Darling Baaka River Health Project 2023 to 2025

Chapter 9 Value of the project and recommendations

Department of Climate Change, Energy, the Environment and Water

Acknowledgement of Country

Department of Climate Change, Energy, the Environment and Water acknowledges the Traditional Custodians of the lands where we work and live.

We pay our respects to Elders past, present and emerging.

This resource may contain images or names of deceased persons in photographs or historical content.

Artist and designer Nikita Ridgeway from Aboriginal design agency Boss Lady Creative Designs created the People and Community symbol.

Cover photo: Darling Baaka River at Kinchega National Park. Bottlebrush photography

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9.1 Final river health condition

The purpose of this chapter is to provide an overview of the data generated in the Darling Baaka River Health Project (the project). In this technical report, there is one chapter allocated to each of the 6 River Condition Indexes (RCI):

1. Geomorphic Condition Index (Chapter 3)
2. Water Quality Index (Chapter 4)
3. Riparian Vegetation Condition Index (Chapter 5)
4. Biodiversity Condition Index (Chapter 6)
5. Hydrological Stress Index (Chapter 7)
6. Landscape Disturbance Index (Chapter 8).

Data presented in this report were sourced from 36 sampling trips, 2,935 water quality samples, 2 rounds of biological sampling, 6 rounds of eDNA sampling, and between 6 and 13 months of continuous smart buoy monitoring data. Further details are available in supplementary reports that are associated with this project.

Water quality sampling at sites across the lower Darling Baaka River provides data at a higher spatial resolution than previously available. Surface water sites were sampled monthly since April 2023, with the 6 smart-buoys providing an array of continuous data. 18 groundwater bores were sampled twice, with loggers deployed providing 12 months of continuous data. This provides one of the most comprehensive water quality datasets for the lower Darling Baaka River.

High-resolution monitoring of biotic and abiotic indicators provides invaluable data with which to identify trends and accurately assess impacts and recovery from flooding or drought. However, in a system as climatically and hydrologically variable as the lower Darling Baaka, it is critical to extend monitoring over the long term to assess a range of hydrological conditions and to better quantify the variability of water quality, flora and fauna. This is best highlighted in the water quality dataset collected in this program, where the samples after April 2024 are distinctly different in water quality to those sampled prior to April 2024 due to the inflow of significant quantities of water following rainfall in the upper Darling basin.

The 2025 Darling Baaka RCI framework used 152 individual metrics, which formed the 6 RCI indexes to assess overall health. The results were combined into one grade for each subcatchment. Challenges in using a multicriteria analysis such as the RCI framework can arise when the process of combining multiple indicators averages out or mutes the perceived significance of key findings for individual indicators. In this respect, it was important to interrogate the individual indicators beyond the overall RCI score, as has been done in each chapter of this report and the supplementary reports, to highlight significant findings regarding the condition of the lower Darling Baaka. This report presents results from a range of biotic and abiotic indicators which not only assesses the current health of the river and its recovery since the 2022–23 flood, but provides an important baseline dataset of the current condition of the lower Darling Baaka.

The following section summarises the findings for each of the 6 river condition indexes. Section 9.3 provides further details, including data used in the index calculations and maps comparing the 2023 RCI (DPE 2023a) and 2025 Darling Baaka RCI grades.

Geomorphic condition

- Geomorphic condition was found to be in very good condition in 15 subcatchments, good condition in 9 subcatchments, moderate in 3 subcatchments and poor in 1 subcatchment
- The Darling Baaka River between Wilcannia and Lake Wetherell zone was in moderate geomorphic condition. The significantly increased incidence of alluvial gullies in these reaches compared to other parts of the river presents a long-term impediment to the recovery potential of these reaches
- Lake Wetherell was assessed as being in poor geomorphic condition, primarily due to river regulation structures, such as Menindee Main Weir and associated embankments, resulting in the permanent inundation of the floodplain and degradation of geomorphic features and processes
- Field assessments identified 3 key persistent geomorphic threats to the Darling Baaka:
  - increased local sediment supply from alluvial floodplain gullies
  - lack of river red gum (*Eucalyptus camaldulensis*) recruitment in some riparian areas with implications for bank stabilisation and instream woody debris
  - the hydrological and hydraulic impacts of weirs (such as backwater effects) particularly during low flows, compounded by river regulation and catchment-scale water extraction.

Water quality

- Water quality index assessment indicated 17 subcatchments were in poor condition, 4 were in moderated condition, and 7 subcatchments had no data recorded
- Nutrient levels were high throughout the system and often above guideline values. High nutrient concentrations can cause algal blooms, which can be toxic
- High turbidity concentrations were regularly measured at all sites
- The highest concentrations of metals were detected at sites between Wilcannia and Lake Wetherell, frequently exceeding default guideline values
- Cyanobacteria were recorded on several occasions, with chlorophyll-a concentrations indicating high phytoplankton biomass across the study area
- Pesticide concentrations within the river were almost always below recommended guidelines. Exceptions were for the herbicide metolachlor (detected at S9, S11 and S12 in May 2024 and S9 in February 2025), and the herbicide Diuron (detected at S1, S2, S4, S7, S8 in February 2025) at levels about the 95% species protection guideline value

- Groundwater analysis indicated high nutrient levels in several samples. These high levels can indicate human impacts to groundwater. The pesticide atrazine was detected in one sample at levels below guideline values
- The major contributors to poor water quality in the lower Darling Baaka system were:
  – poor inflow water quality from the upper Darling Baaka River
  – river regulation associated with the Menindee Lakes Storage Scheme
  – local hydrological and geological factors.

Riparian vegetation condition

- Riparian vegetation condition was assessed as very good in 1 subcatchment, good in 6 subcatchments, moderate in 18 subcatchments, poor in 3 subcatchments
- Riparian vegetation condition was assessed as good in the Great Darling Anabranch zone, however, was more variable in the lower Darling Baaka River subcatchments. Some subcatchments downstream of Weir 32, around site S15 on the Darling Baaka River, were assessed as having poor riparian vegetation condition
- Plant community types surveyed were dominated by river red gum communities, including river red gum and black box (*Eucalyptus largiflorens*) woodland communities. Limited surveys were conducted in flood-dependant woodlands, for example, black box – lignum (*Duma florulenta*) woodland wetlands
- Field sampling indicated that while mature specimens are widespread, many subcatchments showed limited river red gum recruitment, with no saplings or juveniles recorded at many sites
- The long-term viability of river red gum populations in the lower Darling Baaka River system requires further investigation given the lack of recruitment seen throughout the study area
- Aquatic macrophyte coverage was highly variable across the 3 weir pool study sites, with a *Juncus* sp. and a *Cyperaceae* sp. forming the majority of macrophyte coverage
- Reductions in the volume and frequency of flows in the lower Darling Baaka system, associated with catchment-scale water extractions and river regulation linked to the Menindee Lakes Storage Scheme, may be responsible for the reduction in successful recruitment of river red gums resulting in low riparian condition scores throughout the study region
- The major contributors to riparian vegetation grades in the lower Darling Baaka system were:
  – Lack of recruitment of riparian canopy trees
  – Low ground cover.

Biodiversity condition

- 1 subcatchment was assessed to be in good condition, 6 in moderate condition and 14 in poor condition. 7 subcatchments had no data collected for this indicator

- Biodiversity condition was generally observed to be better in the Great Darling Anabranch when compared to the lower Darling Baaka River
- The study identified seven native fish species, 66 macroinvertebrate families, 27 zooplankton families, 35 bird species, 93 genera of phytoplankton, one reptile species, one mammal species, 23 stygofauna orders and 212 plant species (native and exotic)
- Fish communities in the study area indicate a stressed ecosystem, with introduced species, predominantly European carp (*Cyprinus carpio*), dominating the biomass throughout the study area (on average 70%) and poor to very poor recruitment
- Total abundances of fish steadily declined downstream of the Menindee Main Weir
- Murray cod (*Maccullochella peelii*) was identified in the river, however, none were found north of site S9 (Lake Wetherell near the Menindee Main Weir) or on the Great Darling Anabranch
- Several species of fish known to previously exist in the river were absent, including the threatened eel-tailed catfish (*Tandanus tandanus*)
- Freshwater turtles were seen at sites S4 and S7 within the Wilcannia Downstream subcatchment, and at site S30 in the Cawndilla subcatchment
- Several endangered and vulnerable bird species were detected through eDNA sampling. The vulnerable great crested grebe (*Podiceps cristatus*) was identified at sites S6 and S9 within the Wilcannia Downstream and Lake Wetherell subcatchments. The endangered eastern great egret (*Ardea alba modesta*) was detected at sites S11, S14, S24 and S30 (Lake Wetherell, Lower Anabranch and Cawndilla subcatchments). The vulnerable red-tailed black cockatoo (*Calyptorhynchus banksii*) was detected at site S7 in the Wilcannia Downstream subcatchment
- Macroinvertebrate sampling results indicate long-term impacts to the macroinvertebrate community, signifying degraded river health
- Zooplankton around Wilcannia, Pooncarie and Menindee were dominated by small protozoans, indicating a stressed ecosystem
- Poor water quality, particularly turbidity and dissolved oxygen concentrations are likely having deleterious effects on the biodiversity in the study area
- The major contributors to biodiversity condition grades in the lower Darling Baaka system were:
  - high total biomass of introduced fish species
  - low total abundances and richness of native fish
  - low numbers of pollution sensitive macroinvertebrate species
  - zooplankton dominated by small protozoans.

Hydrological stress

- Hydrological condition for the 28 subcatchments were assessed as very good in 1 subcatchment, good in 2 subcatchments, moderate in 13 subcatchments, poor in 8 subcatchments, and very poor in 1 subcatchment (HSI was not assessed in 3 subcatchments)

- Two-dimensional (2D) modelling indicates that the hydrological condition in most of the lower Darling Baaka River system is characterised by significant flow deviations from natural conditions owing to water extraction and river regulation. Modelling shows that 95% study area is in moderate or poor hydrological condition
- The Lake Wetherell and Cawndilla subcatchments encompass most of the infrastructure associated with the Menindee Lakes Storage Scheme. River regulation operations in these subcatchments drive significant deviations from natural flow conditions and result in poor hydrological stress grades
- The poor hydrological conditions in the study area are primarily driven by changes in the periodicity and duration of zero-flow events
- The model used did not consider the impacts of river regulation upstream of the study area. The cumulative impacts of damming, extraction and modification of flow patterns in the northern Darling basin, more broadly, are likely exerting further hydrological stress on the lower Darling Baaka that is not measured in this modelling approach
- The major contributors to hydrological stress grades in the lower Darling Baaka system were:
  - Frequency of low flow events
  - River regulation and extraction.

Landscape disturbance

- Landscape disturbance index was assessed as very good in 16 subcatchments, good in 8 subcatchments, moderate in 2 subcatchments, and poor in 2 subcatchments
- Results indicated that disturbances were limited, with good to very good gradings reported in most subcatchments
- All subcatchments along Talyawalka Creek received a very good grade, as these subcatchments have little built infrastructure and very little land cover change in the last 25 years
- Subcatchments downstream of Wilcannia, including Lake Wetherell, indicated greater levels of landscape disturbance, primarily owing to the significant impact of weirs and water management infrastructure on the river condition of this region
- Subcatchments surrounding Pooncarie were shown to have moderate to high levels of disturbance. The downstream Pooncarie (1475) subcatchment recorded the lowest Landscape Disturbance Index score as a result of increased cropping and sand mining in this subcatchment
- The Landscape Disturbance Index may require further refinement, predominantly in relation to the assessment of changes to land cover, and particularly the loss of vegetation. This is because land cover changes in the last 10 years (included in the index calculations) are minimal, whereas historical land clearing which occurred earlier in the 19th and 20th centuries was much more extensive. The impacts of this

historical clearing are significant and ongoing but not captured in the current approach

- The major contributors to grades in the landscape condition assessment in the lower Darling Baaka system were:
  - Lack of significant road, energy and building infrastructure
  - Dominance of grazing landuses
  - Presence of weirs.

9.2 Previous reports and raw data

Water quality reports and raw data (from 2023 onwards) can be found on the EPA website. Other data is available on SEED. Real-time data for each of the smart buoys is instantaneously available online at the following website: smart buoys.

9.3 Benefits of implementing the River Condition Index at a fine spatial scale

The 2023 RCI Framework (DPE 2023a) was originally developed to provide a standardised and statewide measurement of river health for New South Wales. This RCI framework has been adapted in this project to include locally derived measurements of river health at a very fine spatial scale. Due to the smaller scale of the Darling Baaka River Health Project, it was possible to refine and improve the 2023 RCI framework for the lower Darling Baaka study area. This project significantly increased the amount of field data collected and completed high-resolution spatial analysis and modelling to contribute to the assessment.

The RCI grades for the 2025 Darling Baaka RCI for each subcatchment differ substantially from the 2023 RCI (Figure 1). These differences are not surprising given the different methodologies, scales and purposes of the two discrete studies. Accordingly, grades derived from RCI calculations associated with each study (Figure 1) should not be directly compared (see Chapter 1, section 1.4.2). The 2025 Darling Baaka RCI indicates that river health is on average moderate, with one catchment assessed as having poor river health.

The following sections indicate the main methodological differences between the 2023 RCI (DPE 2023a) and the 2025 Darling Baaka RCI for each index, and the benefits of implementing the RCI framework at a finer scale.

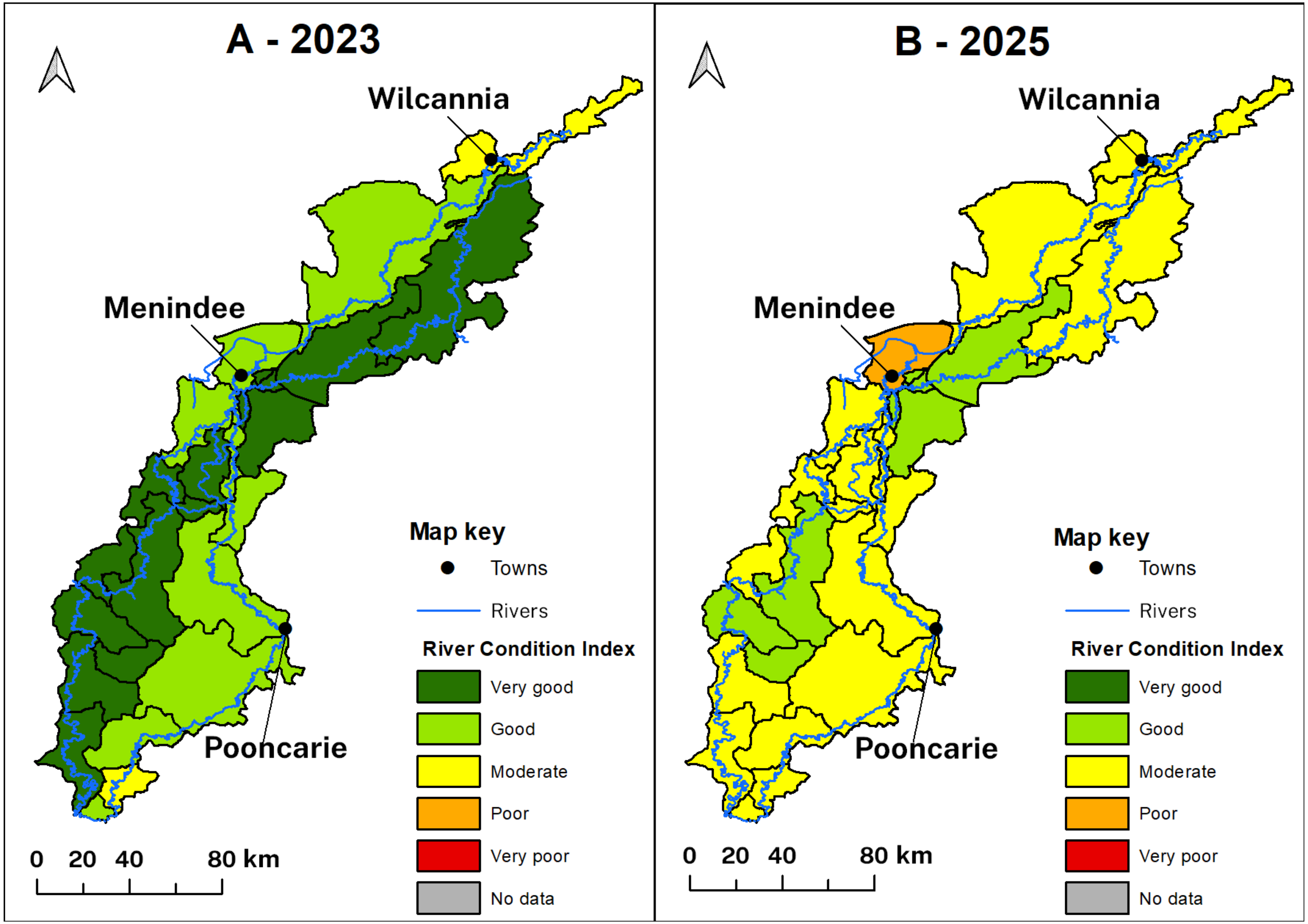

Figure 1 **The 2023 and 2025 River Condition Index grades for the lower Darling Baaka (see Chapter 1)**

9.3.1 Geomorphic condition index

Differences in methodology

The 2023 RCI statewide geomorphic condition assessment relied on existing River Styles data. The River Styles analysis was completed by GHD consultants in 2011 using a rapid assessment approach. This assessment relied solely on remotely sensed satellite and aerial imagery, without any field verification. The absence of field verification in the 2011 River Styles and geomorphic condition assessments was a major limitation of the pre-existing River Styles data for the lower Darling Baaka River (D Workman, pers. comm.). The lack of on-ground field verification of mapping for the 2023 RCI meant that the confidence of the assessment was low.

Additional data, including field verification, were implemented for the 2025 Darling Baaka RCI assessments, and is presented in Table 1. A total of 21 sites were assessed in the field, where qualitative data were collected on channel size and shape, observed geomorphic units within the channel and floodplain, and river behaviour. Gullies and large woody debris were mapped on the ground to ground-truth satellite imagery and ensure accuracy of broader scale assessments of gully and large woody debris density. The geomorphic condition assessments and field verification allowed identification of key long-term geomorphic threats to the lower Darling Baaka River.

Figure 2 shows the 2023 RCI and 2025 Darling Baaka RCI grades for the Geomorphic Condition Index. It highlights the difference that the changes in methodology make to the overall grades.

Table 1 Data used for the Geomorphic Condition Index in the 2023 and 2025 River Condition Index (RCI) calculations

2023 RCI (using 2011 River Styles assessment)	2025 RCI River Styles assessment
Satellite and aerial imagery	Satellite and aerial imagery 2019–20 1-m LiDAR DEM*
No field verification	Field verification of 21 sites across the study area

Table note: LiDAR DEM = light detection and ranging digital elevation model.

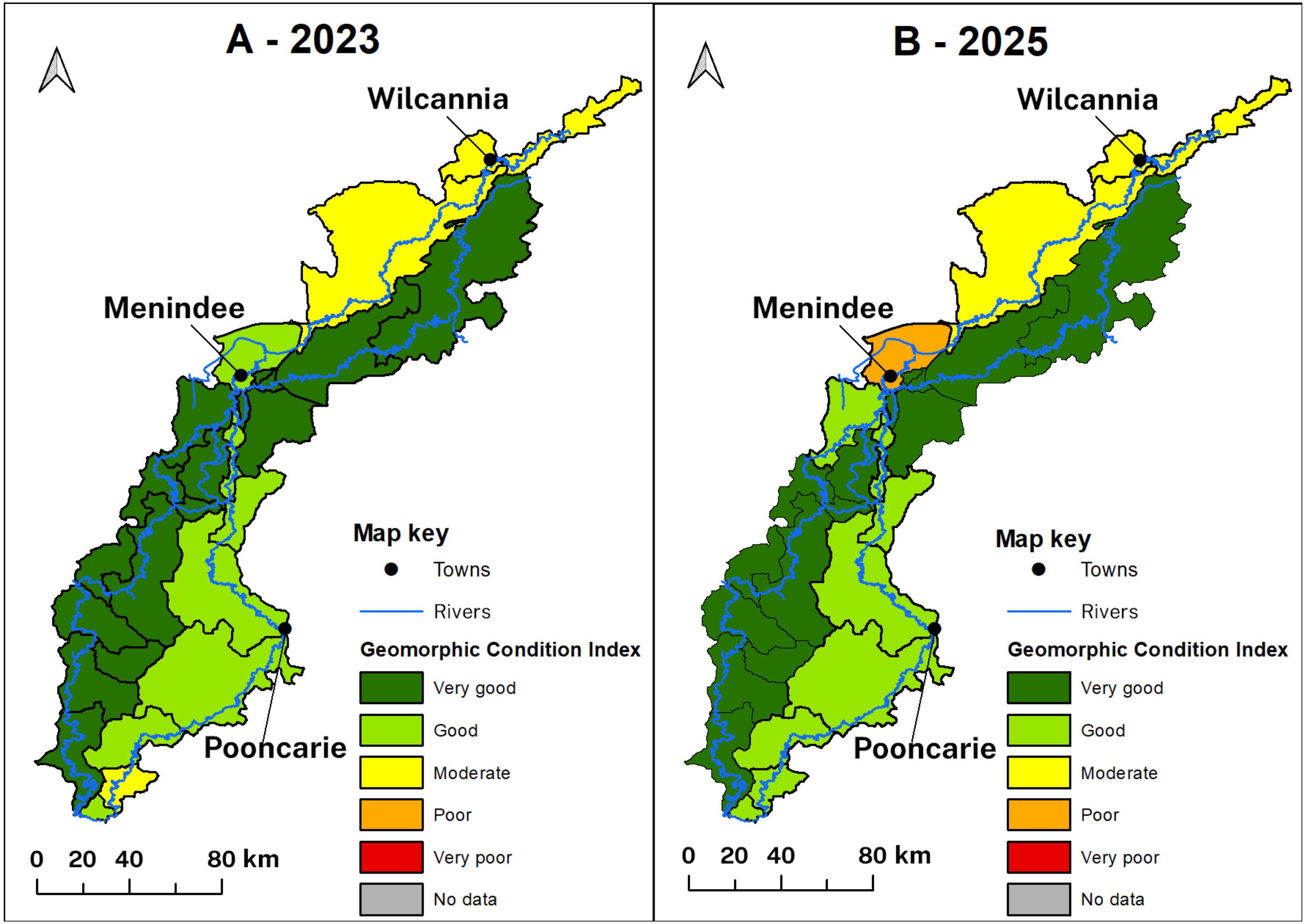

Figure 2 **Geomorphic Condition Index grades for the lower Darling Baaka study area. A: 2023 (DPE 2023a); B: 2025 (Darling Baaka project)**

Benefits of the new methods for assessing Geomorphic Condition Index

Field verification of the lower Darling Baaka River, including the major anabranches improved assessments of geomorphic condition. The field methods were conducted at 21 sites, providing a ground-truthed assessment of the geomorphology. Field verification allowed a nuanced assessment of the spatial differences in geomorphic condition and recovery potential throughout the lower Darling Baaka study area, whereas previous assessments provided a more uniform assessment of geomorphic condition across the study area.

The on-ground assessment provided the resolution required to identify key geomorphic threats to the river, which cannot always be readily understood from remotely sensed data alone. These threats included alluvial gullies, lack of river red gum recruitment, and river regulation which have either degraded geomorphic condition already or act as a long-term impediment to geomorphic recovery.

Although there were only a few differences between the 2 methods for assessing geomorphic condition, the distinct value of performing on-ground assessments include gathering the following data:

- site-specific assessments of geomorphic condition at key targeted locations where impacts may be expected, for example, around weirs or other structures
- baseline geomorphic condition information which permits future change detection analyses as well as further analysis of the impact of floodplain gullies, including assessments of the amount of sediment delivered during gully initiation and expansion
- field-verified locations of alluvial gullies, which can then be comprehensively mapped over a large scale using high-resolution light detection and ranging (LiDAR) data for comparison over time
- evidence of alluvial gullies delivering excess sediment loads to the river, with increases in both fine-grained and coarser, sand-sized sediment depending on the location of the gullies
- qualitative assessments of the recruitment of key species like river red gum (which cannot be completed using desktop methods)

River Styles assessments are generally updated on a rotating 10-year cycle. It is critical that future assessments of geomorphic condition incorporate field verification for the lower Darling Baaka River and for other rivers.

9.3.2 Water quality index

Differences in methodology

The 2023 RCI water quality assessment of lower Darling Baaka was based on data from 3 sites (Wilcannia, Menindee and Burtundy), with grades averaged across the entire study area. Each site was assessed for total nitrogen, total phosphorus, turbidity, dissolved oxygen, pH and electrical conductivity. These parameters were assessed against the ANZECC (2000) south-east Australia lowland river guidelines to calculate a Water Quality Index score.

The water quality condition across the entire study area was assessed as moderate in the 2023 RCI. This contrasts with the results of the 2025 Darling Baaka RCI, which assessed water quality as poor across the majority of the study area (Figure 3) and highlights the differences in the methodologies.

The primary limitations of Water Quality Index calculations for the 2023 RCI for the lower Darling Baaka River are the limited spatial coverage of sampling sites (3), compared to 35 sites for the 2025 RCI; and the absence of analysis for key water quality parameters, including phosphate (soluble reactive phosphorus), nitrogen oxides, ammonium, pesticides and metals. However, the monthly water quality data collected at 3 sites over 5 years for the 2023 RCI Water Quality Index offers good temporal resolution, capturing variability associated with different flow stages (for example floods, droughts, freshes) more effectively than the short-term monitoring undertaken in this project.

The 3 main changes to the methodology between the 2023 RCI and the 2025 RCI assessment were:

- increased number of sites sampled on the lower Darling Baaka River
- increased number of parameters measured
- use of ANZECC (2000) south central Australia (low flow) water quality guideline values.

These differences between the 2023 and 2025 RCI assessments are summarised in Table 2 with details of metrics measured provided in Table 3, Table 4 and Table 5, and discussed below. Additionally, groundwater quality and organic carbon data were collected in 2025, but these data were not used in the RCI assessment.

Table 2 Data used for the Water Quality Index in the 2023 and 2025 River Condition Index (RCI) calculations

Metric	Contributes to the 2023 RCI	Contributes to 2025 Darling Baaka RCI	Contributes to project water quality assessment
Physico-chemical[1]			
Temperature	No	No	Yes
pH	Yes	Yes	Yes
Dissolved oxygen	Yes	Yes	Yes
Electrical conductivity	Yes	Yes	Yes
Turbidity	Yes	Yes	Yes
Fluorescent dissolved organic matter	No	No	Yes
Nutrients[1]			
Total nitrogen	Yes	Yes	Yes
Total phosphorus	Yes	Yes	Yes
Soluble reactive phosphorus	No	Yes	Yes
Nitrogen oxides (nitrates and nitrites)	No	Yes	Yes
Ammonium	No	Yes	Yes
Other metrics			
Chlorophyll-a[2]	No	Yes	Yes
Organic carbon • total organic carbon • dissolved organic carbon	No	No	Yes
Pesticides[3] (x 20; see Table 44)	No	Yes	Yes
Metals[3] (x 12; see Table 5)	No	Yes	Yes
Groundwater quality	No	No	Yes

Table notes: Guidelines used in the 2025 Darling Baaka RCI:
1. ANZECC (2000) south central Australian lowland rivers.
2. ANZECC (2000) south-east Australian lowland rivers.
3. ANZG (2018) 95% species protection guideline value for toxicants in freshwater ecosystems.

Benefits of the new methods for assessing Water Quality Index

Improved spatial coverage and number of sample sites

The 2025 Darling Baaka RCI assessed 35 sites located along the lower Darling Baaka River, between Wilcannia and Wentworth, including the Great Darling Anabranch. The sites were chosen primarily to ensure at least one site in each subcatchment. Sites were also chosen based on accessibility and to cover changes in flow (weirs/lakes). This is vastly different to the data used for the 2023 RCI assessment, which used historical data averaged for the entire study area from just 3 sample sites in the region.

Sites used in the 2025 RCI were sampled monthly, with 6 smart buoys also monitoring physico-chemical parameters every 30 minutes. Due to river conditions, data captured from 35 sites sampled between April 2024 and March 2025 were used in the analysis for the 2025 RCI. Data prior to April 2024 and water quality data from 18 groundwater sites (bores) were sampled and used to inform about river process but were not included in the 2025 RCI water quality index calculations.

Increased number of parameters assessed

The number of parameters assessed for the Water Quality Index was increased from the previous statewide study. Six metrics contributed to the 2023 water quality scores, and 42 metrics contributed to the updated 2025 Water Quality Index (Table 3, Table 4, Table 5).

Nutrients are believed to be a major contributor to eutrophication in the study area. This study expanded the number of nutrient metrics to allows a more comprehensive analysis of the issues in the lower Darling Baaka River system. Additionally, the investigation into pesticides and metals added a level of detail to the study.

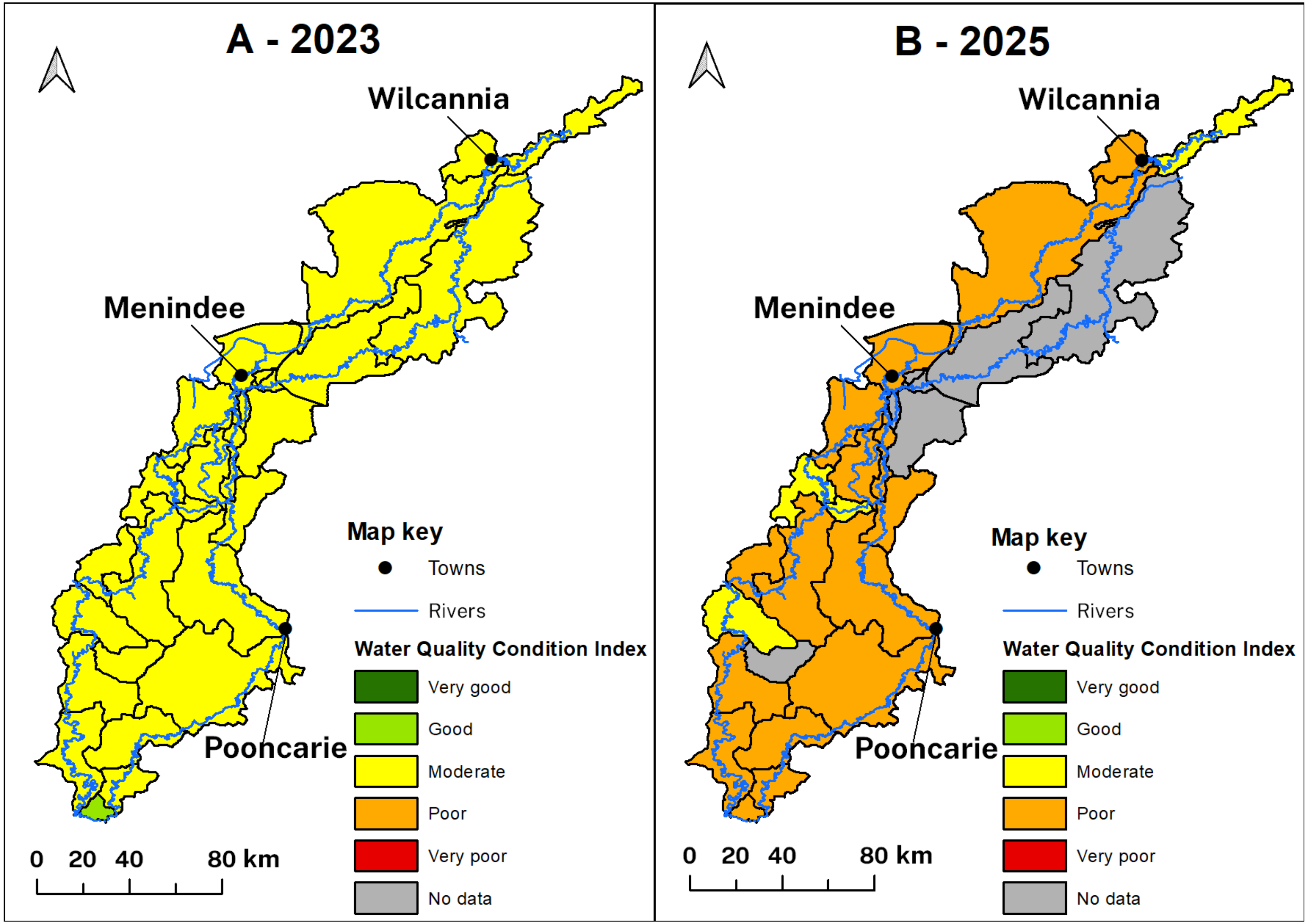

Figure 3 **Water Quality Index grades for the lower Darling Baaka study area. A: 2023 (DPE 2023a); B: 2025 (Darling Baaka project)**

Table 3 Water quality metrics and associated guideline values included in calculation of the Water Quality Index (WQI) in 2023 and 2025

Metric	Contributed to 2023 WQI?	Guideline value (ANZECC 2000, south-east Australian lowland rivers)	Contributes to 2025 WQI?	Guideline value (ANZECC 2000, south central Australian lowland rivers)
Total nitrogen	Yes	500 µg/L	Yes	1,000 µg/L
Total phosphorus	Yes	50 µg/L	Yes	100 µg/L
Soluble reactive phosphorus	No	20 µg/L	Yes	40 µg/L
Nitrogen oxides (NO_x)	No	40 µg/L	Yes	100 µg/L
Ammonium (NH_4^+)	No	20 µg/L	Yes	100 µg/L
Turbidity	Yes	6–50 NTU	Yes	1–50 NTU
Dissolved oxygen	Yes	85–110%	Yes	90%
pH	Yes	6.5-8	Yes	6.5–9
Electrical conductivity	Yes	125–2,200 µS/cm	Yes	100–5,000 µS/cm
Chlorophyll-a	No	5 µg/L	Yes	n.a. (5 µg/L)*
Pesticides (20 variables)	No	n.a.	Yes	95% species protection guideline values (ANZG 2018; Table 4)
Dissolved metals (12 variables)	No	n.a.	Yes	95% species protection guideline values (ANZG 2018; Table 5)

Table notes:
* In order to incorporate chlorophyll-a data into the Water Quality Index calculation, the south-east Australia chlorophyll-a default guideline value of 5 µg/L has been applied to the data.
µg/L = micrograms per litre; NTU = nephelometric turbidity units; µS/cm = microsiemens per centimetre

Table 4 **Pesticides with relevant 95% species protection guideline values incorporated in the 2025 Water Quality Index calculation**

Pesticide	95% species protection default guideline value (mg/L; ANZG 2018)
Atrazine	0.013 mg/L
Diuron	0.0002 mg/L
Glyphosate	0.32 mg/L
Hexazinone*	0.075 mg/L
MCPA	0.0077 mg/L
Methomyl	0.0035 mg/L
Metolachlor	0.00046 mg/L
Molinate	0.0034 mg/L
Picloram	0.087 mg/L
Simazine	0.0032 mg/L
Tebuthiuron	0.0022 mg/L
Trifluralin	0.0044 mg/L
Azinphos methyl^	0.00002 mg/L
Diazinon^	0.00001 mg/L
Dimethoate^	0.00015 mg/L
Endrin^	0.00002 mg/L
Fenitrothion^	0.0002 mg/L
Heptachlor^	0.00009 mg/L
Hexachlorobenzene^	0.0001 mg/L
Malathion^	0.00005 mg/L

Table notes:
* Based on low reliability trigger level using the assessment factor method (AF = 1,000).
^ After September 2024, these additional 8 pesticides were analysed at higher resolution with reporting limit values below default guideline values allowing their incorporation into the WQI calculation.

Table 5 Dissolved metals with relevant 95% species protection guideline values incorporated into the 2025 Water Quality Index calculation

Dissolved metal	95% species protection default guideline value (mg/L; ANZG 2018)
Aluminium	0.055 mg/L
Arsenic	0.013 mg/L
Cadmium	0.0002 mg/L
Chromium	0.001 mg/L
Copper	0.0014 mg/L
Lead	0.0034 mg/L
Manganese	1.9 mg/L
Mercury	0.0006 mg/L
Nickel	0.011 mg/L
Total Selenium	0.011 mg/L
Silver	0.00005 mg/L
Zinc	0.008 mg/L

Guideline values used for water quality assessment

The Water Quality Index that contributed to the statewide 2023 RCI used ANZECC (2000) guidelines for south-east Australia lowland rivers (slightly disturbed ecosystems). These guidelines are applicable to rivers in Victoria, New South Wales, south-east Queensland, the Australian Capital Territory and Tasmania.

There is less national guidance available for water and/or sediment quality assessments for ephemeral surface waters and waterbodies in arid and semi-arid regions of Australia than for intermittent and seasonal waterbodies outside these climatic zones. The majority of runoff contributing to flows in the Darling Baaka River is produced in the relatively wet headwater catchments in the eastern and northern tablelands. However, the majority of the lower catchment including the Darling Baaka River Health Project study area is semi-arid (250–350 mm/year) and arid (<250 mm/year), with an average annual rainfall between 200 mm and 300 mm.

Although the south-east Australia guidelines incorporate some sample data from central and north-west New South Wales, the lack of detailed information on the sampled rivers and methods used limits the confidence in the guideline values' applicability to the lower Darling Baaka River.

The project's Expert Advisory Panel was requested to advise whether it would be appropriate to use the ANZECC default guideline values for south central Australia, which were developed for low-rainfall regions with extreme fluctuations in water availability and quality (Table 3). The panel recommended this approach. A major limitation of the south central Australian guidelines is the absence of a guideline value for chlorophyll-a concentration (representative of algal biomass). To address this, the south-east Australia chlorophyll-a guideline was applied to incorporate chlorophyll-a data into the Water Quality Index calculation (Table 3).

Summary of the benefits of new methods to assess the Water Quality Index

Overall, the finer scale approach to calculating Water Quality Index scores for the lower Darling Baaka River, incorporating more sites, more metrics and different guideline values, provides a more detailed assessment of water quality throughout the study area. With more data contributing to the index calculation, interrogation of the results can provide actionable insights into subcatchments that have routinely poorer water quality scores than others.

By increasing the number of metrics, contaminants such as metals and pesticides can be assessed. Disentangling the drivers of poor water quality is difficult but having a finer spatial scale assessment combined with a broader range of assessed metrics provides an important step to identifying priority water quality issues (namely, nutrient and algae concentrations and turbidity).

There were distinct differences in the assessment of water quality using the 2 different RCI methodologies. The distinct benefits of increasing the number of sites and parameters measured for the 2025 Darling Baaka RCI include:

- site-specific assessments of water quality issues
- baseline detailed assessment of pesticides and heavy metals in the system
- detailed information on the impacts of stratification on oxygen concentrations and algal biomass
- provision of real-time data which can be used to inform environmental releases
- early warning system (smart buoys) to provide alerts of pending oxygen, algal and nutrient issues
- provision of baseline data to allow studies on the interactions between water quality, aquatic biota and bacteria within the river system.

Improved spatial coverage of sampling sites provided a more detailed assessment of the spatial heterogeneity of water quality across the study area between April 2024 and March 2025. However, this study period is not representative of the full range of variability in hydrological conditions and associated changes in water quality that occur on the lower Darling Baaka River. In a system as climatically and hydrologically variable as the Darling Baaka, it is critical to extend monitoring over the long term to assess a range of hydrological conditions and to better quantify the variability of water quality.

9.3.3 Riparian vegetation condition index

Differences in methods

In the statewide 2023 RCI assessment, the Riparian Vegetation Condition Index relied on remotely sensed data for the lower Darling Baaka River. Due to limited data availability for the Darling Baaka region, vegetation condition metrics provided an average result for the study area based on previous statewide mapping. The 2023 RCI assessments used the 2022 NSW State Vegetation Type Map (DPE 2023c) to assess the extent (patch size and connectivity) of native woody vegetation in the riparian zone (within ~30 m of rivers).

However, this assessment method was not adapted to account for the region's unique vegetation communities and history of disturbances. Specifically, the original riparian vegetation index did not include an assessment of recruitment, or lack thereof, of river red gums. In areas where juvenile/sapling recruitment is minimal, there is a potential long-term threat to the riparian vegetation condition (S Bowen, Water Group, pers. comm.). Additionally, no field assessments of vegetation health or verification of the spatial data occurred for the 2023 Riparian Vegetation Condition Index.

The 2025 Darling Baaka RCI study built on the foundational work completed for the 2023 RCI, devising a more relevant riparian vegetation condition map for the lower Darling Baaka study area. In addition to the previously assessed metrics of patch size and connectivity assessed by spatial modelling, the 2025 RCI assessment incorporated field data in the form of floristic plots, tree condition assessments, and rapid appraisal of riparian condition (Table 6). Additionally, spatial modelling used field assessments and satellite imagery to provide spatial layers representing the vegetation health (green cover) of riparian and floodplain vegetation communities. The inclusion of these data in the 2025 Riparian Vegetation Condition Index calculation provided a more detailed, and higher resolution assessment of vegetation condition than what was previously possible using only patch size and connectivity.

Table 6 **Data used for the Riparian Vegetation Condition Index in the 2023 and 2025 River Condition Index (RCI) calculations**

Riparian vegetation indicator	2023 RCI	2025 RCI
Satellite mapping of vegetation condition	2022 NSW State Vegetation Type Map	2023 State Vegetation Type Map Sentinel-1 Sentinel-2 LiDAR data from Global Ecosystem Dynamic Investigation
Floristic plots	No field data	36 plots (at 19 sites)
Tree condition assessments	No field data	34 sites
Rapid appraisal of riparian condition	No field data	53 sites

Benefits of the new methods for assessing Riparian Vegetation Condition Index

Collection of field data

On-ground assessments of riparian condition are essential because they provide detailed, site-specific information that satellite imagery alone cannot capture. While satellite data is excellent for large-scale monitoring and identifying general patterns, it has limitations in detecting finer details.

An intensive field campaign was undertaken to complete on-ground surveys of the riparian vegetation in the study area. Sites were distributed throughout the 28 subcatchments, with a minimum of one site per subcatchment, with access limiting sampling in some subcatchments. This study collected data on the following sub-indicators:

- community condition
- tree stand condition
- overall riparian condition (using the rapid appraisal of riparian condition method, see Chapter 5).

Field surveys also provided information on tree demographics and recruitment. This was used to indicate the population viability within the study area.

Improved spatial analysis

Remote sensing and spatial modelling used for the Darling Baaka River Health project were targeted to the major plant community types. The classification approach, applied to individual plant community type categories, ensured that the condition assessment considered the different ranges in vegetation cover and vegetation health expected for each vegetation functional group. For example, healthy river red gum woodland is known to have a higher vegetation cover than healthy flood-dependent woodland and healthy flood-dependent shrubland. This allowed a more adapted methodology, considered the specific requirements of the plants in the study area, mainly river red gum and black box communities.

Summary of the benefits of the new methods for assessing Riparian Vegetation Condition Index

The 2025 Darling Baaka RCI combined both on-ground assessments and remotely sensed spatial data. This allowed the entire study area to be comprehensively assessed. Field data was used to collected details on community condition and tree health condition. Where surveys could not be undertaken due to logistical issues, the 2025 RCI Riparian Vegetation Condition Index provided spatial data on riparian condition. This combination of methods improved the assessment of riparian condition across the study area.

There were marked differences between the 2023 RCI assessment, where all subcatchments were assessed as having very good riparian vegetation condition, and the 2025 Darling Baaka RCI which assessed the majority of subcatchments to be in moderate condition, and some in poor condition (Figure 4). The finer scale methods used in the 2025 riparian vegetation condition assessment resulted in:

- methods specifically tailored for plant community types present in the study area
- assessments of invasive species
- assessments of microhabitats, such as debris, tree hollows and leaf litter
- assessments of the recruitment and long-term viability of canopy tree vegetation
- assessments of floodplain vegetation communities.

Due to poor correlations between spatial analysis of vegetation condition and the field surveys, it is recommended that a combination of both methods is required for future assessments. It is suggested that the spatial analysis component is only reassessed when new datasets become available (likely 5-year increments), whereas some field methods may be undertaken more regularly to track changes in vegetation.

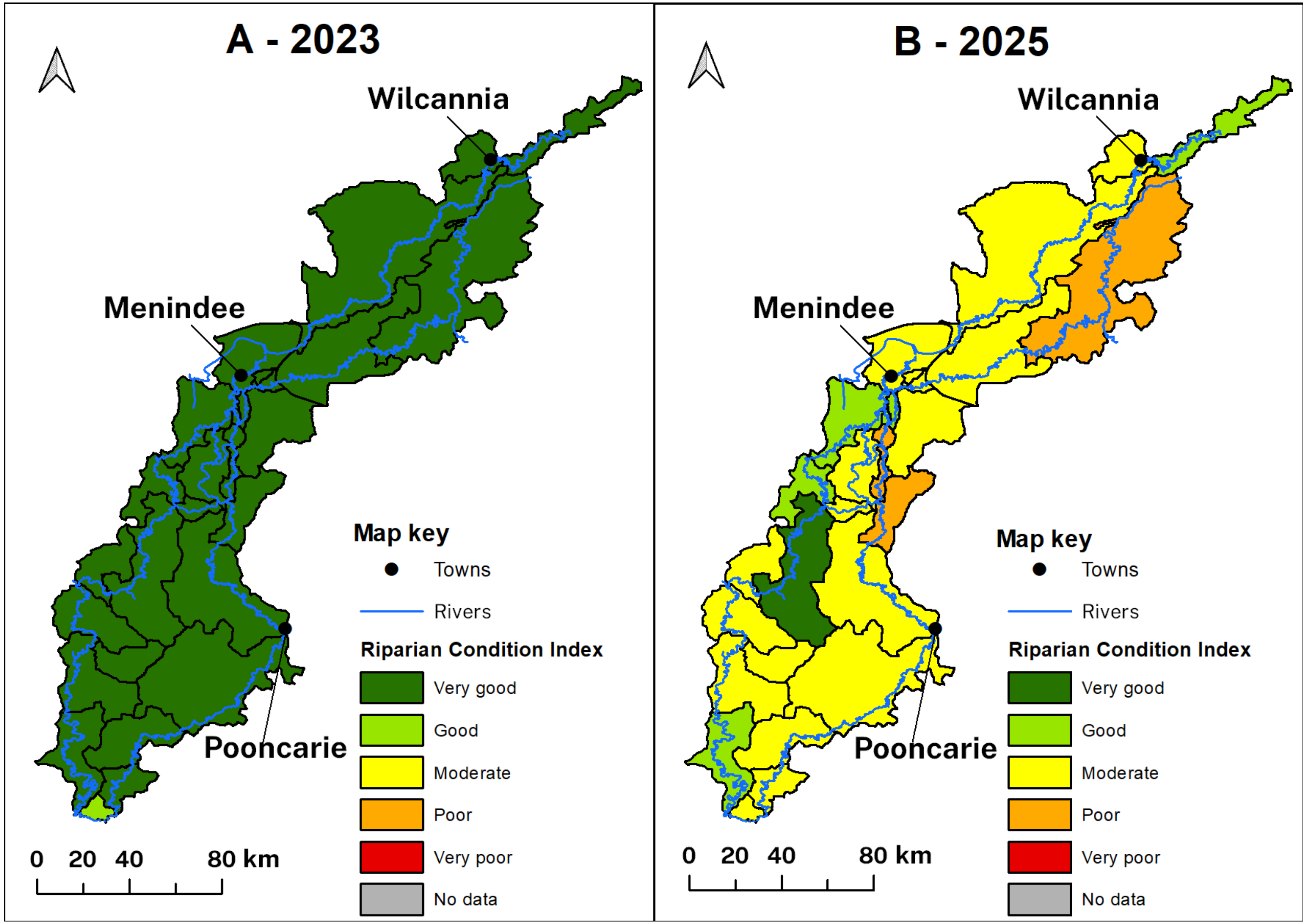

Figure 4 **Riparian Vegetation Condition Index grades for the lower Darling Baaka study area. A: 2023 (DPE 2023a) B: 2025 (Darling Baaka project)**

9.3.4 Biodiversity condition

Differences in methodology

The 2023 RCI assessments for biodiversity in the NSW inland river systems were based on historical datasets. These early calculations relied on relatively sparse fish surveys, with no data available for other important biological indicators such as macroinvertebrates and zooplankton. The 2023 RCI analysis for the Biodiversity Condition Index used fish survey data from the 2012 *Sustainable Rivers Audit 2* (Murray-Darling Basin Authority 2012), as this was the only data available at scale across New South Wales. The Fisheries NSW (part of the Department of Primary Industries and Regional Development) Fish Community Status dataset was developed using these 2012 audit indicator metrics collected from 646 sampling sites across the entire state of New South Wales between 2009 and 2012 (NSW Department of Primary Industries 2016). This led to a very coarse-scale assessment in the 2023 RCI providing a somewhat incomplete picture of river health and biodiversity, particularly in the remote river reaches.

The adaptation of the 2023 RCI into a finer scale for the Darling Baaka River Health Project, localised assessment of river health required intensive sampling of the lower Darling Baaka River at 32 sites for a broad range of biota (Table 7). This approach ensured that several components of the food web, from microscopic organisms to larger species, were accounted for.

Additionally, the lower Darling Baaka River assessment provided detail on the total biodiversity of the river though combining tradition sampling methods with eDNA to assess taxonomic richness. The number of species present did not contribute to the overall Biodiversity Condition Index as a single entity. Instead, the index measured the condition of the communities present in terms of nativeness, expectedness and presence of pollution-tolerant and potentially toxic species.

The 2023 RCI Biodiversity Condition Index score for many subcatchments, was calculated by averaging the biological condition from adjacent subcatchment results. The 2025 Darling Baaka RCI also adopted this approach, however only for four subcatchments, and only when sampling had occurred in flowing waters. As several of the subcatchment (mainly in Talyawalka Creek) did not have water, or water was not flowing it was felt that allocating an aquatic biota score to these subcatchments may misrepresent the conditions at the time of this study. This resulted in 7 subcatchments having no biodiversity condition score allocated to them.

Table 7 **Data used for the Biodiversity Condition Index (BCI) in the 2023 and 2025 River Condition Index (RCI) calculations**

Biological indicator	Used in 2023 RCI?	Collected in 2025?	Contributes to the 2025 BCI?	Justification
Fish	Yes	Yes	Yes	Widely used throughout catchment and in 2023 RCI
Macroinvertebrates	No	Yes	Yes	Ease of sampling, established and scientifically proven indicator of health
Zooplankton	No	Yes	Yes	Ease of sampling, well known to indicate river health, vital in food chain
Microbes	No	Yes	No	Importance in biogeochemical cycling
Algae	No	Yes	No	Important indicator of health
Stygofauna (groundwater invertebrates)	No	Yes	No	Important indicators of groundwater health
Waterbirds	No	Yes	No	Known to be important indicators of biological condition

Benefits of the new methods for assessing Biodiversity Condition Index

Diverse biological responses

Assessing more than one biota type in river condition assessments provides a comprehensive understanding of the ecosystem's health. Stressors related to water quality and quantity can manifest in different ways in different parts of the food web, so assessing condition of communities at the base of the food web (such as zooplankton) as well as much higher in the food web (for example, fish) is important. By studying and understanding the responses and interactions between different taxonomic groups we can further our knowledge of the drivers of stress and increase the reliability of overall river health classifications.

In the 2025 Darling Baaka River Health project, macroinvertebrates, zooplankton and fish were surveyed at 32 sites in the study area. This provided an in-depth and spatially comprehensive assessment of biological condition across a range of trophic levels. Additional biota were sampled, with results presented in supplementary reports and will contribute to the analysis of ecosystem processes occurring in the river.

Targeted sampling

The 32 sites targeted for macroinvertebrate, zooplankton and fish surveys added a fine spatial resolution to the study area. Biota are affected by river regulation, which alters flow and barriers like weirs can restrict movement of biota. By collecting biological data in numerous locations along both the lower Darling Baaka River and the Great Darling Anabranch, scientists and managers can build a more accurate understanding of the biological condition and the biodiversity in the river system. The 2023 RCI used only one taxa and averaged condition using only a few sampling points across the study area. By averaging RCI grades using limited information, the fine-scale assessment of issues within the system cannot be undertaken. The 2025 Darling Baaka RCI greatly expanded the spatial scale of sampling, and reduced the reliance on inferring biological condition from adjacent subcatchments.

The 2025 Darling Baaka RCI dataset is publicly available on SEED and will be further interrogated to build a more comprehensive understanding of the areas of concern.

Summary of the benefits of the new methods to assess the Biodiversity Condition Index

The majority of the subcatchments were classified as in poor biodiversity condition in the 2025 Darling Baaka RCI assessment (Figure 5). The finer scale methods used, the increase in taxa surveyed, and the increased number of data points provided the level of detail required to more accurately assess the condition of the river. New data collected includes:

- fish data, which were collected during two sampling events at 31 sites, with complementary data from eight additional sites, leading to a total of 39 sites contributing to the overall fish health indicators
- zooplankton were surveyed at 32 sites in the study area, uncovering a new species and a new indicator was built into the RCI framework
- macroinvertebrate data, surveyed at 32 sites, were built into the RCI framework
- comparisons between the community health of small and microscopic species, which are consumed by larger organisms such as fish and waterbirds, and the community health of larger taxa were made
- benchmarks were provided for a range of biota in the region, which can be used to assess biodiversity condition in the future
- data on bacteria and algal communities were provided. This data will be used to improve our understanding of biogeochemical cycles, ecosystem processes and overall water quality
- an improved understanding of the links between groundwater ecosystem health and river health.

In addition to the implementation of the RCI on a smaller spatial scale, the 2025 study provided detailed information on:

- waterbird populations (see Davis and Korbel 2025)
- algae species present under various hydrological conditions (see Mitrovic et al. 2025)
- bacterial species richness and diversity (see Seymour et al. 2025)
- links between bacterial functions and water quality (see Seymour et al. 2025)

- stygofauna (groundwater animals) present in the study area (the first such study in the region) (see Hose et al. 2025)
- macrophyte recruitment and recovery post 2023 floods.

It is suggested that macroinvertebrates and fish surveys should be conducted annually to provide an up-to-date assessment of biodiversity condition. Recent biological data are important to be able to indicate potential stressors and provide early warning systems for declining river health.

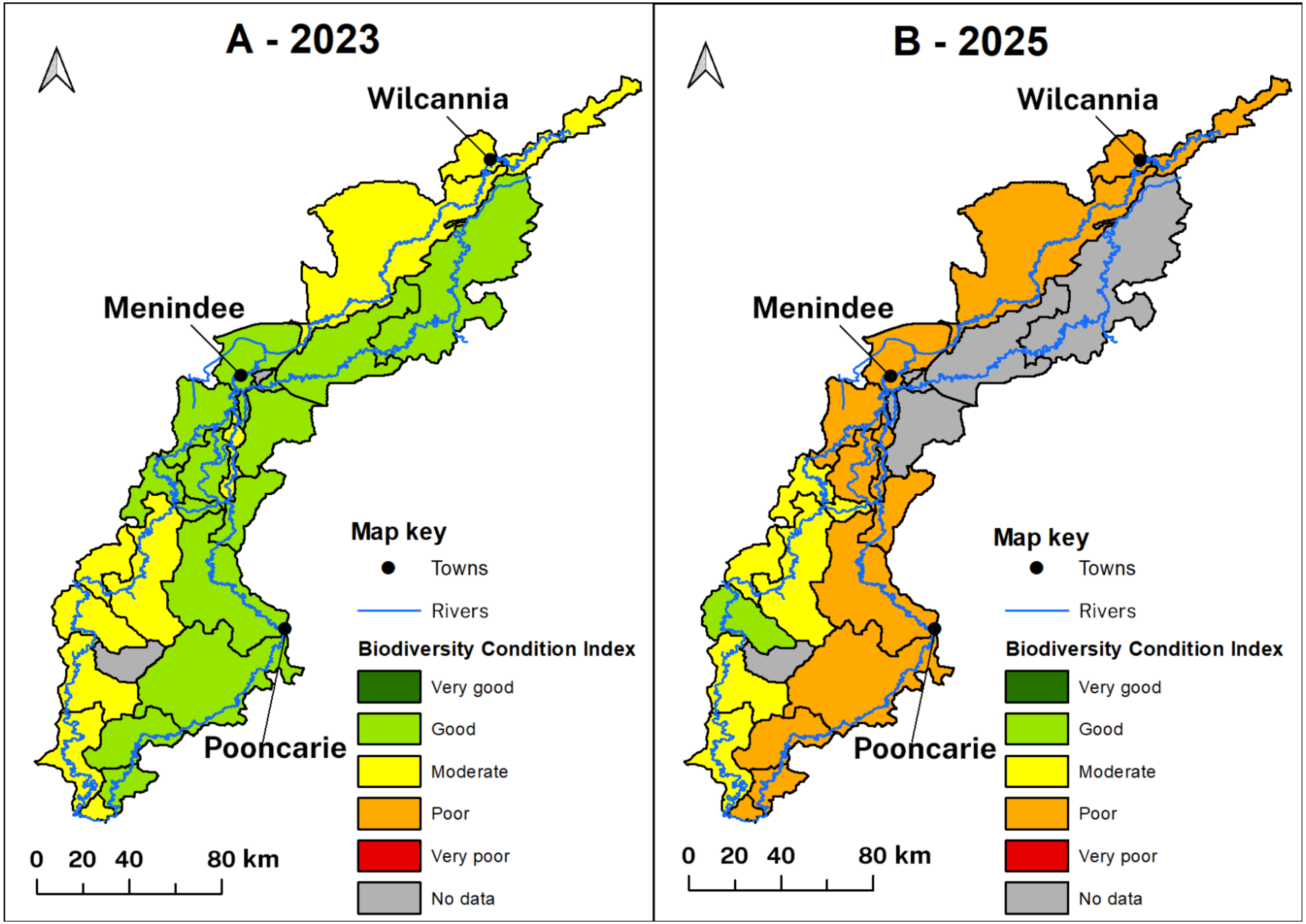

Figure 5 **Biodiversity Condition Index grades for the lower Darling Baaka study area. A: 2023 (DPE 2023a) B: 2025 (Darling Baaka Project)**

9.3.5 Hydrological stress

Differences in methodology

The 2023 Hydrological Stress Index used two 100-year modelling scenarios. These simulated the ‘natural’ (pre-development) state of the system prior to modifications, and the ‘altered’ (current) state of the system considered weirs, dams, water releases and extractions under current water sharing plans. The methodology is described in DPE (2023a). One of the limitations of this model was that groundwater was not included, thus interactions and contributions of groundwater to surface waters were not accounted for.

The 2025 Hydrological Stress Index developed a localised indicator of stress with an increased level of accuracy (Table 8). This was achieved by updating and improving the parameterisation of the hydrological modelling (including groundwater) and incorporating 17 individual hydrological metrics into the calculation of the Hydrological Stress Index score. Improvements to the hydrological modelling include:

- increasing the number of model site (‘node’) locations
- including groundwater fluxes into the surface water hydrological model
- including the operational and water sharing rules in the simulation
- including geomorphic data in the surface–groundwater coupled model
- increasing the spatial resolution by using more subcatchments.

Figure 6 indicates the 2023 RCI and 2025 Darling Baaka RCI grades for the Hydrological Stress Index. It shows that many subcatchments were graded as very good in 2023, but only one subcatchment was graded very good in 2025. In 2025 RCI, there were 3 subcatchment where there was no data to assess hydrological stress, and it was decided not to use the average condition of the upstream catchments to infer condition in these areas.

Table 8 **Data used for the Hydrological Stress Index in the 2023 and 2025 River Condition Index (RCI) calculations**

Metrics	2023 RCI	2025 RCI	Justification
Time-series locations	28	82	Improved resolution within each subcatchment
Operational rules	No	Yes	Improved hydrological understanding
Catchments used	28	34	Improved resolution with more subcatchments
Groundwater modelling	No	Yes	Groundwater–surface water connectivity important in lower Darling Baaka study area
Groundwater monitoring (standing water level)	No	13	Calibrate and validate the groundwater model
High-resolution and borelog data included in the groundwater model	No	Yes	Hydraulic conductivity to improve surface–groundwater connectivity modelling
High-resolution topographic data included in surface water model	No	Yes	Improve river flow estimates by identifying the bank overflow locations and channel morphology
Hydrologic metrics	No	17	Represent the different hydrologic parameters (flow conditions)

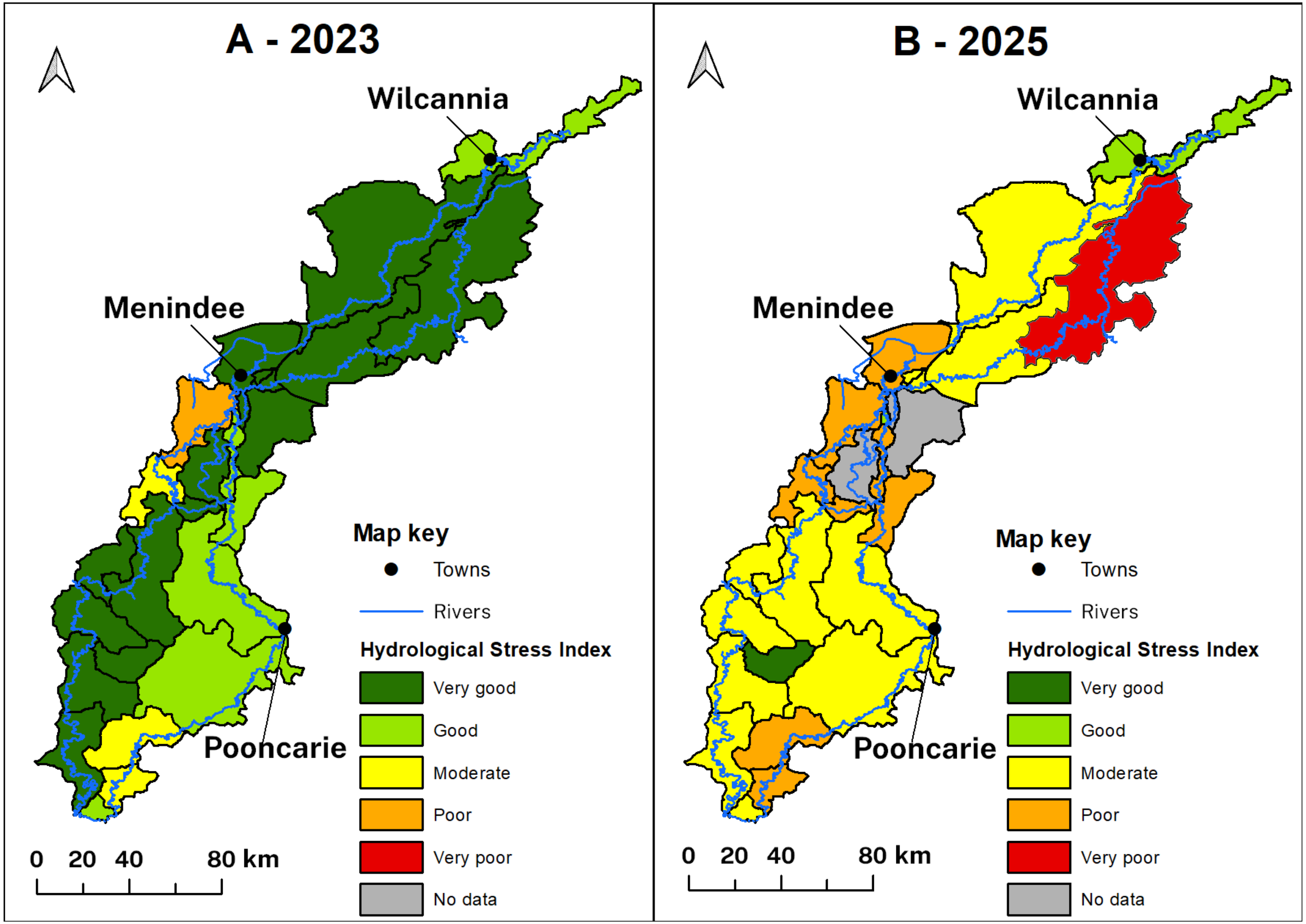

Figure 6 **Hydrological Stress Index grades for the lower Darling Baaka study area. A: 2023 (DPE 2023a) B: 2025 (Darling Baaka Project)**

Benefits of the new methods for assessing Hydrological Stress Index

Given the importance of river regulation structures, such as weirs, in water dynamics in the region, the new hydrological model incorporated operational rules that more realistically represent surface water and groundwater water processes. A substantial increase in the number of sites ('nodes') in the model allowed for better resolution and description of flow regimes throughout the study area.

The performance of the hydrological model in recreating observed low flows was substantially improved with the incorporation of groundwater data into the model calibration (see Chapter 7). This is the first model that indicated which reaches of the lower Darling Baaka River and Anabranch are losing surface water to groundwater. Further work is required to better understand the interactions between surface water and groundwater in the lower Darling Baaka River study area.

Increased number of metrics

For the 2025 assessment of hydrological stress, 17 flow metrics were considered that describe different aspects of the flow regime, giving a more complete understanding of the implications of the deviations in flows (Table 9). Nonetheless, averaging the results across all 17 metrics can mask some key trends. Further detailed analysis and interpretation is required to fully understand changes to flow caused by river regulation (see Chapter 7). All results should be interpreted with caution, as they are derived from numerical modelling. While care has been taken in calibrating and constraining the model to the study period, there are inherent errors in modelling.

Table 9 Summary of the 17 flow metrics used to calculate the Hydrological Stress Index

Metric
Low flow season
80th percentile flow rate (megalitres per day [ML/day])
No. of years with at least one cease-to-flow spell (no.)
Average number of cease-to-flow spells per year (no.)
Average duration of cease-to-flow spells (no. of days)
No. of years with at least one fresh (no.)
Average number freshes per season (no.)
Average duration of freshes (no. of days)
High flow season
80th percentile flow rate (ML/day)
No. of years with at least one cease-to-flow spell (no.)
Average number of cease-to-flow spells per year (no.)
Average duration of cease-to-flow spells (no. of days)

Metric
No. of years with at least one fresh (no.)
Average number freshes per season (no.)
Average duration of freshes (no. of days)
The 1.5-year annual recurrent interval (ARI) (ML/day)
The 2.5-year ARI (ML/day)
The 5-year ARI (ML/day)

Table note: The index used the proportional deviation in each of these metrics between the modelled pre-development scenario and current scenario

Summary of the benefits of the new methods to assess Hydrological Stress Index

The improvements in the spatial resolution of the 2025 Hydrological Stress Index enabled the model to better represent the spatial variability of river flow volumes throughout the study area. The results of the project modelling were:

- improved temporal resolution of model (spanning a 119-year period)
- improved spatial resolution leading to better accuracy of the modelled data
- improved understanding of the contributions of groundwater to river flows.

Updating the hydrological model by incorporating new metrics and groundwater into the analysis takes a considerable amount of time. The benefit of creating the updated model is that it has multiple management uses, including climate change scenario modelling, extraction and water allocation modelling, as well as improved understanding of flows within the lower Darling Baaka River. As with several other RCI indexes, the need for repeat modelling is low, and it is expected that the current model will have a life span of around 10 years.

9.3.6 Landscape disturbance

Differences in methodology

The 2023 RCI Catchment Disturbance Index was calculated by incorporating 3 indicators: land use, infrastructure and land cover change. The method used to calculate the index was based on Norris et al. (2007) and Healey et al. (2012). The weighting factors used in the 2023 RCI assessment of disturbances were derived by expert knowledge and input.

In the updated and renamed 2025 Landscape Disturbance Index, a number of additional datasets that are particularly relevant for the lower Darling Baaka River have been incorporated into the assessment and calculation of index scores. These include the presence of weirs and dams, feral animal density, mining activity, and non-woody vegetation change (Table 10). Incorporation of weirs in the disturbance calculation is a particularly important improvement as these types of infrastructure have profound impacts on the lower Darling Baaka River that were not accounted for in the 2023 RCI.

In addition to the updated datasets, the weighting criteria was altered in the 2025 Darling Baaka RCI assessment of landscape disturbances. The Analytic Hierarchy Process was selected as the weighting method for our multicriteria analysis. The Analytic Hierarchy Process was chosen due to its transparency and reproducibility, making it an ideal approach for complex decision-making processes that involve multiple criteria (Saaty 1980; Lahdelma et al. 2000; Huang et al. 2011). The process requires a pairwise comparison of the relative importance of different factors to derive weights.

The changes to data used in the 2023 and 2025 assessments are summarised in Table 10, and Figure 7 shows the 2023 RCI and 2025 RCI grades.

Table 10 **Data used for the Landscape Disturbance Index in the 2023 and 2025 River Condition Index (RCI) calculations**

Indicator/metric	2023 RCI	2025 RCI	Justification
Land use			
Land use data	Land Use 2017 v1.2	Land use 2017 v1.5	Improved resolution
Mining data	No	Mining data	Mining impacts on region
Feral animal density	No	Feral animal layer	Ferals impact vegetation/soil
Infrastructure			
Road types	5	11	Increased resolution
Buffers	Standard	Defined by cadastre	Literature review (e.g. Motha et al. 2004)
Weightings	Expert opinion	Specified weightings using Analytical Hierarchy Analysis	Analytical Hierarchy Analysis provides scientific rigour
Dams and weirs	No	Weir locations	Weirs have direct impact on waterways
Land cover			
Satellite imagery	Sentinel-2 imagery	Sentinel-2 imagery	No update available
Woody vegetation change	Statewide Land and Tree Survey (SLATS) woody vegetation change 2017–2020	SLATS woody vegetation change 2017–2020	No update available
Non-woody vegetation change	No	SLATS non-woody vegetation change 2018–2020	Important for landcover disturbances in this bioregion

Benefits of the new methods for assessing Landscape Disturbance Index

The updated Landscape Disturbance Index calculations for this project better captured local land use and infrastructure-related stressors on the lower Darling Baaka River, such as the presence of weirs and feral animal grazing impacts. While these improvements have incorporated important aspects impacting the river, the disturbance index approach is generally more weighted to assessing impacts from built infrastructure and high-intensity land uses such as urban developments or cropping, respectively.

The new methodology has provided additional data which has:

- incorporated the impacts of feral animals on river health
- incorporated weirs into the assessment of disturbances
- provided a robust, statistically derived weighting system for multicriteria analysis.

In order to better calibrate the Landscape Disturbance Index for the landscapes of far western New South Wales, future efforts should incorporate historical-scale legacy impacts associated with broadscale clearing, river de-snagging and overgrazing (see Chapter 8). The impacts of these activities are not explicitly captured in the current approach to assessing landscape disturbance, however they are still likely to be impacting river health and should be incorporated into the RCI framework.

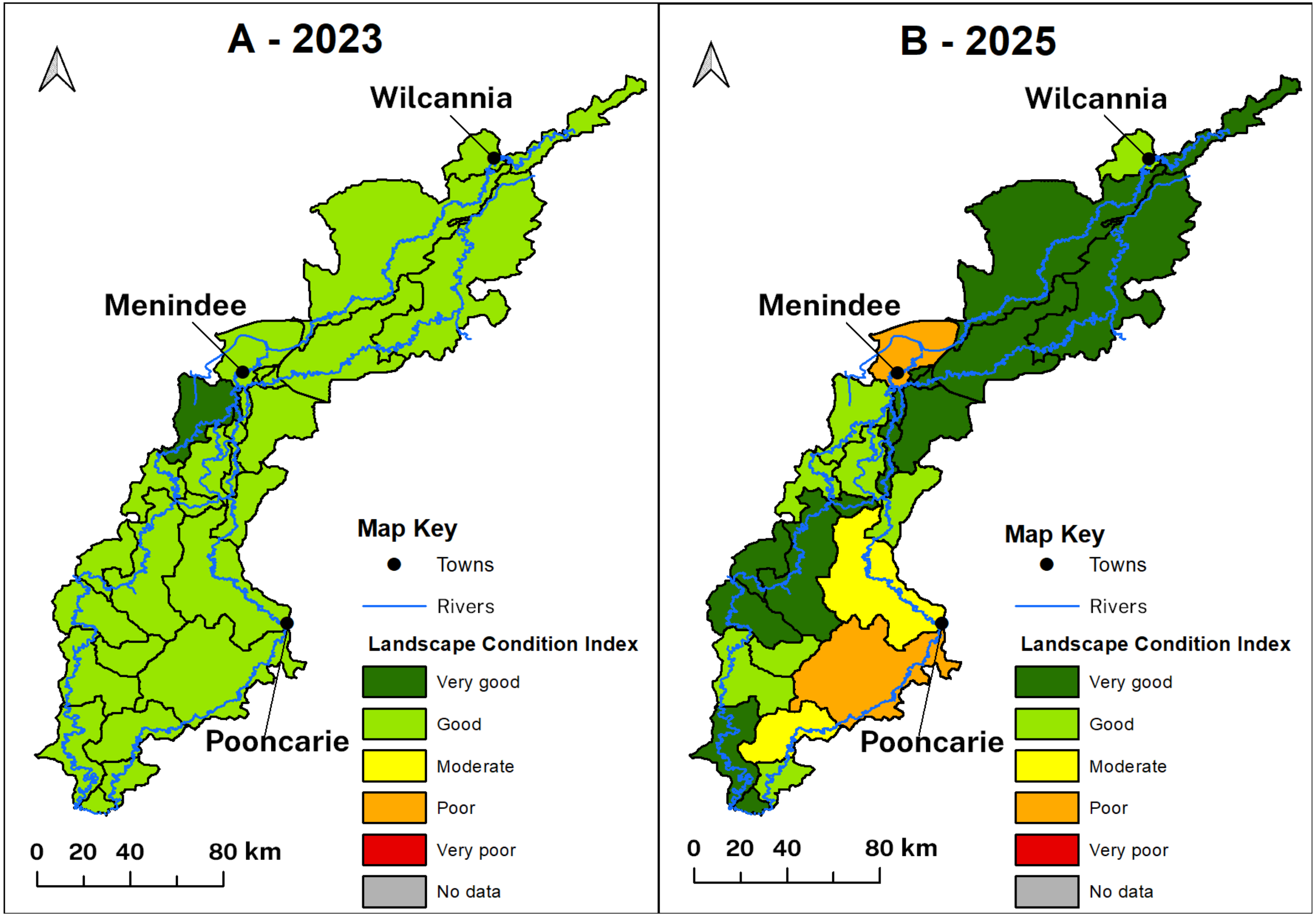

Figure 7 Landscape Disturbance Index grades for the lower Darling Baaka study area. A: 2023 (DPE 2023a) B: 2025 (Darling Baaka Project)

9.4 Cultural indicators and the River Condition Index framework

Australia has a rich history of human occupation, extending over 40,000 years. Over millennia, Aboriginal people across New South Wales have sustainably managed our lands, waters, wetlands and natural resources for the health of their Countries and peoples. They have understood the importance and cultural significance of water and its centrality to life and have cherished it accordingly. Their traditions and practices, like ecological knowledge, stories and cultural practices, are passed down from generation to generation. Aboriginal people see humans as part of nature, not separate from it. This relational approach encompasses land, water and sky. Aboriginal people have taken care of their Country using sustainable customary practices which are deeply rooted in their cultural values. These practices are alive and vibrant today.

Rivers, floodplains and wetlands play an important role in Aboriginal people's understanding of life (Verschuuren 2006; Pyke et al. 2018). In inland Country, rivers, groundwater and wetlands underpin Aboriginal history and culture and are fundamental to spiritual beliefs and ceremonies, and these waters often marked boundaries between language groups. They provide freshwater resources, food and a place for spiritual rituals and practices. Aboriginal culture explains that creator spirits came to rest within landforms such as rivers and wetlands (Toussaint et al. 2001, 2005), thus the obligations to care for waterways and care for Country are deeply set within Aboriginal cultural practices and traditions.

Culturally, water quality means different things to different people. For example, Ngardji holes and the links between surface waters and groundwaters are areas of great cultural significance to the Barkandji people. In the semi-arid regions of the lower Darling Baaka River, water is vital for survival and strongly linked to spiritual meaning for the Barkandji people.

9.4.1 Cultural indicators and the River Condition Index framework

The RCI framework (DPE 2023a) does not include cultural indicators of river health. Although cultural values were not included in the initial framework, it is possible to incorporate such criteria if desired (Aquatic Ecosystems Task Group 2012) and consent is explicitly provided by knowledge holders. This can be undertaken by considering:

- visible values, such as water clarity, cultural uses of waters, middens, camp ovens, engravings
- spiritual values, such as Dreamtime stories and song-lines
- ongoing values, such as food sources, continued use of cultural places, culturally significant species.

One such way to incorporate cultural values of rivers, floodplains and groundwaters into planning and management was initiated by NSW Office of Water (now Department of Climate Change, Energy, the Environment and Water; the department), to engage Aboriginal nations with implementing water resource plans. This initiative resulted in a list of cultural values specific to water ecosystems (Moggridge et al. 2019).

It is acknowledged that there are aspects of culture and spirituality than cannot be separated from the environment, making it difficult to incorporate and align with a Western framework which attempts to separate and classify individual components. Additionally, there are challenges that arise when attempting to place values on Aboriginal people's connectivity to Country. Further research is required with western knowledge systems to fully appreciate the cultural and spiritual importance of the Darling Baaka River and its connected groundwaters and floodplains to Barkandji people. To support two-way learning in this space and on Barkandji Country, the EPA also partnered with the Barkandji PBC to deliver the Ngarratja Warrkina Project which monitored cultural indicators of river health for the Barkandji community (see Chapter 1).

The parallel delivery of the Darling Baaka River Health Project and Ngarratja Warrkina Project resulted in collaborations between the Barkandji Rangers and a departmental scientist, whereby the Rangers devised and developed cultural indicators for river health and the departmental scientist provided mentorship and training in Western scientific methods for monitoring river health.

In the future, the RCI framework should investigate the potential of incorporating cultural values and indicators into the framework as a potential seventh indicator, where consent is provided by knowledge holders.

Figure 8 **Dr Kathryn Korbel (departmental scientist) and Max Quayle (Barkandji Ranger). Photo: Bottlebrush photography**

9.5 Recommendations

A number of recommendations for future monitoring, research and management priorities for the lower Darling Baaka River, specifically between Wilcannia and Wentworth, and including the Great Darling Anabranch are listed below. The recommendations address key knowledge gaps that aim to:

- improve understanding of the complex functioning of the lower Darling Baaka River and the key threats it is facing
- incorporate cultural knowledge into this understanding
- provide information that is directly useable for local communities, stakeholders and water management agencies.

1. Restore flows and connectivity across the catchment

Hydrological stress, mainly associated with river regulation and water extraction, was found to be a primary driver of poor water quality, biodiversity condition and riparian vegetation in the study area. These findings support the Office of the Chief Scientist and Engineer's review into the fish deaths at Menindee (OCSE 2023). A long-term goal should be to improve the hydrological connectivity across the study area, which would benefit both the water quality and biodiversity condition of the lower Darling Baaka River. A program installing a fish passageway at Menindee Main Weir began in 2025, this aims to improve the ability of fish to move within the river system.

2. Incorporation of cultural indicators into the River Condition Index framework

By incorporating cultural indicators, with knowledge holders consent, a more holistic view of river health could be assessed using both Western scientific and cultural methods for assessing river condition.

The Ngarratja Warrkina Project established a partnership between the Barkandji Prescribed Body Corporate and the EPA. In this project, local knowledge holders devised cultural indicators for river health. In the future two-way knowledge sharing projects, devised to protect data sovereignty and ICIP, could aid the incorporation of these cultural indicators via a multicriteria analysis into the RCI framework. This would build local capacity to enable the routine assessment of river health and would recognise the importance of cultural knowledge to river management and identify the protection requirements for culturally significant species.

3. Continuation of biological and water quality monitoring program

The lower Darling Baaka River system is complex and undergoes long periods of drought occasionally punctuated by extensive flooding. This study was conducted in a relatively wet period and has provided data on conditions experienced between 2023 and 2025. In a system as climatically and hydrologically variable as the Darling Baaka, it is critical to extend monitoring over the long term to assess a wide range of hydrological conditions and to better quantify the range of variability of both water quality and biodiversity condition.

Long-term monitoring, minimum of monthly over 2 years, is required to inform the development of local water quality guidelines for the lower Darling Baaka River. This is critical for the ongoing assessment of river health and application of the RCI approach, because reporting against inappropriate guidelines results in a misleading assessment of river health and its drivers. Due to the lack of appropriate reference systems (intact/pre-development systems) with which to develop guideline values, it will be necessary to undertake ecosystem response modelling to better understand appropriate thresholds for maintaining key ecosystem processes.

The smart buoy network installed as part of the Darling Baaka River Health project allows for a real-time assessment of water quality. There are 4 buoys located from Wilcannia to Pooncarie, and 2 on the Great Darling Anabranch. They have provided important insights into the interactions between water quality dynamics, weather, hydrology and water regulation actions. Data from these buoys have been used on a weekly basis to inform water release decisions from the Menindee Lakes Water Storage Scheme. Data also provide early warnings of poor water quality or harmful algal blooms which may affect local communities or water management operations.

Continuation of monitoring is important for:

- water managers – data can be used to inform water release and management priorities
- local communities – real-time data can be, and has been, used to inform stock watering and swimming decisions
- assisting with the development of local water quality guidelines
- help develop trigger values for key parameters (including dissolved oxygen, temperature and chlorophyll-a) which would guide water releases to prevent water quality issues
- assisting with appropriate guidelines against which the ongoing health of macroinvertebrate and zooplankton communities can be assessed
- providing early warning systems of deteriorating conditions (both chemical and biological monitoring)
- recognising the contribution of biota to river health.

This recommendation aligns with OCSE (2023) Recommendation 2, which promoted a whole-of-system approach to data collection and analysis.

The OCSE (2023) Recommendation 4, to monitor iconic species – such as river red gum, Murray cod and cultural species including mussels, turtles, Rakali and perch – could be achieved by continuing the biological monitoring established under the Darling Baaka River Health project.

4. Management of invasive species

This study indicated that over 70% of the total fish biomass in the region was European carp. This species is known to contribute to declines in water quality and biodiversity condition, and carp often outcompete native species. Carp can also survive in particularly low oxygen concentrations, when native species cannot.

The OCSE (2023) report recommends an integrated national invasive fish species management strategy (Recommendation 4). The finding from the fish surveys conducted under the Darling Baaka River Health project support this recommendation.

5. Improved methodology for calculating the River Condition Index

The differences between the 2023 RCI and the 2025 Darling Baaka RCI should be clearly acknowledged when using the RCI framework for management decisions. The 2025 Darling Baaka RCI methodology offers finer spatial resolution and integrates field-collected data, yielding insights that diverge from the state-wide 2023 RCI, and more accurately reflect the river's condition. Care must be taken when combining statewide spatial and historical datasets in the RCI framework to avoid misrepresenting the on-ground river health. There is potential to incorporate a confidence ranking into the RCI framework to indicate the reliability, spatial resolution, accuracy of the data and the overall RCI score to avoid misleading interpretations of river health.

This study has adapted the RCI methods to a finer spatial scale to allow more specific analysis of river health issues in the study area. There are a number of improvements that could be incorporated into this adapted method.

a. Geomorphological assessments

Alluvial floodplain gullies are a poorly understood source of excess sediment in the lower Darling Baaka River, and this can impact cultural heritage as well as geomorphic functioning and water quality. Further work on the lower Darling Baaka River is required to better characterise the drivers of gully formation, their implications for ecological processes and the amount of excess sediment delivered to the lower Darling Baaka River by active gully enlargement.

Interactions between geomorphology, hydrology and biogeochemistry across the complex floodplain environments of the lower Darling Baaka River are not well understood. The floodplain palaeochannels, anabranches and shallow flow paths are important sources of nutrients and organic matter for the lower Darling Baaka River, with implications for the transmission of potential hypoxic (low oxygen) 'black water' during and after significant flooding.

b. Water quality assessments

The development of a hierarchical framework for weighting different water quality metrics was used in Water Quality Index to better characterise the relative environmental risks posed by different parameters. This framework should be further developed to account for dependencies and interactions among the various metrics included in the Water Quality Index calculation.

The development of site-specific water quality guideline values would aid the assessment of river health. It may be necessary to investigate the value of having specific guideline values based on climatic conditions, such as drought or flood.

c. Riparian vegetation condition assessments

Ongoing field monitoring of river red gum and flood-dependent vegetation is critical to better understand long-term threats to the viability of riparian vegetation communities, particularly river red gum. Reduced recruitment of river red gum along the lower Darling Baaka River is a significant long-term threat. A better understanding of the spatial variability of recruitment and the water requirements for successful recruitment of river red gums may help to guide management actions.

Increased on-ground assessment of riparian vegetation and recruitment is required throughout the catchment as, due to access issues associated with wet-weather, several catchments did not have data collected in this study.

d. Biodiversity condition assessments

Due to the timeframes required for sequencing, and the short-time frame of this project, substantial amounts of data collected for this project were not included in the calculation of the RCI. The development of bacterial and algal indicators of river health is currently underway. Future river health monitoring programs should consider the findings of these reports which will be published as supplementary material once available.

An assessment of interactions between biological components should be undertaken with data collected by this study. This will incorporate elements of food web dynamics and should investigate biotic and abiotic interactions which are likely to impact on water quality. Improving our understanding of how the interactions and feedbacks between biotic and abiotic factors influence variability in water quality and overall river health is critically important. For example, biogeochemical processes facilitated by bacteria can have profound impacts on water quality due to nutrient and carbon cycling.

While eDNA provided additional data that was useful for assessing biodiversity of the study area, the data cannot provide details on abundances of taxa and, as such, did not add to the fine resolution required for analysis of biodiversity condition. However, eDNA results provided valuable data on bacteria, algal and smaller organisms that is useful in understanding ecosystem functioning. Further investigations of eDNA datasets generated by this project should be undertaken to inform of biogeochemical processes relating to water quality.

e. Hydrological and water quality modelling

The substantial truncation of flows in the Darling Baaka River upstream of Wilcannia are currently unaccounted for in the Hydrological Stress Index modelling. A better assessment of catchment-scale hydrological stress for the lower Darling Baaka River should incorporate assessment of the deviation in natural flows associated with water extraction and river regulation in the catchment area upstream of Wilcannia.

Improvements in the hydrological model described in this project (Chapter 7) as well as the monthly water quality dataset would allow the potential development of a predictive water quality model for the lower Darling Baaka River, particularly relating to nutrient dynamics under different flow stages and the implications for algal growth and dissolved oxygen dynamics. Similarly, the development of a hydrodynamic model for the Menindee weir pool will improve our understanding of mixing dynamics as a function of inflows. This will better help to understand flow requirements to break up thermal stratification or to flush algal blooms.

Understanding and accounting for nutrient inflows can be assisted through modelling. Incorporating the nutrient data collected in the project (surface and groundwater) can be used to help create nutrient load models. This would help to inform the OCSE (2023) Recommendation 4 regarding accounting for and managing nutrient inflows across the catchment.

f. Landscape disturbance assessment

Future efforts should incorporate historical-scale legacy impacts associated with broadscale clearing, river de-snagging and overgrazing to better calibrate the Landscape Disturbance Index for the landscapes of far western New South Wales. The impacts of these activities are not explicitly captured in the current approach to assessing landscape disturbance, however the impacts of these past activities are still likely to be impacting river health.

6. Investigation and analysis of the most appropriate suite of indicators to monitor river health

The data collected in this project is substantial, and occurs across multiple indicators within each of the 6 RCI indexes. The project incorporated a multidisciplinary team, utilising skills from geomorphologists, hydrodynamic modellers, spatial analysts, hydrologists, geochemists, aquatic ecologists, plant biologists, microbiologists, and bioinformaticians.

There is a need to identify the abiotic and biotic indicators that are most sensitive to changing conditions and thereby provide a more cost-effective method to assess broader ecosystem health, rather than the large-scale intensive sampling as undertaken in this project.

7. Improved understanding of the complex relationships between surface waters and groundwaters, and the importance of groundwaters to river health

Groundwaters in the study area are important for sustaining groundwater-dependent ecosystems. They support riparian vegetation, river baseflows as well as subterranean ecosystems (including stygofauna). There is a need to further our understanding of the interactions between surface water and groundwater and how these interactions may influence water quality, water availability and ecosystem health.

Current models can be improved by:

- increasing the number of groundwater locations incorporated into modelling – this will help improve the representation of the different storages along the river length
- gathering and using longer groundwater level time-series data to develop a more robust correlation with the river water level

- implementing more complex groundwater modules available in SOURCE models and gathering relevant geomorphic datasets required to implement these modules
- including relevant groundwater and overbank flow metrics into the Hydrological Stress Index – this extends the current ‘channel-oriented’ metrics to include areas beyond the river into the condition index.

In addition, the continuation of monitoring groundwater health and its impacts on river health is recommended. This would help understand connections between shallow alluvial floodplains aquifers and the river, with a particular focus on the biogeochemical cycling of nutrients and carbon.