resident populations of aquatic species cannot survive through extended dry periods without refuge habitat. A lack of drought refugia could lead to local extinctions of these species, particularly if barriers to fish passage prevent recolonisation.

For the Lachlan Habitat Mapping project, refuge areas were defined as areas of water greater than 3 m in depth during low flow conditions (Figure 22 & Figure 23). Along the 210 km study area, 186 areas of refugia were identified (Figure 24 & Appendix B).

Figure 22. Example of refuge habitat in the lower Lachlan River taken at zero flow taken on 19/12/2009.

Figure 23. Example of fully inundated refuge habitat on 19/11/2015 at a flow of 1,659 ML/day.

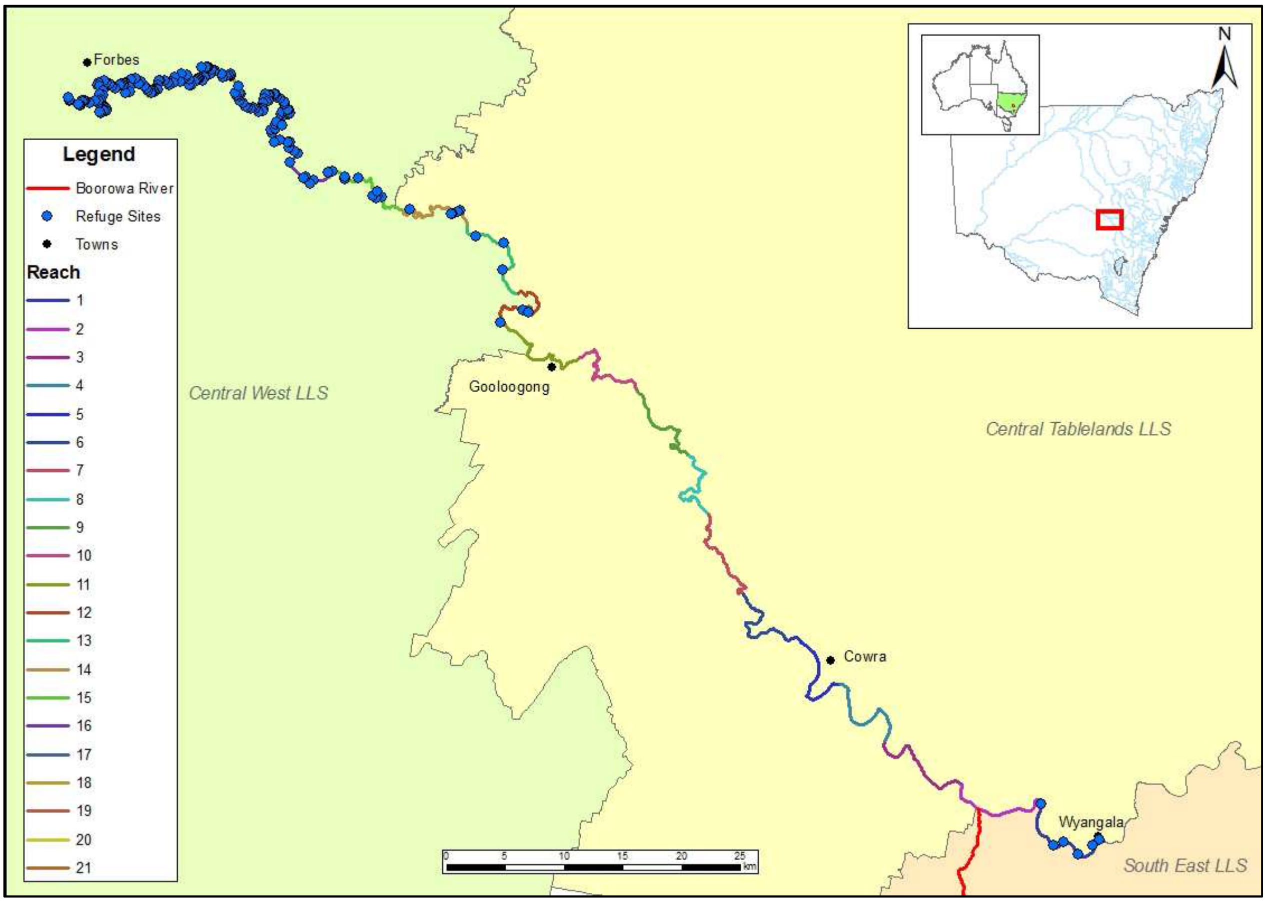


Figure 24. Refuge habitat availability in project area. Note the lack of any refugia for more than 90 km of the Lachlan River.

The average number of refuge areas per reach was nine with the highest number recorded in Reach 21 (Figure 25). This was due to the high deposition rate of sandy sediments dispersing from the Boorowa River. Reaches 2 to 11 contained no refugia while Reach12 to 16 contained 33 and 17 to 21 contained 147. While it hasn't completely filled in refuge habitat in Reaches 12 to 16, the influence of the sand slug extending for approximately 150 km can be seen.

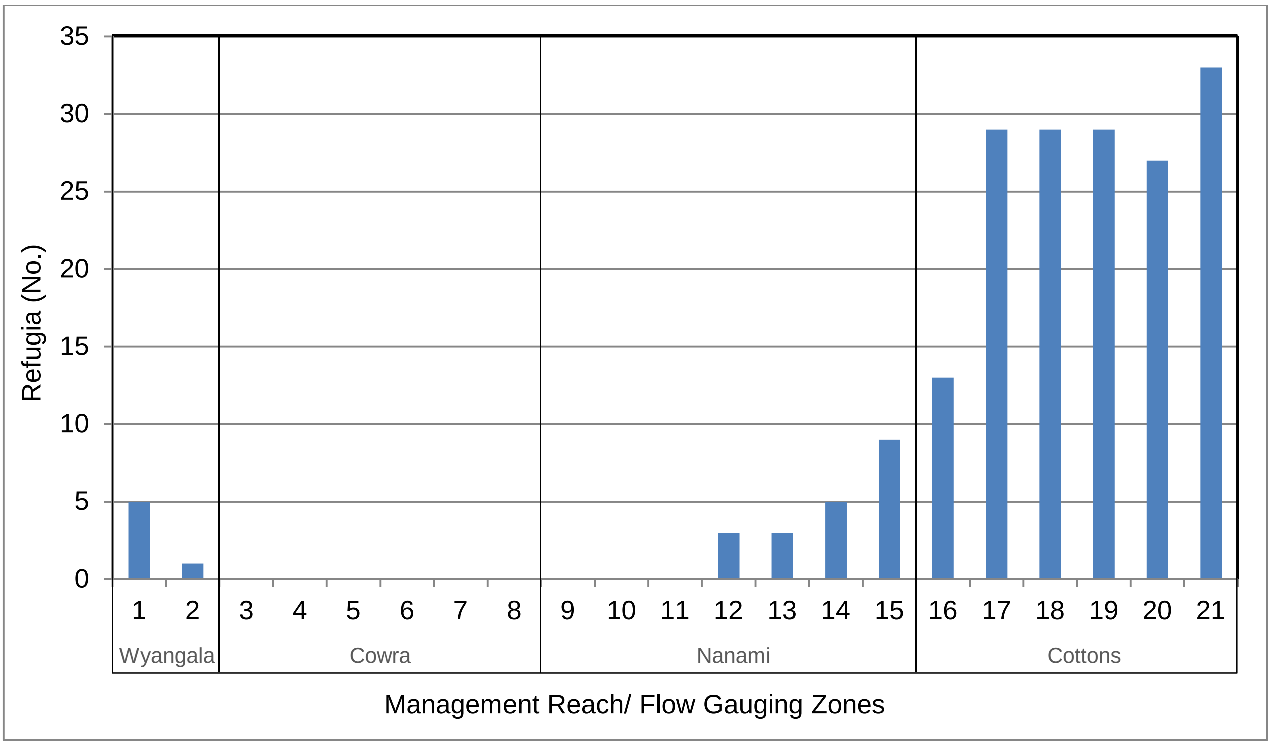


Figure 25. Number of refugia in each Management Reach.

The average depth of refuge areas for each reach was generally between 3.5 and 4 m (Figure 26). Reaches 1 and 21 had the highest averages while Reach 12 had the lowest average following a trend of little stream depth downstream of the Boorowa River.

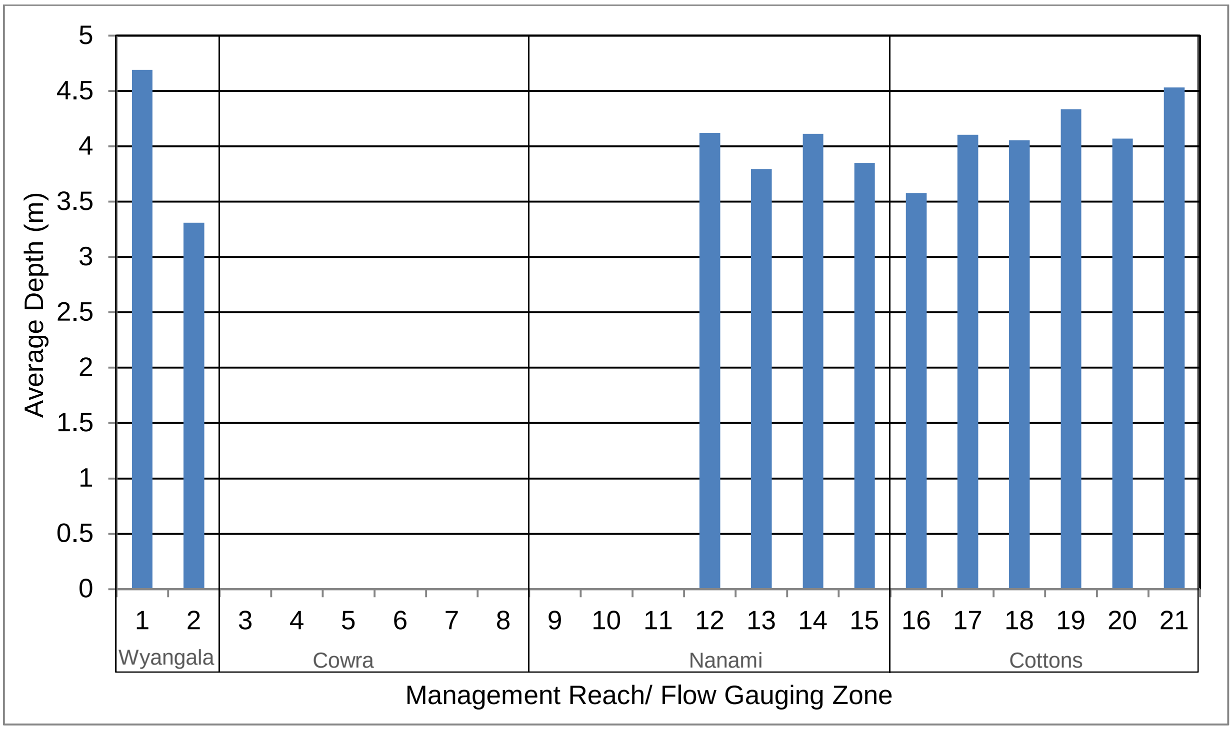


Figure 26. Average depth of refugia by Management Reach.

The habitat feature total for refugia within each management reach was calculated as the combined depth of refuge pools at the deepest point (in metres) (Figure 27). This approach does not take into account other health characteristics such as the quality of refuge habitat, shape and surface area, but focuses on the presence of available refuge habitat using total depth as a measure of persistence of refuge habitat to support resident native fish populations though extended dry periods. See Appendix B for a comprehensive dataset of the refuge habitat in the project area.

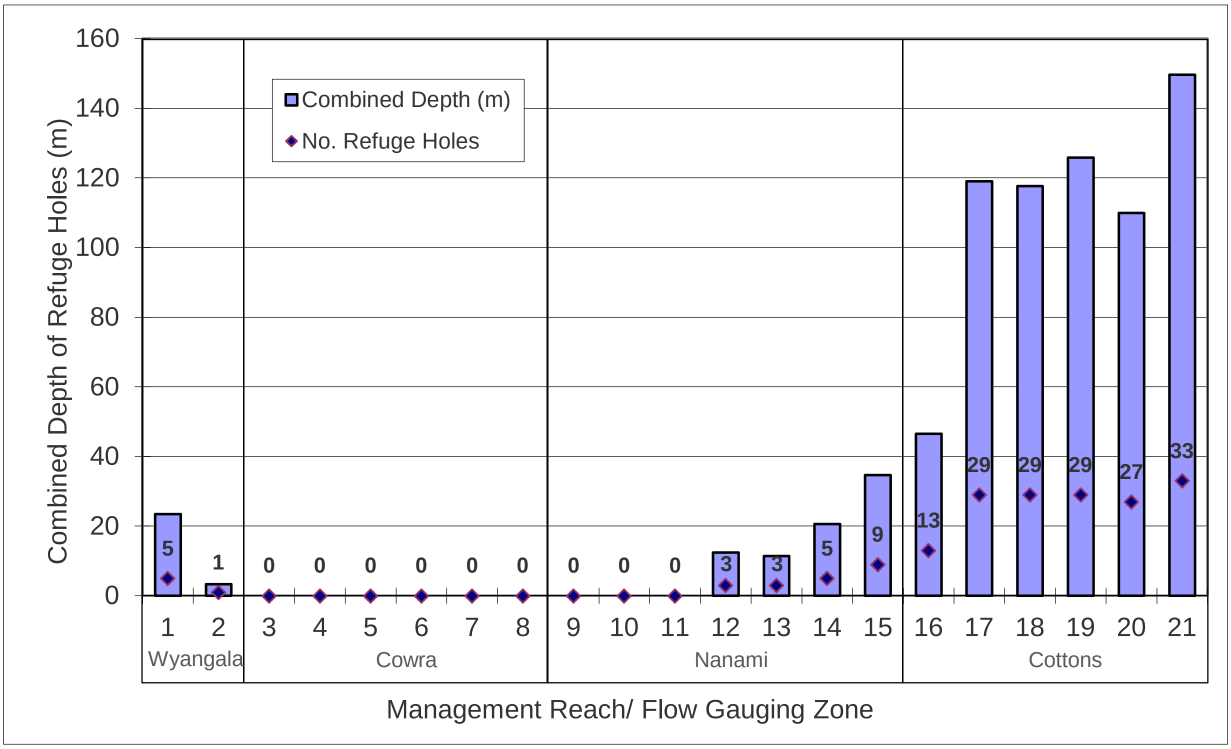


Figure 27. Combined depth and number of refuge holes per Management Reach.

5.3.4. 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 (Figure 28). 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). The methodology used to identify benches is limited to those that could be observed from the boat and as a result not all high level and submerged benches will have been identified.

There were 100 benches in the project area covering a total 9.8 ha. Reaches 6, 2 and 7 had the greatest number of benches with 16, 15 and 14, respectively (Figure 29 & Figure 30). The three Reaches (2, 6 and 7) with the greatest number of benches were in the top half of the project area with fewer benches moving downstream.

Figure 28. Example of a vegetated bench in the project area.

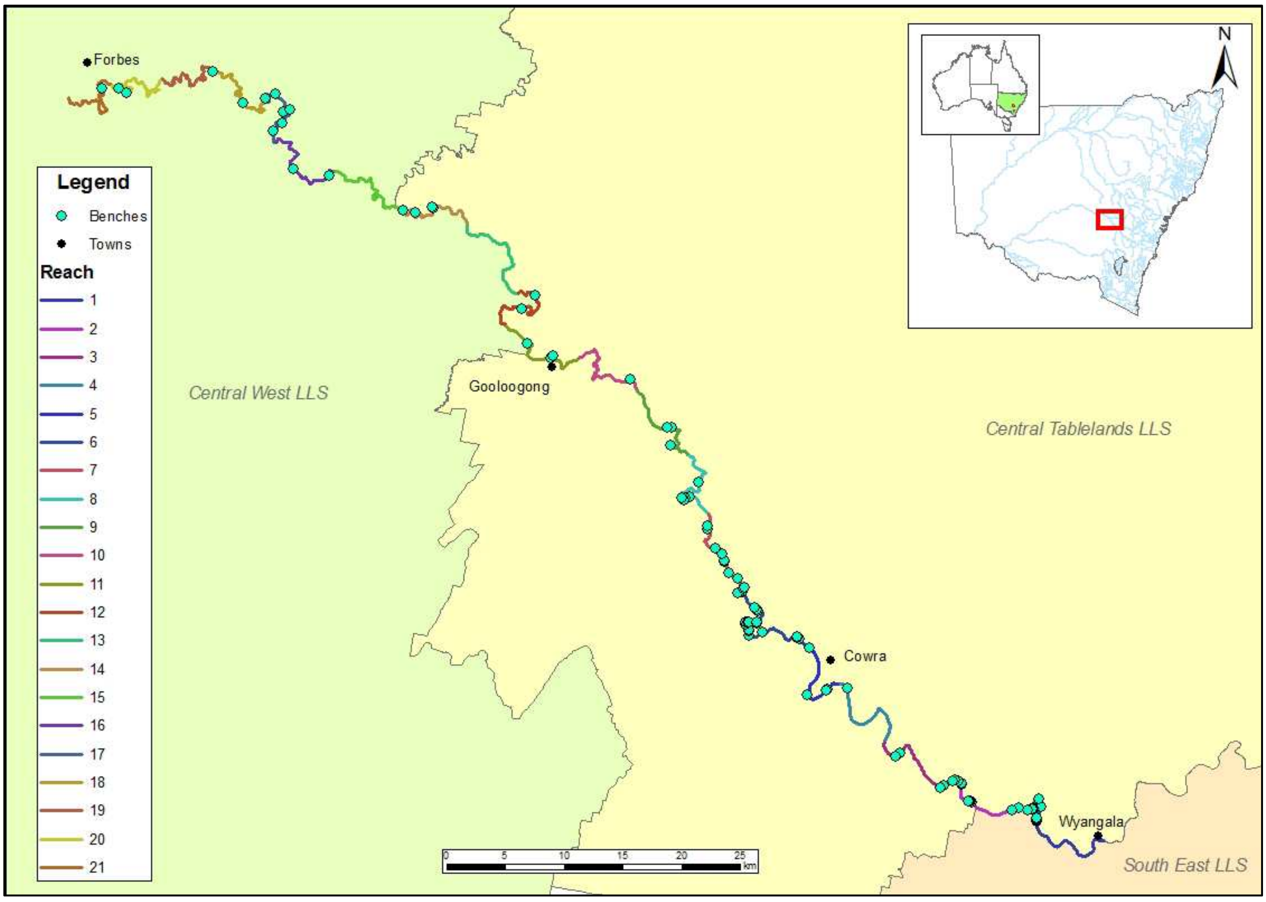


Figure 29. Locations of benches in the project area.

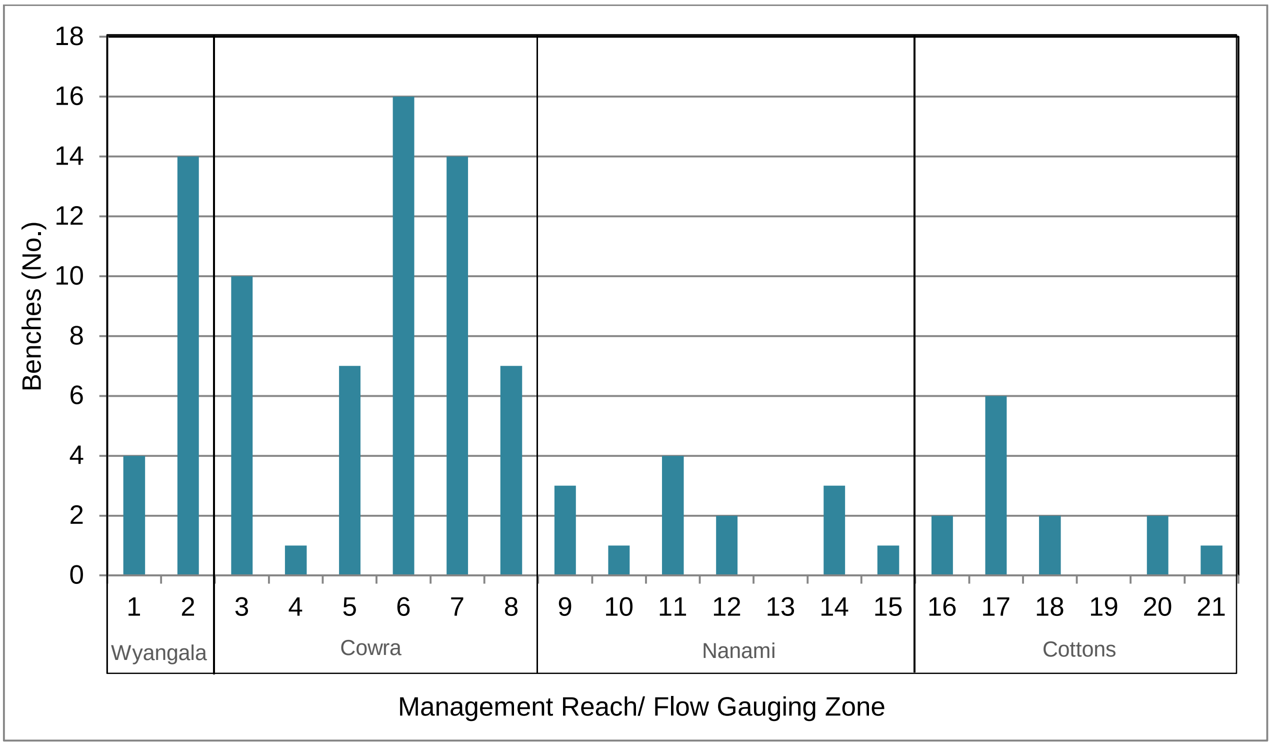


Figure 30. Distribution of benches by Management Reach.

Bench area for each Management Reach followed a similar pattern to the number of benches with the main variation in proportion shown in Reach 17 (Figure 31). In Reaches 1 and 2 benches were associated with forced pool and riffle sequences and some meander however, in the remaining reaches they were related to channel meander. Flow height may have influenced the number of benches recorded in the lower reaches, though channel width and bank steepness may have also predisposed lower sections of the project area to be naturally lower in bench extent.

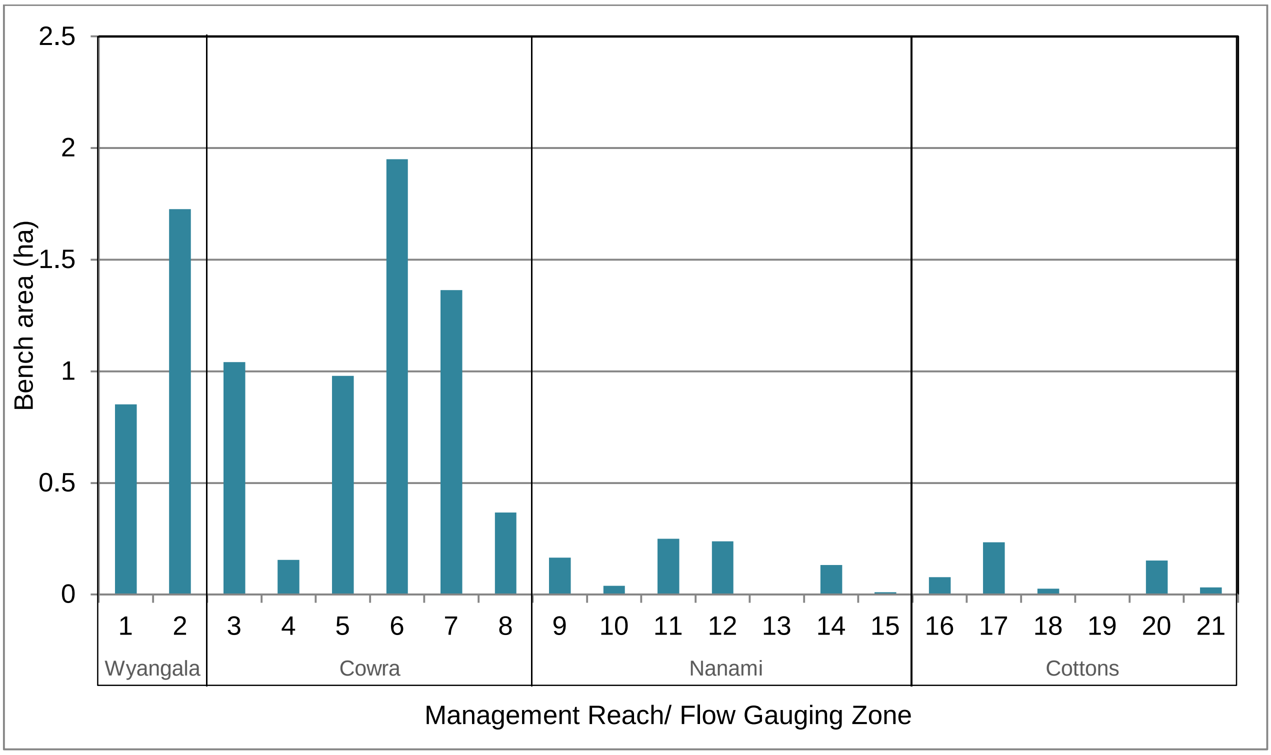


Figure 31. Bench area by Management Reach.

5.3.5. Connected Wetlands

There were 60 entry/exit points to connected wetlands (Figure 32) recorded in the project area (Figure 33 & Figure 34). Reach 19 and 18 recorded the highest numbers of connection points, with 9 and 7 respectively. Three reaches (1, 6 & 14) had no entry/exit points recorded.

Figure 32. Example of a wetland entry point. Commence to inundate point for this feature was 1900ML/day.

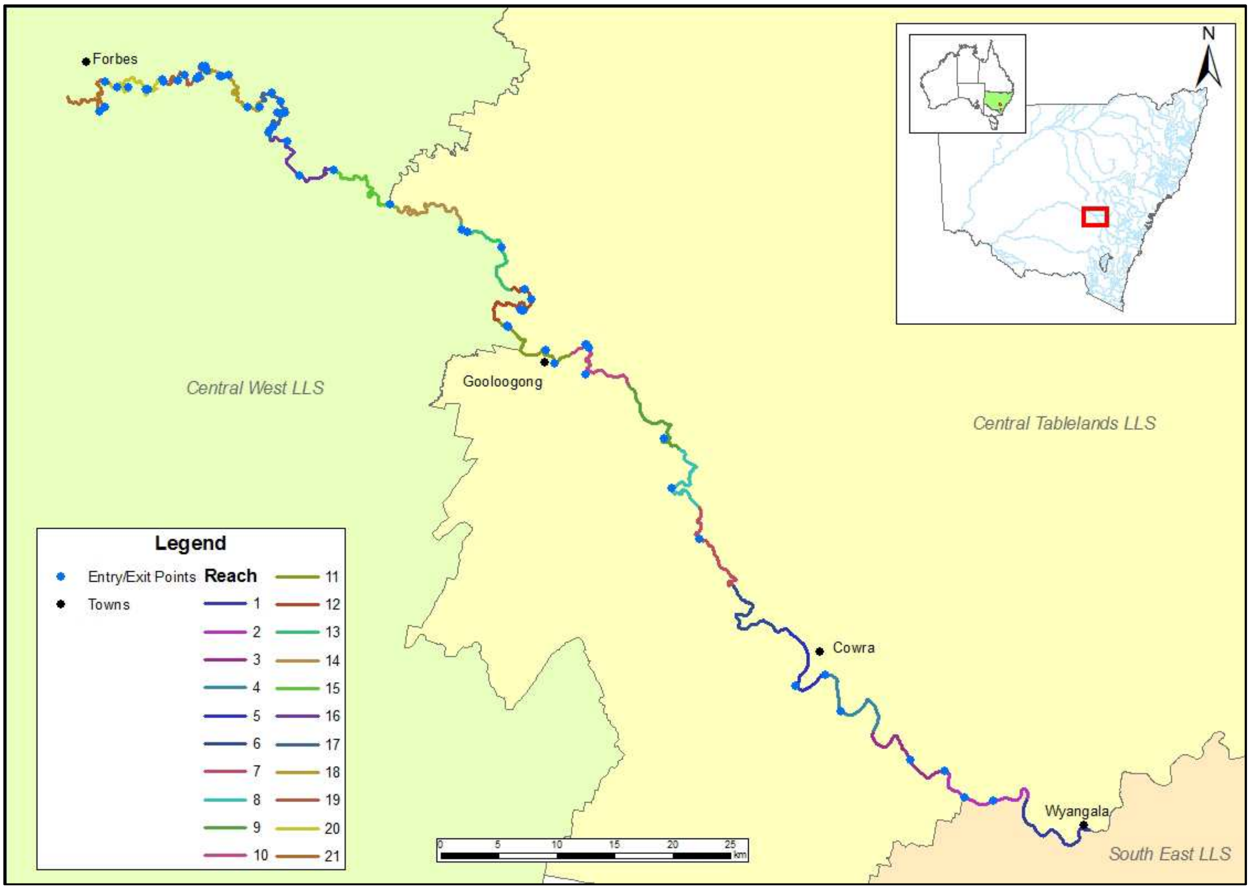


Figure 33. Distribution of wetland entry and exit points.

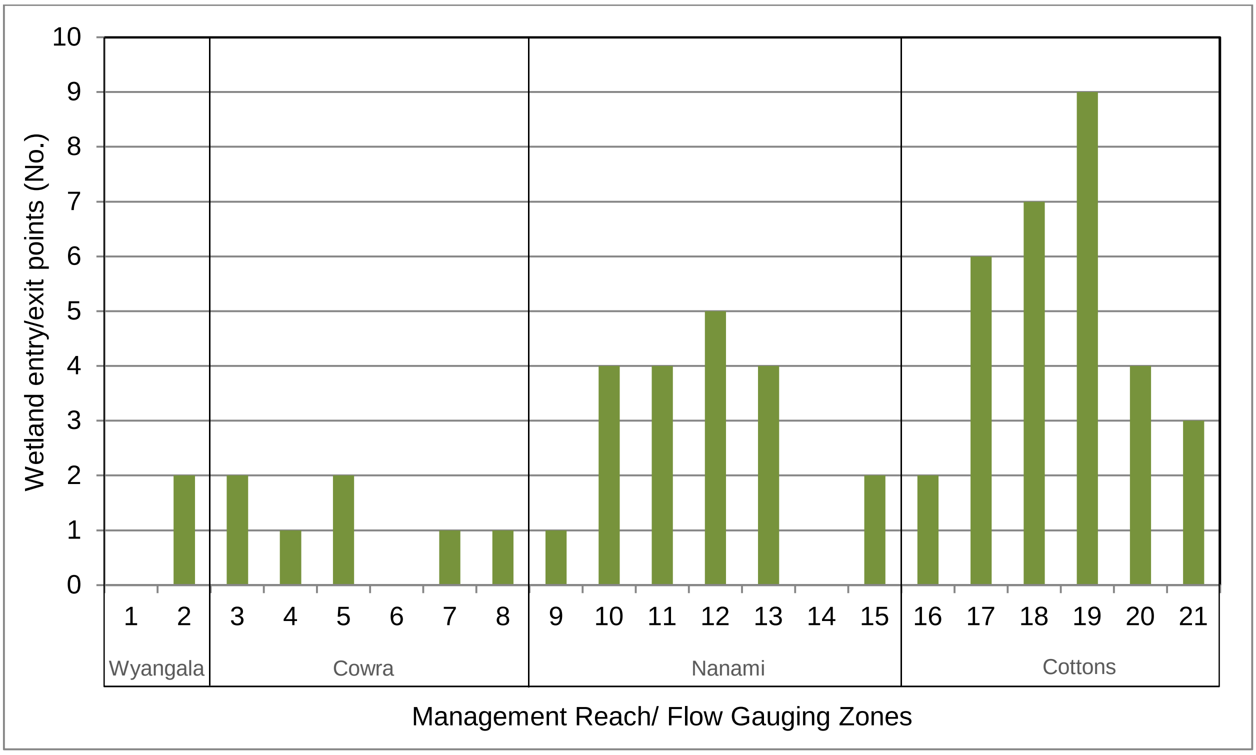


Figure 34. Number of entry and exit points in each Management Reach.

5.3.6. Aquatic macrophytes

Various species of floating-attached, submerged and emergent aquatic macrophytes were found throughout the study area during the course of the fieldwork (Figure 35). Macrophytes covered 85.1 ha of the project area. Phragmites and juncus/sedge covered the greatest area with 51.5 ha and 29.2 ha respectively. Figure 36 shows an example of a typical section of bench covered in Phragmites. Curly pond weed and water speedwell were both recorded at single sites.

The following species were recorded:

- Water milfoil (*Myriophyllum salsugineum*)
- Cumbungi (*Typha spp.*)
- Curly pondweed (*Potamogeton crispus*)
- Blunt pondweed (*Potamogeton ochreatus*)
- Phragmites (*Phragmites australis*)
- Juncus/sedge (*Juncus spp., Bolboshoenus spp.*)
- Water speedwell (*Veronica anagallis aquatica*)
- Water primrose (*Ludwigia peploides ssp. montevidensis*)
- Ribbon weed (*Vallesneria americana*)

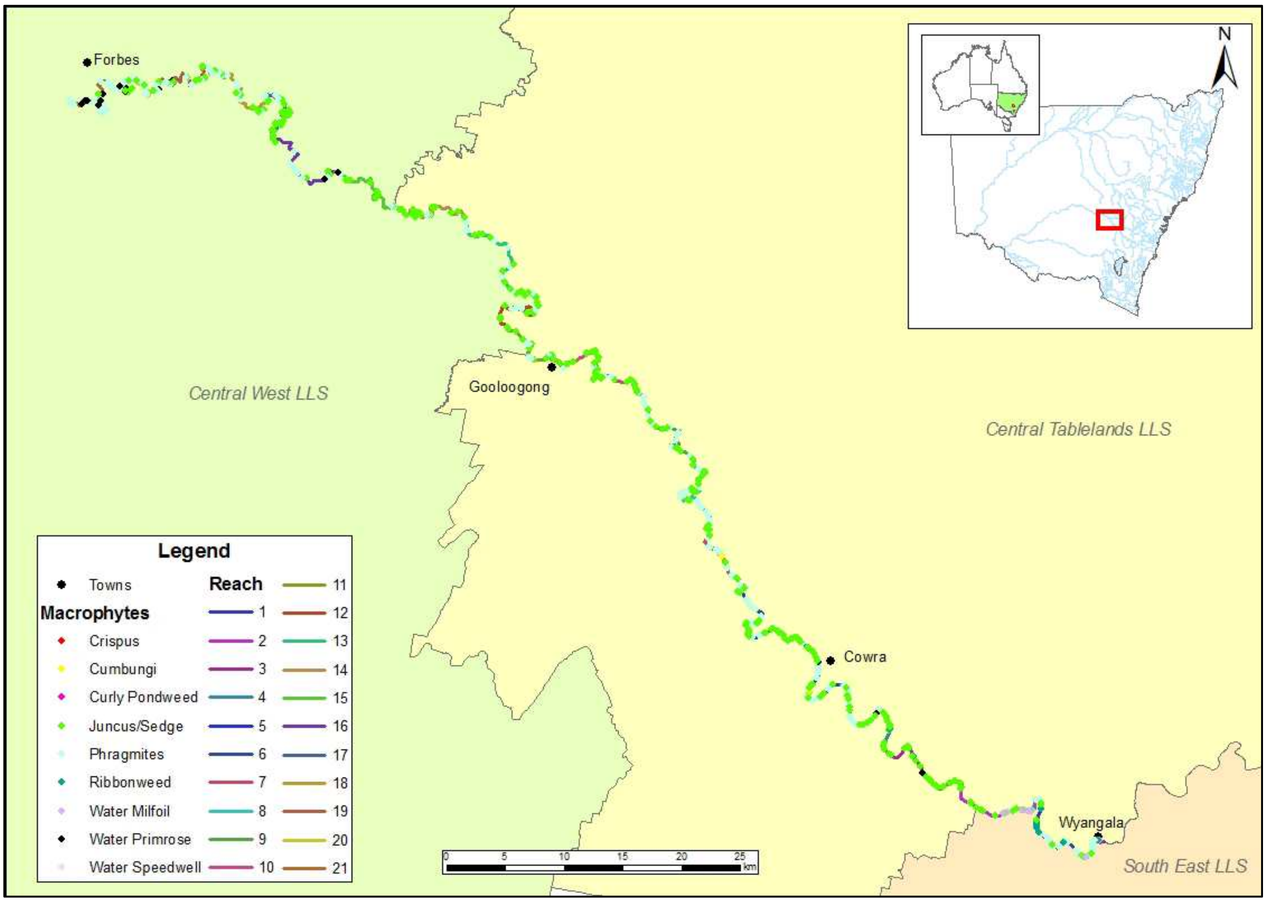


Figure 35. Distribution of aquatic macrophyte species.


Figure 36. Phragmites growing on a low bench in the project area.

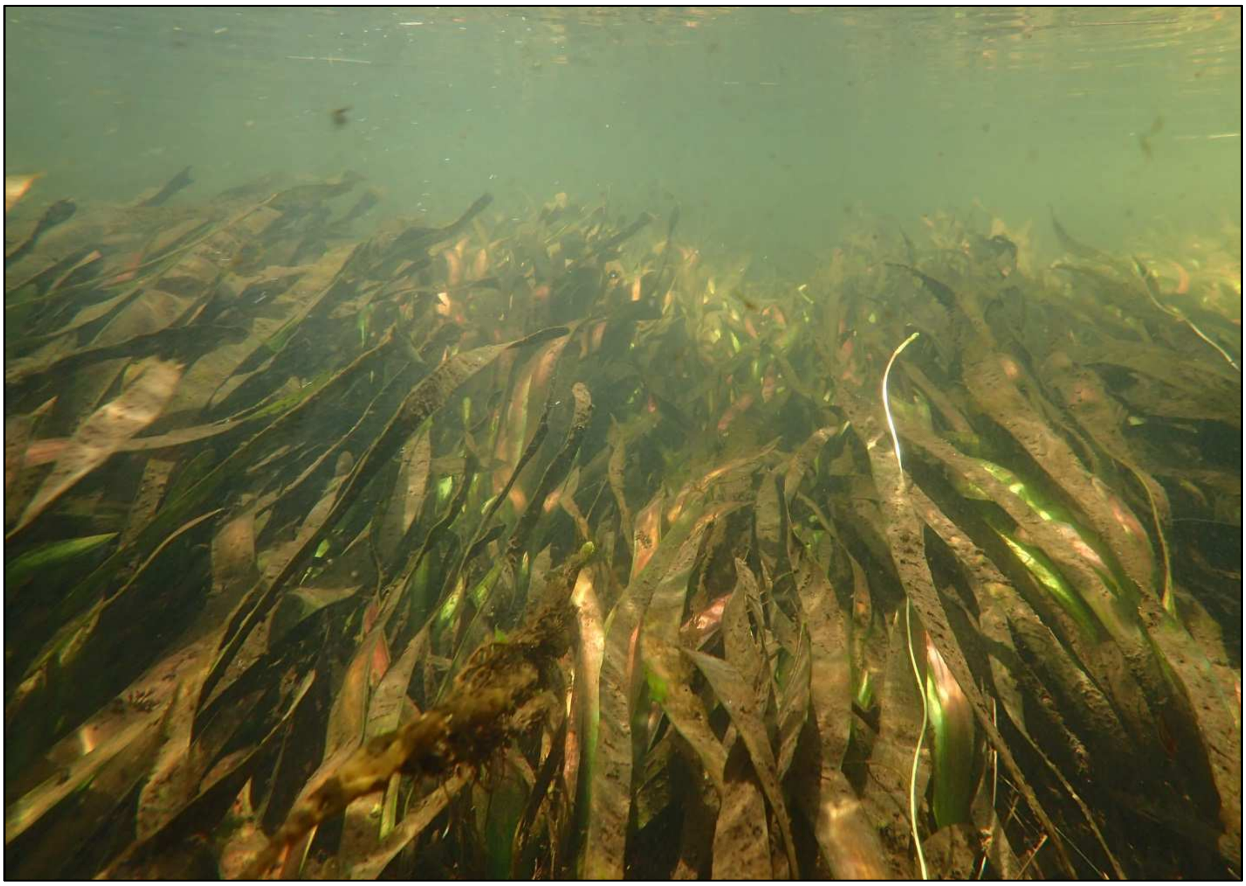


Figure 37. Bed of ribbon weed in a fast flowing section.

5.4. Flow relationship results

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 megalitres per day (ML/day). Features were separated into Flow Gauging Zones (FGZs) according to the nearest NSW DPI Water gauging station. Figure 38 shows the FGZ boundaries. Cumulative frequency was calculated for each feature type for each FGZ. Nanami and Cottons Weir FGZ include weir pools of varying extents, therefore some results may be influenced by persistently elevated water levels. Flow components as shown in Figure 39 (cease to flow, base flow, small pulse, large pulse, bankfull and overbank) were determined using data from NSW DPI Water gauging stations and information from Green (2011) and Kemp (2010).

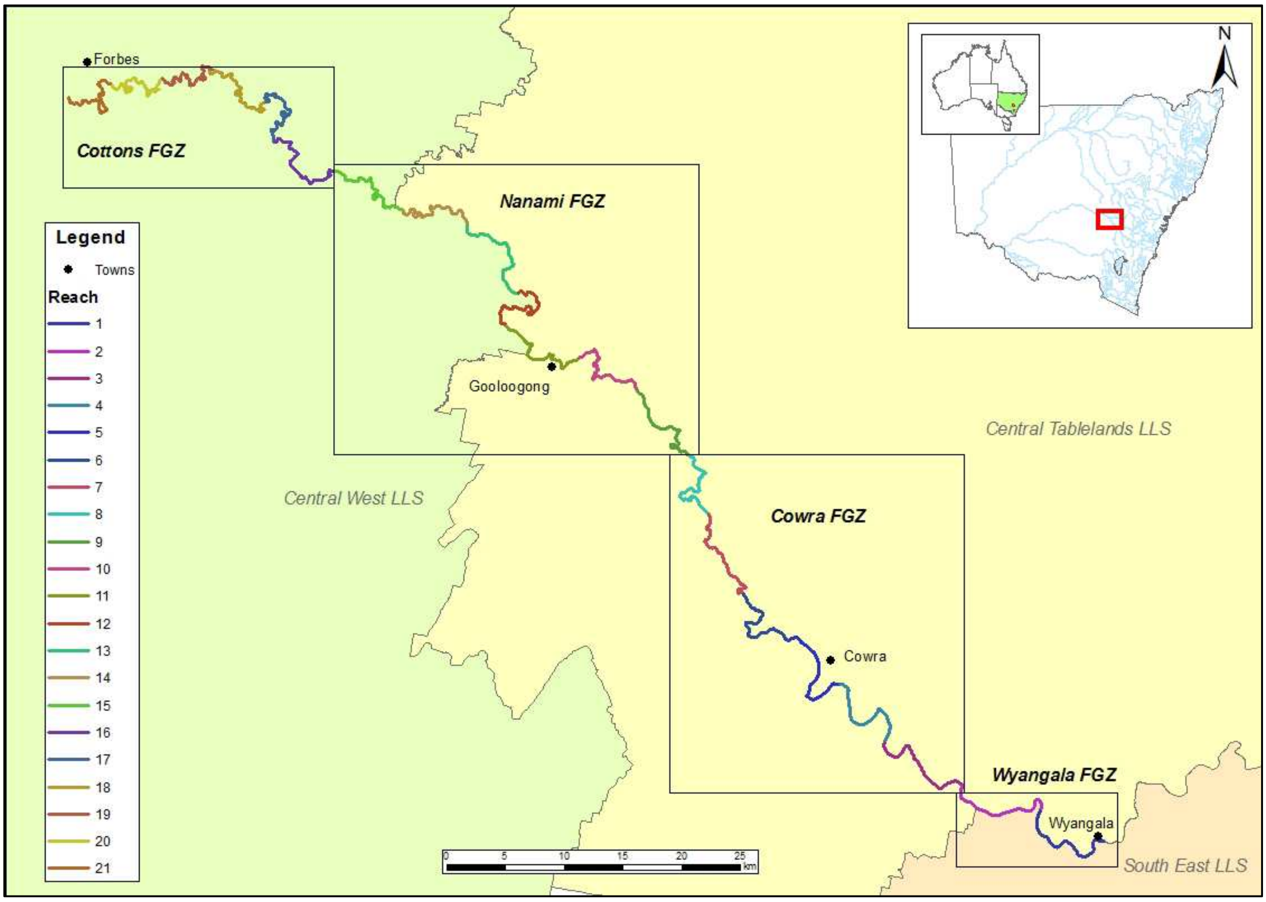


Figure 38. Flow Gauging Zone boundaries used during the project to assess flow relationships for habitat features during the project.

5.4.1. Summary of project area hydrology

Differing flow events may be separated into several ecologically significant components with each of these providing a diverse range of ecosystem services (Figure 39 &

Table 5). To provide water managers with a greater understanding of what specific flows may achieve in the Wyangala to Cottons Weir reach of the Lachlan River, detailed flow height relationships were determined (

Table 6,

Table 7,

Table 8 &

Table 9). Cross-sections (see Appendix C) and flow data for each gauge were used to approximate thresholds for flow regime components in conjunction with bank heights that were recorded in the field using the hypsometer. These will assist in identifying hydrological components for each of the FGZs.

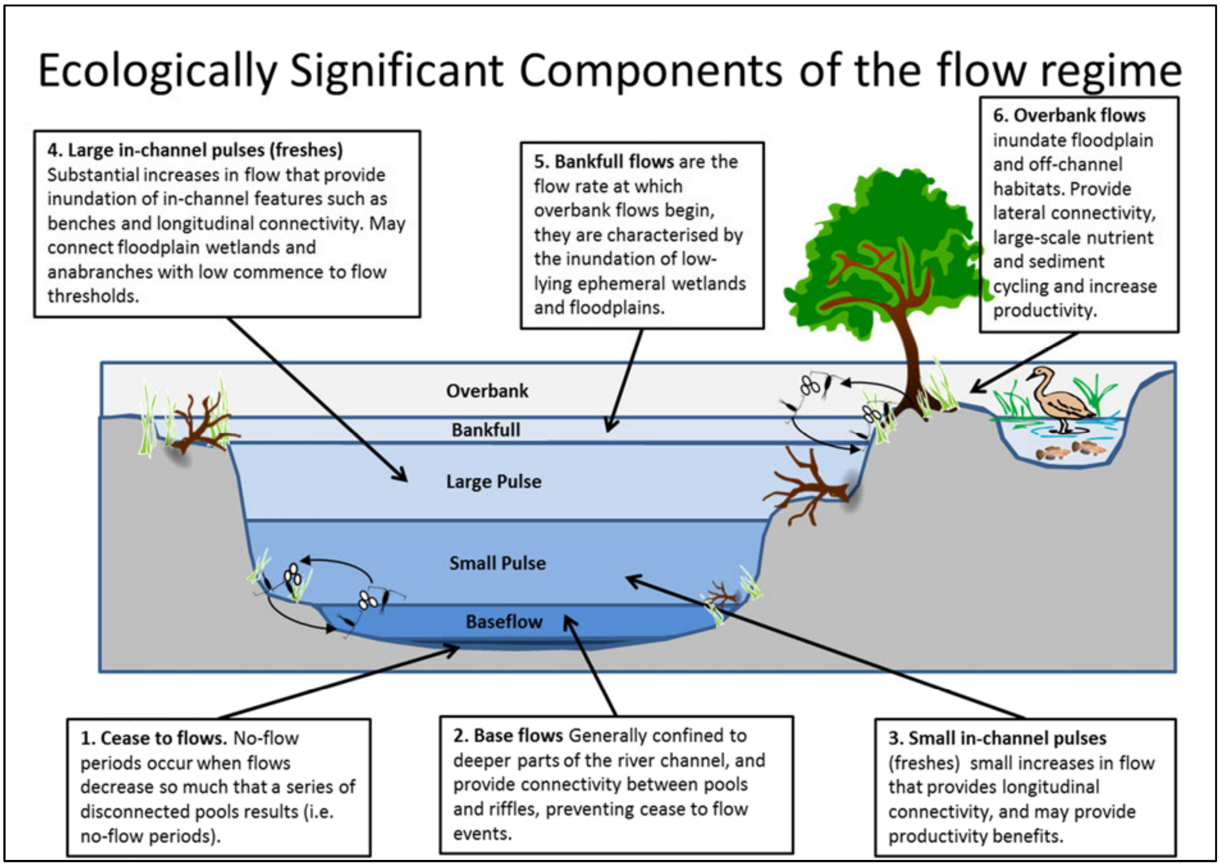


Figure 39. Components of the within-channel flow regime (adapted from Ellis et al. 2016).

Table 5. Definition of the five flow regime components identified for this study (adapted from MDBA in prep.)

Flow regime component	**Definition**
Baseflow	Confined to the low flow part of the channel, these flows would typically inundate geomorphic units such as pools and riffle areas between pools. Base flows are important to fish as they retain habitat area when low inflow conditions prevail; retain longitudinal connectivity for small bodied fish and maintain reasonable water quality
Small Pulse	'No bench inundation' but longitudinal channel connection longitudinal connectivity. Supports maintenance of refugia and habitat. Could also support winter conditioning and oxygenation through riffle habitats (Blackfish species and Galaxids) and historically may have benefitted small-bodied native species in terminal wetlands. Base flows in upper perennial streams may be higher now due to irrigation flows (but will be lower downstream due to offtakes)
Large Pulse	In channel flows up to bankfull that provide lateral and longitudinal connectivity and inundation of in channel features such as benches as well as anabranches with low commence to flow thresholds. Important for productivity and system- scale connectivity, including tributaries. Large events may allow tributary connectivity (anabranches).
Bankfull Flow	The flow rate at which overbank flows begin, or maximum regulated flow releases. These are also characterised by the inundation of ephemeral wetlands and floodplains.
Overbank event	Overbank flows, including floodplain and off-channel inundation. Important for productivity and system-scale connectivity, including tributaries.

Table 6. Summary of flow components, stage heights and mean daily flow range for Lachlan for Wyangala FGZ.

Component of flow regime	Stage height (m)	Mean daily flow range (ML/day)	No. (& area) of benches inundated	No. of wetlands connected	LWH inundated
CTF	*	*	2 (2,003 m^2)	2	32***
Base flows	1.359 – 1.4	60 – 80	4 (4,785 m^2)	2	43
Small Pulse	1.4 – 1.6	80 – 320	4 (4,785 m^2)	2	46
Large Pulse	1.6 – 2.5	320 – 4,620	18 (24,328 m^2)	2	72
Bankfull	2.5 – 5	4,620 – 40,500	18 (24,328 m^2)	2	113
Overbank	5 – 9.081**	40,500 – 145,509**	18 (24,328 m^2)	2	119

Table 7. Summary of flow components, stage heights and mean daily flow range for Lachlan for Cowra FGZ

Component of flow regime	Stage height (m)	Mean daily flow range (ML/day)	No. (& area) of benches inundated	No. of wetlands connected	LWH inundated
CTF	*	*	0	3	191**
Base flows	1.13 – 1.18	80 – 120	0	3	192
Small Pulse	1.18 – 1.3	120 – 350	2 (3,657 m^2)	4	193
Large Pulse	1.3 – 3.1	350 – 5,500	50 (53,548 m^2)	6	339
Bankfull	3.1 – 8	5,500 – 30,500	55 (60,062 m^2)	7	573
Overbank	8 – >9	30,500 – >50,000	55 (60,062 m^2)	7	605

Table 8. Summary of flow components, stage heights and mean daily flow range for Lachlan for Nanami FGZ

Component of flow regime	Stage height (m)	Mean daily flow range (ML/day)	No. (& area) of benches inundated	No. of wetlands connected	LWH inundated
CTF	*	*	0	0	2,563**
Base flows	0.228 – 0.286	90 – 120	0	2	2,563
Small Pulse	0.286 – 0.655	120 – 350	0	2	2,563
Large Pulse	0.655 – 5	350 – 13,200	14 (8,372 m^2)	18	3,011
Bankfull	5 – 8	13,200 – 23,700	14 (8,372 m^2)	20	3,552
Overbank	8 – >9.7	23,700 – >31,000	14 (8,372 m^2)	20	3,757

Table 9 Summary of flow components, stage heights and mean daily flow range for Lachlan for Cottons FGZ

Component of flow regime	Stage height (m)	Mean daily flow range (ML/day)	No. (& area) of benches inundated	No. of wetlands connected	LWH inundated
CTF	*	*	0	0	3,499**
Base flows	0.236 – 0.264	70 – 90	0	0	3,499
Small Pulse	0.264 – 0.413	90 – 250	0	0	3,499
Large Pulse	0.413 – 2	250 – 8,900	2 (1,402 m^2)	1	3,518
Bankfull	2 – 3.4	8,900 – 15,100	10 (3,546 m^2)	3	3,609
Overbank	3.4 – >3.8	15,100 – >16,500	13 (5,228 m^2)	31	4,455

*No cease to flow recorded at this site. **CTF LWH inundated taken at 0 ML/day.

5.4.2. Large Woody Habitat

The inundation height for LWH recorded in the Lachlan River between Wyangala Dam and Cottons Weir were compared against flow data to determine the flow (ML/day) required to inundate each LWH as shown in Figure 40, Figure 41, Figure 42 & Figure 43. Flow components identified within each FGZ are represented by boxes moving left to right: base flow, small pulse, large pulse, bankfull, overbank and above gauge range. LWH identified as above the gauge range are higher than the relevant DPI Water gauge, so it is not possible to detect the flow (ML/day) at which they would be inundated. Due to the lack of data for the cease to flow range, this component was excluded from the cumulative frequency curves and base flow has been plotted from 0 ML/day.

Flow relationship analysis was conducted on 8,936 LWH with an average loading of 42.55 LWH/km. The number of LWH varied between FGZ, with the highest number recorded in Cottons FGZ (4,455) followed by Nanami FGZ (3,757), Cowra (605) and Wyangala (119). The flows required to inundate 100% of LWH in all FGZs are greater than could be manipulated from water storages and could only be achieved through uncontrolled tributary flows and/or a dam spill. However, 80% of LWH are inundated at all sites with a bankfull flow greater than 15,000 ML/day. A flow of this magnitude could be manipulated from Wyangala Dam, making this a potential inundation target for an environmental flow. Cottons Weir FGZ has nearly 95% of LWH inundated at base flow, however flows above the gauge range would be required to inundate the remaining 5% of the LWH in the FGZ.

It is important to note that the plotted points in the graph series below do not represent inundation of individual features, but rather indicate the flow point in megalitres at which one or more features become inundated.

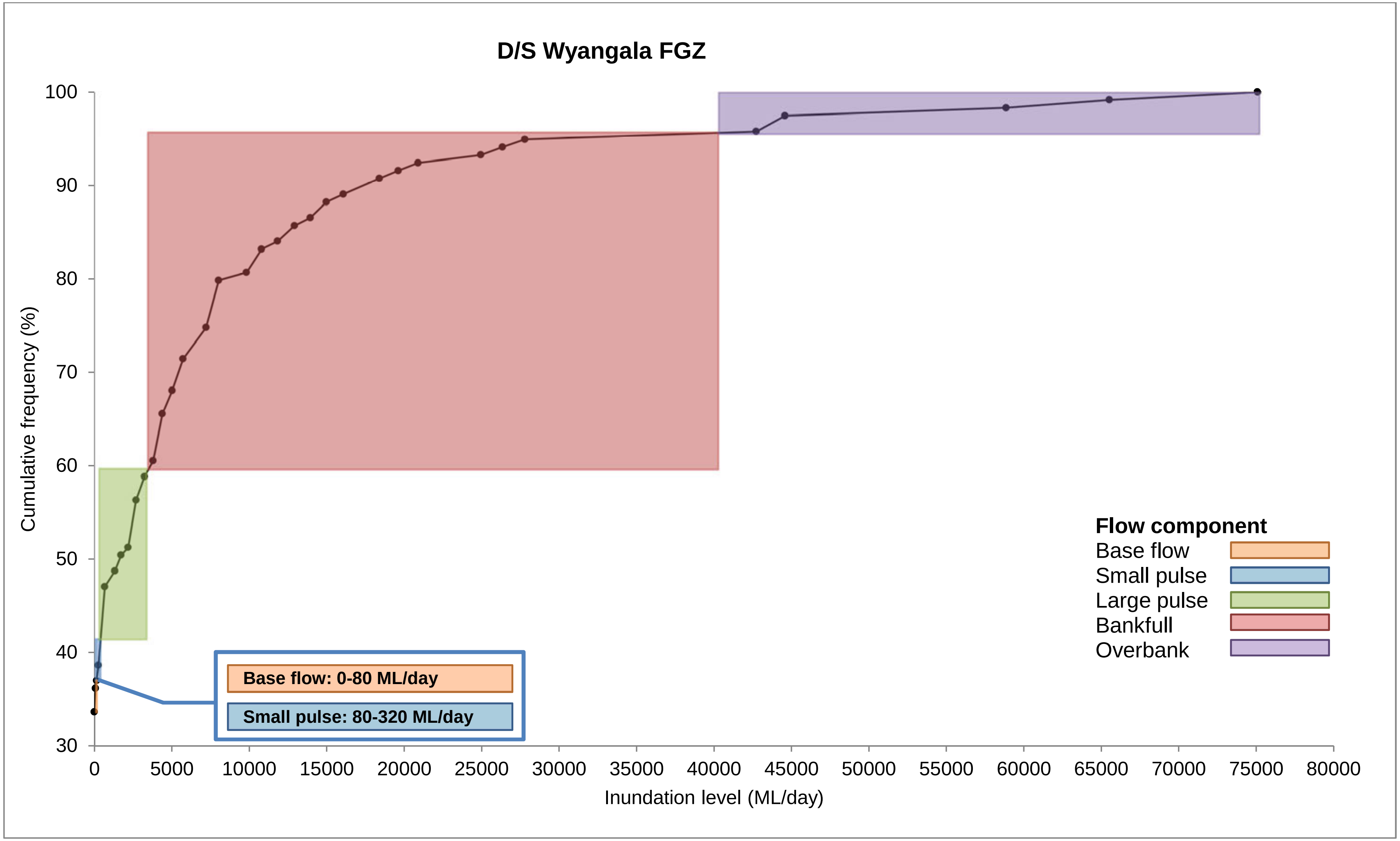


Figure 40. Cumulative inundation frequency curves for LWH in the Wyangala FGZ.

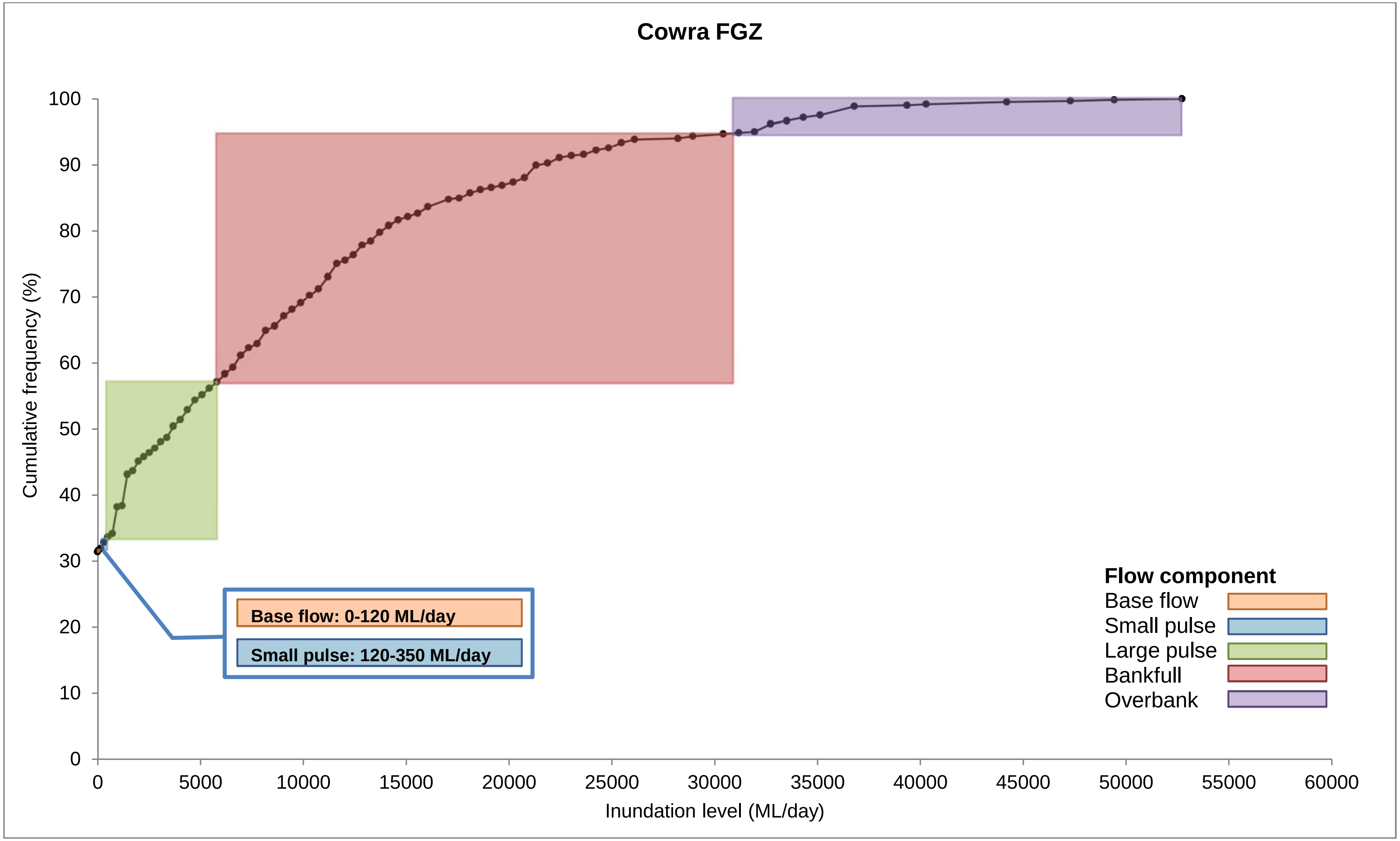


Figure 41. Cumulative inundation frequency curves for LWH in the Cowra FGZ.

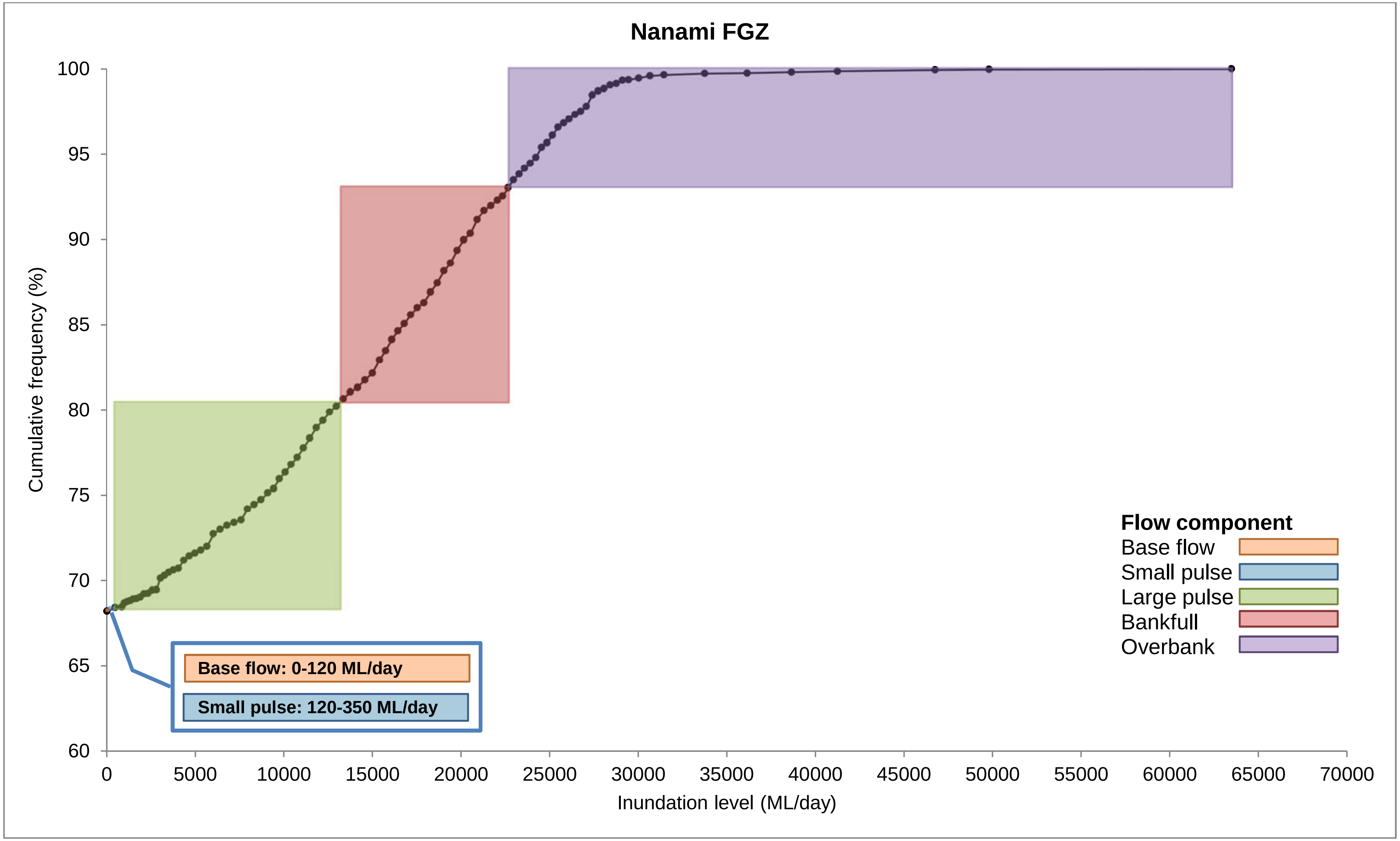


Figure 42. Cumulative inundation frequency curves for LWH in the Nanami FGZ.

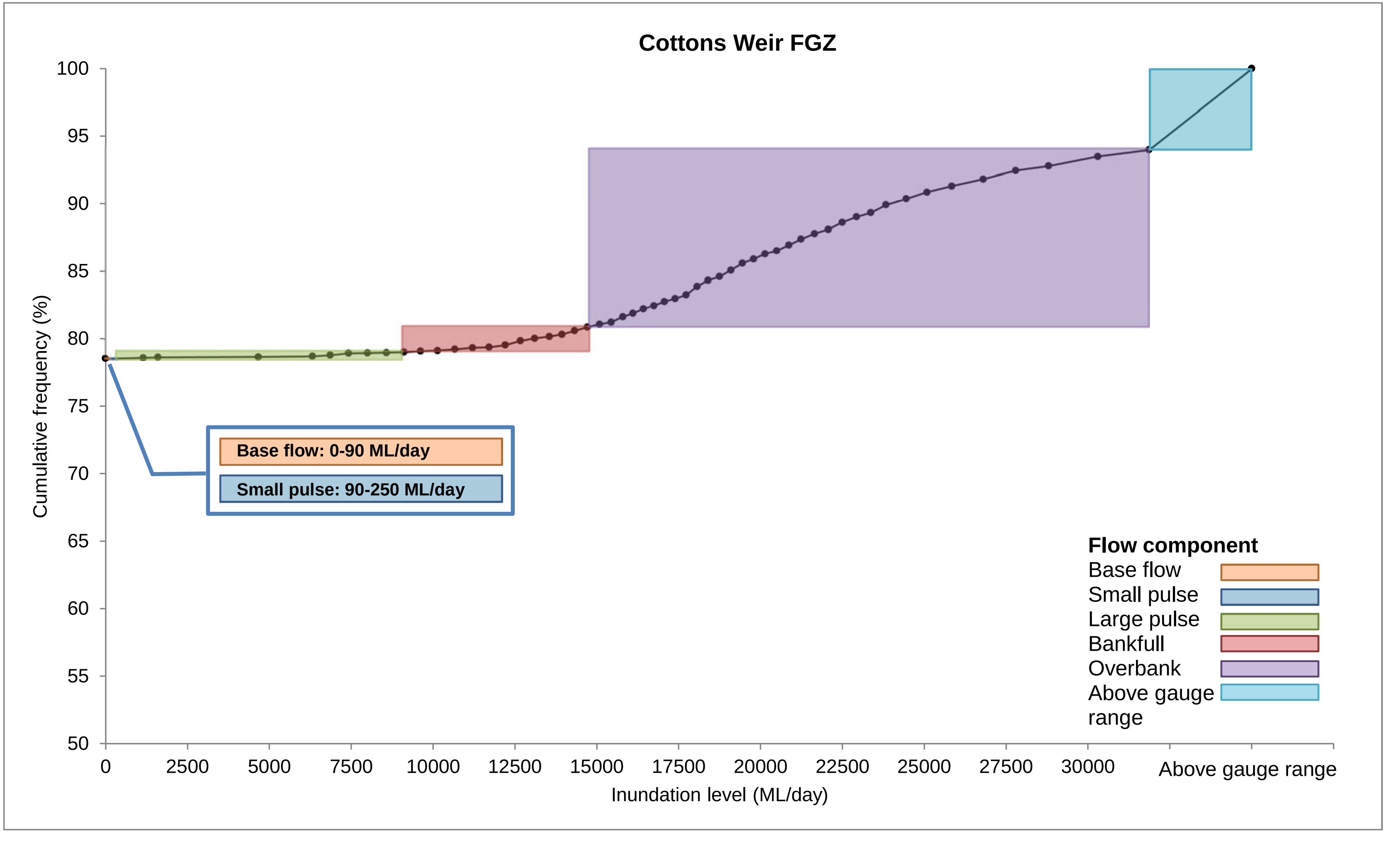


Figure 43. Cumulative inundation frequency curves for LWH in the Cottons Weir FGZ.

5.4.3. Benches

The inundation height for benches recorded in the Lachlan River between Wyangala and Cottons Weir were compared against flow data to determine the flow (ML/day) required to inundate the entire bench area recorded (Figure 44, Figure 45, Figure 46 & Figure 47). Due to the lack of data for cease to flow, this component was excluded from the cumulative frequency curves and base flow has been plotted from 0 ML/day. Flow relationship analysis was conducted on 100 benches. Cowra FGZ had the highest number with 55 recorded, followed by Wyangala (18), Nanami (14) and Cottons Weir (13).

A large pulse flow approaching 10,000 ML/day would inundate 90% of the bench area in all FGZs, except Cottons Weir FGZ. This FGZ would require an overbank flow greater than 15,000 ML/day to inundate the same proportion of bench area. A trend of higher flows is evident to inundate 100% of bench area in the lower FGZ. This is likely attributed to the system transitioning from upland to lowland in the project area.

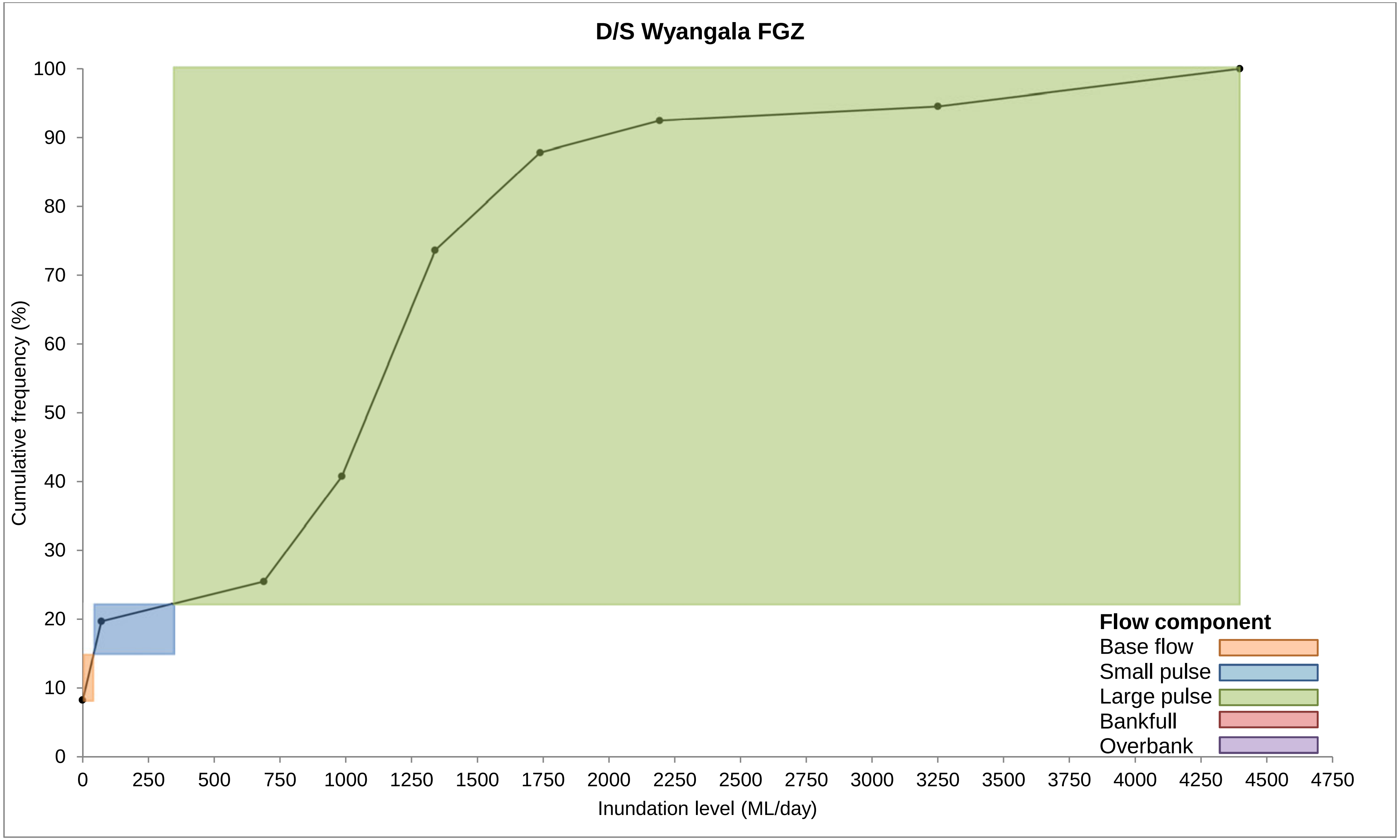


Figure 44. Cumulative inundation frequency curves for bench area in Wyangala FGZ.

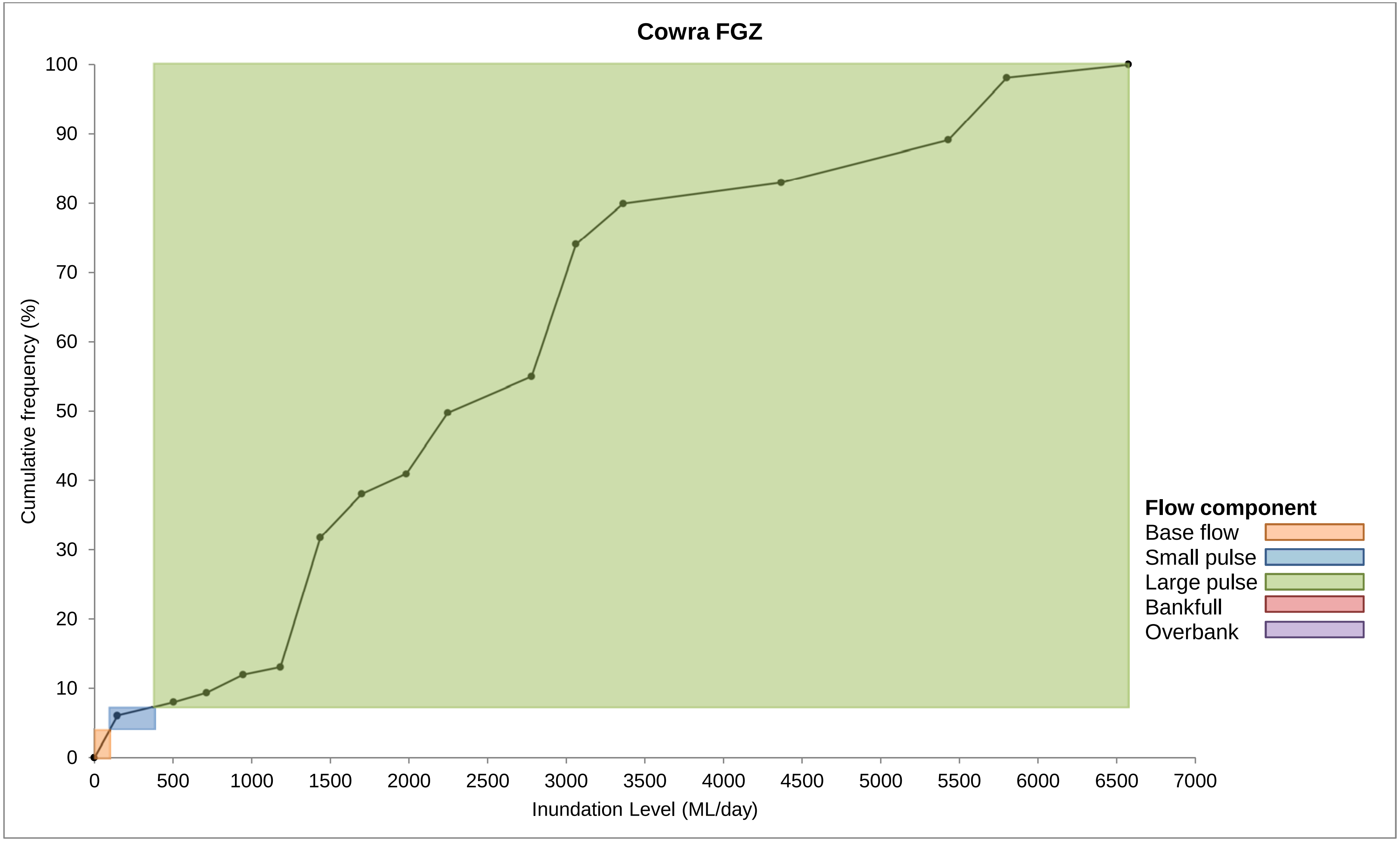


Figure 45. Cumulative inundation frequency curves for bench area in Cowra FGZ.

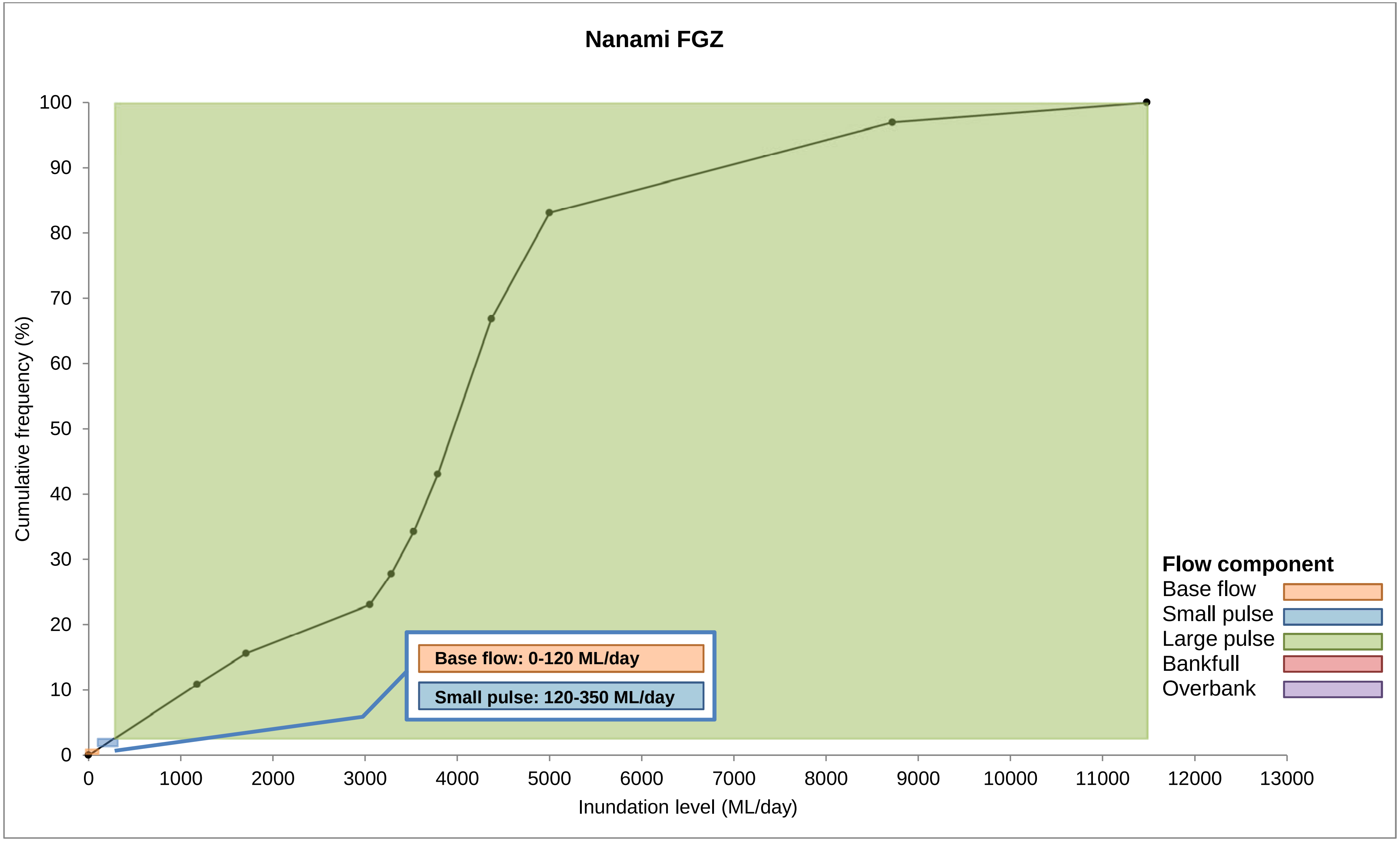


Figure 46. Cumulative inundation frequency curves for bench area in Nanami FGZ.

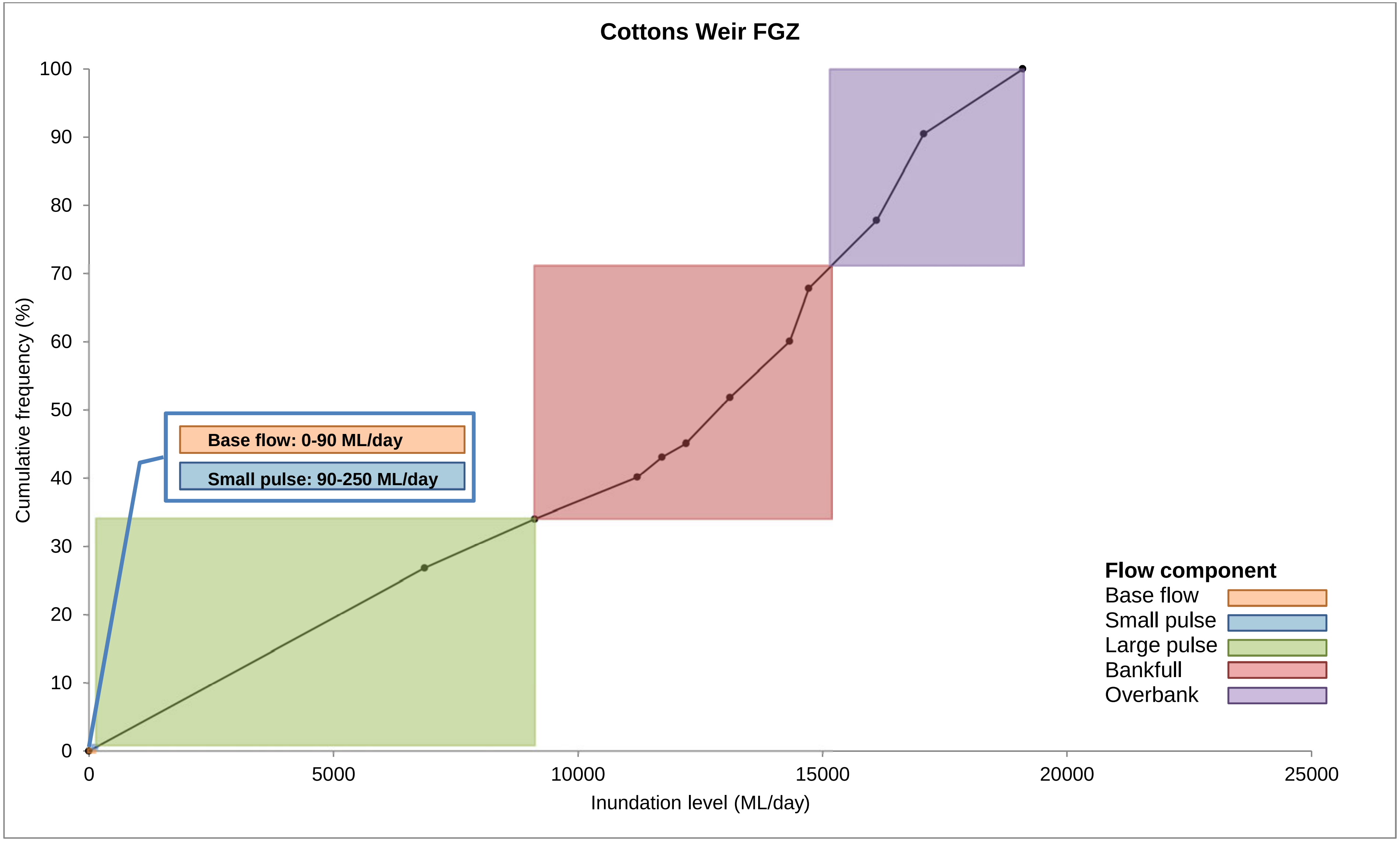


Figure 47. Cumulative inundation frequency curves for bench area in Cottons Weir FGZ.

5.4.4. Connected Wetlands

The inundation height for entry points to connected wetlands recorded in the Lachlan River between Wyangala and Cottons Weir were compared against flow data to determine the flow (ML/day) required to inundate each individual entry point as shown in Figure 48, Figure 49 & Figure 50. Flow relationship analysis was conducted on 60 connected wetland entry points. Due to the lack of data for cease to flow, this component was excluded from the cumulative frequency curves and base flow has been plotted as a range of 60-120 ML/day. The highest number of entry points were recorded in the Cottons Weir FGZ (31) followed by Nanami (20) Cowra (7) and Wyangala (2). The low number of entry points in the Wyangala FGZ was due to the more upland nature of the system in that area.

There is considerable variation in the flows required to inundate 100% of connected wetland entry points ranging from base flow to overbank flows. The two wetland entry points in Wyangala FGZ are inundated at low flows of less than 80 ML/day and could not be represented as a cumulative frequency curve. A large pulse flow of approximately 5,000 ML/day in the Cowra FGZ would inundate 90% of entry points. To achieve the same outcome downstream, an overbank flow of 13,000 ML/day and 22,000 ML/day would be required in Nanami and Cottons Weir FGZ respectively. A similar pattern to that represented in the bench data was evident for entry points with higher flows required moving down the system to inundate 100% of entry points.

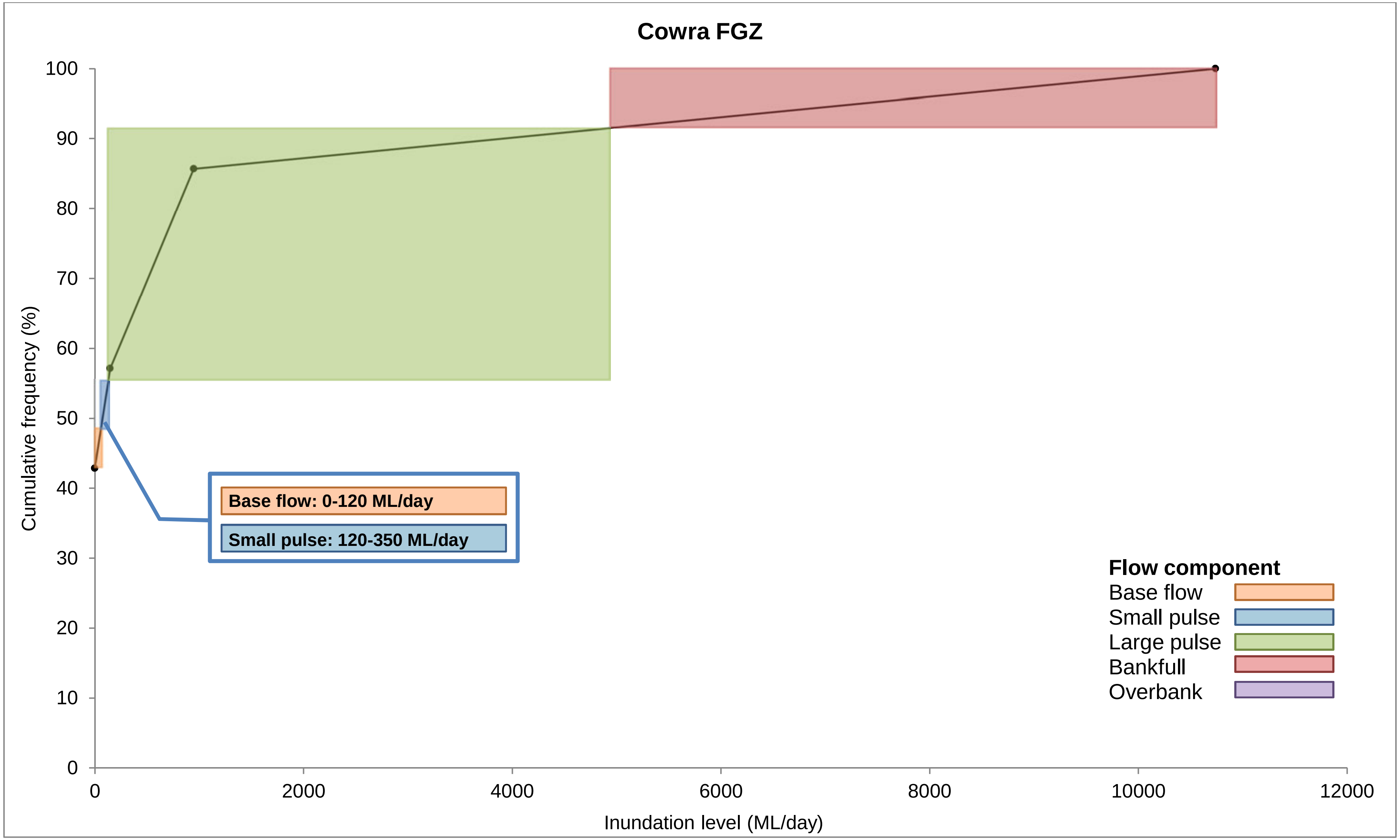


Figure 48. Cumulative inundation frequency curves for connected wetlands in Cowra FGZ.

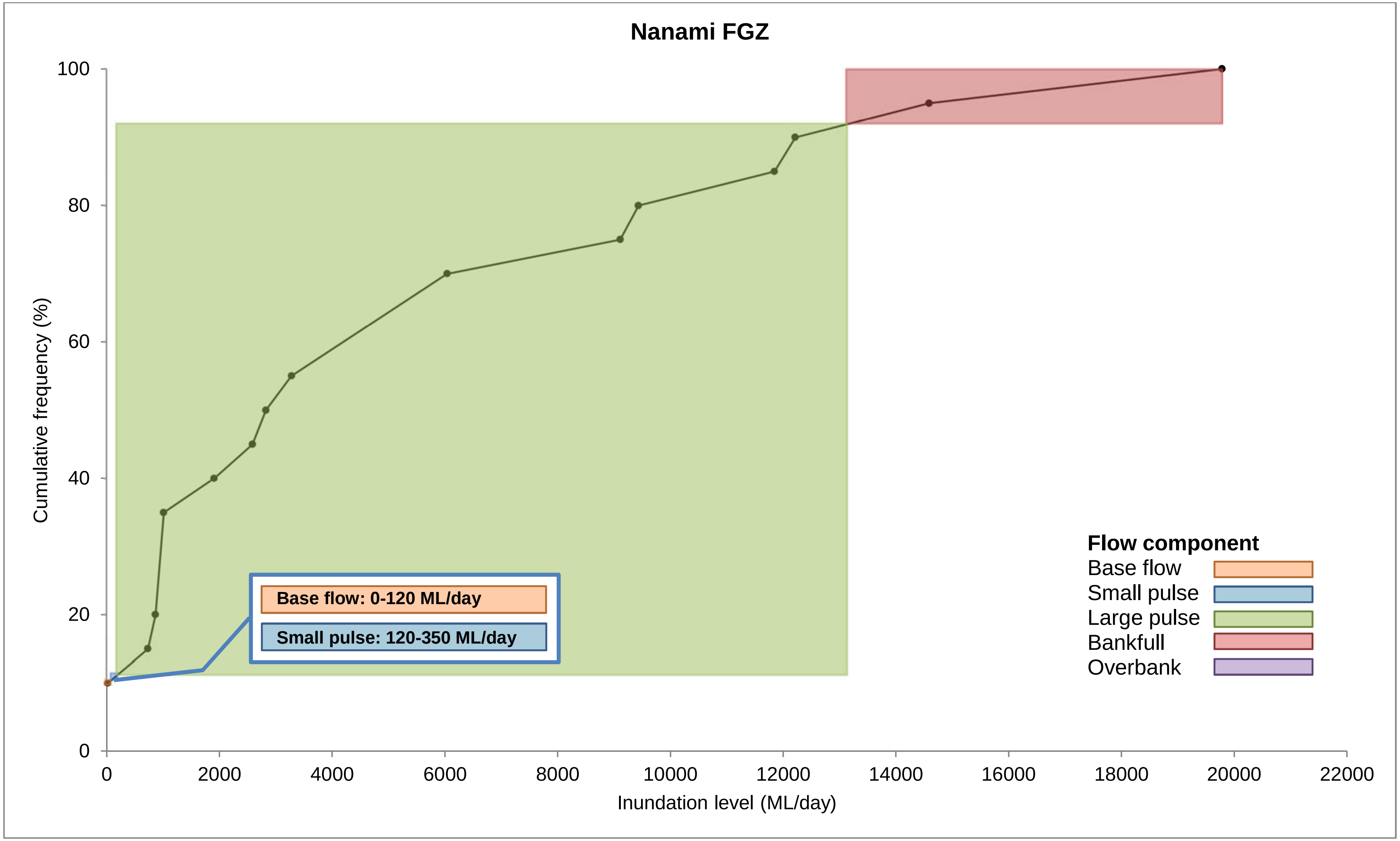


Figure 49. Cumulative inundation frequency curves for connected wetlands in Nanami FGZ.

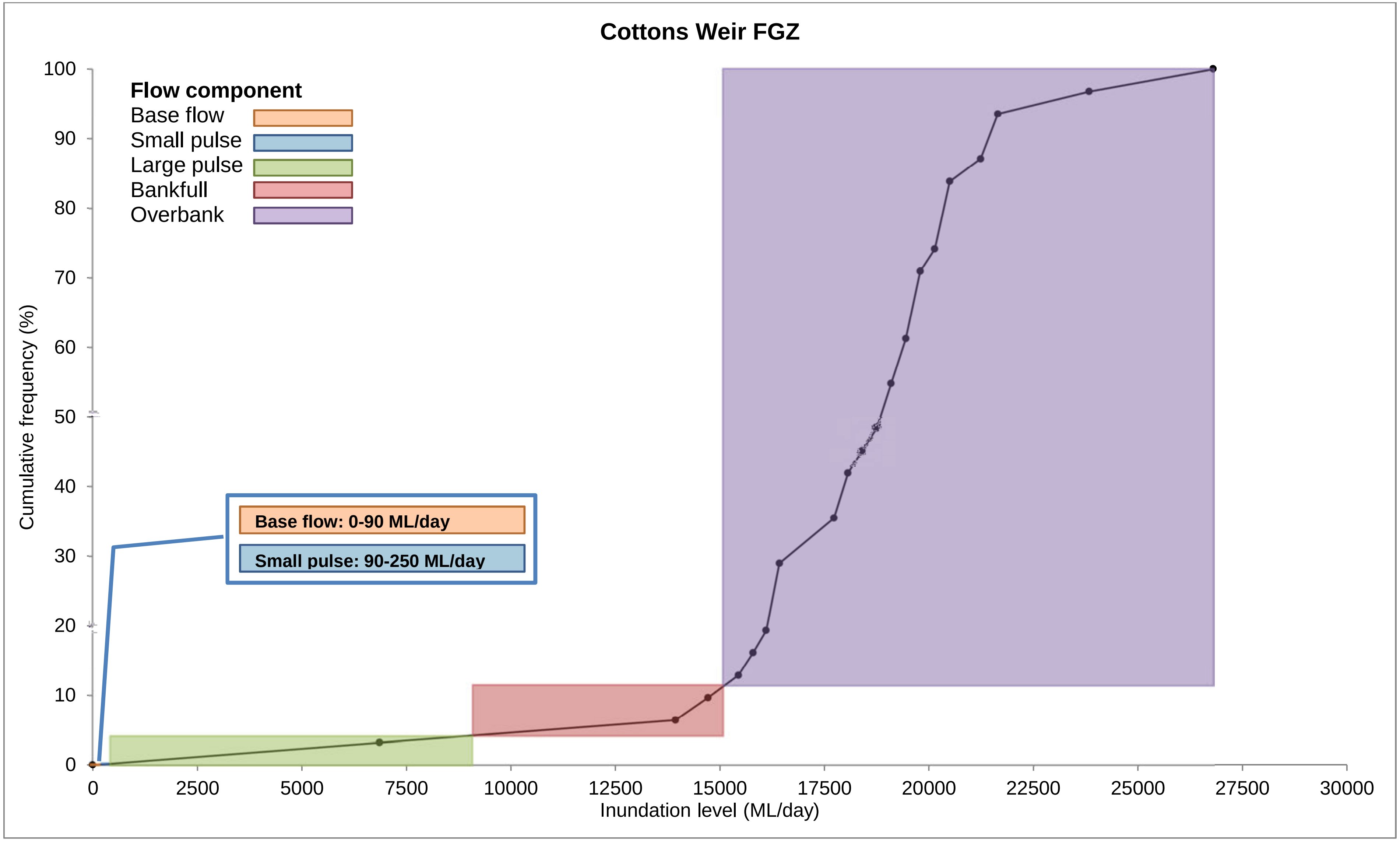


Figure 50. Cumulative inundation frequency curves for connected wetlands in Cottons Weir FGZ.

5.5. Water management implications from flow analysis

This project has enabled the generation of a dataset that has assisted with quantifying the contribution that a flow event in 2015 made to the ecologically significant components of the flow regime in the reaches of the Lachlan River below Wyangala Dam to Cottons Weir. *The Water Sharing Plan for the Lachlan Regulated River Water Source 2016* and the previous iteration of the Lachlan Water Sharing Plan contain translucency rules which require a portion of the inflows to Wyangala Dam to be released to mimic a proportion of natural flow conditions downstream. Translucent flows can only be made from Wyangala Dam or the downstream tributaries during the period from the 15th May to the 15th November if inflows to the Dam exceed 250,000 ML in that calendar year.

Translucent flows are to be made when the combination of Wyangala Dam inflows plus downstream tributary inflows are sufficient to produce a target level at Brewster Weir. The target levels are reached when flows provide a flow of 4,000 ML/day at Brewster Weir when Wyangala Dam is less than 50% of the full supply volume (FSV) or 3,500 ML/day when the Dam is greater than 50% of the FSV.

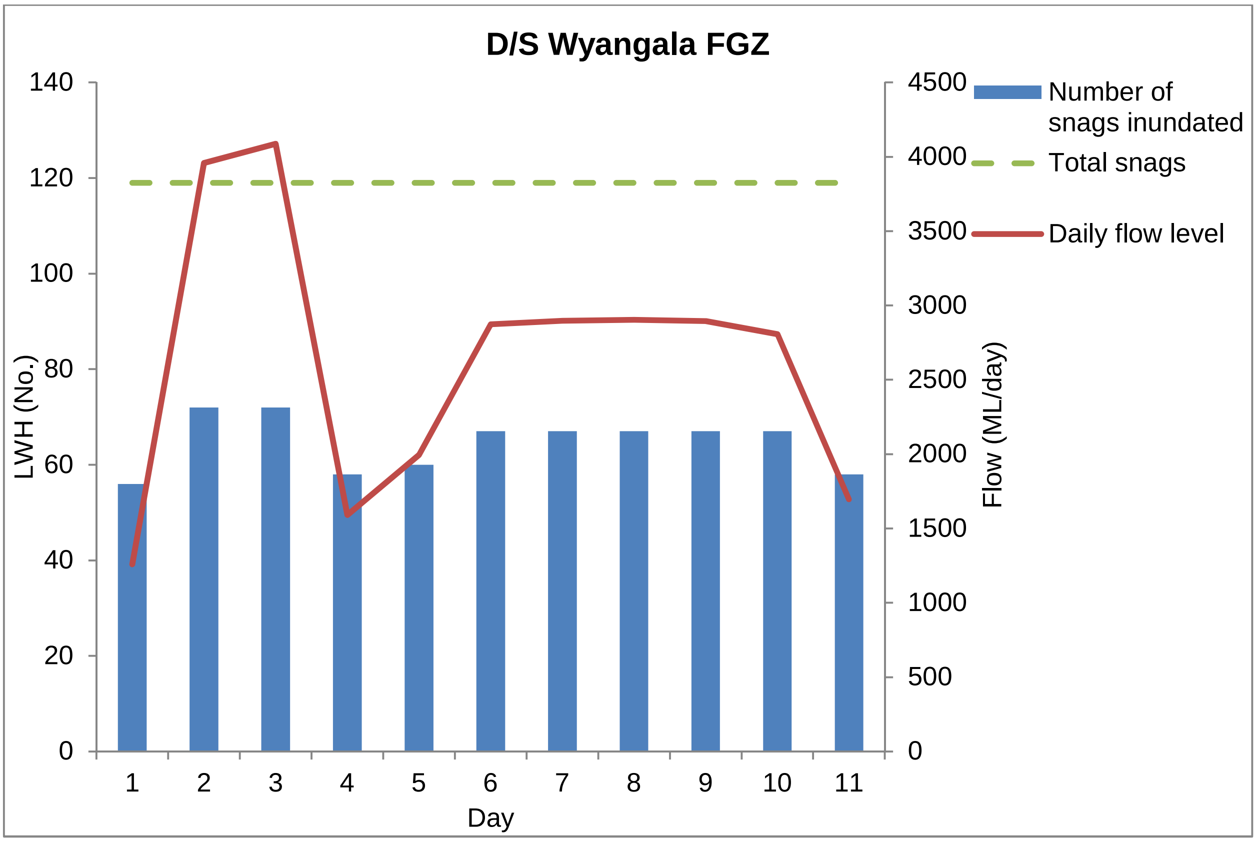
The volume of translucent flows can vary from 3,500 ML/day to 8,000 ML/day at Lake Brewster depending on the volume of water in Wyangala Dam. Translucent flows can be made up of a combination of tributary flows and dam releases. The outlet valves at Wyangala Dam only have the capacity to release 7,400 ML/day, however when the storage exceeds 55% it is possible to release water via the spillway gates. The translucent flows are then capped if flows below Lake Brewster Weir exceed 350,000 ML (excluding releases for water orders, replenishment for effluent streams and environmental flows) since June that calendar year.

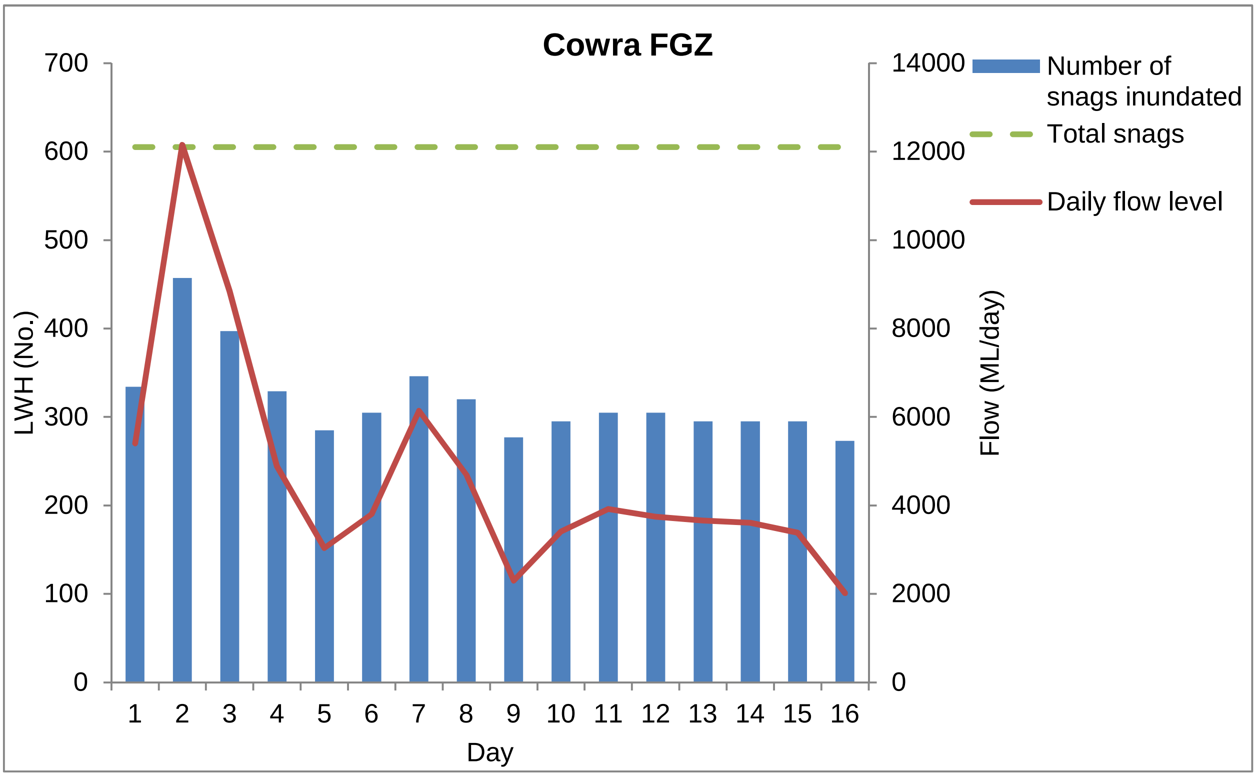
In August 2015 translucent flow rules were triggered in the system and an event that peaked at 5,500 ML/day at Brewster Weir was allowed to pass through the system. The flow was the result of a combination of releases from Wyangala and tributary flows from a substantial rain event. In the project area, the flow peaked at 18,172 ML/day at Nanami which is over 12,000 ML/day more than at Lake Brewster. The translucent flow duration and magnitude varied between Flow Gauging Zones as a result of stream hydrology and channel morphology.

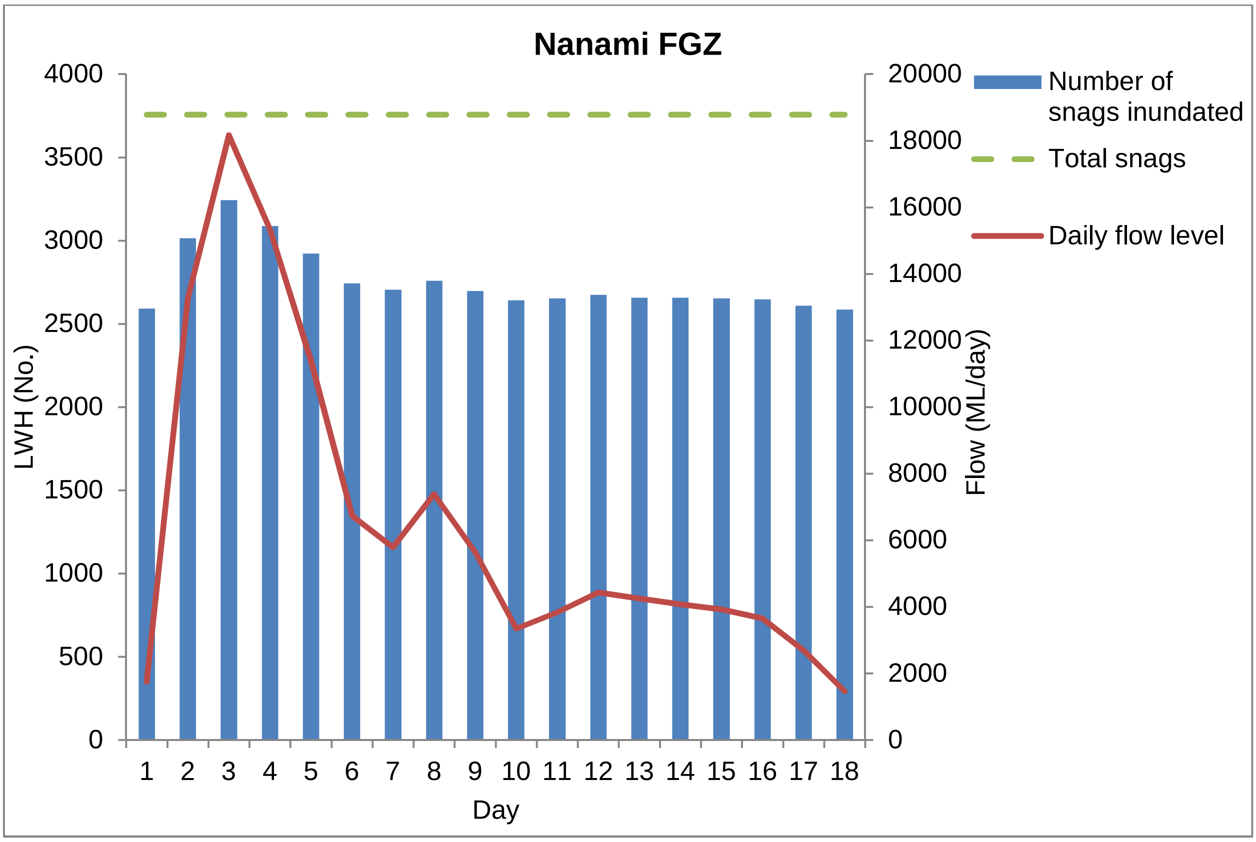
As the translucent flow peak passed through the river reaches, quantities of LWH were submerged, benches were inundated and water exited the main channel of the river into connected wetlands. The contribution of these features into river productivity processes such as carbon inputs and trophic webs are generally understood but rarely quantified or deliberately targeted in management actions and objectives because of deficits in reach-specific information. The information gathered has great potential to inform objective setting and specific environmental outcomes relating to water management and in particular, availability of specific assets during events.

5.5.1. Large Woody Habitat inundation in 2015 translucent flow event

The largest impact on LWH inundation was seen in the Cowra and Nanami FGZ, while little variation was seen in the other FGZs (Figure 51). The smallest impact was seen in the Cottons Weir FGZ which may be attributed to the location of the gauge in the weir pool. No FGZ had 100% of existing LWH inundated by the translucent flow.


D/S Wyangala FGZ
LWH (No.)
Flow (ML/day)
Day
Number of snags inundated
Total snags
Daily flow level
140
120
100
80
60
40
20
0
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1 2 3 4 5 6 7 8 9 10 11


Cowra FGZ
LWH (No.)
Flow (ML/day)
Day
Number of snags inundated
Total snags
Daily flow level
700
600
500
400
300
200
100
0
14000
12000
10000
8000
6000
4000
2000
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16



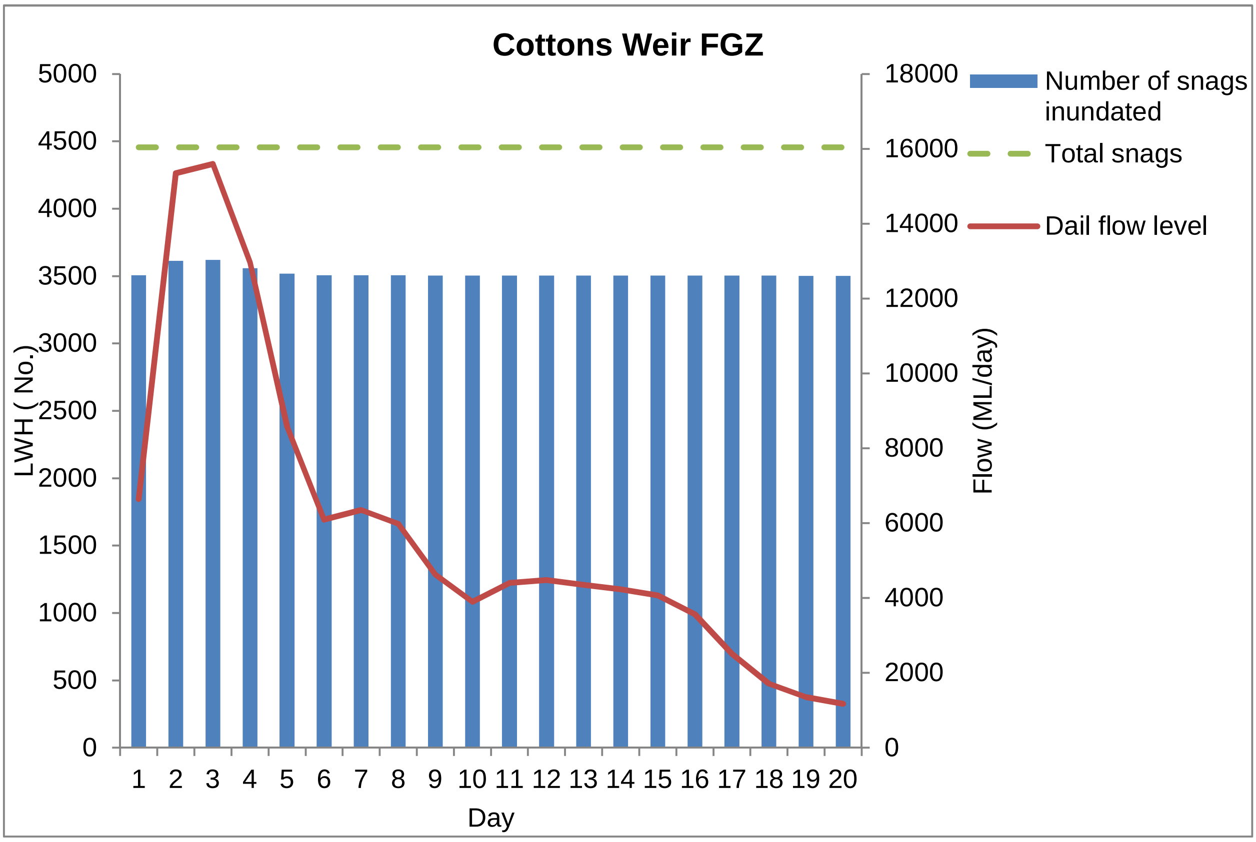
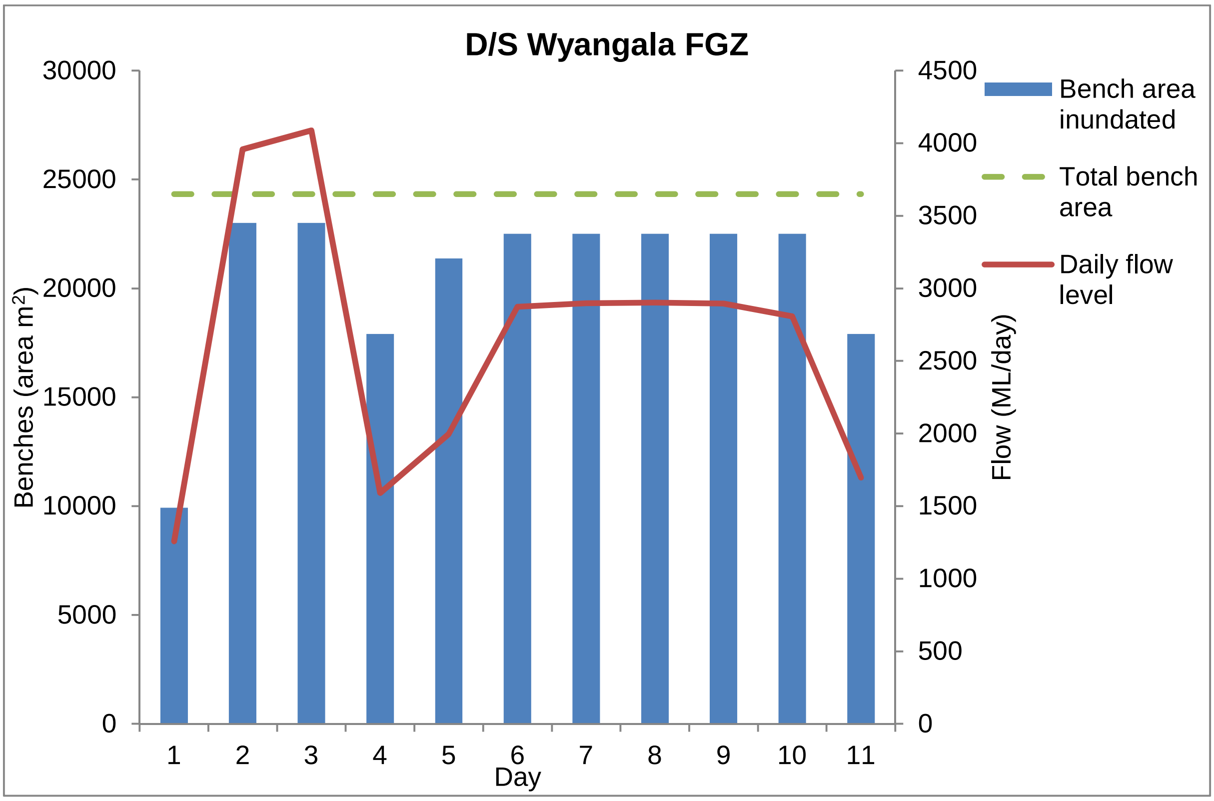
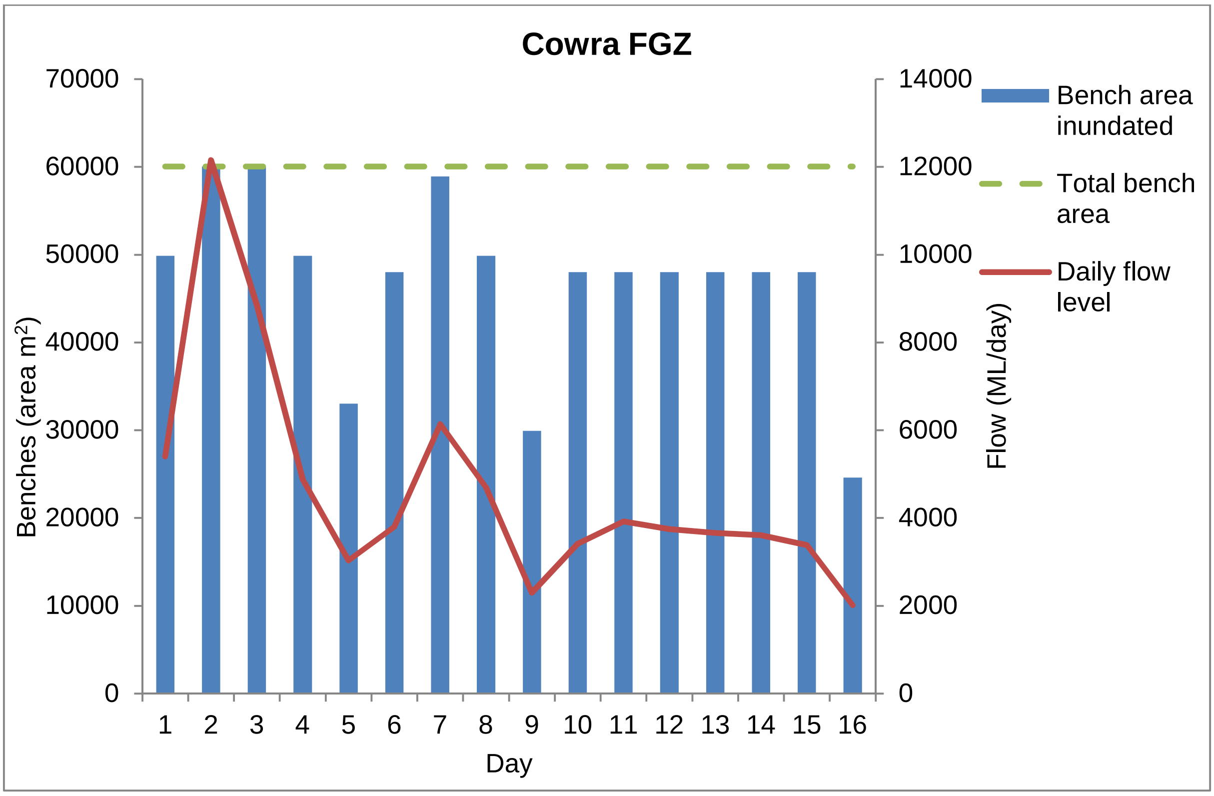


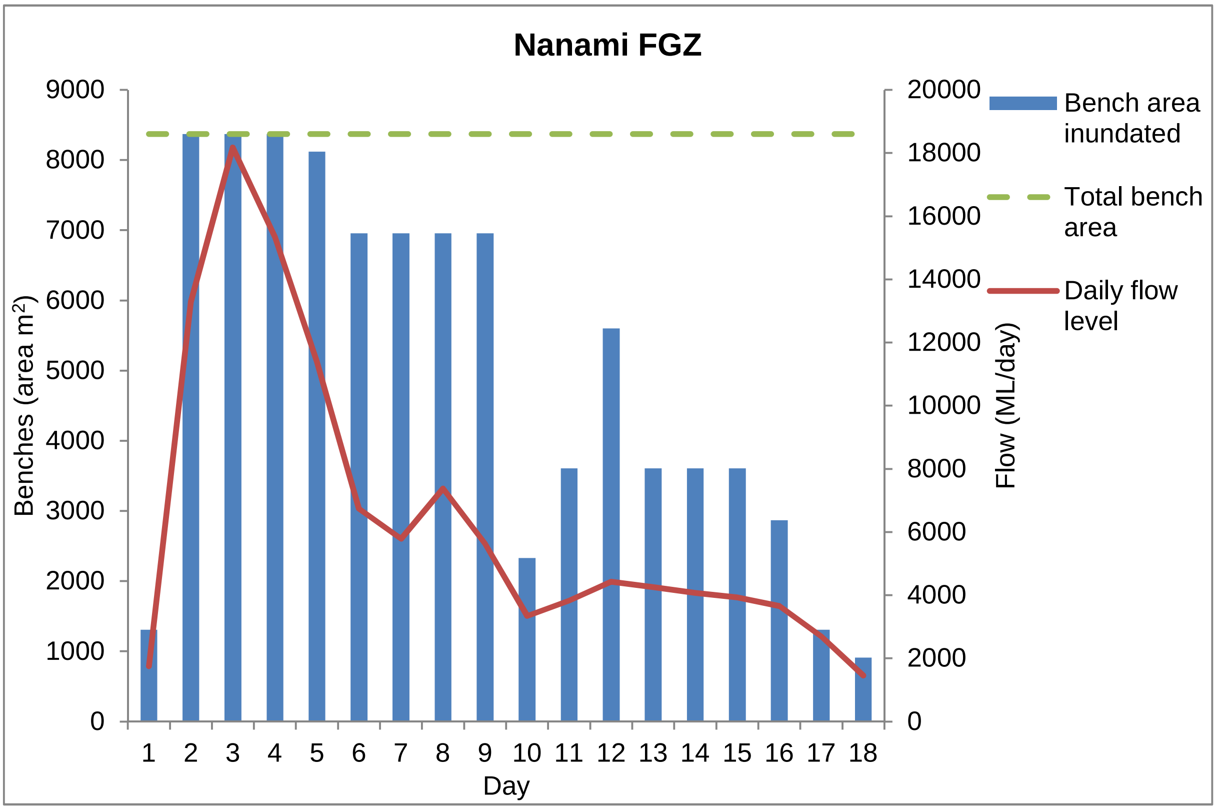
Figure 51. Number of LWH inundated in each FGZ by the 2015 translucent flow.

5.5.2. Bench inundation in 2015 translucent flow event

Considerable variation in bench area inundation was seen as a result of the 2015 translucent flow. The bench area inundated increased substantially in the Nanami FGZ from just over 1000 m^2 to 100% of the total bench area (8,372 m^2) the following day with the peak of the flow. Releases from Wyangala were substantially increased on the second day of the event followed by a sharp recession and a small rise with relatively stable inundation levels ensuing. The largest bench area overall was inundated in the Cowra FGZ. Cottons Weir FGZ saw a considerable increase from no bench area inundated to a peak of 3546 m^2, however there was only four days with any bench inundation in this FGZ.




Cowra FGZ
Benches (area m2)
Flow (ML/day)
Day
Bench area inundated
Total bench area
Daily flow level
70000
60000
50000
40000
30000
20000
10000
0
14000
12000
10000
8000
6000
4000
2000
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16


Nanami FGZ
Benches (area m2)
Flow (ML/day)
Day
Bench area inundated
Total bench area
Daily flow level
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

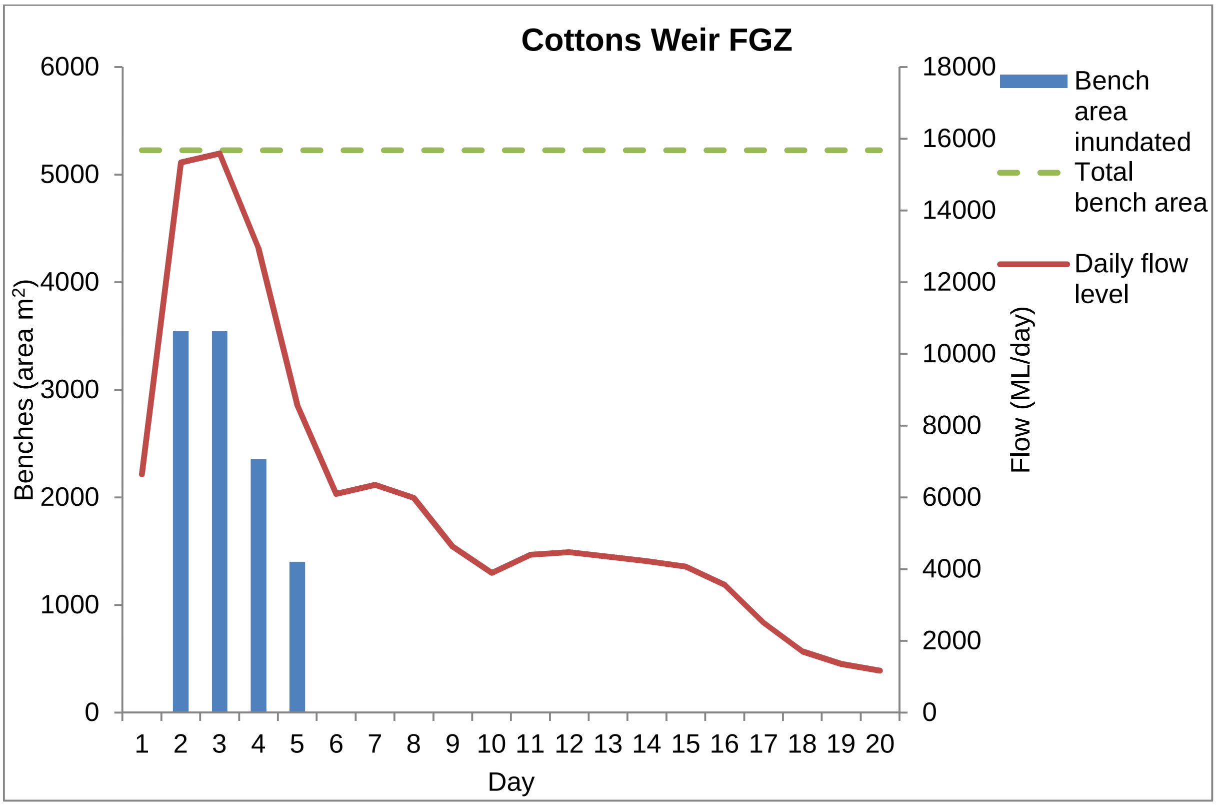
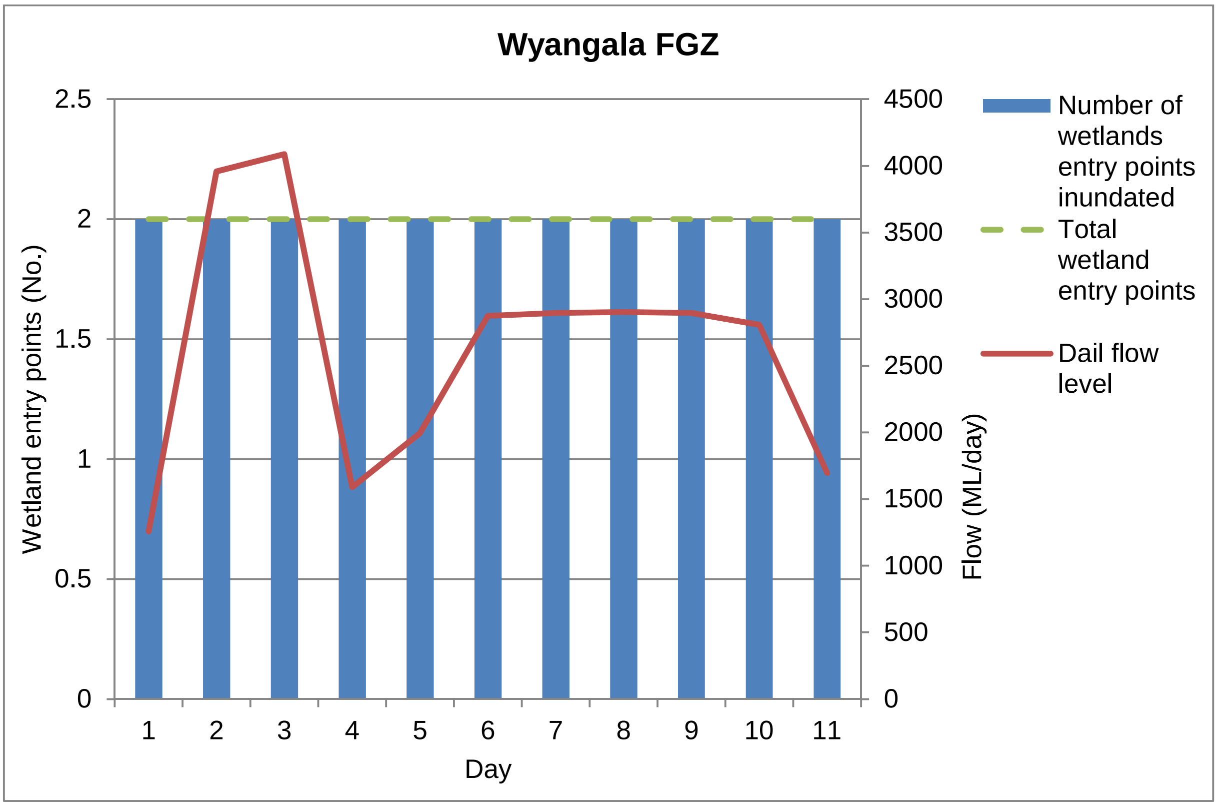
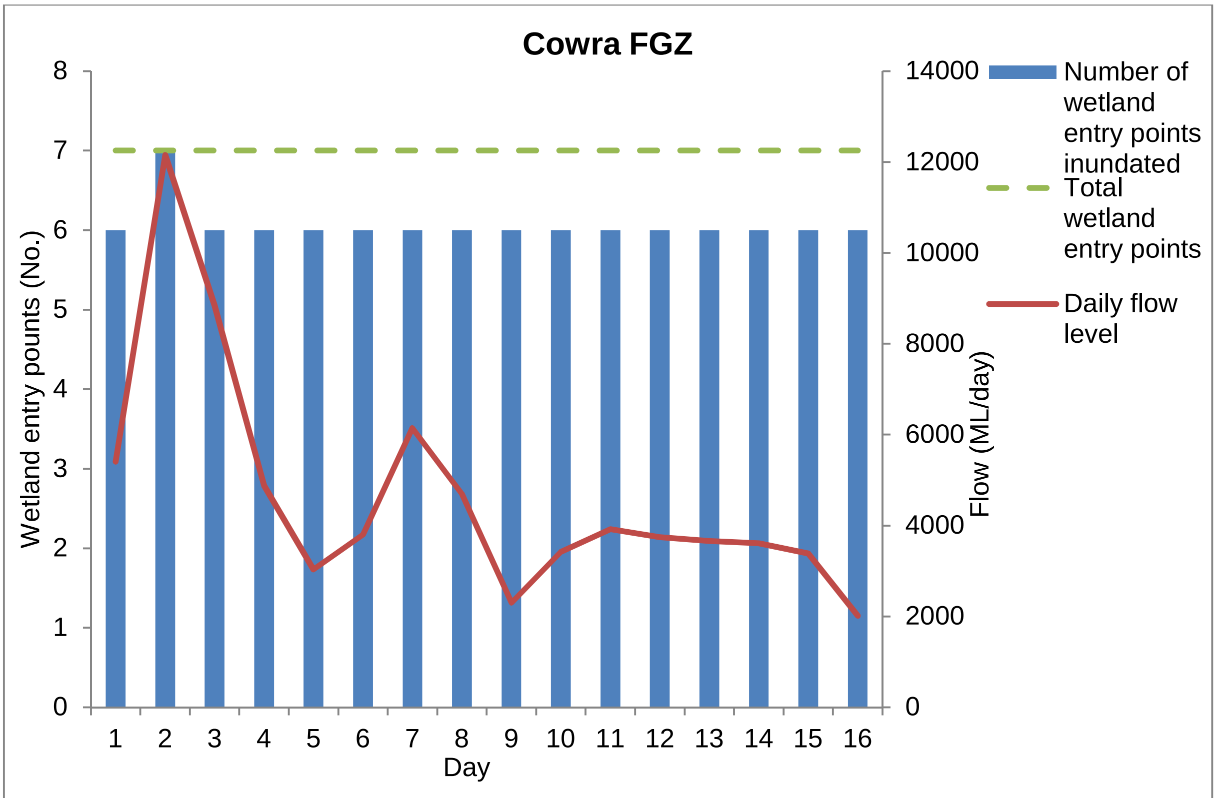


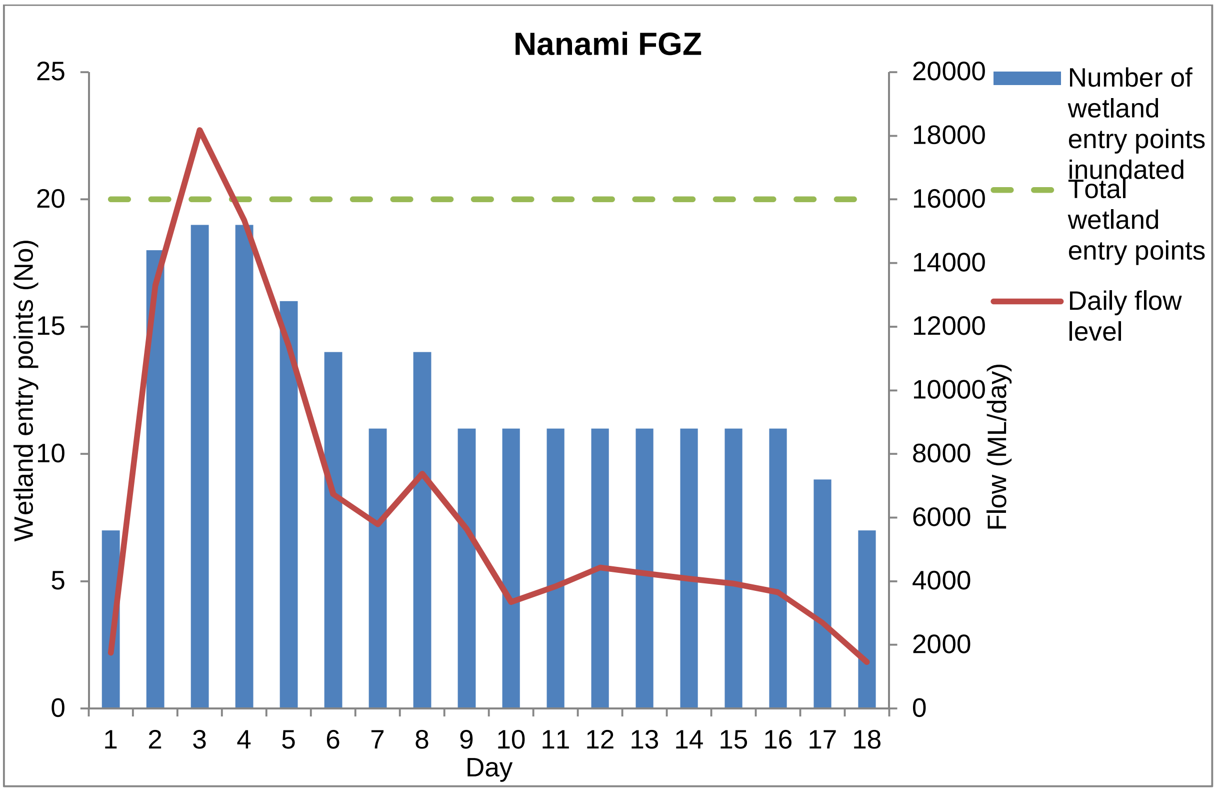
Figure 52. Bench area inundated in each FGZ by the 2015 translucent flow.

5.5.3. Wetland entry point inundation in 2015 translucent flow event

The 2015 translucent flow resulted in considerable inundation of wetland entry points in the Nanami and Cottons Weir FGZ, however there were still very few entry points inundated in the Cottons Weir FGZ (Figure 53). There was only the inundation of one additional entry point in the Cowra FGZ, however this made 100% of entry points in this FGZ. The two entry points in Wyangala FGZ are inundated at 0-80 ML/day.







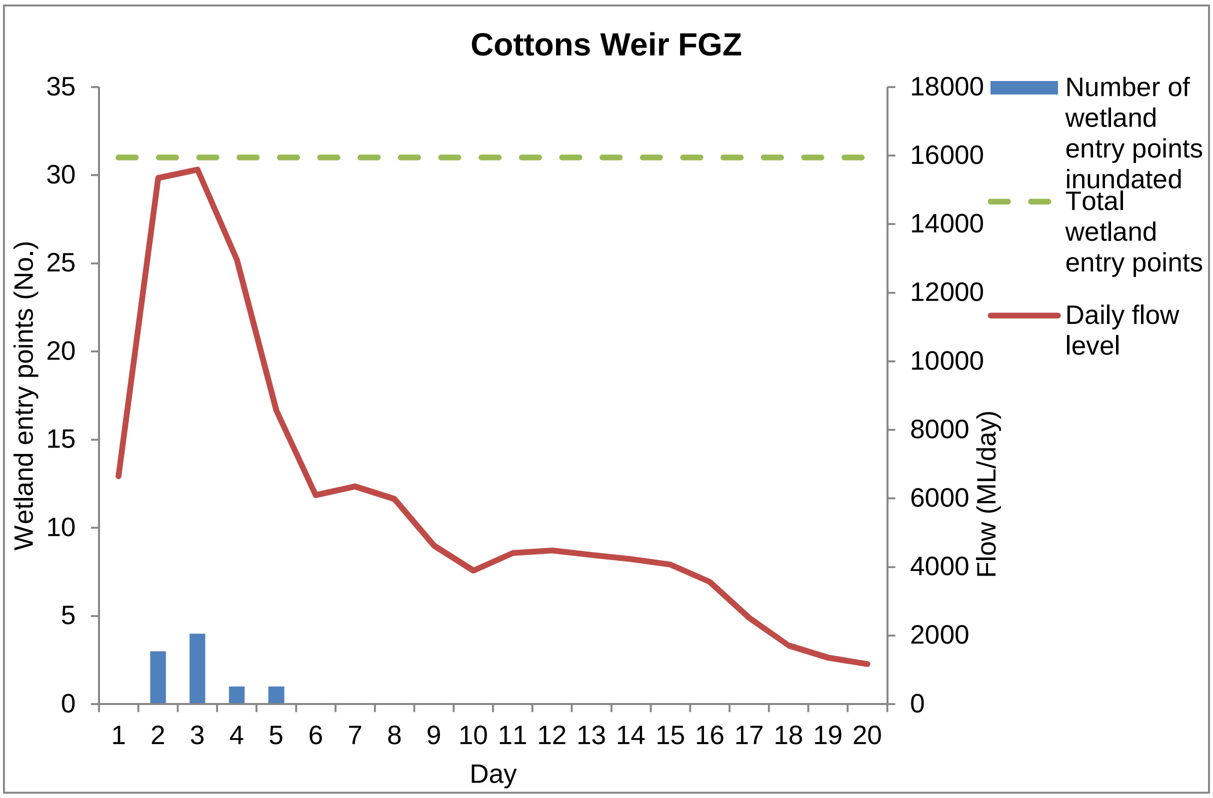


Figure 53. Number of wetland entry points inundated by the 2015 translucent flow.

5.6. Impacts on habitat condition

5.6.1. Livestock access and damage

Constant livestock grazing reduces natural regrowth of trees, shrubs and grasses and can result in complete loss of some or all of these important vegetation layers on the banks of rivers and streams. Poorly managed grazing pressure can also contribute to bank erosion and loss of productive land. Banks denuded of vegetation are highly susceptible to erosion which in turn leads to increased turbidity and eutrophication of waterways. Livestock manure can also impact on downstream water quality and the health of others using the waterway for recreational (swimming) and commercial use (e.g. aquaculture production, town water) (NSW DPI, 2012). Cattle defecate 25% of the time when drinking, with 1kg of phosphorus from manure resulting in up to 500 kg of algal growth (Fitch *et al*. 2003).

Overall, the extent of bank instability and damage caused by livestock trampling throughout the study area was variable as shown in Figure 54. In upper management reaches the extent was relatively low, however it increased in the Nanami and Cottons Weir Flow Gauging Zones. Note that the area of each reach is 40 ha.

In the project area, 6.2 ha of stock damage was recorded with most of this extent found between Gooloogong and Forbes. The impacts of stock and grazing activity were noted to varying degrees across the majority of the project area, however there are differing impacts up and downstream of Reach 10, possibly due to land form or soil type. The highest level of damage was seen in Management Reach 21 (Figure 55) which was in close proximity to the township of Forbes (Figure 54).

There is a low amount of riparian fencing; of the 422 km of riverbank just 48.42 km of fencing was recorded in the project area. Many permanent waterways are seen as a generally reliable source of stock water and a boundary fence substitute that requires little or no maintenance. The consequences of these stocking practices are that native vegetation has no opportunity to recover, seeds that do germinate are trampled or eaten and the condition of the riparian area becomes severely degraded.

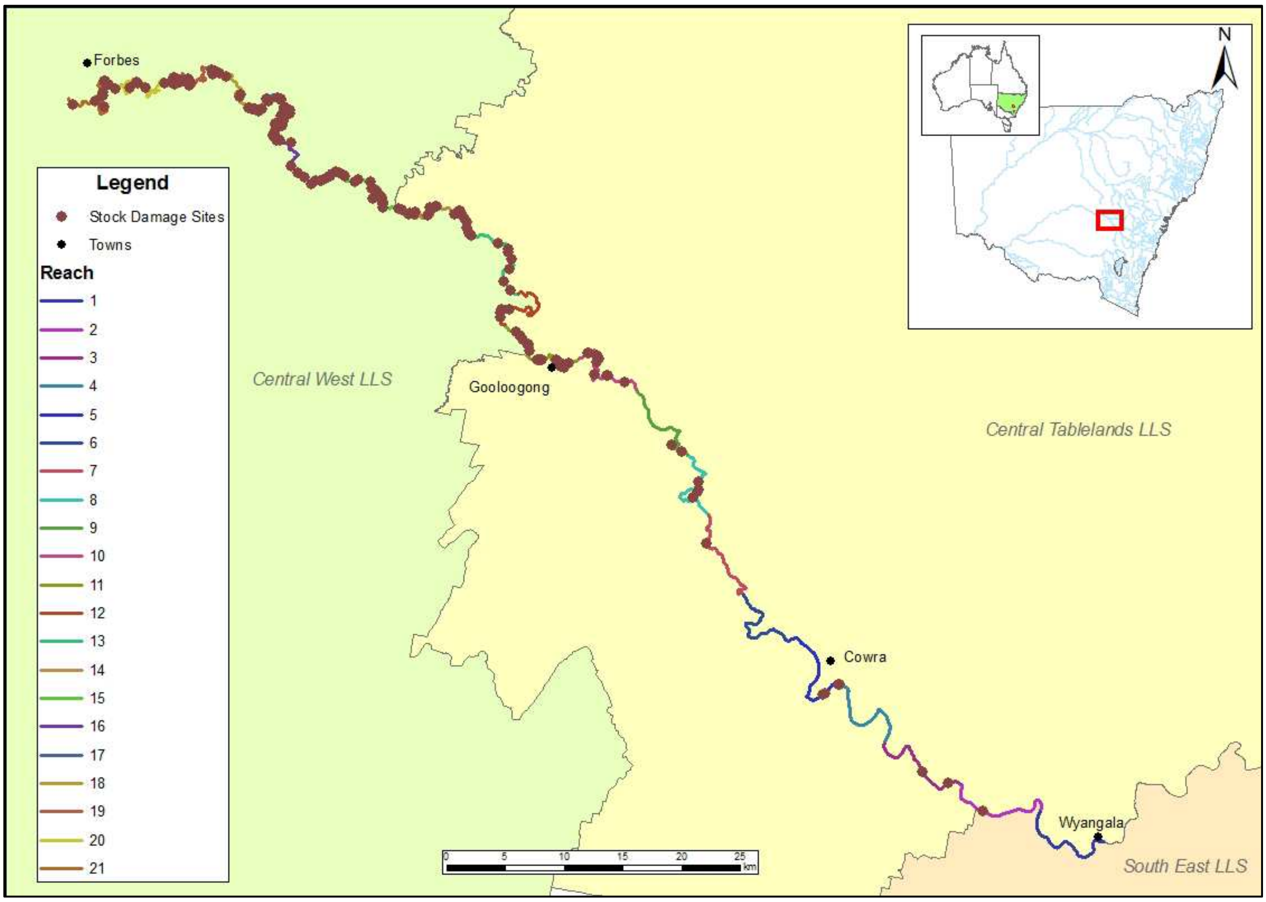


Figure 54. Stock damage sites in the project area.

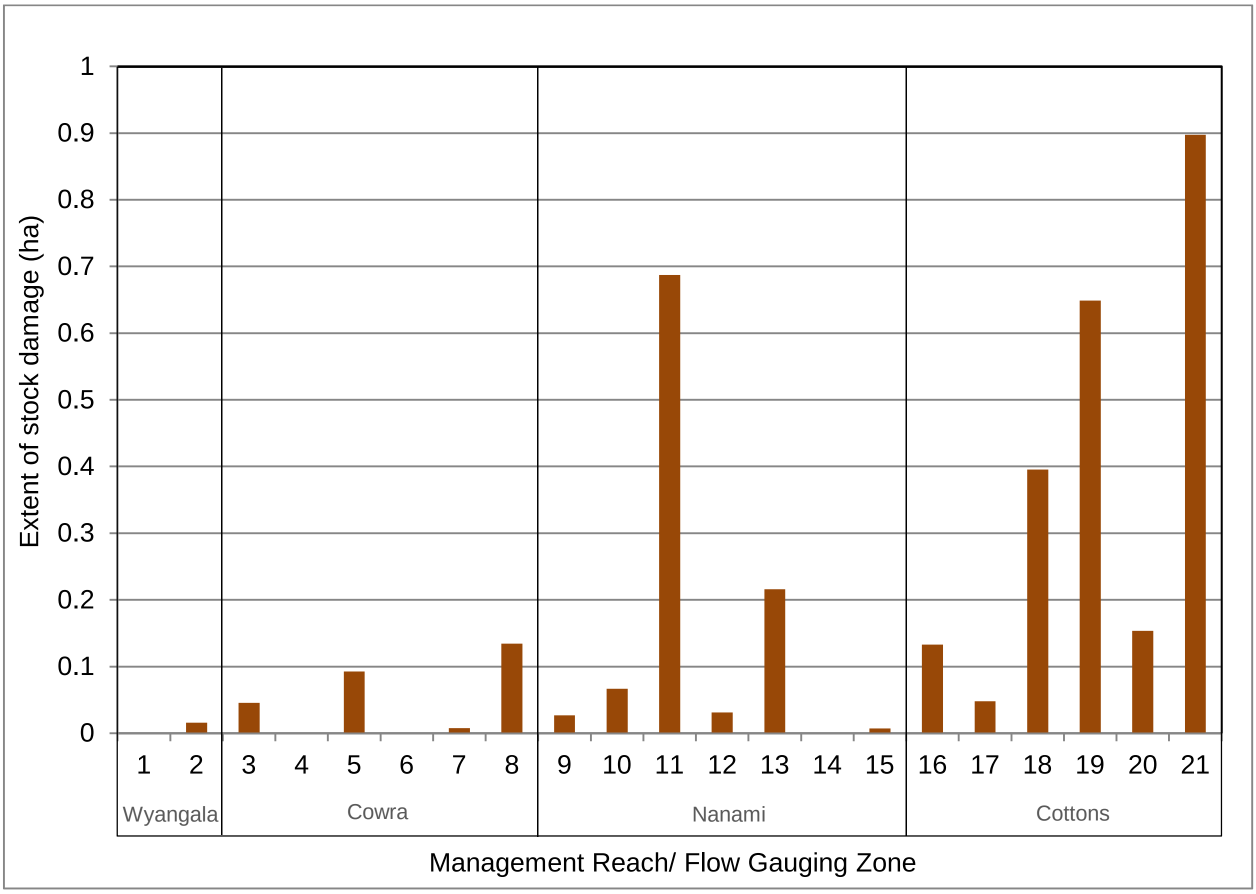


Figure 55. Extent of stock damage by Management Reach.

5.6.2. Erosion

While it is a dynamic and natural process, streambank erosion can be accelerated by the influence of human activities (BRG CMA, 2010). Erosion in waterways can result in siltation of refugia, increased turbidity and increased eutrophication.

For the aquatic environment the impacts include: loss of fish habitat; reduction in light penetration and therefore a loss of submerged aquatic macrophytes and; increased risk of algal blooms. For agriculture the loss of riparian land to erosion over subsequent flood events can result in the loss of significant areas of cropping land (NSW DPI, 2016).

Erosion in the project area was confined to two reaches, with just 325 m^2 of the study area affected. However, sediment input from the erosion in the Boorowa River catchment has resulted in the formation of a sediment slug which is having a severe impact on several management reaches in the project area as can be seen in Figure 56. From the confluence of the Boorowa River to Management Reach 11 (90 km) there are no refuge holes, while between Reach 11 and Reach 16 (40 km) there are just 34 refuge holes.

The scale and impact of the issue can be appreciated when it is considered that in the Lachlan River below the sediment slug from Reach 16 to Reach 21 (60 km) 147 refuge holes were identified. The Boorowa River catchment is entirely in the South East Local Land Services Area and the impacts of sediment transfer has spread beyond individual sites and is having far reaching consequences such as infilling refuge holes, covering gravel beds and LWH with silt and increasing turbidity.

Erosion was recorded at three sites in two management reaches (2 (two sites) and 15 (one site)). Reach 2 recorded the highest total area of erosion with 185 m^2 (Figure 57). In comparison to stock damage, erosion was relatively minor.

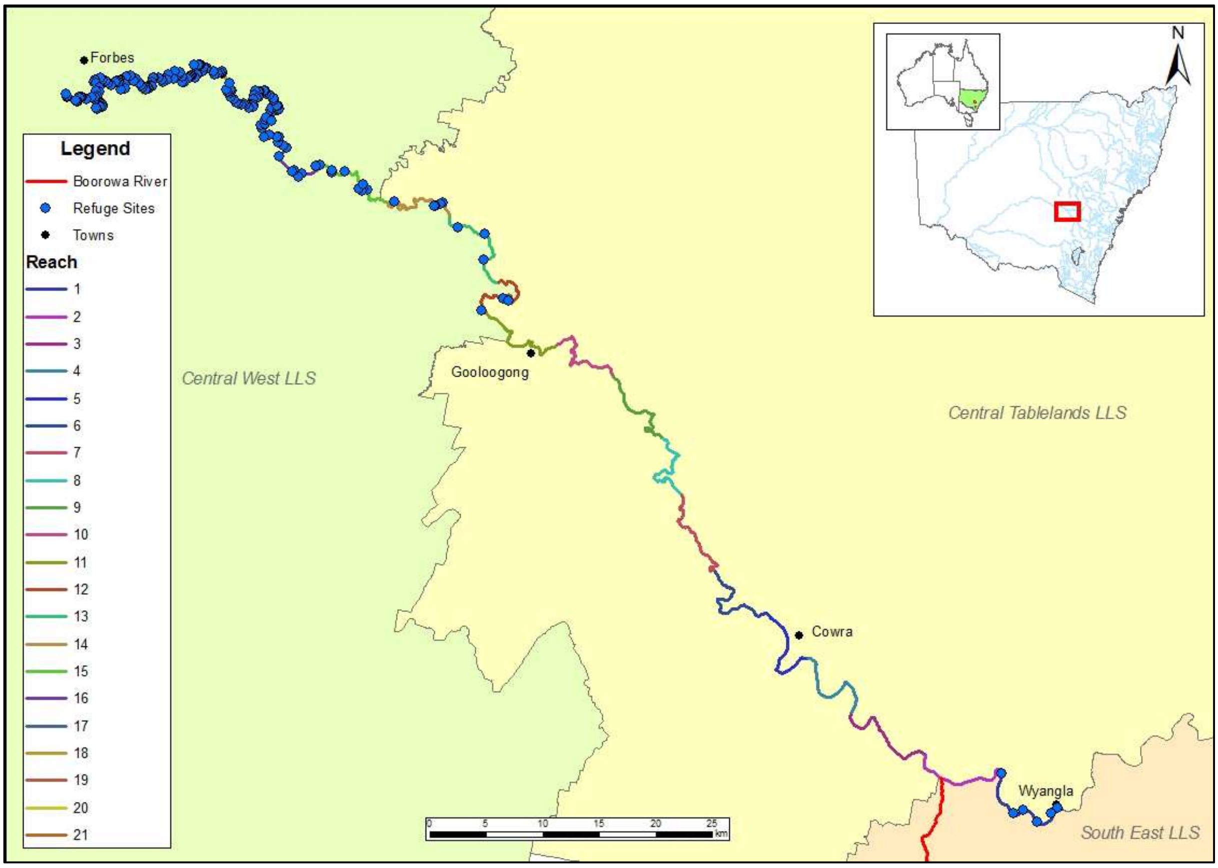


Figure 56. Decreased number of refugia in reaches downstream of the Boorowa-Lachlan confluence for a distance of approximately 90 km.

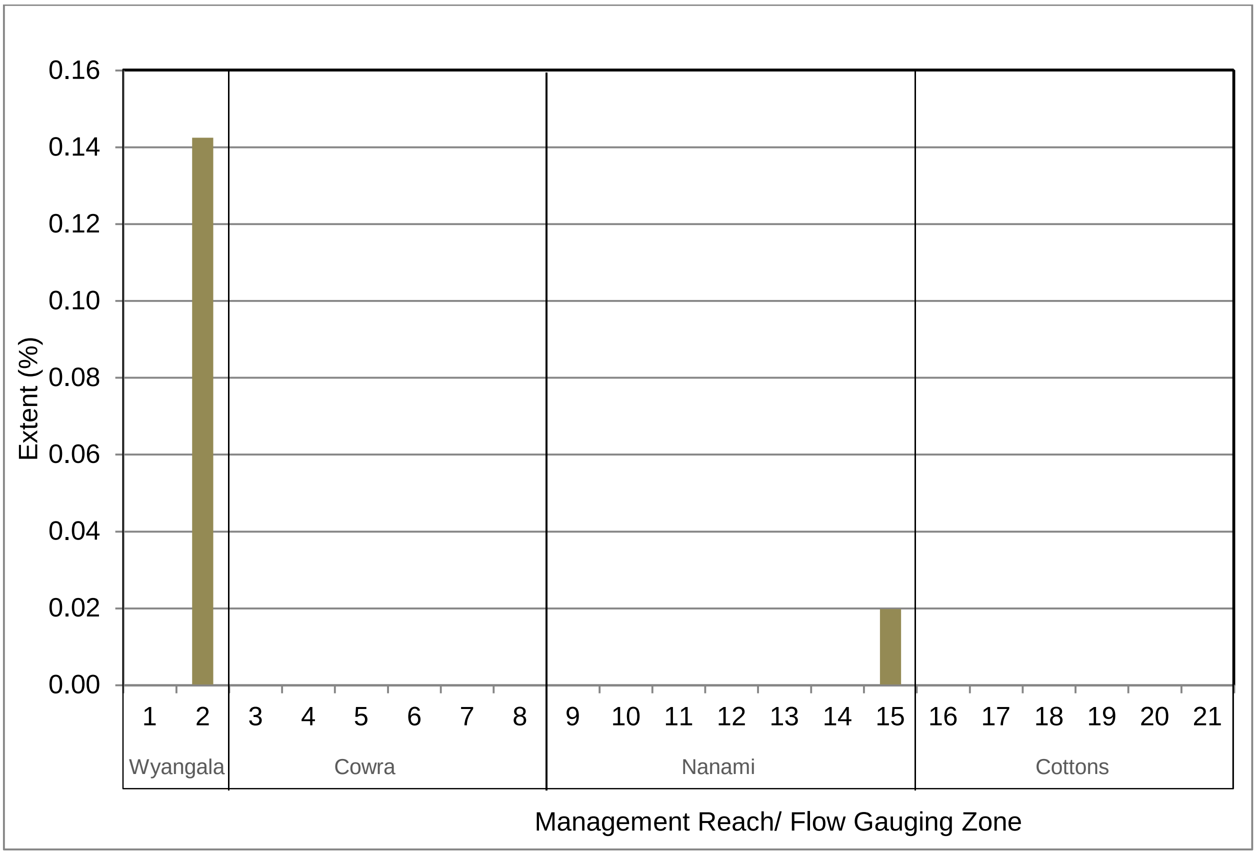


Figure 57. Erosion extent by Management Reach.

5.6.3. Fish passage

Australian native fish have evolved to be reliant on a variety of habitat types to complete their life cycle. One of these habitat requirements is the need to migrate both short and long distances to move between varying aquatic environments (Thorncraft and Harris, 2000; Barrett, 2008; Fairfull and Witheridge, 2003). 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.

Unfortunately, riverine connectivity has been severely disrupted within Australia by the creation of instream barriers to migratory fish that limit habitat and resource availability and diminish the opportunities for species to adapt to changing environmental conditions (Pethebridge *et al.* 1998). Instream barriers also impact on the diversity and hydrodynamic complexity of habitats by creating areas of low to no flow environments (Figure 58).

The installation and operation of instream structures, and the alteration of natural flow regimes, have been recognised as Key Threatening Processes under the *Fisheries Management Act 1994* (FM Act) and the *Threatened Species Conservation Act 1995*.

Three weirs were recorded in the project area (Figure 59), two of which presented a significant barrier to fish passage. Barriers were recorded in reaches 1 and 21. Wyangala Dam (Figure 60) in Reach 1 and Apex Weir (Figure 61) & Cottons Weir (Figure 62) in Reach 21. Wyangala Dam is the biggest impoundment in the Lachlan Catchment and is a fixed crest structure with lift gates in the spillway. Fish passage is not available at this site under any flows.

Figure 58. Section of weir pool with no visible flow (top) and a section of natural river with visible hydrodynamic variability (bottom).

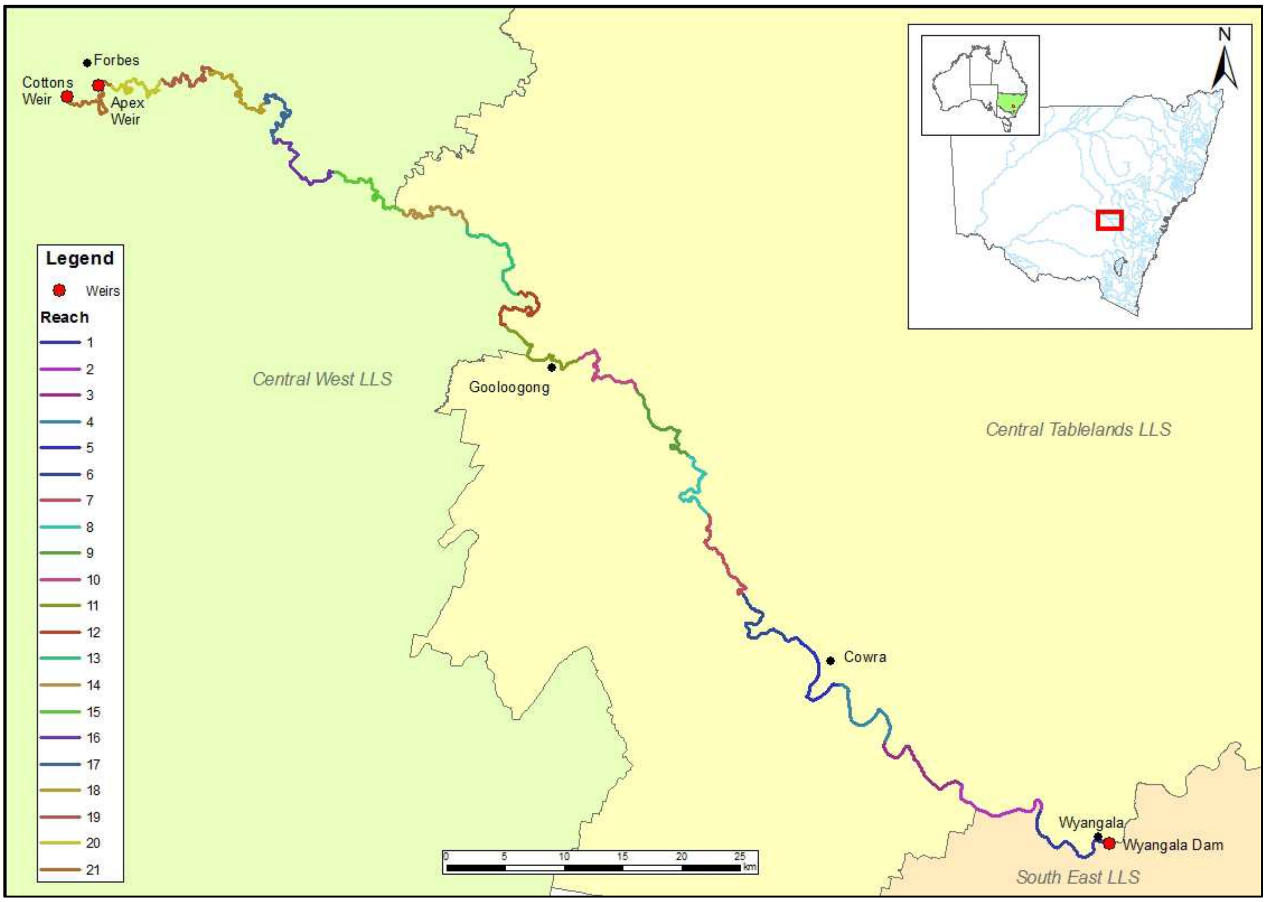


Figure 59. Location of barriers to fish passage created by weirs in the project area.

Apex Weir is a low head fixed crest weir and is approximately 1.2 m high and 20 m wide. It is a barrier at flows <1,000 ML/day (NSW DPI, 2006b). Based on the most recent 30 years of flow data from NSW DPI Water (1986-2016) this site is likely to be a barrier for 40% of the time (Figure 63).

Cottons Weir is a fixed crest structure and is approximately 2 m high and 35 m wide. It is a barrier to fish passage at flows <5,000 ML/day (NSW DPI, 2006b). Based on the most recent 30 years of flow data from NSW DPI Water (1986-2016) this site is likely to be a barrier for approximately 92% of the time (Figure 64).

Figure 60. Wyangala Dam. Image courtesy Water NSW.

Figure 61. Apex Weir. Image taken 21/01/2016, 1,844 ML/day.

Figure 62. Cottons Weir. Image taken 14/09/2015, 1,357 ML/day.

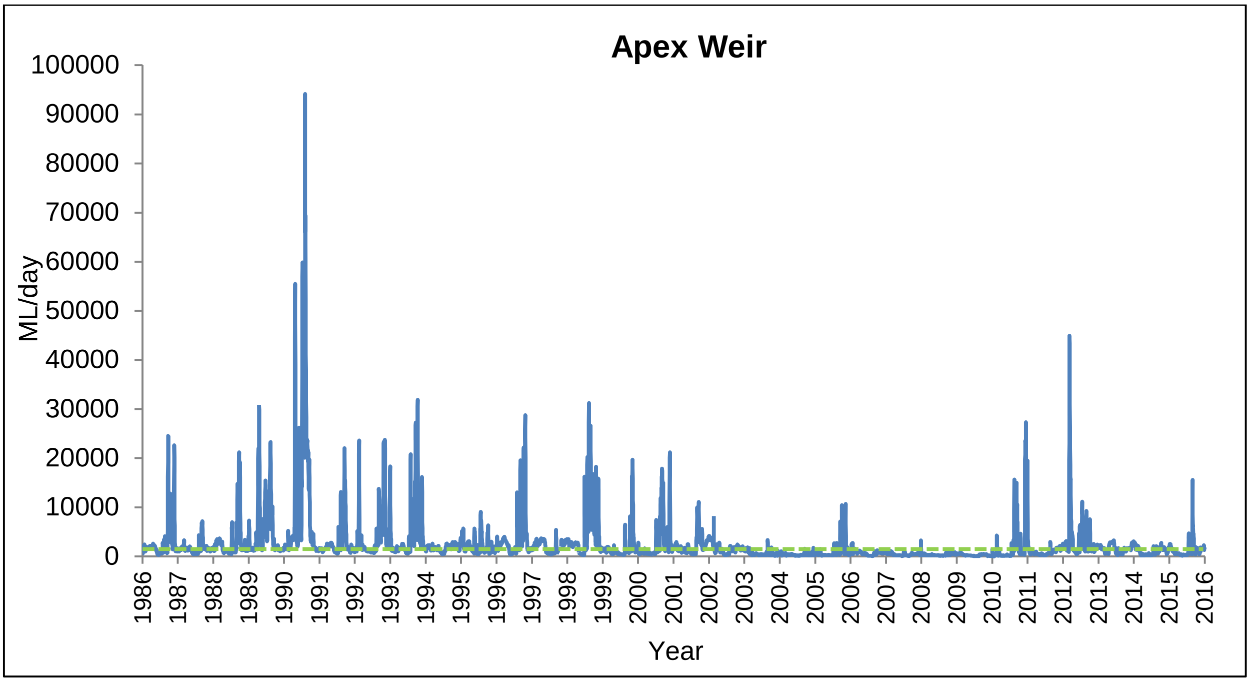


Figure 63. Fish passage availability at the Apex Weir over a 30 year period. Green line indicates approximate flow volume at which fish passage is possible.

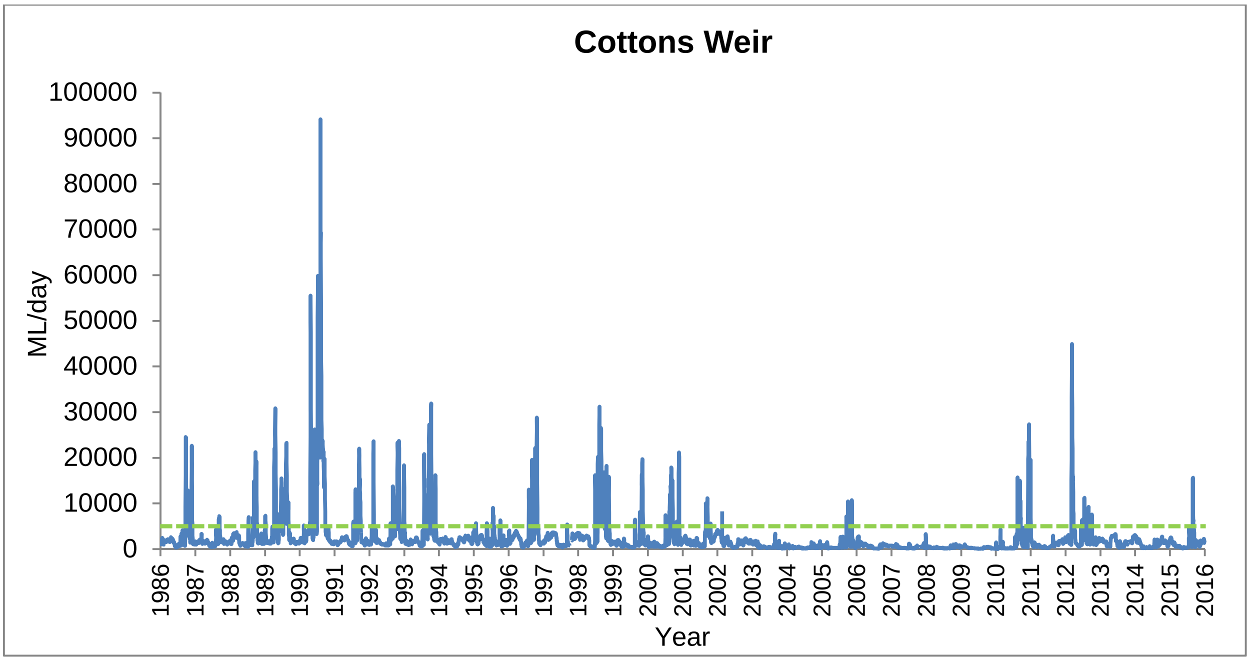


Figure 64. Fish passage availability at the Cottons Weir over a 30 year period. Green line indicates approximate flow volume at which fish passage is possible.

5.6.4. Pumpsites

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). During habitat mapping, 292 pumpsites were found in the project area (Figure 65).

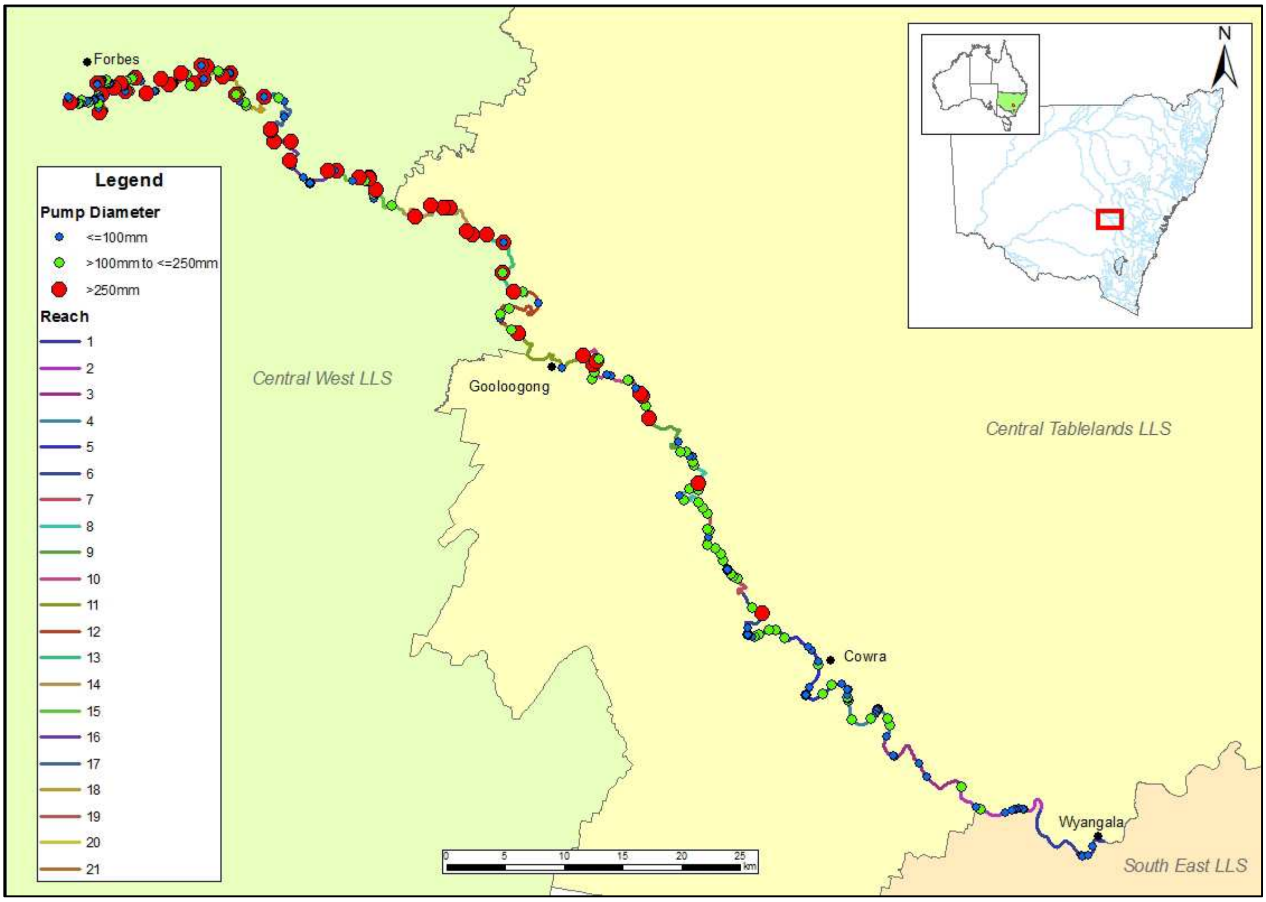


Figure 65. Pumpsite distribution and diameter in the project area.

Pumpsites were categorized in to three size categories <100 mm, 100 mm to 250 mm and >250 mm. The majority of pumpsites (132) were stock and domestic, having a diameter of 100 mm or less (Figure 66 and Table 10). 104 larger diameter pumps of between 100 and 250 mm were also located while a further 56 had a diameter greater than 250 mm. Management Reach 21 had the highest number of pumpsites with 52 recorded (Figure 66). This is likely attributed to the close proximity of the Reach to the township of Forbes.

Table 10. Number of each pumpsite size class.

Size class of pumpsite (diameter)	Number
<100 mm	194
>100 mm to <250 mm	74
>250 mm	95

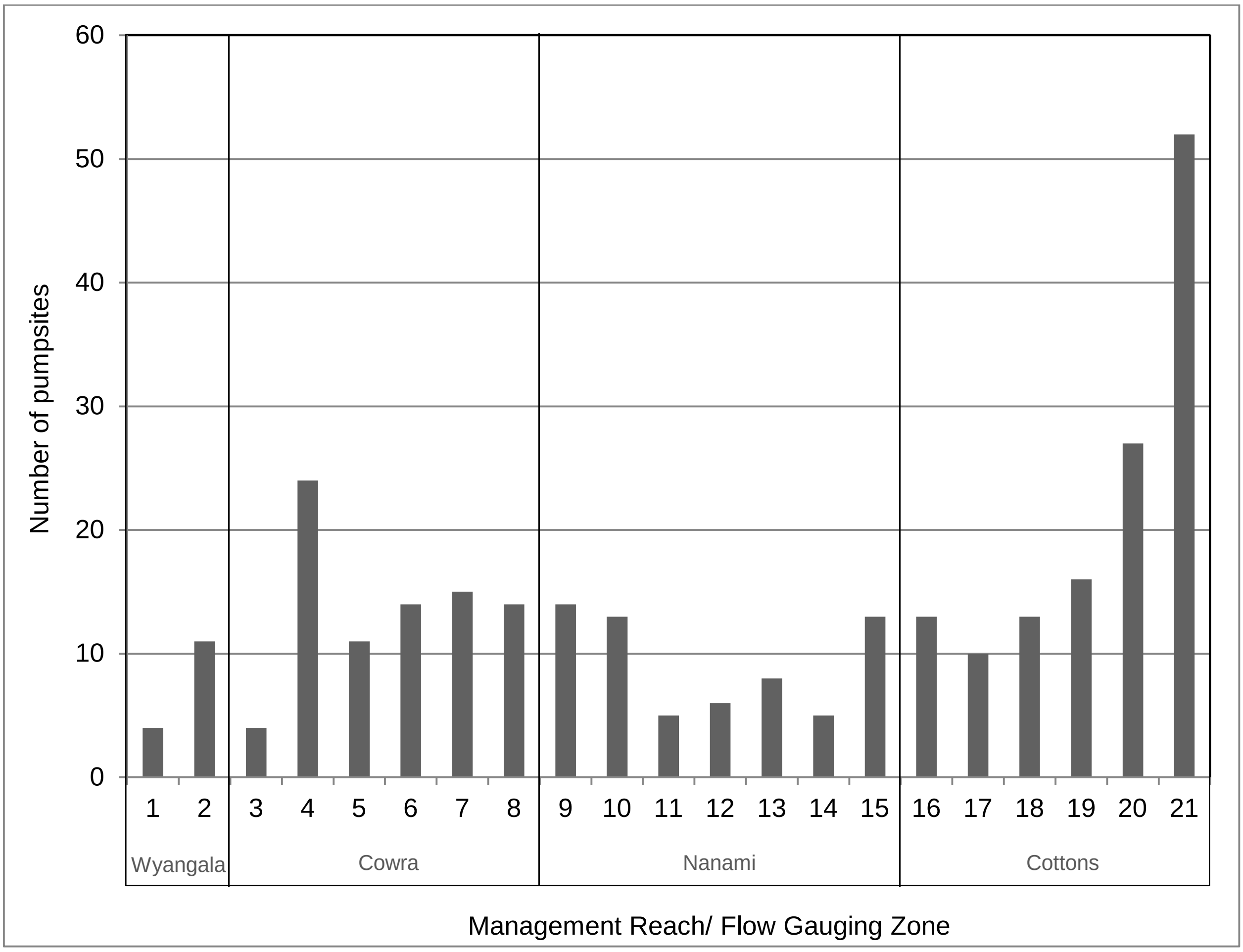


Figure 66. Number of pumpsites in each Management Reach.

In other parts of the world pump screens are routinely used to reduce the number of fish and debris that enter pumps and irrigation systems. One pump site was found to be using a screened pump system as shown in Figure 67. Pump screening considerably reduces the risk of irrigation pumps killing or injuring fish and reduces pump maintenance and operational costs by filtering out debris.

Figure 67. Example of a pump with screen.

5.6.5. Thermal Pollution

Thermal pollution (also called cold water pollution) refers to an artificial lowering of the temperature in a water body. Cold water pollution is caused by cold water being released into rivers from large dams during warmer months. The release of water from deep below the surface of large dams causes significant disturbance to water temperature regimes in downstream river channels with consequent impacts upon aquatic biota and river health (Lugg & Copeland 2014). Between spring and autumn, the water stored in large dams can form two layers: a warm surface layer overlaying a cold bottom layer (Figure 68).

Cold water pollution was not evaluated in this project, however the magnitude of impact is well documented in the Lachlan River below Wyangala due to previous assessments. Its influence is known to extend as far away as Forbes, 210 km downstream (Figure 69), with river temperatures artificially lowered over warmer seasons by as much as 16 degrees Celsius.

In a world first, activities for remediating cold water pollution at Burrendong Dam, in the Macquarie River Catchment have been undertaken, with the installation of a thermal curtain that surrounds the intake tower (Figure 70). While operational protocols have not yet been fully developed the installation of the curtain at Burrendong has reduced the impacts of thermal pollution downstream.

Most older dams are only equipped to draw water from the base of the dam, water that is much colder than the natural river temperature is released downstream, causing cold-water pollution. However, Wyangala Dam has a multi-stage off-take and investigations by stakeholders are ongoing to determine if this can be utilised to address the issue or if a thermal curtain will need to be installed.

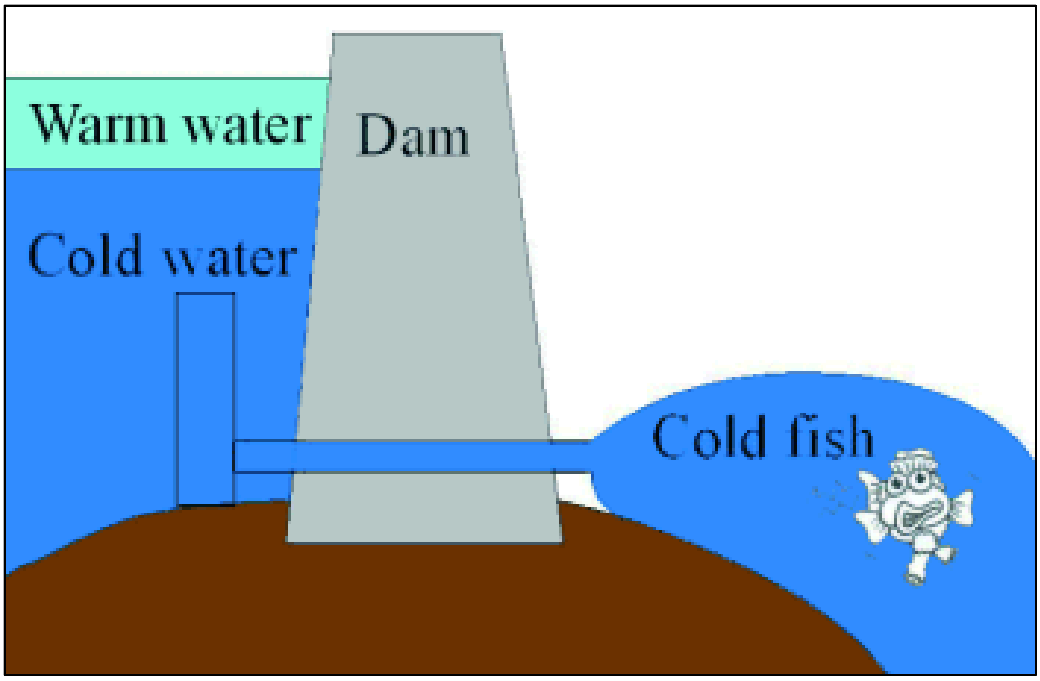


Figure 68. Cold water pollution occurs through drawing of water from the bottom of large storages. NSW DPI, 2005.

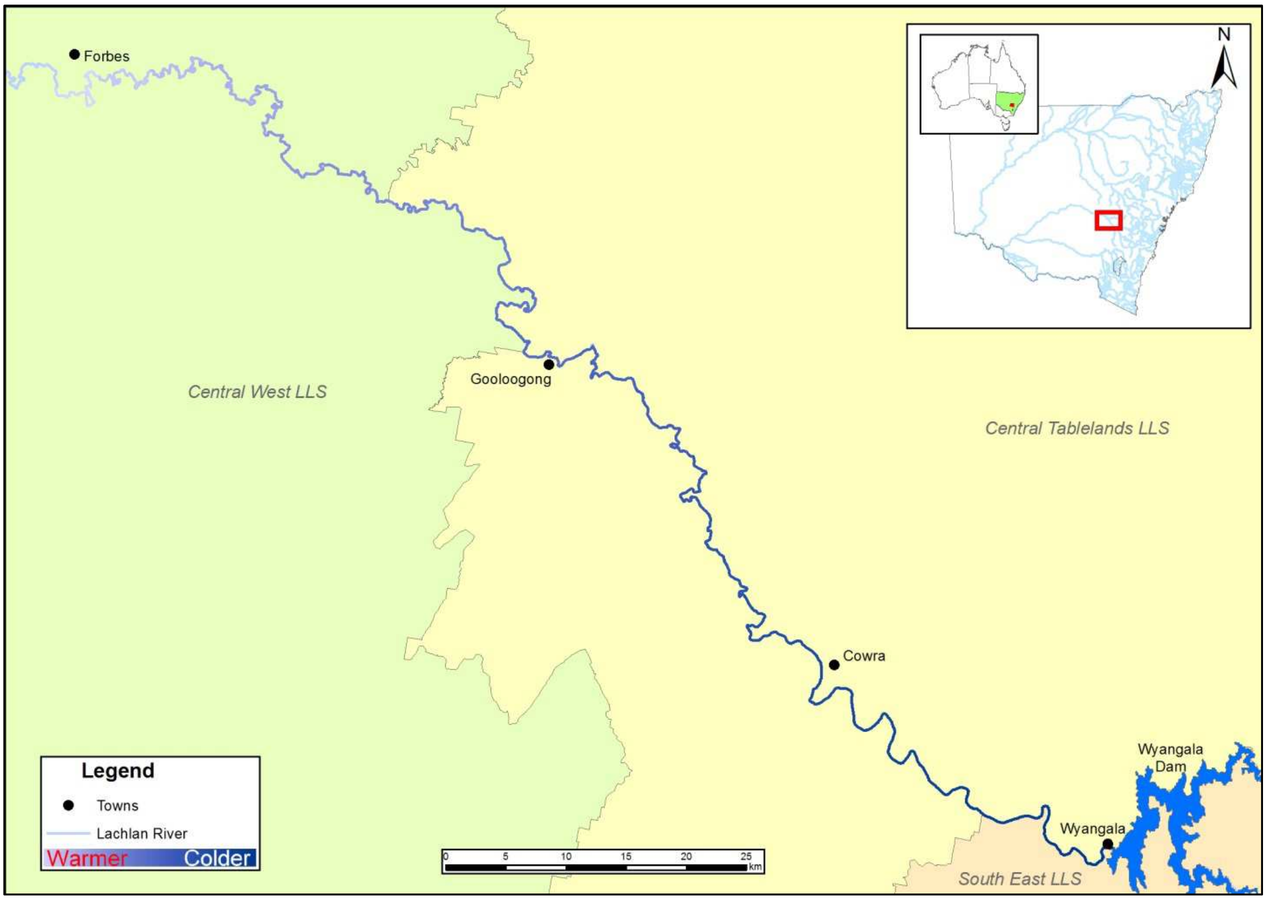


Figure 69. The influence of cold water pollution below Wyangala Dam.

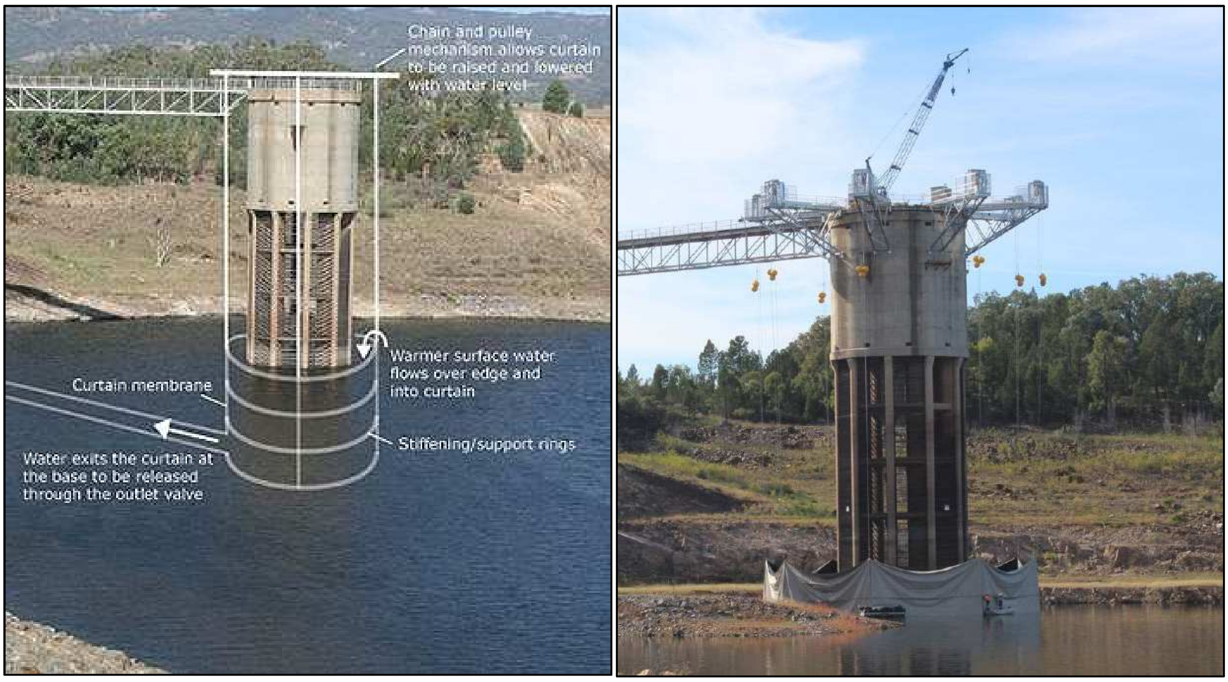


Figure 70. Left: Burrendong Dam offtake tower overlaid with concept features of thermal curtain. Right: The thermal curtain under construction in May 2014 (Images courtesy WaterNSW and Daily Liberal)

6. Management Reach assessments and recommendations

The DSS provided a ranking of reaches based on overall reach condition score. The main drivers for setting priorities include available instream habitat for native fish, such as drought refugia and LWH but can also be influenced by habitat features such as the presence and extent of exotic plants, erosion, stock damage and artificial barriers to fish passage. The impacts of cold water pollution also influenced the scores to some degree for reaches in the project area.

The results of the DSS prioritisation are provided in Figure 71 and Table 11, showing condition scores by Management Reach for individual habitat features, the combined reach condition scores, priority ranking and condition classification. This assessment is based on ecological outcomes, therefore other considerations such as social, economic, political and opportunistic factors may influence investment priorities.

- Green reaches are considered to be in better health and measures should be taken to protect the existing values from future decline and rehabilitate issues posing the greatest threats to these areas where required;
- Amber reaches are considered to be of moderate condition and in need of some repair or rehabilitation; and
- Red reaches are considered to contain areas of degraded habitat and in need of comprehensive intervention and rehabilitation and potentially, a much greater level of effort and investment is required when compared with the other reaches

No Management Reaches were identified as being in better health between Wyangala Dam and Mandagery Creek. Management Reaches 1, 12, 13 and 14 are ranked as being in moderate condition (Table 11 & Figure 71). Activities that may be carried out in these reaches to enhance the habitat are outlined in Section 6.1, however, it is recommended that the full spatial dataset is consulted in each instance to determine the actual interventions required. This, in conjunction with the individual habitat value scores in Table 11, will assist in identifying particular habitat features in a priority reach that have a greater influence to the reach ranking, providing a logical focal point at which to commence works. The Reaches in poorer health appear to be associated with sediment inputs from Boorowra River that have infilled refuge holes and buried LWH, thermal pollution from Wyangala Dam, and exotic plants near the townships of Cowra and Gooloogong (Figure 72).

Table 11. Habitat feature and reach priority scores for Management Reaches.

Management Reach	Habitat Value Scores: Drought Refuge	Large Woody Habitat (Snags)	Exotic Plants	Erosion	Stock Access/ Damage	Barrier Impacts	CWP Impacts	Total Score	Priority Ranking	Condition
1	11.70	2.50	1.02	0.27	1.93	-3.00	-8.40	6.0	1	Moderate Health
2	-0.98	-0.50	-0.48	-3.47	1.69	-2.70	-8.00	-14.4	14	Poorer Health
3	-3.06	-0.50	-0.93	0.27	1.23	-2.40	-7.60	-13.0	12	Poorer Health
4	-3.06	-0.50	-0.68	0.27	1.06	-2.10	-7.20	-12.2	11	Poorer Health
5	-3.06	-0.50	-1.71	0.27	1.39	-1.80	-6.80	-12.2	10	Poorer Health
6	-3.06	1.00	-1.22	0.27	1.93	-1.50	-6.40	-9.0	9	Poorer Health
7	-3.06	1.00	-0.62	0.27	1.81	-1.20	-6.00	-7.8	7	Poorer Health
8	-3.06	1.00	-0.24	0.27	-0.12	-0.90	-5.60	-8.6	8	Poorer Health
9	-3.06	1.00	-0.18	0.27	1.52	-0.60	-5.20	-6.3	6	Poorer Health
10	-3.06	1.50	0.57	0.27	0.91	-0.30	-4.80	-4.9	5	Poorer Health
11	-3.06	1.50	0.79	0.27	-8.54	0.00	-4.40	-13.4	13	Poorer Health
12	4.73	2.00	1.25	0.27	1.45	0.00	-4.00	5.7	2	Moderate Health
13	4.11	2.50	1.02	0.27	-2.38	0.00	-3.60	1.9	4	Moderate Health
14	7.98	2.00	1.40	0.27	-3.88	0.00	-3.20	4.6	3	Moderate Health

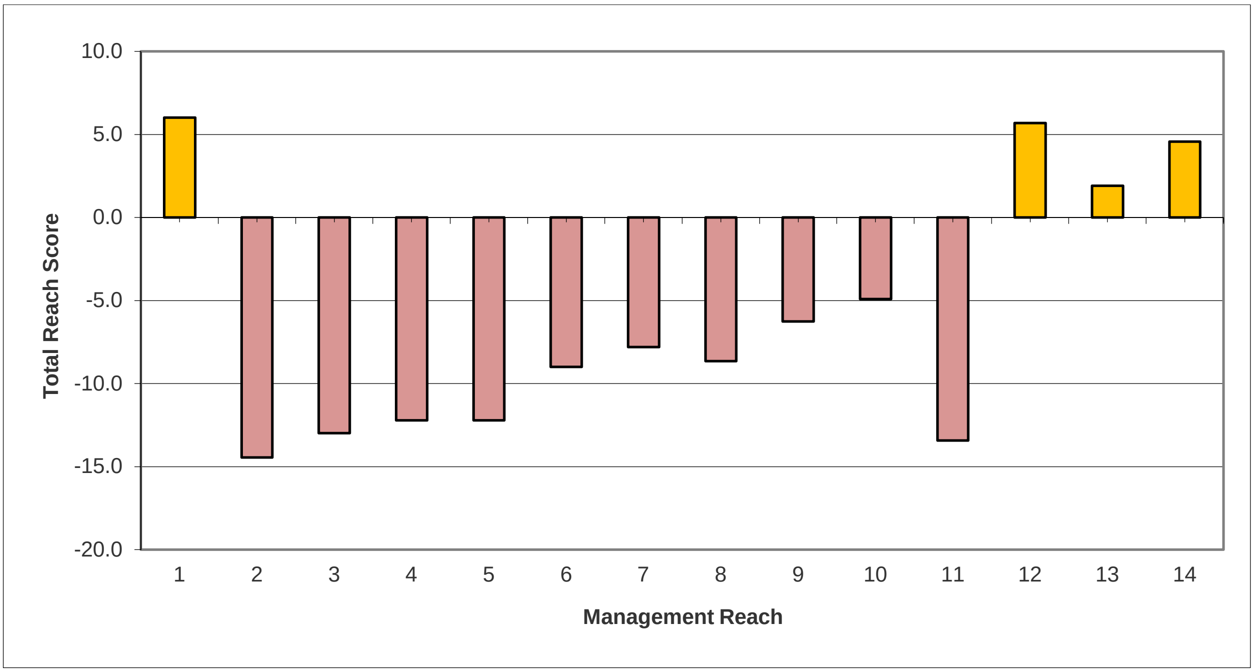


Figure 71. Total Reach Condition Scores by Management Reach.

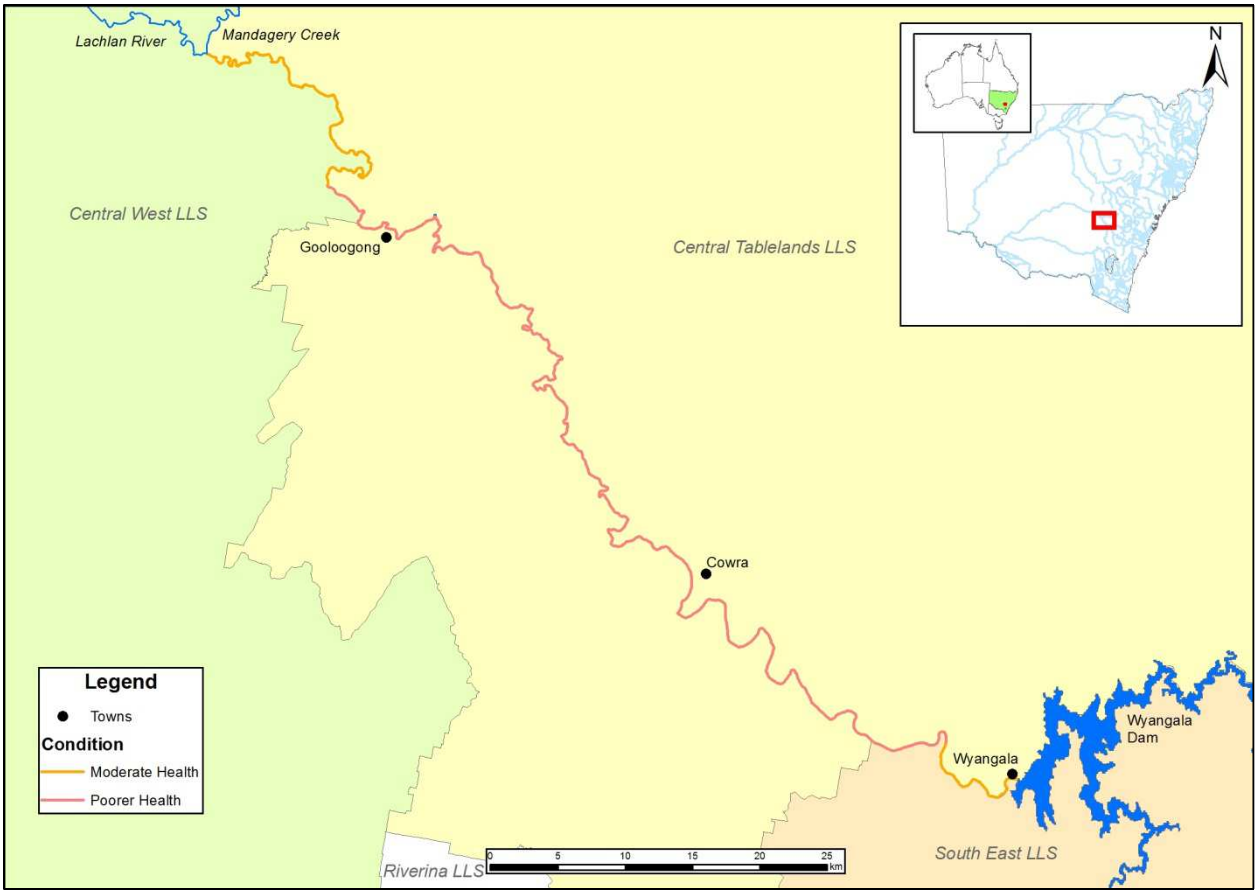


Figure 72. Wyangala to Cottons Weir project overview. Management Reaches ranked and coded according to condition score.

6.1. Interventions for Priority Management Reaches

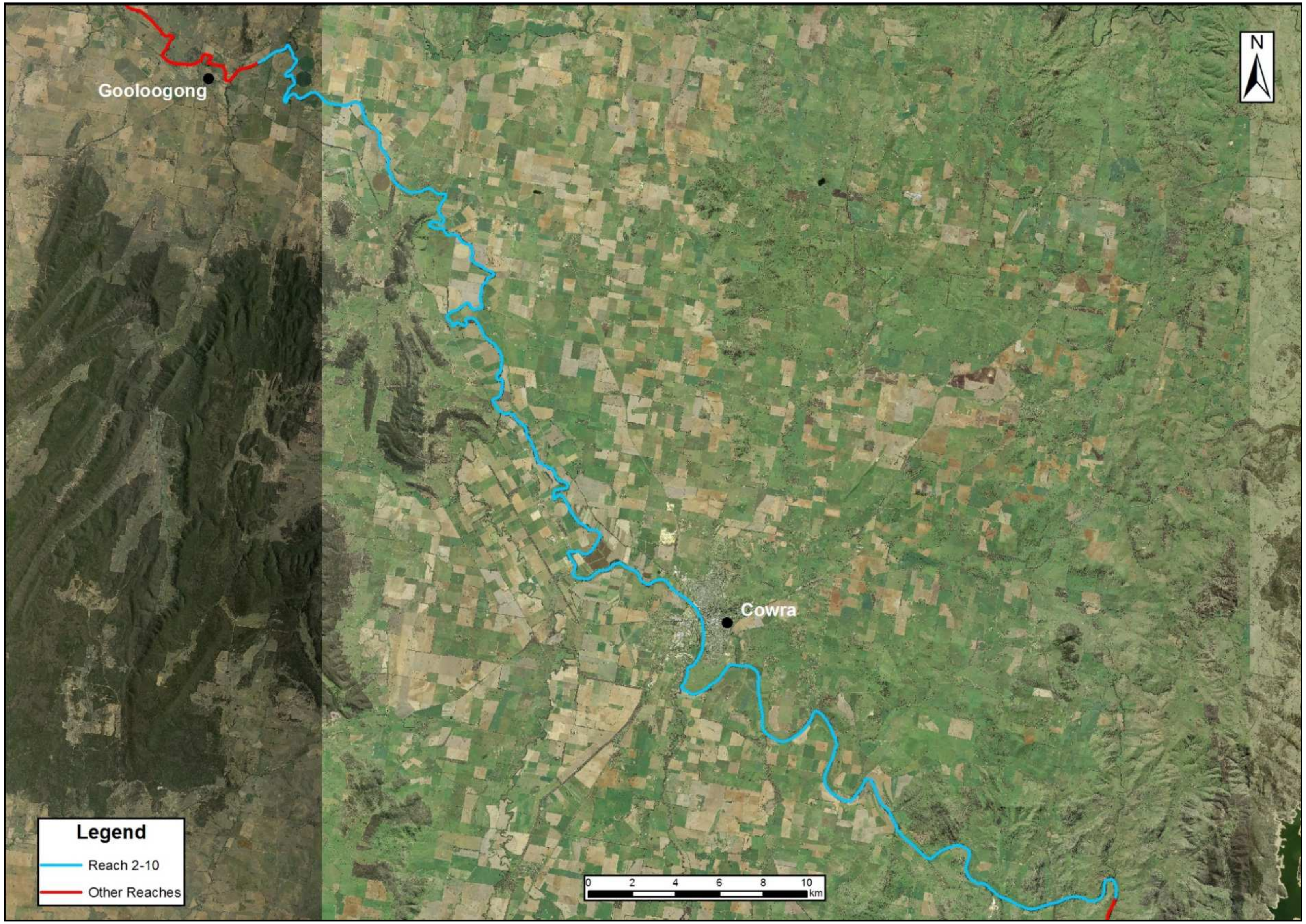
Management Reaches 2-16 (Priority 1)

Summary of key habitat features and issues

- Major sediment input from Boorowa River having a significant impact in these reaches. No refugia due to infilling, loss of LWH due to burying, loss of geomorphic diversity
- No barriers to fish passage in this reach
- Ossage orange present in low densities

Priority protection and rehabilitation activities

- Work with South East LLS (Boorowa River catchment location) to identify and address sediment sources
    - Use aerial imagery to identify erosion sites
    - NSW DPI has guides available to assist landholders such as *Saving Soil – A landholder's guide to preventing and repairing soil erosion* available at http://www.dpi.nsw.gov.au/land-and-water/soils/erosion
- Commence resnagging program in Reach 2-10 to assist in creating scour holes
- Riparian fencing and revegetation program to create a future source of instream woody habitat
- Investigate potential options for reintroduction of stream bed heterogeneity by creating scour and recreating refugia at selected appropriate sites



Map 6-1: Summary of habitat features and priority issues in Management Reaches 2-10.

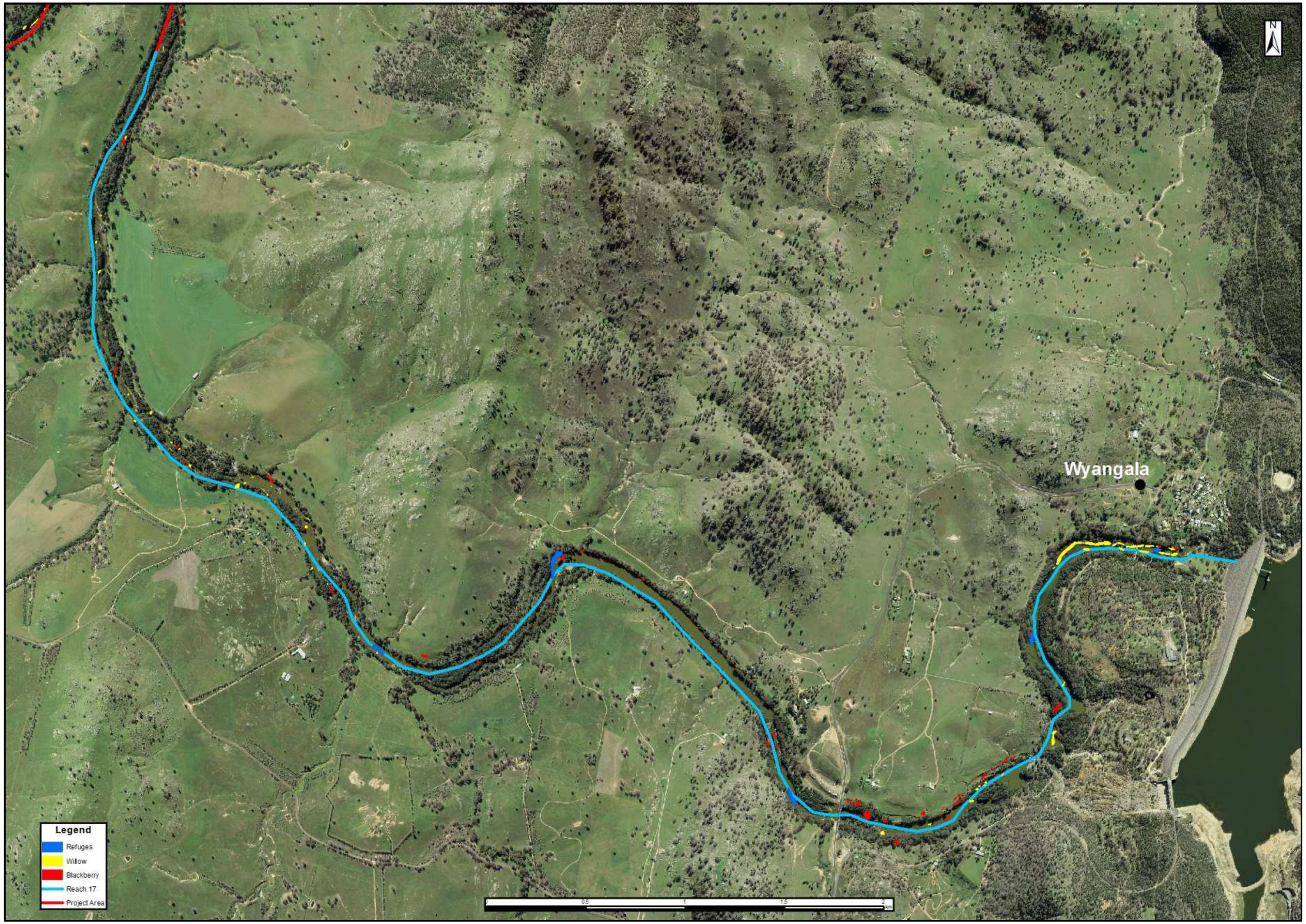
Management Reach 1 (Priority 2)

Summary of key habitat features and issues

- Wyangala Dam a barrier to fish passage and source of thermal pollution
- Five refuge holes
- 60 willow sites covering 0.96 ha
- No stock damage however minimal fencing identified
- Small areas of native tree regeneration only found in areas where stock cannot access

Priority protection and rehabilitation activities

- Control of WONS and Class 4 Noxious Weeds including willow followed by revegetation using appropriate species
- Education and awareness and on-ground investment program focussing on:
    - Stock management throughout entire Management Reach with additional targeted engagement of landholders using GIS layers to identify areas in need of improved riparian management
    - Provide stock management infrastructure (riparian fencing and alternative watering points) through incentive funding where necessary and develop stock management/grazing plans



Map 6-2: Summary of habitat features and priority issues in Management Reach 17

Management Reaches 12 - 14 (Priority 3)

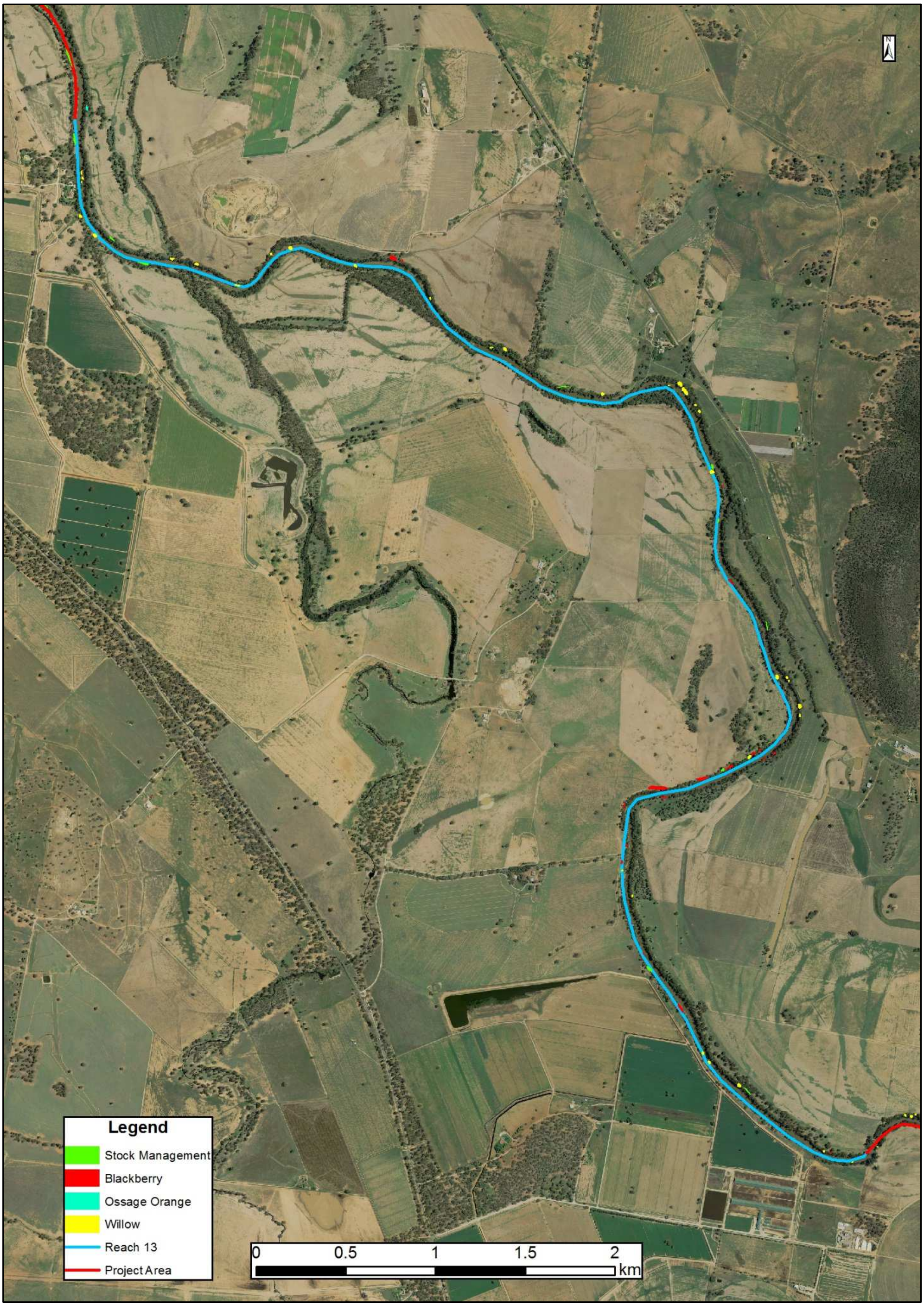
Summary of key habitat features and issues

- No barriers to fish passage in these reaches
- Sediment slug from Boorowa River (Reach 2) infilling refugia
- 59 willow sites covering 0.89 ha
- Stock access damage at four sites but limited to one property

Priority protection and rehabilitation activities

- Education and awareness and on-ground investment program focussing on:
    - Stock management throughout entire Management Reach with additional targeted engagement of landholders using GIS layers to identify areas in need of improved riparian management
    - Provide stock management infrastructure (riparian fencing and alternative watering points) through incentive funding where necessary and develop stock management/grazing plans
- Control of WONS and Class 4 Noxious Weeds including willow followed by revegetation using appropriate species

Map 6-3: Summary of habitat features and priority issues in Management Reach 12



Map 6-4: Summary of habitat features and priority issues in Management Reach 13

Map 6-5: Summary of habitat features and priority issues in Management Reach 14

7. Recommendations and future directions

NSW DPI recommends that the priority management reaches be the focus of targeted management actions to protect and rehabilitate these reaches that are in moderate condition and prevent deterioration. Management Reaches 1, 12, 13 & 14 are ranked in moderate health based on overall ecological condition score.

The analysis identified a range of immediate and emerging issues affecting the condition of the entire study area. These issues included the presence of significant weeds, riparian management practices and barriers to fish passage, for which recommendations are provided to manage these issues at a study area scale. These include:

- The sediment slug that runs from Reach 2 to Reach 16 is having a major impact on refugia in this part of the project area. The source of this sediment is the Boorowa River, whose catchment is entirely in the South East LLS Area. The impacts are having far reaching consequences such as infilling refuge holes, burying Large Woody Habitat, covering gravel beds with finer sediments and increasing turbidity. Without intervention, this sediment slug is likely to extend downstream, covering more habitat. NSW DPI recommends that Central Tablelands LLS works closely with South East LLS to identify sediment sources and erosion sites then develop remediation options.

  A combination of Engineered Log Jams (ELJ) and rock groynes can be used to increase the diversity of available fish habitats in a hydraulically homogenous section of stream. ELJ are constructed of interlocked hardwood logs, some with roots attached and are keyed into the stream bed (Figure 73) (ACT Environment and Sustainable Development, 2013). ELJ increase hydraulic diversity and can also add woody habitat that is currently lacking in the affected area of the system. Rock groynes cause a hydraulic constriction which increases flow velocity through a channel confined by the structures (SCS, 2013). Rock groynes are constructed perpendicular to the flow and built around the ELJ, as can been seen in Figure 73, the structures are built in pairs on opposing side of the river. This increases flow energy and causes isolated scour holes adjacent to the structures and deposition in the channel to further constrict the channel capacity (SCS, 2013).

Figure 73. Left: ELJ placed prior to construction of rock groyne Right: Rock groyne constructed around ELJ (image curtesy of SCS, 2013).

The success of using a combination of ELJ with rock groynes has been demonstrated in the Upper Murrumbidgee Demonstration Reach. Deflecting structures were recommended over the use of sand extraction and placement of boulders, piers or LWH (GHD, 2011). This stretch of the Murrumbidgee where the structures were constructed has a similar sedimentation issue to that in the project area. The channel depth adjacent to the structures was found to have increased from approximately 40 cm to over 2 m, after the first flood (Figure 74) and fish surveys have shown the areas to be hotspots for native fish, in particular Murray Cod (SCS, 2013; Evans, pers. comm. 2017). These structures could be used as 'stepping stones' for fish to move through the affected stretch of the system and alleviate the loss of habitat diversity as a result of the sand slug.

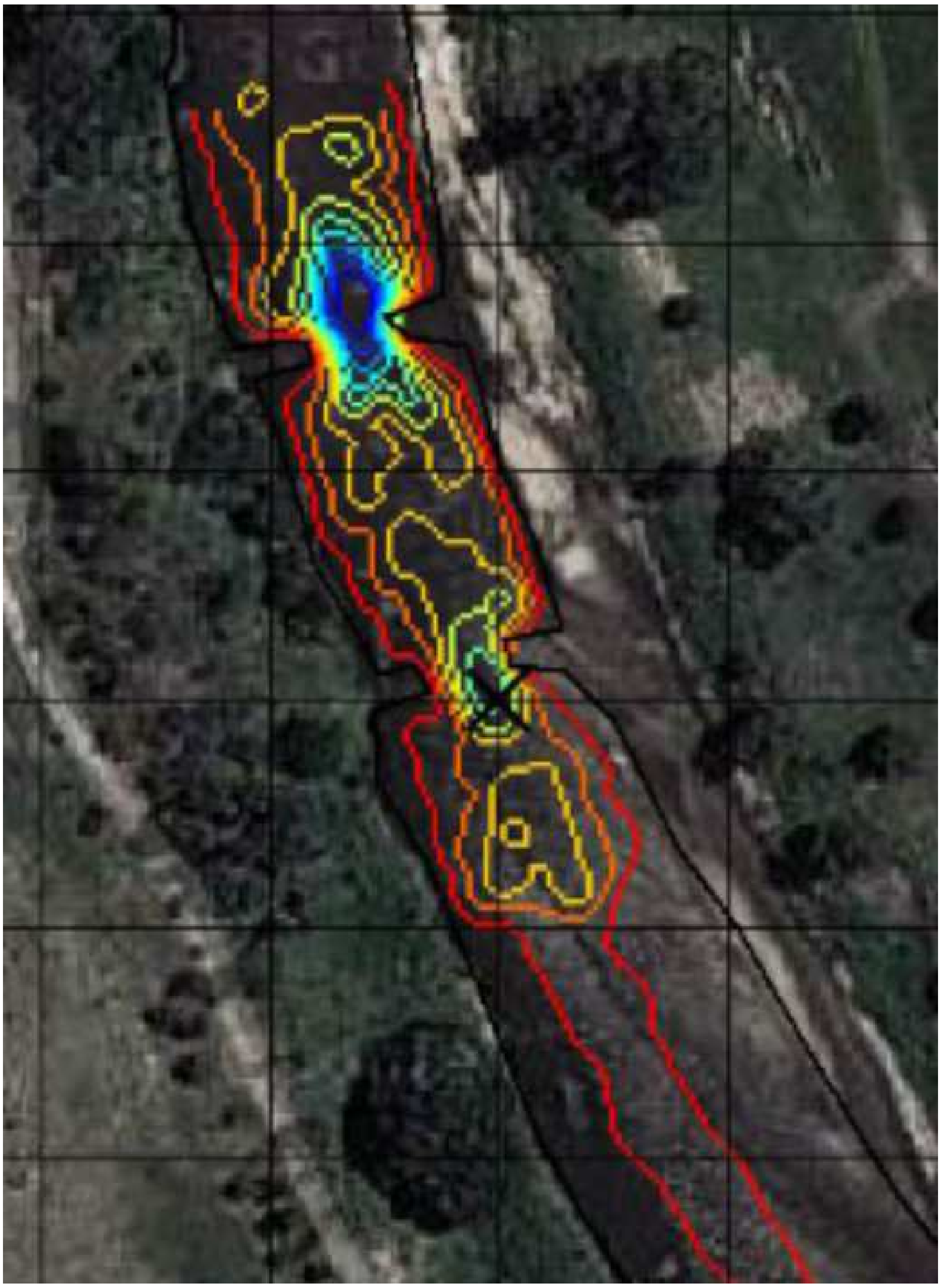


Figure 74. Sonar showing the bed of the Murrumbidgee River with the increased depth as a result of ELJ and rock groyne construction (Image curtesy of SCS).

- There is 422 km of riverbank in the project area and livestock exclusion fencing was identified along 48.4 km. Livestock were commonly observed accessing the river channel and riparian zone and while there was some damage, there was very little groundcover, leaving the bank susceptible to erosion. NSW DPI recommends that a landholder education and awareness program be developed and implemented to highlight the multiple benefits of controlling livestock access to waterways and encourage active landholder stewardship of the Lachlan River, including improved water quality and recovery of native vegetation. It is also recommended that LLS conducts an audit of riparian fencing projects that were funded by CMA/LLS to ensure that landholders are meeting their obligations under any agreements that may be in effect as a result.
- Ossage orange (*Maclura pomifera*) was observed at 423 sites covering 166,378m^2. Minor infestations are found in Reaches 8, 9, 10, 14, 17, 18 and 19 before becoming the dominant species in Reaches 20 and 21. Left unmanaged, this weed has the potential to spread in the catchment over time; therefore, it is recommended that a management program for ossage orange be established and implemented as soon as practical.
- Weeds of National Significance observed throughout the study area included blackberry, African boxthorn and willow. All of these weeds are also classified as Class 4 noxious weeds in the Local Government Areas in the project area under the *Noxious Weeds Act 1993* and as such, must be managed to reduce their spread and continuously inhibit their reproduction. It is recommended that an awareness program be conducted in collaboration with Local Government and landholders to actively treat these weeds long the length of the project area. If any infestations of notifiable weeds are deemed by the landholder to have become unmanageable, they should also be encouraged to report the issue to the Council Weeds Officer for potential deployment of additional resources.
- Three artificial barriers were identified in the project area: Wyangala Dam, Apex Weir and Cottons Weir. Fish passage remediation would require significant financial investment at Wyangala Dam due the height of the structure; however options have been investigated previously by NSW DPI Fisheries. Reducing the Impact of Weirs on Aquatic Habitat - New South Wales Detailed Weir Review (NSW DPI, 2006c) provides a comprehensive prioritisation of barrier remediation recommendations and should be referred to when considering addressing fish passage.
- Cold water pollution impacted all Reaches to varying extents. The impacts of cold water pollution are known to dissipate moving downstream from Wyangala Dam, with no impact beyond Forbes. Scoring was scaled accordingly with fewer points deducted moving down the system. Cold water pollution and barriers to fish passage had a considerable impact on the score for Reach 1 as it is directly below Wyangala. This Reach would be considered to be in Moderate Health if cold water pollution alone was addressed at the site (Table 12). This would be possible by the use of a thermal curtain similar to that installed at Burrendong Dam. If fish passage at Wyangala Dam could be addressed, along with cold water pollution Reach 1 would be considered to be in Better Health. A number of other Reaches impacted by cold water pollution would be considered to be in Moderate Health if cold water pollution alone was addressed.

Table 12. Habitat feature and reach priority scores for Management Reaches with CWP and Barrier impacts removed.

	Habitat Value Scores							
Management Reach	Drought Refuge	Large Woody Habitat (Snags)	Exotic Plants	Erosion	Stock Access/ Damage	Total Score	Priority Ranking	Condition
1	-1.29	2.50	1.63	0.25	1.98	5.1	7	Moderate Health
2	-3.22	-0.50	-1.12	-4.32	1.79	-7.4	21	Poorer Health
3	-3.54	-0.50	-1.94	0.25	1.45	-4.3	18	Poorer Health
4	-3.54	-0.50	-1.50	0.25	1.98	-3.3	17	Poorer Health
5	-3.54	-0.50	-3.39	0.25	0.91	-6.3	19	Poorer Health
6	-3.54	2.50	-2.50	0.25	1.98	-1.3	13	Poorer Health
7	-3.54	1.00	-1.32	0.25	1.89	-1.7	15	Poorer Health
8	-3.54	1.00	-0.56	0.25	0.43	-2.4	16	Poorer Health
9	-3.54	1.00	-0.73	0.25	1.67	-1.3	14	Poorer Health
10	-3.54	1.50	0.75	0.25	1.21	0.2	12	Moderate Health
11	-3.54	1.50	1.22	0.25	-5.93	-6.5	20	Poorer Health
12	-2.35	2.00	2.00	0.25	1.62	3.5	9	Moderate Health
13	-2.44	2.50	1.65	0.25	-0.51	1.4	11	Moderate Health
14	-1.56	2.00	2.33	0.25	1.98	5.0	8	Moderate Health
15	-0.21	2.50	1.87	-0.39	1.89	5.7	6	Better Health
16	0.93	2.00	2.17	0.25	0.45	5.8	5	Better Health
17	7.88	2.50	1.94	0.25	1.42	14.0	1	Better Health
18	7.75	2.50	1.62	0.25	-2.57	9.5	2	Better Health
19	8.53	2.50	1.83	0.25	-5.49	7.6	3	Better Health
20	7.01	2.50	-3.12	0.25	0.21	6.8	4	Better Health
21	10.81	2.00	-2.81	0.25	-8.35	1.9	10	Moderate Health

- There were 292 pumpsites recorded in the project area, all of them have the potential to remove, injure or kill native fish. Once fish are drawn into a pump they are also lost to the population, reducing both the population size and genetic variability. Preventing this from occurring is possible through the use of screening technology that minimises entrainment. To reduce the impact of pumpsites on native fish the attachment of screens to all pumps is recommended.

While no specific riparian vegetation assessment was undertaken as part of the mapping, the recovery of vegetation may be monitored after livestock access is controlled through the use of Rapid Appraisal of Riparian Condition (RARC) analysis. A PDF of the tool is available online at http://lwa.gov.au/files/products/river-landscapes/pr050994/pr050994.pdf. Any such monitoring would need to be conducted on annual basis (minimum) to determine any change that may have been effected as a result of a changed grazing regime and management.

The reduction in grazing pressure as a result of these actions is expected to provide the opportunity for native vegetation along the riparian zone of project area to regenerate naturally. Revegetation works are not recommended in most areas of the study area due to the high level of maintenance required to ensure a high survival rate. Where landholder willingness to control stock movement and provide close monitoring and maintenance is identified, any plantings should only be undertaken with a formal management agreement or riparian grazing plan.

Surveying additional cross-sectional areas of the river would provide a further opportunity to refine the ecologically significant flow component information. Currently, the cross-sectional areas used in the calculations are based on available data associated with existing flow gauges and is unable to account for channel capacity variation between gauges. Further information in this regard would add a degree of refinement to the flow components.

The extension of habitat mapping through the 235 km reach from Booberoi Weir to Willandra Weir would greatly benefit the knowledge base for the Lachlan River. Filling the current knowledge gaps for this reach would greatly enhance the ability to effectively manage the aquatic environment of the mainstem Lachlan River. The reach encompasses important areas including the Lake Cargelligo and Lake Brewster off-takes which can extensively regulate the flows through this area. The area also encompasses the Mountain Creek and Booberoi Creek in-flows.

In addition to this reach, the 122.5 km reach from Whealbah to Booligal has also not been mapped. Through this reach the river changes substantially, becoming a much smaller, meandering channel. Little is known of this area however it is considered to be highly likely to be impacted by low flows and the regulation of pulse flows.

8. References

ACT Environment and Sustainable Development. 2013. Helping our native fish navigate the Murrumbidgee. Fact sheet.
Accessed at:
http://www.environment.act.gov.au/__data/assets/pdf_file/0008/576701/Helping_our_native_fish_navigate_the_Murrumbidgee.pdf

Armstrong, J., Kingsford, R. and Jenkins, M. 2009. *The Effect of Regulating the Lachlan River on the Booligal Wetlands- The Floodplain Red Gum Swamps*. Wetlands & Rivers, School of Earth & Environmental Sciences, University of New South Wales, NSW 2052

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

Bartly, R. and Rutherford, I. 1999. *The recovery of geomorphic complexity in disturbed streams: using migrating sand slugs as a model*. Second Australian Stream Management Conference. 8-11 February 1999, Adelaide, South Australia.

Baumgartner, L., Reynoldson, N., Cameron, L. and Stanger, J. 2009. Effects of Irrigation Pumps on Riverine Fish. *Fisheries and Ecology Management*. 16: 429-437.

Beechie, T., Pess, G., Roni, P. and Giannico, G. 2008. 'Setting River Restoration Priorities: a Review of Approaches and a General Protocol for Identifying and Prioritizing Actions'. *North American Journal of Fisheries Management,* 28: 891-905.

BioMedware. 2013. BoundarySeer; Software for the detection and analysis of geographical boundaries. *User Manual.* Version 1.5.

BRG CMA .2010. *Waterways: streambank erosion*. Border Rivers-Gwydir Catchment Management Authority.

Brierley, G.J. and Fryirs, K. (2005) *Geomorphology and river management: applications of the river styles framework.* Blackwell Publishing.

Department of the Environment. 2013. Lachlan Catchment
Accessed at: https://www.environment.gov.au/water/cewo/catchment/lachlan

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.

Fitch, L., Adams, B. and O'Shaughnessy 2003 *Caring for the Green Zone; riparian areas and grazing management – 3rd edition*. Lethbridge, Alberta: Cows and Fish Program.

Frissell, C. and Bayles, D. 1996. “Ecosystem Management and the Conservation of Aquatic Biodiversity and Ecological Integrity’. *Water Resources Bulletin,* 32: 229-240.

GHD. 2011. Report on Upper Murrumbidgee Demonstration Reach: Feasibility study to address the ecological impact of sedimentation. Department of Territory and Municipal Services. Accessed at:
http://upperbidgeereach.org.au/files/UMDR_Sediment_Feasibility_FINAL_MAY_2011.pdf

Green, D., Petrovic, J., Moss, P. and Burrell, M. 2011. *Water resources and management overview: Lachlan catchment*. NSW Office of Water, Sydney

Industry and Investment NSW. 2009. *Bringing Back the Fish – Inland NSW Extension. Final Report to the Southern Rivers Catchment Management Authority.* Industry and Investment NSW, Cronulla, NSW.

Koehn, J. 2004. ‘Carp (*Cyprinus carpio*) as a Powerful Invader in Australian Waterways’. *Freshwater Biology,* 49: 882–894.

Lintermans, M. 2007. *Fishes of the Murray Darling Basin: An introductory guide.* MDBC Publication No.10/07.

LRWG. 2015. Lachlan River and Wetlands
Accessed at: http://www.lrwg.com.au/lachlan-river-wetlands/

Lovett, S. and Edgar, B. 2002. ‘*Planning for River Restoration’, Fact Sheet 9.* Land & Water Australia, Canberra.

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

Macdonald, J. and Tonkin, Z. 2008. *A Review of the Impact of Eastern Gambusia on Native Fishes of the Murray-Darling Basin*. Arthur Rylah Institute for Environmental Research. Department of Sustainability and Environment, Heidelberg, Victoria.

McDowall, R.(ed). 1996. *Freshwater Fishes of South-eastern Australia*, Reed, Sydney.

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

NSW Department of Infrastructure, Planning and Natural Resources. 2004. *A Guide to the Water Sharing Plan for the Lachlan Regulated River Water Source*. NSW Department of Infrastructure, Planning and Natural Resources, Forbes.

NSW DPI. 2012. *Living & working on a riverbank.* Promotional flyer. NSW Department of Primary Industries, Sydney, NSW.

NSW DPI. 2013. NSW Biosecurity Stragey 2013-2021. Department of Primary Industries, Sydney, NSW.

NSW DPI. 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 DPI. 2006a. *Primefact 145, Aquatic Ecological Community in the Natural Drainage of the Lowland Catchment of the Lachlan River*. First Edition.

NSW DPI. 2006b. *The Identification, Assessment and Prioritisation of Threatening Processes to the Aquatic Environment of the Lower Lachlan Catchment.* Report to the Lachlan Catchment Management Authority. NSW Department of Primary Industries, Sydney, NSW.

NSW DPI. 2006c. *Reducing the Impact of Weirs on Aquatic Habitat - New South Wales Detailed Weir Review. Lachlan CMA region*. Report to the New South Wales Environmental Trust. NSW Department of Primary Industries, Flemington, NSW.

NSW DPI. 2016. Water Flow
http://www.dpi.nsw.gov.au/fishing/habitat/threats/water-flow

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.

Prosser, I.P., Rutherfurd, I.D., Olley, J.M., Young, W.J., Wallbrink, P.J., and Moran, C.J. 2001 Large-scale patterns of erosion and sediment transport in river networks, with examples from Australia. *Marine and Freshwater Research*. 52: 51-99.

Roberts, J. and Tilzey, R (eds.). 1997. *Controlling Carp: Exploring the Options in Australia.* Proceedings of a Workshop 22-24 October 1996, Albury. CSIRO Land and Water, Canberra.

Rutherford, I., Jerie, K. and Marsh, N. 2000. *A process for rehabilitating Australian Streams.* CD ROM. Cooperative Research Centre for Catchment Hydrology, Land & Water Australia 2000.

SCS. 2013. River Works.
Accessed at:
http://www.scs.nsw.gov.au/project-management/project-work-summaries/tharwa-murrumbidgee-act

Stuart, I. G., William, A., McKenzie, J. and Holt, T. 2006. 'Managing a Migratory Pest Species: A Selective Trap for Common Carp'. *North American Journal of Fisheries Management*, 26: 888-893.

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.

Victoria Department of Sustainability and Environment. 2009. *Native Fish Recovery: following removal of alien fish (Gambusia).* The State of Victoria Department of Sustainability and Environment 2009.

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.

Ziemer, R. 1997. 'Temporal and spatial scales'. Pages 80-95 in J.E. Williams, C. A. Wood and M. P. Dembeck (eds) *Watershed Restoration: Principles and Practices*. American Fisheries Society, Bethesda, Maryland.

Appendix A. Supplementary spatial feature class information

The following is the list of GIS data files that was used for prioritising the 17 reaches in the study area. All data is projected in the Geographic Coordinate System – GDA94 NSW Lambert Conformal Conic. An electronic copy of the project data is available on the disc provided.

Habitat Data

Feature Class	File Name
Large Woody Habitat (LWH)	Wyangla_to_Cottons_Prioritisation_LWH_Reaches.shp
Exotic Plants	Wyangla_to_Cottons_Prioritisation_Exotics.shp
Refuge Hole	Wyangla_to_Cottons_Prioritisation_Refuge.shp
Stock Damage	Wyangla_to_Cottons_Prioritisation_StockDamage.shp
Erosion	Wyangla_to_Cottons_Prioritisation_Erosion.shp
Study Area	Wyangla_to_Cottons_10kReaches.shp

Other Data	
Wetland Entry/Exit	Wyangla_to_Cottons_EntryExitPoints.shp
Benches	Wyangla_to_Cottons_Prioritisation_Benches.shp
Fencelines	Wyangla_to_Cottons_Prioritisation_Lines.shp
Aquatic Macrophytes	Wyangla_to_Cottons_Prioritisation_Macrophytes.shp
Native riparian regen	Wyangla_to_Cottons_Prioritisation_Regen.shp
Pumpsites	Wyangla_to_Cottons_Pumpsites.shp

All Points	Wyangla_to_Cottons_Prioritisation_Points_Reaches.shp
All Polygons	Wyangla_to_Cottons_Prioritisation_Polys_Reaches.shp

Appendix B. Refugia Data

Reach	FID	Depth (m)	Area (m2)	X Coordinate	Y Coordinate
1	170	3.61	643.86	9479696.08	4418599.57
	171	3.01	966.02	9479100.36	4418198.67
	172	6.81	1262.48	9477864.76	4417411.11
	173	6.81	2597.27	9476666.52	4418490.17
	174	3.21	1155.59	9475789.52	4418123.55
2	175	3.31	1289.33	9474736.26	4421665.68
12	176	4.69	2934.17	9428778.40	4462644.07
	177	4.19	1748.97	9430738.40	4463628.51
	178	3.49	1147.69	9431139.51	4463482.15
13	179	3.43	2956.32	9429026.83	4467064.44
	180	4.63	8668.29	9429038.40	4469343.40
	181	3.33	2814.22	9426727.96	4469971.44
14	182	3.03	1129.27	9425361.32	4472143.56
	183	4.23	1555.15	9425145.40	4472048.26
	184	5.03	818.46	9424670.20	4471815.33
	185	4.33	1727.52	9424619.55	4471845.39

	0	3.94	1474.17	9421113.26	4472220.35
15	1	3.04	1141.15	9418680.33	4473271.98
	2	4.44	810.37	9418321.62	4473404.20
	3	3.04	842.56	9418181.15	4473159.16
	4	3.24	630.44	9417920.61	4473328.11
	5	4.14	288.63	9417927.03	4473335.14
	6	3.54	998.66	9418296.44	4473725.15
	7	3.64	1454.41	9416714.73	4474858.59
	8	5.74	2502.27	9415567.71	4474746.94
	9	3.84	3023.34	9415604.76	4475018.08
16	10	3.04	1752.02	9414540.78	4475425.13
	11	3.74	1827.93	9414098.73	4475363.04
	12	3.14	698.67	9412937.33	4474737.45
	13	3.34	1781.11	9412644.04	4474411.81
	14	3.54	1554.40	9412197.93	4475001.87
	15	4.84	1431.18	9411998.62	4474874.35
	16	3.24	886.48	9410880.38	4476251.85
	17	5.04	1161.76	9411534.88	4476964.53
	18	3.04	1081.81	9411322.25	4477161.78

	19	3.44	687.83	9410822.11	4477433.48
	20	3.34	5670.41	9410945.22	4477900.44
	21	3.44	1025.92	9410746.03	4477921.15
	22	3.34	1853.01	9410044.75	4478166.05
17	23	3.54	4195.13	9409580.13	4477925.37
	24	3.05	544.86	9409398.92	4478656.68
	25	4.85	1878.26	9409314.01	4478943.55
	26	3.05	589.10	9409696.30	4479066.59
	27	4.85	2098.53	9409781.96	4479452.43
	28	4.85	1283.18	9409654.91	4479489.38
	29	3.55	216.74	9409790.93	4479616.06
	30	6.35	1341.92	9410249.14	4479369.00
	31	3.95	1972.96	9410442.81	4480222.31
	32	3.85	5209.81	9410110.56	4480328.33
	33	6.45	2433.84	9410276.34	4480513.43
	34	4.25	1243.87	9410850.28	4480288.86
	35	3.05	574.33	9410866.47	4480400.40
	36	5.25	2535.36	9410792.04	4480714.69
	37	4.55	1359.33	9410671.43	4480723.52

	38	3.35	647.02	9410399.33	4481175.60
	39	4.55	351.67	9410396.23	4481350.09
	40	3.25	1248.60	9410031.04	4481655.89
	41	3.25	748.66	9409744.31	4481729.36
	42	3.35	483.20	9409570.45	4481799.02
	43	5.55	437.17	9409566.96	4481815.25
	44	4.95	923.16	9409662.15	4482018.36
	45	3.25	792.38	9409558.45	4482065.17
	46	3.25	475.89	9409190.63	4481898.38
	47	3.25	1112.88	9409090.01	4481918.61
	48	4.05	1668.43	9408847.59	4481979.04
	49	4.55	945.53	9408755.70	4481652.68
	50	3.55	1107.52	9409053.43	4481410.25
	51	3.45	1348.23	9408942.82	4481350.79
18	52	3.05	539.38	9408646.23	4481275.38
	53	3.25	613.38	9408364.93	4480827.87
	54	3.45	363.85	9408553.67	4480832.20
	55	3.35	785.60	9408601.51	4480791.08
	56	3.45	1109.19	9408632.11	4480602.88

57	4.85	1448.74	9408263.12	4480466.10
58	4.45	1269.31	9407992.56	4480741.81
59	4.25	957.51	9407792.44	4480870.19
60	4.25	582.63	9407559.20	4480833.70
61	3.05	411.47	9407296.52	4480912.77
62	4.35	2421.84	9407111.98	4480992.10
63	4.45	2414.91	9406906.75	4481300.40
64	5.05	532.18	9406602.82	4481417.98
65	5.55	1561.51	9406655.05	4481864.27
66	3.25	469.00	9406709.44	4482017.48
67	4.05	1508.80	9406655.11	4482121.70
68	4.95	688.00	9406325.08	4481911.68
69	4.85	484.27	9406268.21	4482093.00
70	3.65	518.78	9406477.18	4482681.04
71	4.95	1886.11	9405813.20	4483533.10
72	4.75	1638.13	9405876.65	4483686.35
73	3.95	859.34	9405822.73	4483738.16
74	3.55	1805.74	9405679.77	4483671.11
75	3.25	363.95	9405485.83	4483556.76

	76	4.65	2373.63	9405152.83	4483465.16
	77	3.55	2916.87	9405083.30	4483748.30
	78	4.05	1518.01	9404488.35	4483987.68
	79	3.35	604.13	9404407.08	4483942.48
	80	4.05	2830.56	9404133.84	4483738.87
19	81	3.95	446.07	9404077.36	4483975.52
	82	4.25	351.98	9404090.66	4484007.33
	83	5.05	1545.93	9404236.25	4484105.63
	84	3.35	211.11	9403980.23	4484284.04
	85	4.45	488.63	9403837.62	4484352.99
	86	3.25	399.30	9403772.13	4484342.11
	87	4.05	2444.13	9403368.45	4484318.10
	88	5.05	1326.41	9403278.92	4483488.92
	89	4.85	771.38	9403544.84	4483510.95
	90	3.05	508.42	9403686.64	4483467.94
	91	4.05	1108.55	9403501.23	4483192.66
	92	4.05	613.11	9403217.70	4483334.05
	93	3.15	596.67	9403095.66	4483342.04
	94	3.85	1735.89	9403000.18	4483301.78

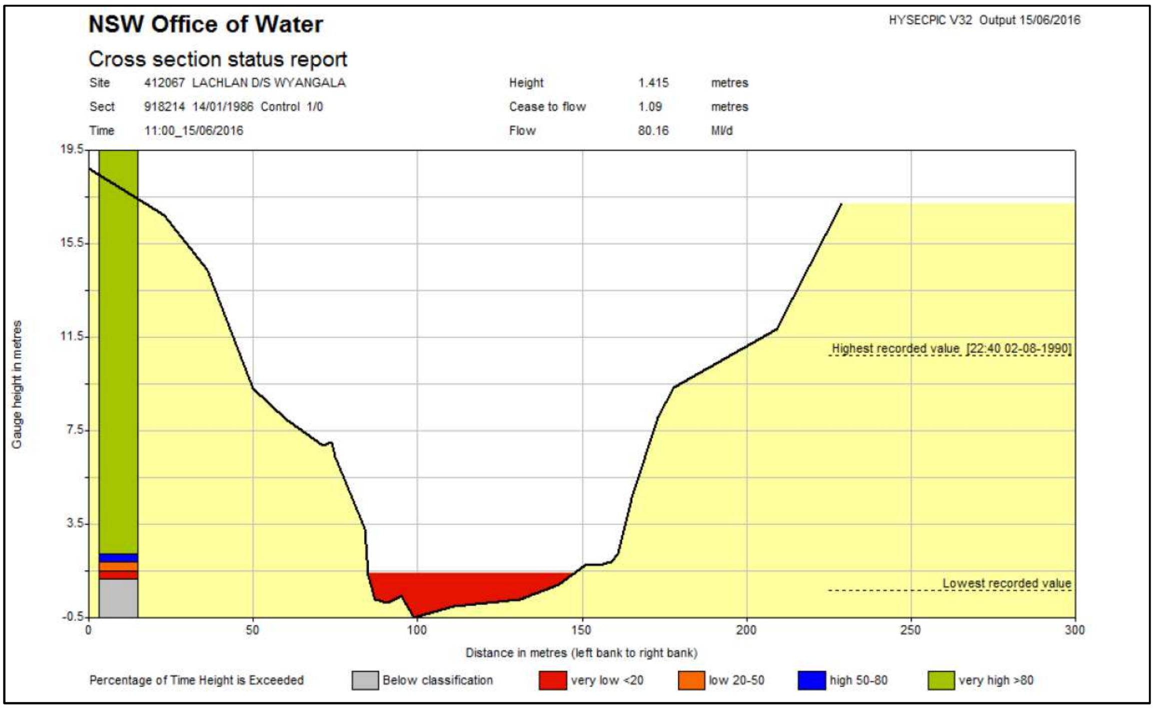
	95	4.25	347.60	9402876.88	4483202.69
	96	3.85	1199.63	9402839.28	4483034.13
	97	3.06	324.97	9402513.10	4482781.03
	98	5.06	1569.00	9402364.78	4482754.87
	99	5.76	784.18	9402286.90	4483307.62
	100	3.86	629.63	9402085.78	4483450.67
	101	7.06	1672.31	9402153.48	4483637.59
	102	4.36	1158.10	9401652.24	4483760.59
	103	5.56	1329.77	9401528.18	4483074.87
	104	5.26	1549.80	9401075.22	4483462.17
	105	5.26	1347.93	9400850.00	4483073.29
	106	3.16	652.12	9401046.92	4482999.05
	107	4.06	1591.13	9400609.49	4482803.98
	108	5.66	906.92	9400541.98	4482964.88
	109	3.16	293.92	9400259.84	4483182.98
20	110	3.36	1087.29	9399856.93	4483196.82
	111	3.26	1502.47	9399810.42	4483163.99
	112	5.16	2058.98	9399675.24	4482767.81
	113	3.26	1104.08	9399526.52	4482455.71

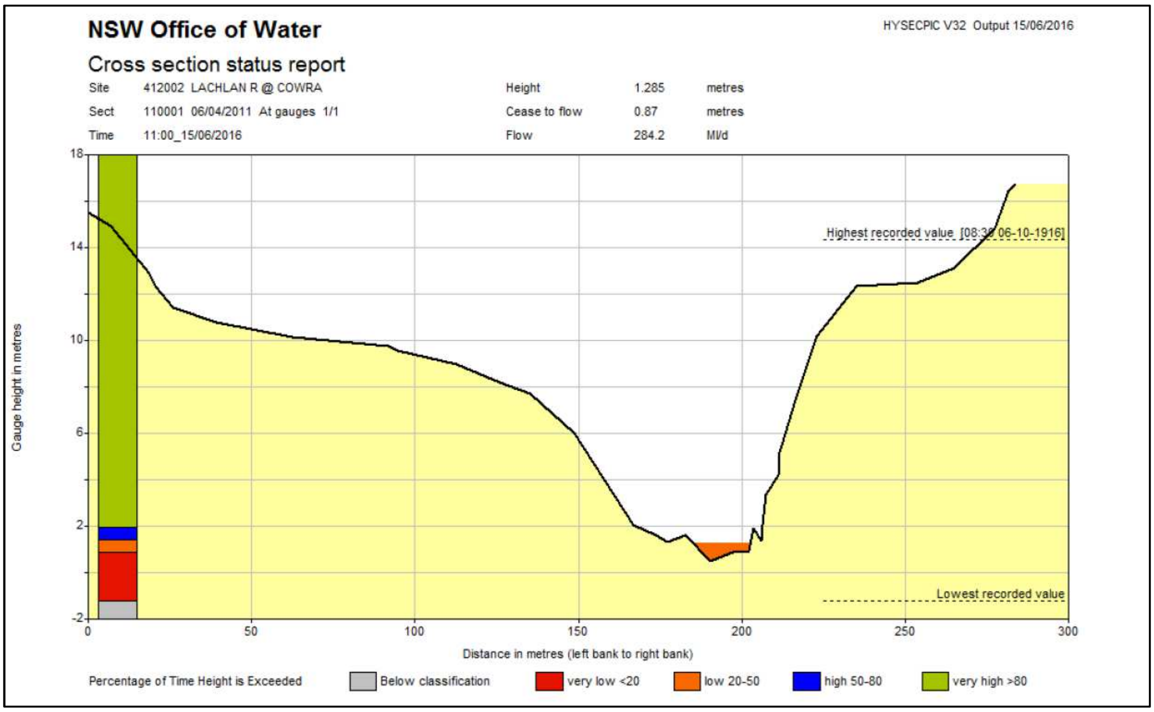
114	5.26	1063.72	9399700.88	4482437.16
115	5.56	439.03	9399387.51	4482190.71
116	3.06	673.22	9399288.55	4482321.51
117	7.16	1104.33	9399051.07	4482325.41
118	3.06	969.06	9399049.68	4482160.44
119	3.26	1460.73	9398810.12	4482315.31
120	3.06	1345.29	9398696.23	4482455.27
121	3.96	2490.03	9398572.70	4482717.55
122	4.56	898.09	9398252.14	4483053.25
123	6.76	1277.13	9398051.36	4482906.51
124	4.46	854.21	9397732.83	4483344.20
125	3.36	577.24	9397422.16	4483222.41
126	4.26	3010.31	9396933.42	4482967.06
127	3.36	955.31	9396933.60	4482841.20
128	3.36	798.48	9396965.47	4482668.26
129	3.66	863.15	9397298.29	4482564.81
130	3.46	889.10	9397299.72	4482254.07
131	4.36	1579.02	9396870.60	4482137.99
132	3.66	366.01	9396686.81	4482812.12

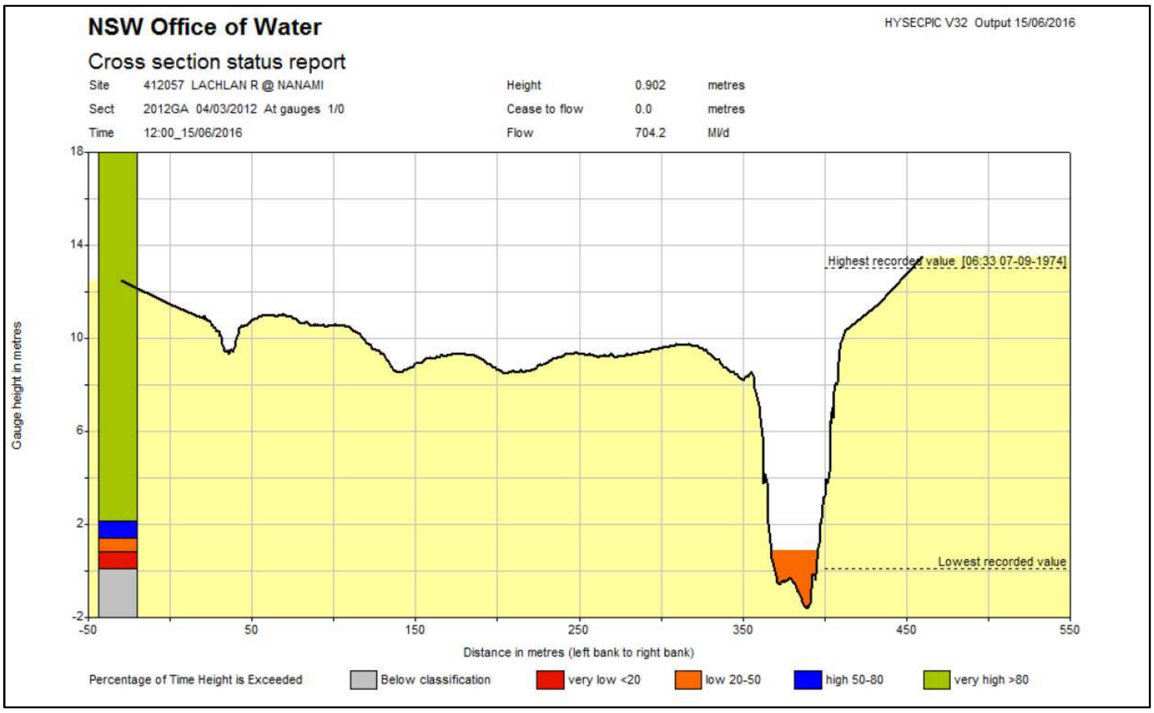
	133	3.46	3179.20	9396484.16	4482842.94
	134	4.56	1588.18	9396449.51	4482776.02
	135	3.76	3963.20	9396010.87	4482496.74
	136	3.46	493.55	9395745.76	4482734.56
21	137	7.16	2675.47	9395544.16	4482849.34
	138	3.86	605.85	9395293.13	4483010.03
	139	4.66	3434.12	9395097.08	4483206.54
	140	4.06	4602.82	9394645.44	4482959.53
	141	5.96	5742.90	9394511.02	4482829.20
	142	3.36	4703.45	9394762.72	4482694.97
	143	4.96	5617.07	9394965.80	4482274.87
	144	6.36	1921.11	9394991.98	4481912.10
	145	4.86	2491.07	9394676.32	4482017.18
	146	3.06	2240.49	9394811.62	4481529.66
	147	3.36	1176.91	9395037.55	4481067.43
	148	3.46	539.69	9395079.86	4481000.13
	149	3.46	1061.02	9395139.37	4480903.71
	150	3.06	1700.36	9395248.39	4480767.07
	151	6.76	2240.86	9395279.12	4480641.81

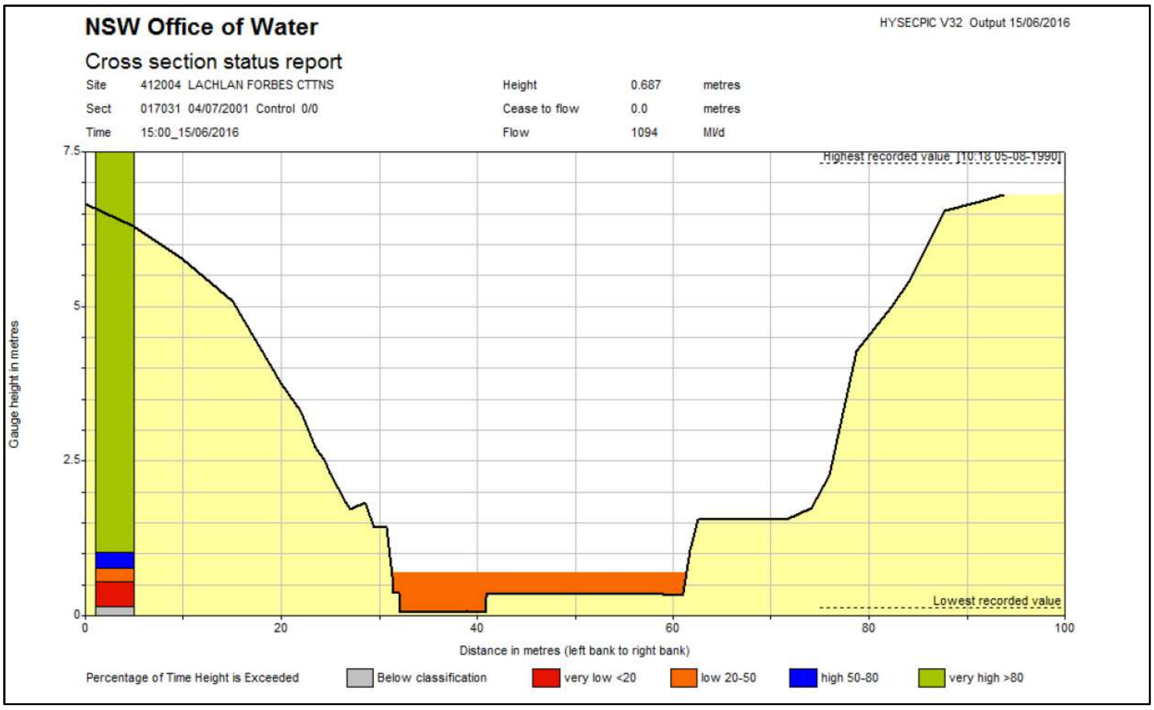
152	3.06	2750.88	9395135.18	4480555.30
153	9.06	2099.04	9394852.98	4480385.84
154	3.26	1989.01	9394706.43	4480483.47
155	3.06	703.04	9394652.66	4481281.01
156	3.96	1558.18	9394616.72	4481416.69
157	3.46	3386.50	9394347.61	4481499.41
158	5.26	8431.44	9393829.71	4481254.88
159	4.06	712.38	9393523.52	4481478.43
160	5.26	1299.22	9393403.92	4481484.98
161	8.16	1247.90	9393242.31	4481455.32
162	3.06	1392.66	9393246.18	4481374.22
163	3.66	476.77	9393104.25	4481094.38
164	3.96	1390.88	9393026.35	4481067.31
165	4.06	1187.11	9392965.76	4481109.70
166	5.86	6163.62	9392888.45	4481208.91
167	4.96	319.34	9392169.58	4481440.18
168	3.26	1211.55	9392136.29	4481579.23
169	3.76	1647.34	9392062.39	4481765.07

Appendix C. Measuring gauge cross sections






NSW Office of Water
HYSECPIC V32 Output 15/06/2016
Cross section status report
Site 412057 LACHLAN R @ NANAMI
Sect 2012GA 04/03/2012 At gauges 1/0
Time 12:00_15/06/2016
Height 0.902 metres
Cease to flow 0.0 metres
Flow 704.2 Ml/d
Highest recorded value [06:33 07-09-1974]
Lowest recorded value
Gauge height in metres
Distance in metres (left bank to right bank)
Percentage of Time Height is Exceeded
Below classification
very low <20
low 20-50
high 50-80
very high >80


NSW Office of Water
HYSECPIC V32 Output 15/06/2016
Cross section status report
Site 412004 LACHLAN FORBES CTTNS
Sect 017031 04/07/2001 Control 0/0
Time 15:00_15/06/2016
Height 0.687 metres
Cease to flow 0.0 metres
Flow 1094 Ml/d
Highest recorded value [10:18 05-08-1990]
Lowest recorded value
Gauge height in metres
Distance in metres (left bank to right bank)
Percentage of Time Height is Exceeded
Below classification
very low <20
low 20-50
high 50-80
very high >80