Options for Managing Sediment in the Barmah-Millewa Reach of the River Murray

Preliminary Investigations

Report for Murray–Darling Basin Authority

November 2021

Cover Photo	Banks of the River Murray through Barmah Forest, Ian Rutherfurd 2021
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Executive Summary

The Issue
The natural narrowing of the River Murray through the Barmah-Millewa reach has always presented a control on the flow capacity of the river. The restriction provides an operational challenge for the MDBA as it attempts to manage delivery of water from upstream to downstream of the reach to meet peak water demands, primarily for irrigation.

The regulated capacity of the Barmah-Millewa reach as measured by the water level at Picnic Point, and the corresponding releases from Yarrawonga Weir have been declining over time, reducing from 11,500 ML/day in the 1980s to a current capacity of approximately 9,200 ML/day.

In conjunction with the loss of capacity, ongoing degradation of riverbanks has been occurring throughout the broader Yarrawonga to Torrumbarry reach of the River Murray due to regulated flow patterns and exacerbated by other factors such as vessel wash and deterioration of riparian vegetation. Recent investigations (Streamology, 2020; Grove, 2021) have now identified that the presence of excessive deposits of coarse sand in the river channel downstream of Yarrawonga Weir are most likely to be the major contributing factor to the loss of capacity and contributes to the acceleration of the rates of bank erosion, and channel degradation through loss of diversity and habitat.

The Scope
The Murray–Darling Basin Authority (MDBA) has been directed by the Basin Officials Committee (BOC) to investigate what can be done to stop further loss of channel capacity and possibly reinstate capacity through the Barmah-Millewa reach of the River Murray.

Given the enhanced understanding of the issue developed through this project, and concerns raised by stakeholders during the engagement process, it has become clear that capacity through the reach cannot be separated from other aspects such as bank erosion, ecological degradation, and the loss of values, especially cultural values.

The scope of this project has therefore been to develop a comprehensive understanding of several aspects, including:

- The processes leading to the accumulation of sand in the reach,
- The extent and volume of excess sand,
- The projected trajectory for flow capacity as well as environmental, social, cultural, and economic values if nothing is done to manage the sand, and
- The potential options for managing the sand.

This has involved the capture and analysis of new data, desktop review, and stakeholder consultation to understand the values of the reach. Technical evaluation and interpretation of the data and information has provided a thorough and detailed understanding of current conditions and future trajectories. Additional desktop assessments have explored specific sand management options.

Engagement with First Nations people and stakeholders has been on-going throughout the project, to provide updates on the progress of work and canvas their input in defining the values of the reach and how predicted changes to the river may impact them.

Main Outcomes

The data collected and analysed has shown that there is in excess of 20 million m^3 of coarse sand on the bed of the River Murray Channel between Yarrawonga Weir and Picnic Point, which is referred to as the 'sand slug'. Much of this sand was most likely mobilised through land use changes and mining in the 1800s, whereby large volumes of sediment were deposited into catchment waterways upstream. The sand then slowly migrated downstream and is currently building up in the Barmah-Millewa reach.

The build-up of sand is a result of the nature of the River Murray in this reach. Water tends to flow out of the main channel, through creeks and flood runners instead of into it. Less water flowing down the main channel means less ability to transport the sand downstream, causing it to accumulate. While sediment build-up is therefore a natural process, the bed of the river would normally only contain small quantities of sand and the process would be very slow. With the presence of the large volumes of sand from the sand slug in the river, this process is now happening much faster.

The result is the loss of flow capacity, the acceleration of bank erosion processes, and the filling in of deep pools with coarse sand reducing diversity and habitat. The acceleration of bank erosion is also leading to the loss of levees on the riverbanks, which causes trees to fall in, the damage and loss of cultural sites such as middens, and the creation of new flow connections into the floodplain and wetlands. These new flow connections enhance unseasonal flooding, and the fine silts eroded from the banks can smother vegetation in these areas. These changes will adversely affect values in the reach, such as the changes in the condition of the Ramsar wetlands, the loss of access to camping sites and recreational areas, damage to cultural sites or loss of cultural practices, reduced visitation and tourism and the associated economic benefits. Doing nothing to manage the sand therefore has a range of unacceptable outcomes.

A range of options to manage the sand have been investigated and no single option has been identified that effectively addresses all the issues of concern. Instead, a suite of solutions is likely to be required which could include:

- Protection of priority sections of riverbank through on-ground works,
- The physical removal of sand in targeted areas, and
- Moving water around the reach to reduce summer and autumn flow rates.

These options need to be investigated further to determine how, where and when they should be applied.

Glossary

Aggradation	Increase in elevation (e.g., of a riverbed) due to the deposition of sediment carried by a river, stream, or current
Avulsion	The rapid abandonment of a river channel and the formation of a new river channel
Bathymetry	The study of the depth of water bodies, also often used to describe the data (i.e., depth measurements) produced through bathymetric surveying
Bedform	A feature that develops at the interface of fluid and a moveable bed, the result of bed material being moved by fluid flow. Examples include ripples and dunes on the bed of a river
Bedload	Sediment (in particular sand) that is transported along the bed of a river, as opposed to suspended in the water column
Breakaway	See effluent
Conveyance	Geometric characteristic of a river or watercourse at a given point that determines the flow-carrying capacity at that point (also referred to simply as flow capacity)
Discharge	The volumetric flow rate of water that is transported through a given cross-sectional area of river channel
Distributary	A stream channel that branches off and flows away from a main river channel (as opposed to a tributary which flows towards the main channel)
Distributive Fluvial System (DFS)	Class of river system commonly characterised by flow distributaries and a downstream decrease channel width, discharge, bedload transport
Dunes (also referred to as 'mega-ripples')	Dunes are large two-dimensional bed features that form on sand bed rivers when the flow velocity exceeds a threshold value. Dunes tend to develop in medium to coarse sands whereas ripples are smaller bed features associated with fine to medium sands. The term 'mega-ripple' is occasionally used to refer to these larger bed features
Effluent	Also referred to as *offtakes, flood runners, and breakaways*, effluents are distributary channels that carry flow away from the main River Murray channel. Includes Gulf Creek, the Edward River and Culpa Creek (among many others)
Flow	See discharge
Flood runner	See effluent
Grain size	Diameter of individual grains of sediment, commonly described using descriptive classes from the Wentworth scale that ranges from clay (smallest) through silt, sand, gravel, cobbles, and boulders (largest)
Levee	A levee can form as a ridge of sediment naturally deposited along the margins of a river channel by overflowing water. Levees can also be artificially constructed along a channel to prevent flooding
Morphology	In geography and related disciplines, morphology is synonymous for the physical form (or shape) of landforms, including rivers
Natural flow	The flow rate in the River Murray, produced using hydrological modelling, that would be expected if there were no infrastructure like dams and regulators, or consumptive water uses like irrigation. Used in contrast to *regulated flow*
Offtake	See effluent
Regulated flow	The flow rate in the River Murray under actual regulated conditions (with infrastructure, irrigation etc.), measured using gauging stations. Used in contrast to *natural flow*
Ripple	Ripples are small two-dimensional bed features that form on sand bed rivers when the flow velocity exceeds a threshold value. Ripples tend to develop in fine to medium sands. The term 'mega-ripple' is occasionally used to refer to the larger bed features more accurately described as dunes

Sand slug	A body of sand deposited in a stream channel, often conceptualised as a wave migrating along the bed of the stream. Normally they disperse over time and are often spread over long distances of river
Sediment transport rate	The rate at which sediment (e.g., sand) is moved along a stream channel, either as bedload or suspended sediment. Typically measured in kilograms/second
Sediment load	The amount of sediment (e.g., sand) carried through a particular location in a stream, over a given period. Typically measured in cubic meters/day but can also be considered over longer periods (e.g., cubic metres/year)
Sub-bottom profile	The results of a type of bathymetric surveying technique that uses acoustic instruments to measure the thickness of different layers of material on a riverbed (e.g., bedload thickness)
Suspended sediment	Sediment that is transported along a river within the water column, as opposed to along the bed of a river

contents

Acknowledgement

Streamology and the Murray-Darling Basin Authority (MDBA) acknowledge and offer respects to the Traditional Owners, and their Nations, of the Murray-Darling Basin, who have a deep cultural, social, environmental, spiritual, and economic connection to their lands and waters.

The MDBA understands the need for recognition of Traditional Owner knowledge and cultural values in natural resource management associated with the Basin. The approach of Traditional Owners to caring for the natural landscape, including water, can be expressed in the words of Darren Perry (former Chair of the Murray Lower Darling Rivers Indigenous Nations):

> *'The environment that Aboriginal people know as Country has not been allowed to have a voice in contemporary Australia. Aboriginal First Nations have been listening to Country for many thousands of years and can speak for Country so that others can know what Country needs. Through the Murray Lower Darling Rivers Indigenous Nations and the Northern Basin Aboriginal Nations the voice of Country can be heard by all.'*

section one

1. Introduction

1.1. Project Background

The Barmah-Millewa reach is a narrow section of the River Murray where it flows through the Barmah-Millewa Forest (Figure 1). The reach is associated with the tract of the River Murray where it leaves a narrow section of floodplain (a confined reach) and enters a large, low-angle, distributary alluvial fan, known as the Barmah Fan.

The natural narrowing of the River Murray through the Barmah-Millewa reach has always presented a major constraint on the discharge capacity of the river. The restriction provides an operational challenge for the MDBA as it attempts to manage delivery of water from upstream to downstream of the Barmah-Millewa reach (sometime referred to as 'the Choke' or 'Barmah Choke') to meet peak water demands, primarily for irrigation.

The Murray-Darling Basin Authority (MDBA) river operations currently maintain an operational threshold water level (stage) at the Picnic Point gauge of 2.6 m, which is used to define the target flow capacity through this reach. This threshold level was first used to define the Barmah-Millewa reach capacity in 1996 and to limit undesirable (unseasonal) flooding of the forest (HARC, 2021).

The regulated capacity of the Barmah-Millewa reach as measured by the water level at Picnic Point, and the corresponding releases from Yarrawonga Weir, have been declining over time, reducing from 11,500 ML/day in the 1980s to a current capacity of approximately 9,200 ML/day.

In conjunction with the loss of capacity, ongoing degradation of riverbanks has been occurring throughout the broader Yarrawonga to Torrumbarry reach of the River Murray due to regulated flow patterns and exacerbated by other factors such as vessel wash and deterioration of riparian vegetation. Recent investigations (Streamology, 2020; Grove, 2021) have now identified that the presence of excessive deposits of coarse sand in the river channel downstream of Yarrawonga Weir is most likely to be the major contributing factor to the loss of capacity and exacerbates bank erosion and channel degradation through loss of diversity and habitat.

The MDBA is coordinating and leading a planning process to manage the ongoing reductions in flow conveyance and associated channel degradation through the Barmah-Millewa reach over the long term. This project has investigated a suite of options to both manage flows and protect the environmental, cultural, social, and economic values throughout the reach.

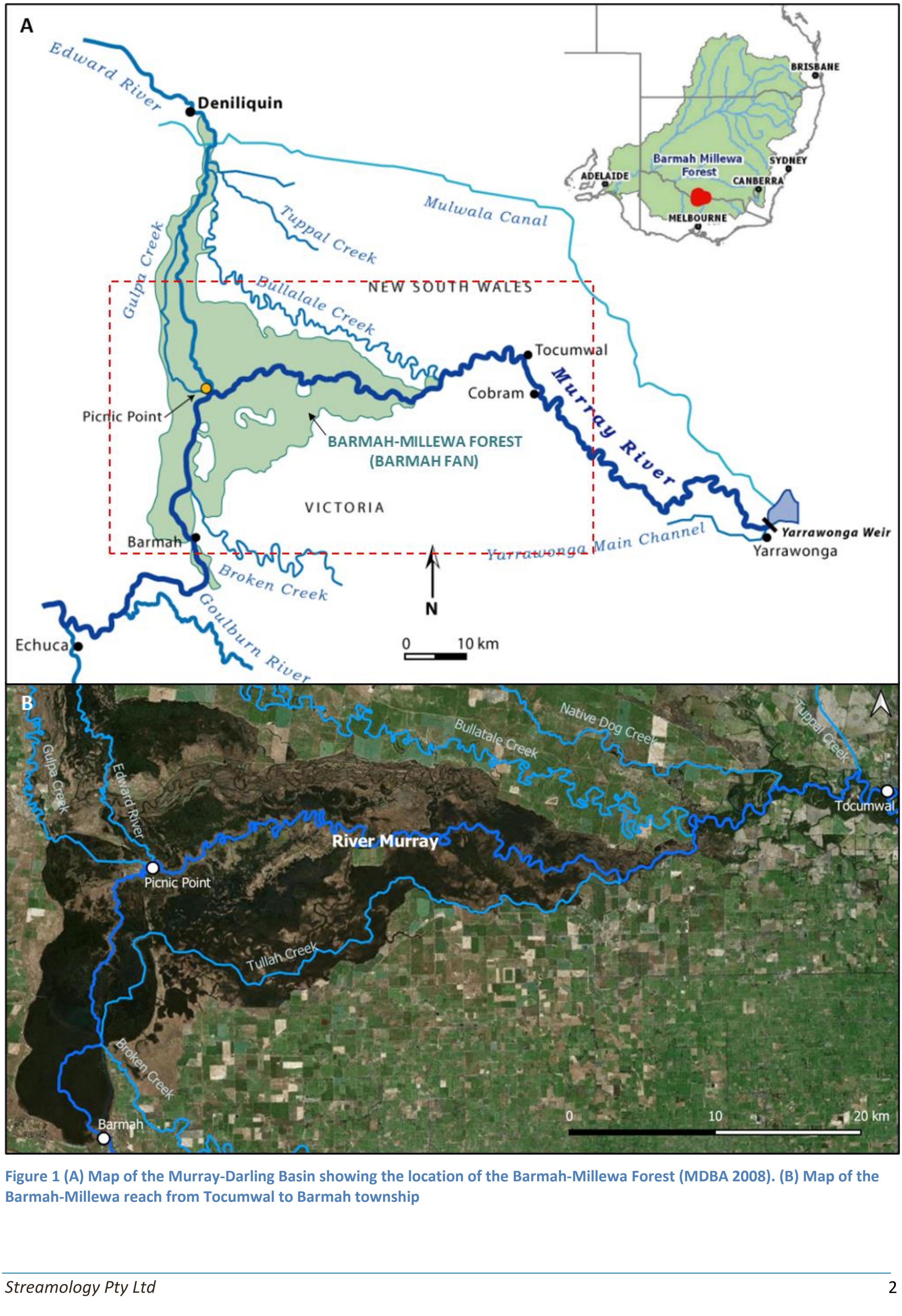


Figure 1 (A) Map of the Murray-Darling Basin showing the location of the Barmah-Millewa Forest (MDBA 2008). (B) Map of the Barmah-Millewa reach from Tocumwal to Barmah township

1.2. **Scope of the Study**

The MDBA has been directed by the Basin Officials Committee to investigate what could be done to stop further loss of channel capacity and possibly reinstate capacity through the Barmah-Millewa reach.

However, given the enhanced understanding of the issue developed through the project and concerns raised by stakeholders during the engagement process it has become clear that the issue of capacity through the reach cannot be separated from other aspects such as bank erosion, ecological degradation, and the loss of values especially cultural values.

To address this broadened scope, the approach taken has aimed to answer the following questions:

- What are the social, cultural, environmental, economic, or other values of the Barmah-Millewa reach?
- What are the effects of the excess sand in the river on flow capacity?
- Are there other effects? And what will happen if there is no sand management undertaken?
- What options are available for managing the sand in the Barmah-Millewa reach?

Once options were identified, a multi-criteria analysis was completed to identify those most effective at addressing all the key issues identified. The options were therefore evaluated based on their effectiveness at addressing the main issues of concern, the feasibility of implementing the option (where relevant), the impact on values, and finally cost.

1.3. **Projects Impacting the Barmah-Millewa Reach**

There are many other projects currently underway or about to commence which also impact the Barmah-Millewa reach of the River Murray. They include:

- **Constraints** – (Reconnecting River Country) targeting higher flows to inundate more of the forest
- **Enhanced Environmental Water Delivery** – environmental flows in sync with other ecological triggers
- **Hume to Lake Victoria – Tar-Ru transfers** – work in greater harmony with environmental watering
- **Water movement across the Barmah-Millewa reach** – review of historical trade across the Barmah Choke and investigate impediments to large developments above the Choke
- **Investigating use of the irrigation systems** (NSW & Vic) to transfer water around the forest in summer–autumn
- **Interim River Works program** – developing an agreed focus for short term bank protection works (5 years)

While not directly linked to this project, the outcomes from the work presented in this report can inform concurrent projects.

1.4. Structure of the Report

The report has been structured as follows:

- Section 2 presents recent investigations, analysis and interpretation which improved our understanding of the Barmah-Millewa reach, particularly the extent and magnitude of the excess sand present in the bed of the channel.
- Section 3 provides a background review of the environmental, social, cultural, and economic values of the reach, combined with the outcomes from a range of consultation activities with local community and government agency stakeholders.
- Section 4 outlines the current understanding of the processes impacting the Barmah-Millewa reach because of the excess sand and details the future trajectory if nothing is done to manage the sand.
- Section 5 summarises the 'do something to manage the sand' options assessment, presenting the multi-criteria analysis of all the options with the 'do nothing to manage the sand' as the base case.
- Section 6 presents a summary of the study along with recommendations for the next stage of the project.

section two

2. **Recent Investigations**

2.1. **Overview**

In 2020, Water Technology was commissioned by the Murray-Darling Basin Authority (MDBA) to undertake a geomorphic and hydraulic investigation into the apparent channel capacity changes and conveyance loss within the Barmah Choke. The work (detailed in Water Technology, 2020) provided some insight into the condition of the River Murray in the Barmah Choke area and the processes occurring within the channel. However, it was not able to fully answer the questions around the drivers of channel change and further investigations were recommended. The work was subsequently followed by a series of studies including Streamology (2020), Grove (2021), and HARC (2021) along with the collection of a range of supporting datasets. The datasets, analysis and interpretation are briefly summarised in the following sections.

2.2. **Datasets**

2.2.1. **Bathymetric surveys**

In 2018 the MDBA organised for a 78 km bathymetric survey of the River Murray from Bullatale Creek to Barmah Lake (River Murray chainages 1770 to 1858 km). The survey data captured is shown in Figure 2.

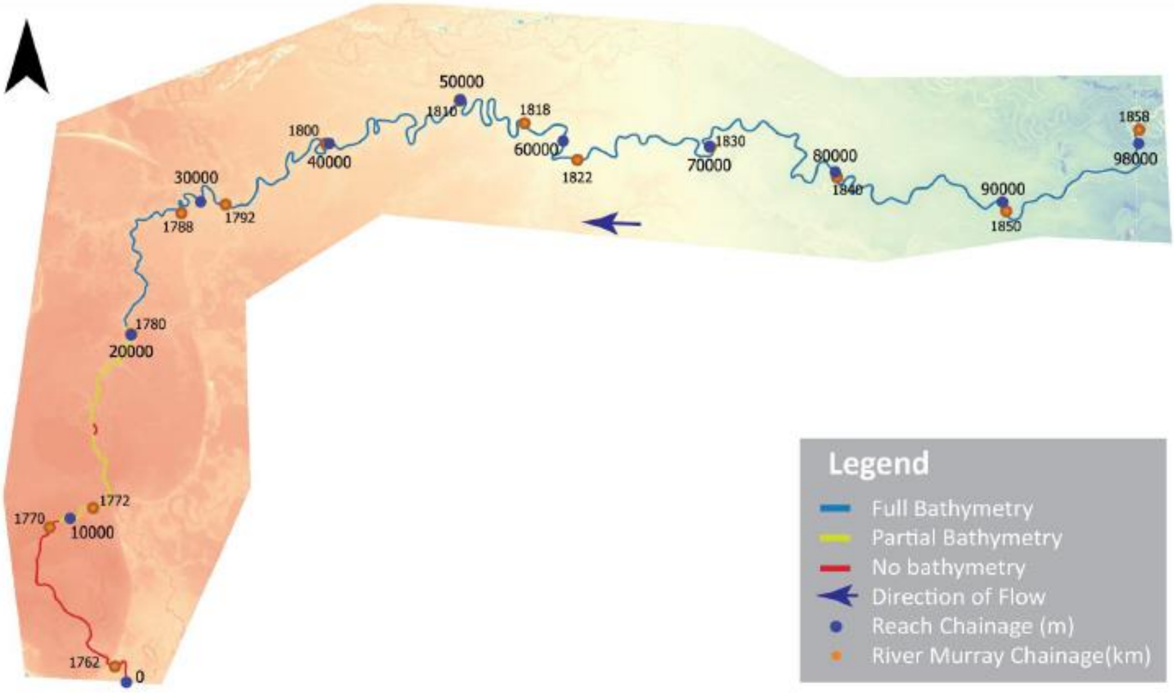


Figure 2 Bathymetric survey extent, relative to both reach chainage and River Murray chainage (Water Technology, 2020)

The water depths measured in the survey showed dune forms on the riverbed indicative of mobile sands, Figure 3. The observed volume and extent of bed sediment was unexpected, and triggered the further data collection and investigations, described in Section 2.

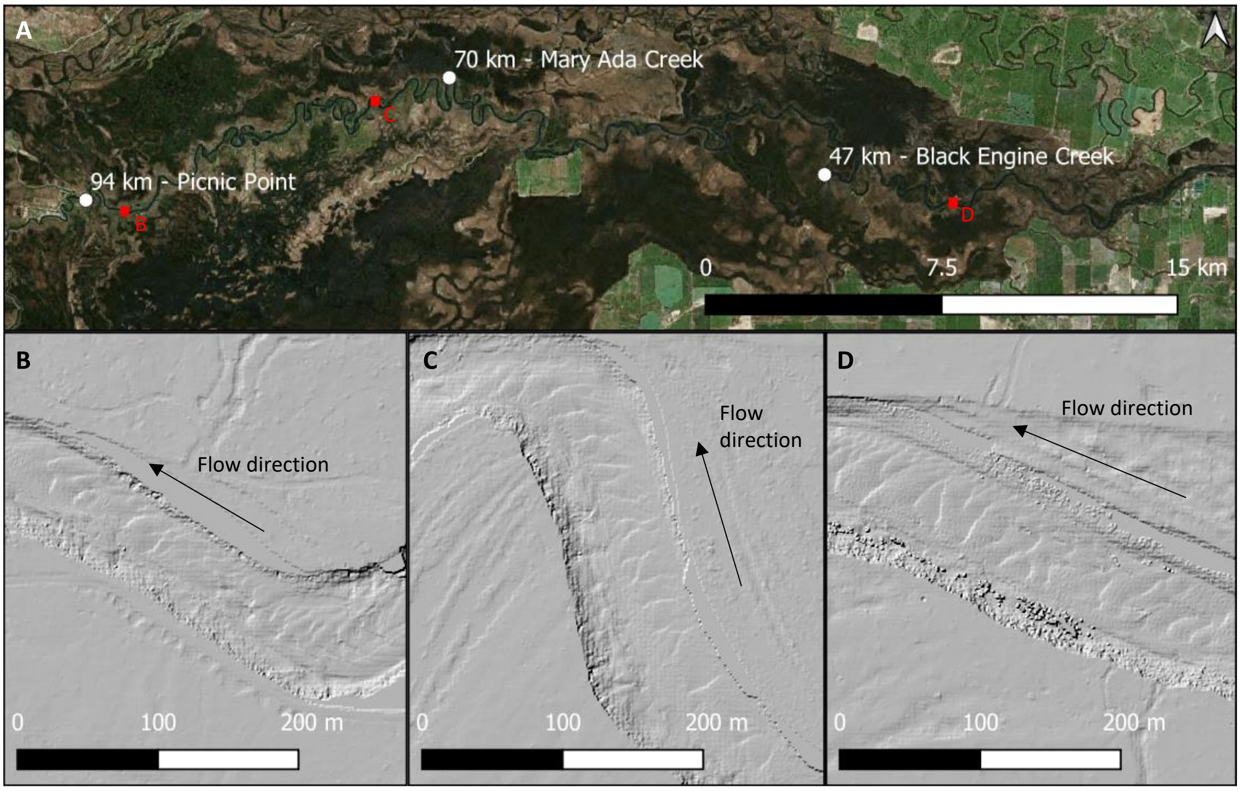


Figure 3 Dune bedforms in the Barmah-Millewa reach. (A) Map of the reach upstream of Picnic Point, showing the location of panels (B-D) shaded relief maps of the channel bed showing dunes (Streamology, 2021)

2.2.2. Sediment bedload measurements

SA Water and Acoustic Imaging were engaged by MDBA to measure the depth of the bedload using sub-bottom profiler. The technique involves capture (by SA Water) along with processing and interpretation of geophysical imaging (by Acoustic Imaging) of the sediments on the bottom of the riverbed. Differences in the reflectivity of the acoustic signal from an echo sounder can indicate different sediment densities and composition. Bedload material is defined as mobile layer of sediment that remains in contact with the bed below but moves along the bed surface. From the images it is therefore possible to discern an interface between the underlying bed substrate and this more mobile layer.

A trial was initially undertaken in March 2020 which involved measuring the bedload depth over a 25 km reach of the Murray River extending from 20 km upstream of Picnic Point to 4 km downstream of Picnic Point (orange section in Figure 4). The survey found that the sandy bedload material was on average between 1 m and 1.2 m thick along the surveyed reach.

This work was expanded in February 2021, along a reach of the River Murray from Yarrawonga to Nine Panel Creek (blue section in Figure 4). Then in March 2021, SA Water further extended the survey data collection to the south, measuring the bedload depth from approximate the Picnic Point Caravan Park to Barmah Township (green section in Figure 4).

A summary of the data capture and depth data interpretation are provided in Acoustic Imaging and SA Water (2020), Acoustic Imaging and SA Water (2021a), Acoustic Imaging and SA Water (2021b).

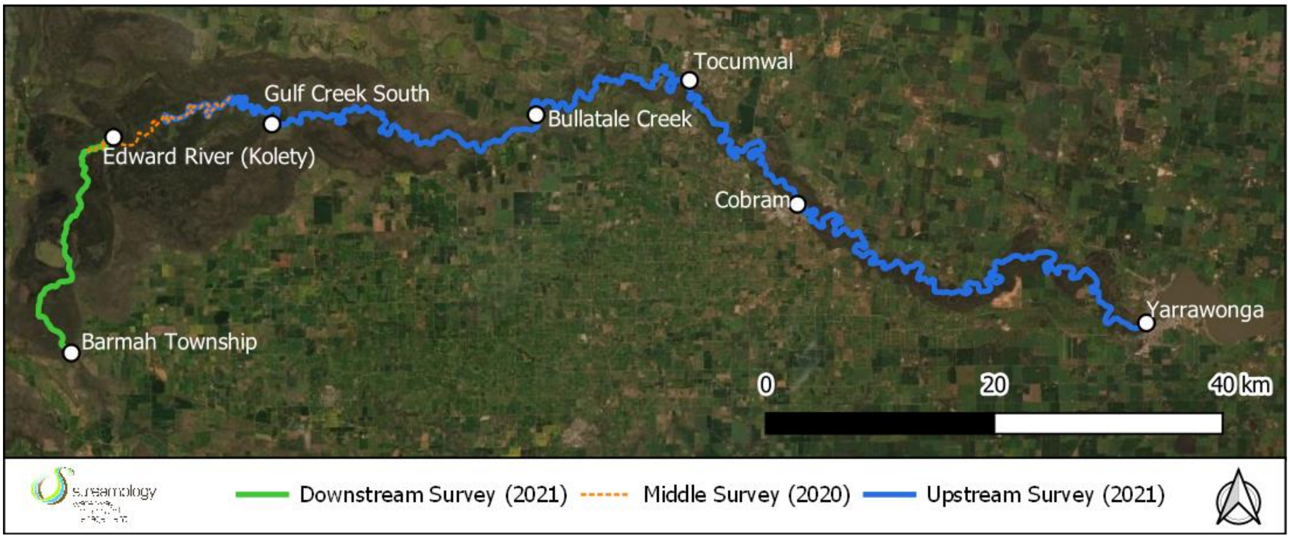


Figure 4. Map showing the extent of the sub-bottom profiler surveys.

As part of their field campaign, (Water Technology, 2021) undertook a field validation of the sub-bottom profile dataset by measuring the depth of sediment at selected locations in the field. The bedload depth validation locations were selected as areas that the sub bottom-profiling identified as having consistent bedload thickness across a reasonably large area. This was considered important, as the bedload measurements were taken from a boat on a flowing river, and it was not possible to accurately pinpoint identified validation points. The validation points also targeted a range of bedload thicknesses. Sampling locations and depth of bedload are shown in Figure 5.

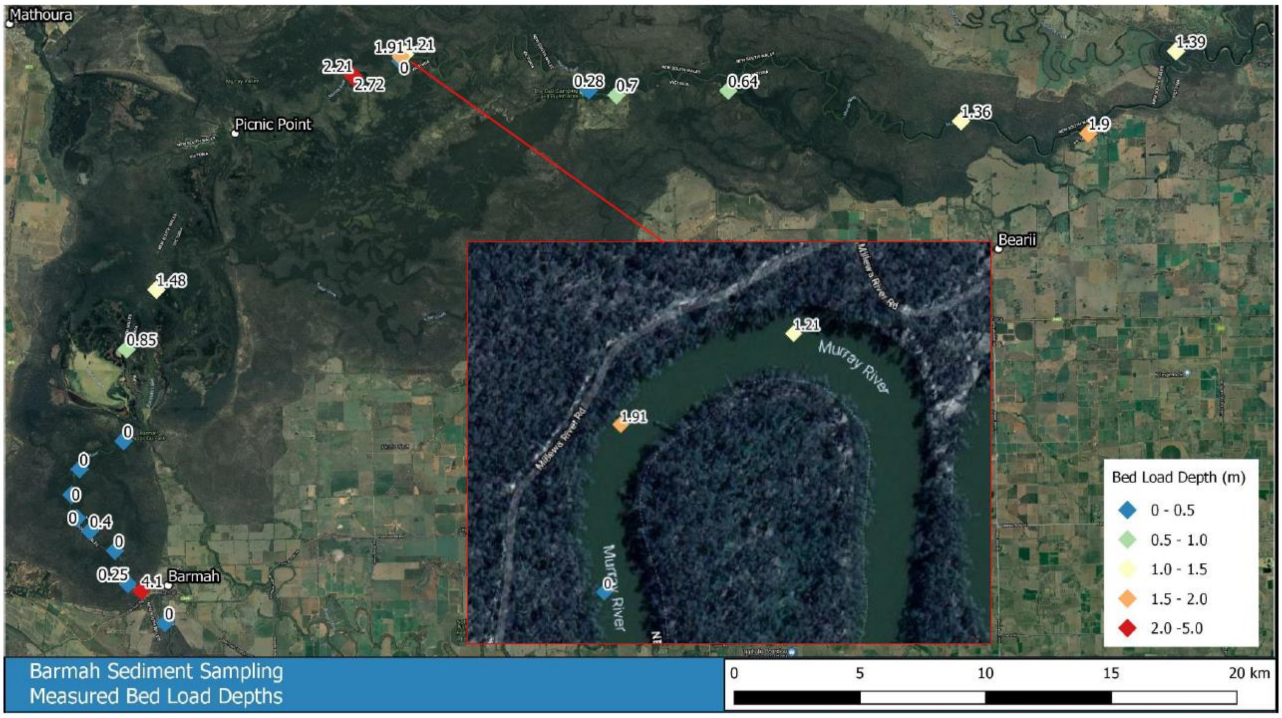


Figure 5 Bedload validation sampling locations (Water Technology, 2021)

Overall, the results of the validation were mixed with some locations showing good agreement between the two approaches, while at other locations there were discrepancies. This variability is expected given the challenges of undertaking these measurements in the field and the spatial and temporal variability of bedload thickness across and along the channel. Further field validation measurements of the bedload thickness and rate of movement are recommended during the next stages of the options assessment process.

2.2.3. Sediment size (bed and banks)

Historic records indicate that while most of the bed of the River Murray was dominated by sand, the Choke had sections of clay bed, although it had sandy point bars in sections (Grove, 2021). Given the identification of large quantities of sand on the riverbed it is important to characterise the range of sediment sizes present to assist in determining the source of the material and for estimating how fast it can move through the system. The sediment sampling completed to date is summarised in Table 1.

Table 1 Summary of sediment samples collected

Year	Collected by	Sample Types	Description
2019	Soil Conservation Service	Bed	14 bed samples collected between Nine Panel Bend and just downstream of Moira Lake confluence
2021	MDBA	Other	1 lunette sample, 3 in-channel point bar samples
2021	Water Technology	Bed & Bank	12 bed samples, 6 bank samples

During the field campaign in March 2021, Water Technology (2021) collected sediment samples from the bed of the Murray River through the Barmah Choke using an undisturbed-wet-soil-sampler. The samples were generally collected from near the middle of the river, away from any obvious snags that would have the potential to locally influence the bed profile. In addition to the collected bed samples, bank material samples were collected at six locations within the project reach, targeting eroding bank faces on outside bends. Samples were analysed for particle size distribution at Southern Cross Universities (SCU) Environmental Analysis Laboratory, and the results are presented by Water Technology (Water Technology, 2021). To supplement this data, MDBA staff collected four samples, at the lunette south of Moira Lake and on three in-channel point bars upstream of the forest.

The location of the bed and bank samples is provided in Figure 6. Additional upstream sites on in-channel point bars at Tocumwal Beach and Thompsons Beach at Kennedy Park in Cobram are not shown.

Figure 6 Bed and Bank Sediment Sampling Locations (Water Technology, 2021)

A selection of the bed material sample results is presented in Figure 7 (B). These show that the material on the riverbed is dominated by coarse sand, averaging ~80% coarse sand (the sand slug samples averaging 90%+ of coarse sand).

Bank material samples, shown in Figure 7 (C), are dominated by fine sand, silt, and clay. In contrast to the bed samples, there is far less coarse sand in the banks, which average 5-13% coarse sand. These results indicate that the sampled bank material typically contains only a small fraction of the coarse sand. Although the banks within this reach are prone to ongoing erosion processes, it is unlikely that the bank material is the primary source of the coarse sand found on the riverbed. This is discussed further in Grove (2021).

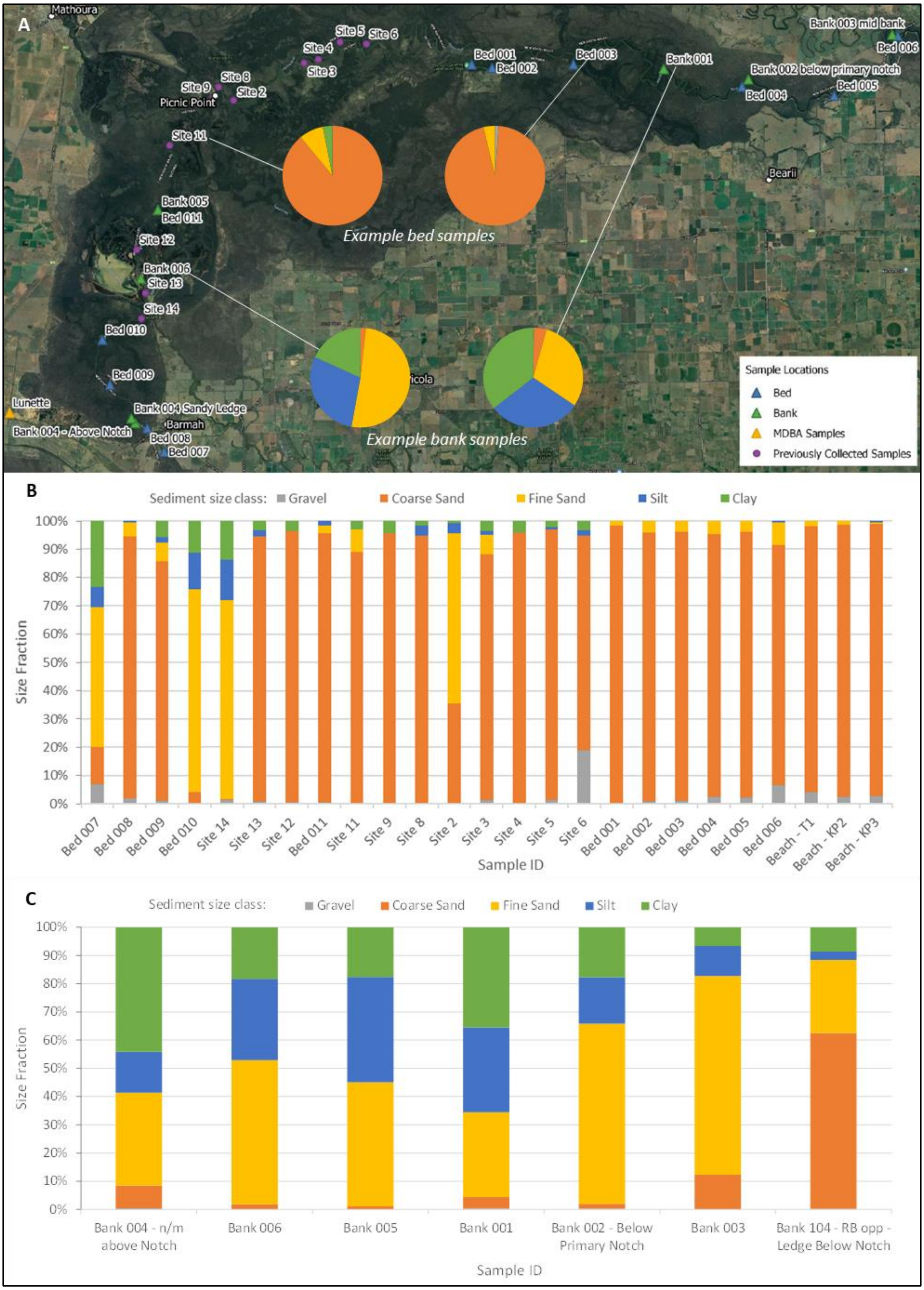


Figure 7 Sediment size sampling results showing a map of sample locations (A) with example size distributions; grain size fraction for each bed sample (B); and bank sample (C) in downstream to upstream order.

2.2.4. Sediment quality

Water Technology (2021) collected sediment samples from the bed of the river which were analysed for sediment size distribution (described previously) and the presence of 26 different heavy metals (see Water Technology, 2021 for complete suite of results). For the ten metals that have Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG, 2018) default guideline trigger values (Table 2), no samples returned results above the trigger.

Table 2 Selected heavy metal concentration results for sediment samples (only elements that have ANZG trigger values are shown).

Metal	Min (mg/kg)	Max (mg/kg)	Mean (mg/kg)	Trigger value (mg/kg)
Antimony	<1	<1	<1	2
Arsenic	2.6	7.6	4.8	20
Cadmium	<0.5	<0.5	<0.5	1.5
Chromium	1.6	24.1	5.1	80
Copper	1.5	38.2	6.3	65
Lead	2.1	14.1	4.3	50
Mercury	<0.1	<0.1	<0.1	0.15
Nickel	1.6	19.2	4.1	21
Silver	<1	<1	<1	1
Zinc	4.9	47.2	11.3	200

The results for six metals (arsenic, chromium, copper, lead, nickel, and zinc) are plotted in order from downstream to upstream in Figure 8. There is a very slight trend of increasing concentrations downstream (although still well below threshold values), which is likely reflective of the increasing proportion of finer sediment in the samples in the downstream direction. The highest concentrations for all six metals were found in sample Bed 007, just downstream of Barmah township, and Bed 010, downstream of the Barmah lakes.

All metal concentrations for all samples were below the threshold limits.

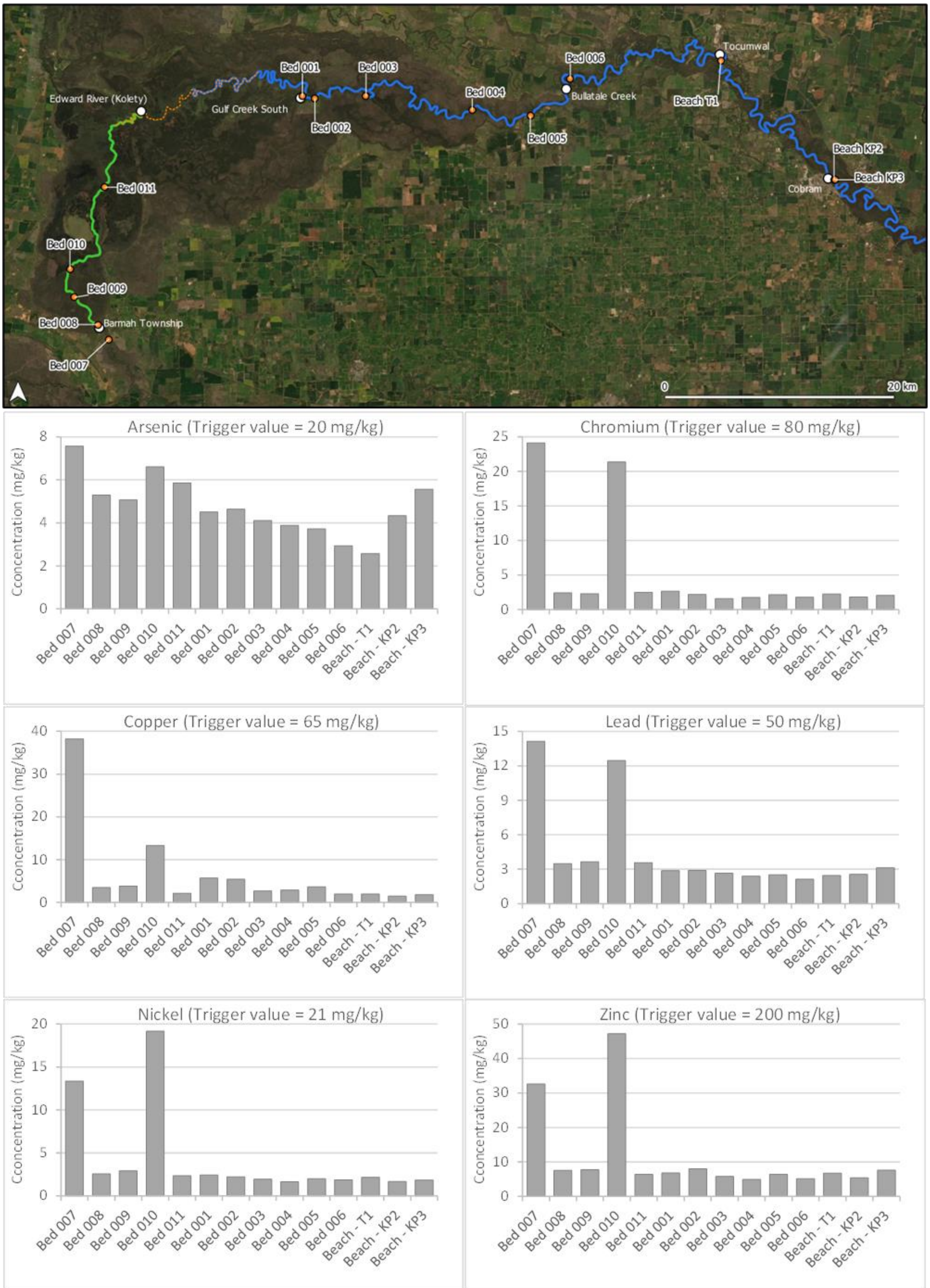


Figure 8. Map of sediment sample locations (top) and plots of heavy metal concentrations in samples from 14 locations along the River Murray, between Cobram and Barmah township.

2.3. **Analysis and Interpretation**

The studies by Streamology (2020 & 2021) and Grove (2021) focussed on locating and understanding where the excess coarse sand was on the bed of the River Murray channel, the volumes present, and the potential sources of this material. The work involved:

- Analysis of sediment samples (as described in the preceding sections),
- Validation of sediment thickness data,
- Reviewing and assessing potential sediment sources,
- Quantifying sediment volumes, and
- Developing an understanding of the likely trajectory of the river in response to the excess sediment.

The focus of the Streamology (2020) work was to investigate sediment transport dynamics within the Barmah-Millewa reach, and the impact that variability in transport rates and channel form along the reach are likely to have on channel capacity in this narrow part of the River Murray. The main elements of the work involved:

- Analysis of channel dimensions and bedload volume,
- Sediment transport modelling, and
- Assessment of channel capacity change.

Each of these aspects are briefly summarised in the following sections.

2.3.1. **Sediment extents and thickness**

The bedload measurements detailed in Section 2.2.2 were analysed by Streamology (2020) for the initial trial section (25 km) and then this analysis was extended in 2021 to include the full 220 km. The focus of the analysis was to understand the variability and volumes of bed sediments along the river. The full variability of the bed sediment thickness is most easily assessed using the original spatial dataset of measurements from the sub-bottom profiles. A map of these values is provided in Appendix A.

Key observations from the original thickness data:

- Overall average thickness for the entire reach from Yarrawonga to Barmah township is 1.16 m (*S.D.* = 0.51). Minimum thickness is 0.03 m recorded immediately downstream of the Barmah Lakes. Maximum thickness is 4.9 m, located on bend 1 km downstream of Picnic Point.
- The thickest bedload is found on the outside of bends, where deep pools have been filled in. The highest concentration of these very thick deposits (>4 m) is found downstream of the Edward River (Kolety) confluence, the narrowest stretch of the river where channel capacity is most constrained.

To appreciate the broader patterns in sediment thickness it is useful to view the data linearly, with much of the variability smoothed. To do this, spatial analysis was used to convert the very highresolution two-dimensional dataset of bedload measurements (a point layer) into a linear dataset of measurements that could be plotted versus chainage (distance from Yarrawonga). The average thickness was calculated for points every 100 m along the channel using overlapping areas (Figure 9), resulting in a more manageable smoothed dataset.

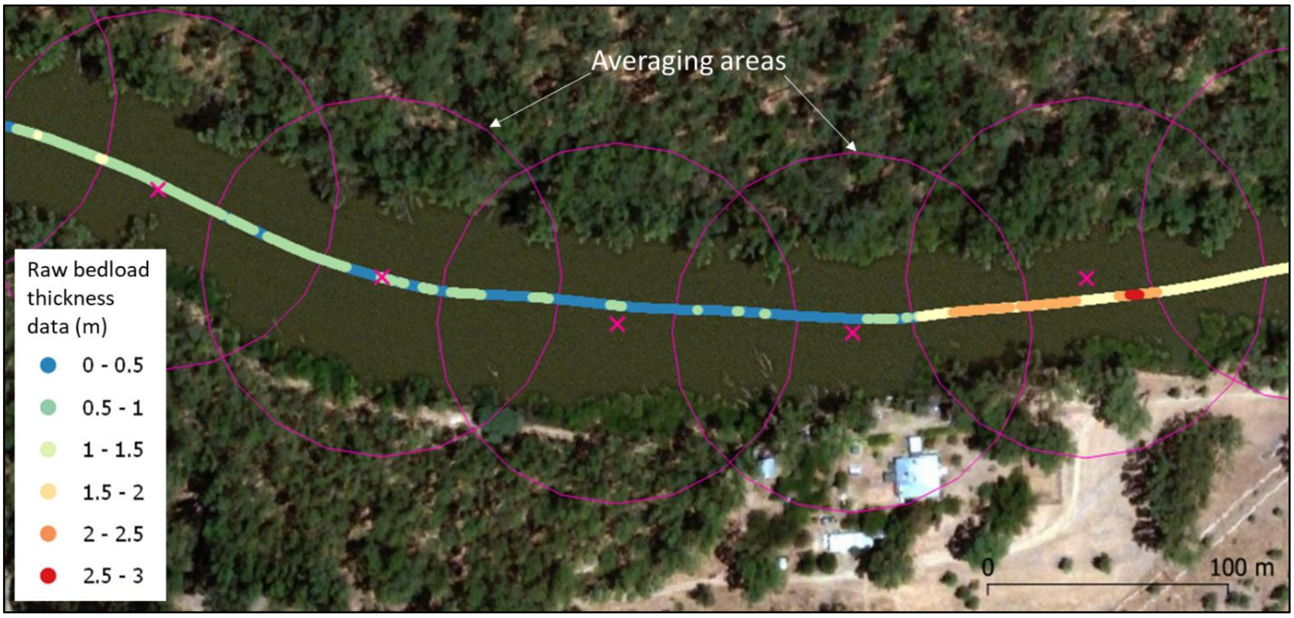


Figure 9. Diagram illustrating process used to calculate average bedload thickness values from the raw data.

The linear bedload thickness results presented Figure 9 have been smoothed during the spatial averaging process (pale blue, orange, and green lines), and then smoothed again using a moving average (dark blue, orange, and green lines). The smoothing reduces the extreme variability of the original data, thus allowing larger scale patterns to emerge, but it should be noted that this has the effect of supressing extreme values (very thick or very thin bed sediments).

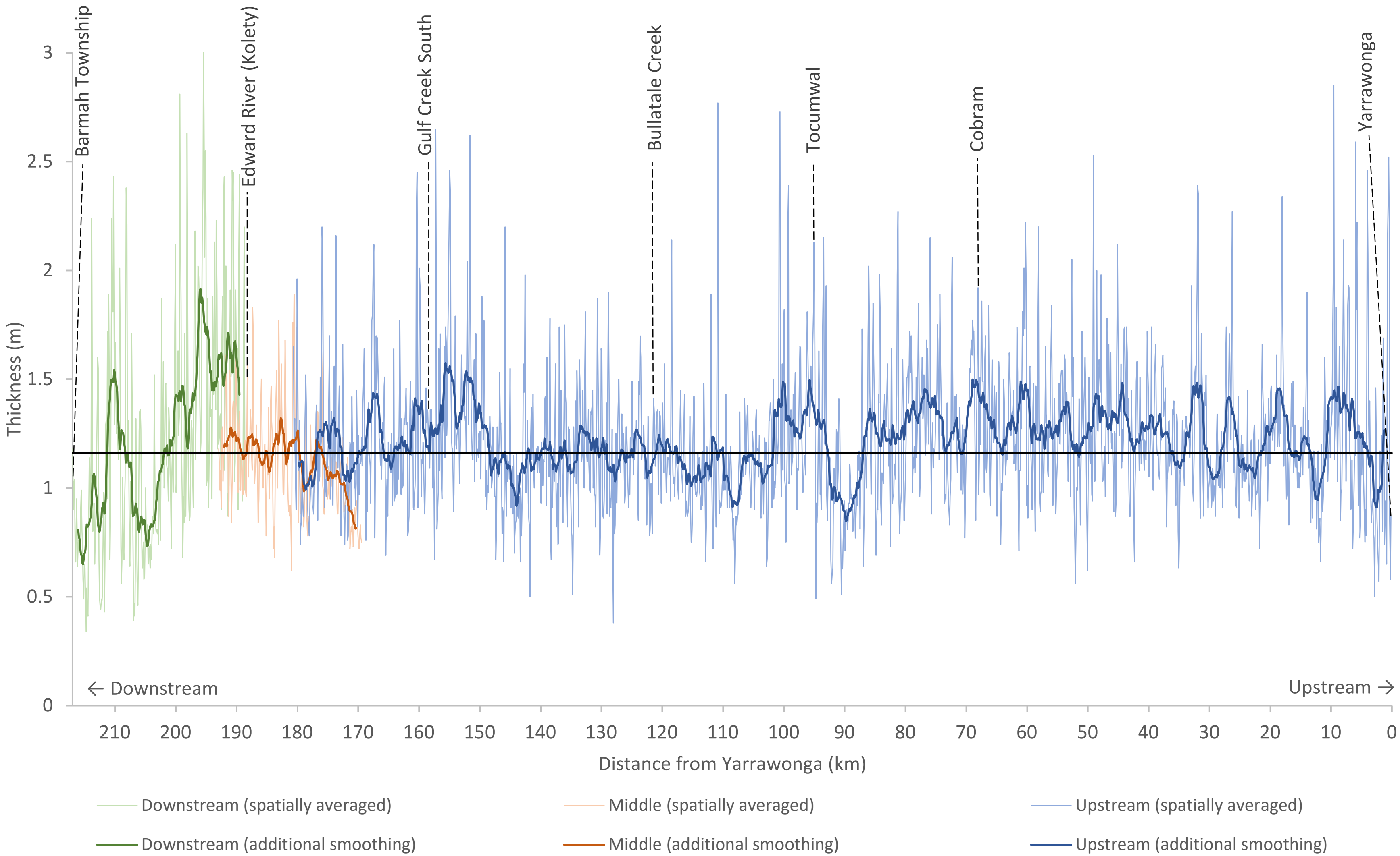


Figure 10. Plot of average bedload thickness from Yarrawonga Weir to Barmah township. Pale lines represent raw thickness data that has been spatially averaged using overlapping buffers every 100 m (see Figure 9). Dark lines are the result of additional linear smoothing using a 1.8 km moving average. Black line is the overall mean for the complete dataset.

The following observations are based on the averaged bedload thickness data presented in Figure 9:

- For almost the entire 220 km from Yarrawonga to Barmah township, there is a substantial layer of bedload material, on average over 1 m thick with many pockets several metres thick.
- For the first 86 km downstream from Yarrawonga thickness fluctuates largely above the overall mean of 1.16 m, with a pronounced drop 10 km upstream of Tocumwal (coinciding with a relatively straight section of river).
- Downstream of Tocumwal (from the 100 to 150 km mark), thickness is generally lower and less variable and with fewer very thick deposits and fluctuates mostly below the overall mean.
- Downstream of the Edward River (Kolety) confluence there is a marked increase in the variability of measurements, and an increase in the mean depth. The 12 km stretch (from 188 to 200 km) is the most variable section of the whole dataset with the highest peak and mean thickness values. This coincides with the narrowest stretch of the river, where channel capacity is lowest.
- There is a strong relationship between effluent channels/offtakes and thick deposits. However, these are mostly found on the outside of bends, where thick bedload is common due to infilled pools, so it is not yet clear what role effluents play.

For a section of the Barmah-Millewa reach, from Bullatale Creek to approximately Porters Creek (~80km), it is possible to assess bedload thickness as a proportion of the channel cross-sectional area (Figure 11). The following observations are based on the data on bedload thickness as a proportion of channel cross-sectional area:

- For the 180 km of the Barmah-Millewa reach for which channel dimensions are available, bedload sand reduces the total channel capacity by an average of 24 % overall.
- Because channel dimensions decline progressively downstream, the same thickness of bed material occupies proportionally more of the channel cross section downstream versus upstream.
- For the first 30 km of the Barmah-Millewa reach (120 – 150 km) the reduction in capacity caused by bedload is approximately 20 %.
- From the 150 km mark downstream to the Edward River (~190 km mark) the reduction in capacity averages 25 – 30 %.
- Downstream of the Edward River, 30 – 35 % of the channel is occupied by bedload sand.

Details of the calculation approach used is detailed in Streamology (2020).

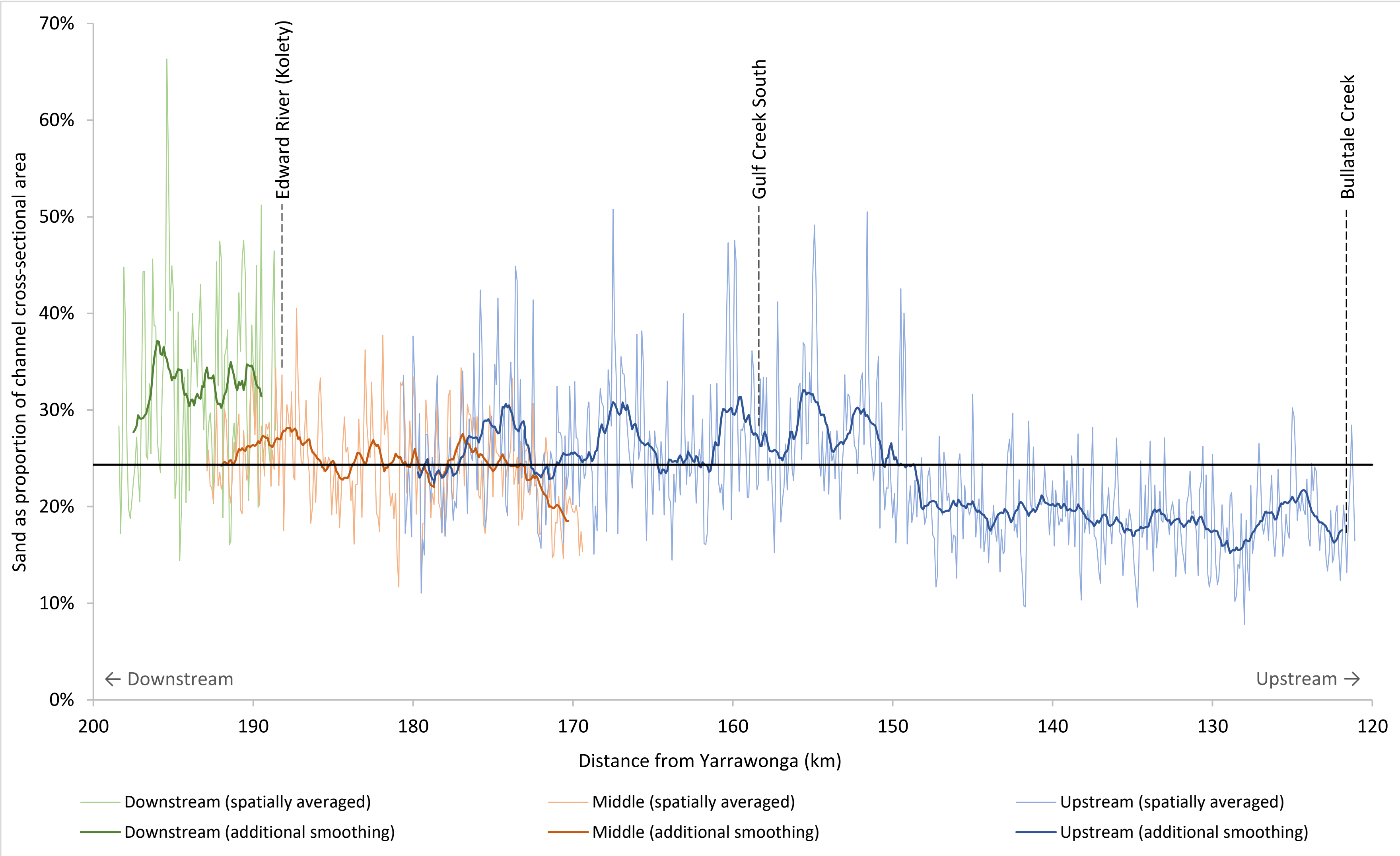


Figure 11. Plot of average bedload thickness as a proportion of channel cross-sectional area for the 80 km reach downstream of Bullatale Creek. Pale lines represent raw thickness data that has been spatially average using overlapping buffers every 100 m (see Figure 9). Dark lines are the result of additional linear smoothing using a 1.8 km moving average. Black line is the overall mean for the complete dataset.

Key learnings:

- Channel dimensions decrease progressively downstream with width declining at a consistent rate, but with depth decline being more variable.
- The sand is moving as distinct dunes with around 0.5 to 1 m amplitude and 20 to 40 m wavelength.
- Average bedload thickness (sand depth) along the 220 km stretch covered by sub-bottom profiler data is 1.16 m, with the highest concentration of very deep deposits found in the narrowest sections downstream of the Edward River (Kolety).
- The absolute volume of sand will be greater upstream than downstream, however, further downstream a greater proportion of the channel is filled with sand (owing to the downstream decreasing channel size).
- Former pools (deep points) at the outside of meander bends have been filled by sand leaving a uniform sand bed.
- Sand depth is greatest at offtakes.
- More irregular bedform morphology and lower bed material thickness suggests that in the most downstream reach (from the Barmah Lakes to Barmah township) there is less sand stored in the channel.

2.3.2. **Sediment volumes**

Grove (2021) extended the bedload analysis described above to estimate the current coarse sand volume in the 190 km of riverbed between Yarrawonga and Picnic Point in excess of 20 million m^3.

The work also investigated where the sand has come from and the relative potential contribution of different sources. The main sources of sediment were identified as:

- Catchment disturbance upstream from gold mining (1859-1981)
- Upstream land clearance triggering bank erosion and gullying
- Bank erosion within the reach from Yarrawonga to Picnic Point
- Point bar erosion within the reach from Yarrawonga to Picnic Point

It was estimated that upstream gold mining could have mobilised a volume of bedload over six times the current bedload volume within the reach (> 100 million m^3). Bank erosion and gullying because of upstream catchment land clearance were estimated to have potentially mobilised around 15 million m^3. Within the reach itself, bank erosion is estimated to have mobilised up to 2.5 million m^3 and bar erosion of up to 1.5 million m^3. While bank and bar erosion within the reach are active contributors of coarse sand, historic gold mining and land use change in upstream catchments are the only sources which could have supplied the bulk of the 20 million m^3 currently in the reach.

2.3.3. **Channel capacity and sediment transport**

Streamology (2020) provides a detailed analysis of the River Murray channel and how it changes downstream of Tocumwal. The main findings were:

- The Barmah Choke is not a single point but rather an 80 km stretch of the River Murray (from Bullatale Creek to the Barmah Lakes) along which channel depth and width progressively decreases.
- This is a low gradient (0.0001 m/m), low-energy section of the River Murray with multiple effluent channels that carry water onto and across the floodplain.
- Channel width peaks at 150 m at the upstream end of the Barmah-Millewa Forest, declining to a minimum of 40 m at the narrowest point at Cutting Creek near the Barmah Lakes.
- Downstream of this minimum, the width increases rapidly, reaching 86 m at Barmah Township (Figure 12).
- Maximum bankfull depth also decreases through the Barmah-Millewa reach, although not as steadily as width.
- The combination of the declining width and depth compounds to substantially reduce the cross-sectional area through the reach. From a peak cross-sectional area of about 1,000 m^2 at 34 km downstream of Tocumwal, area declines to a minimum of 250 m^2 at the 94 km mark, 10 km downstream of Picnic Point (Figure 13). This decrease represents a 75 % reduction in cross-sectional area which will translate into corresponding decreased flow conveyance, depending on channel slope and roughness.

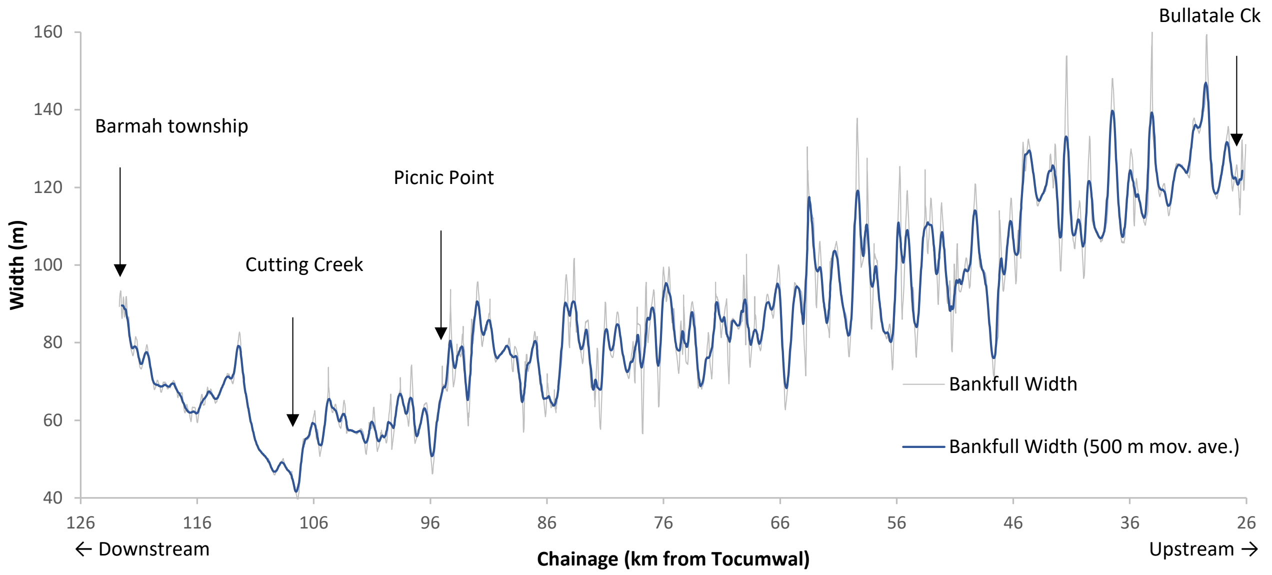


Figure 12 Plot of the River Murray bankfull width from Bullatale Creek to Barmah township (Streamology, 2020)

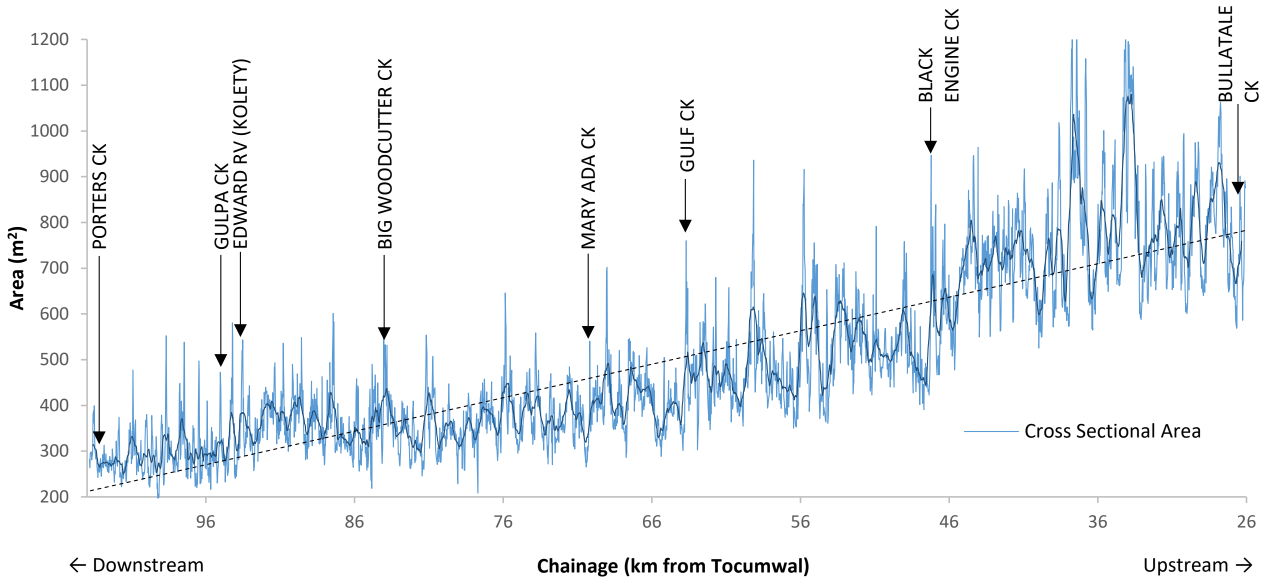


Figure 13 Plot of River Murray cross-sectional areas from Bullatale Creek to Porters Creek

The sediment transport analysis also detailed in Streamology (2020) mirrors the trends in channel capacity, showing a clear decrease in energy and transport rates downstream through the Barmah-Millewa reach. The works identified that:

- Sand in the Barmah-Millewa reach mostly moves as large bedforms (dunes) on the channel bed.
- Constrained channel capacity acts as a fundamental control, reducing sediment transport rates downstream even under high upstream discharge scenarios.
- Step changes in transport rates occur at offtakes (i.e., effluent channels) where diversion of flow reduces water discharge without removing bedload.
- At the upstream end of the Barmah-Millewa reach annual sediment loads range from 230,000 – 250,000 m^3/year during years with no major floods, to over 500,000 m^3/year during a major flood year (180,000 ML/d event recorded at Tocumwal in 2016).
- Downstream, where transport rates are lowest, annual sediment loads ranged from 70,000 – 80,000 m^3 with loads during a flood year greater than non-flood years, but still greatly reduced compared to upstream.

Sediment transport in this reach under current regulated flow conditions was also compared to what would be expected under theoretical ‘natural’ conditions (no dams, infrastructure, irrigation etc.) using hydrologic model outputs. The results reveal the following differences in transport dynamics under regulated and ‘natural’ flow:

- Regulation reduces the magnitude of peak flood discharges entering the Barmah-Millewa reach compared to natural flow conditions, while also increasing baseflow with long duration regulated irrigation flows.

- Flow regulation has had the effect of increasing the sand transport rate through the Barmah-Millewa reach. In a non-flood year, long duration regulated flows increase transport capacity by about 10 %. Natural flood events increase the sand transport upstream of the Barmah-Millewa reach but do not increase transport capacity through the reach.

Critically, this increase in capacity due to regulation is balanced by a reduction in sand entering the Barmah-Millewa reach, due to a reduction in peak flood discharges from upstream.

Figure 14 summarises the outcomes of the sediment transport analysis to highlight the differences between what volume of sand can be transported into the upstream section of the Barmah-Millewa reach, compared to what can be transported out of the reach downstream. As the sediment moves as bedload (i.e., transported along the bed of the river, not with the water in suspension) the excess sand cannot be deposited on the floodplain but instead builds up on the bed of the river.

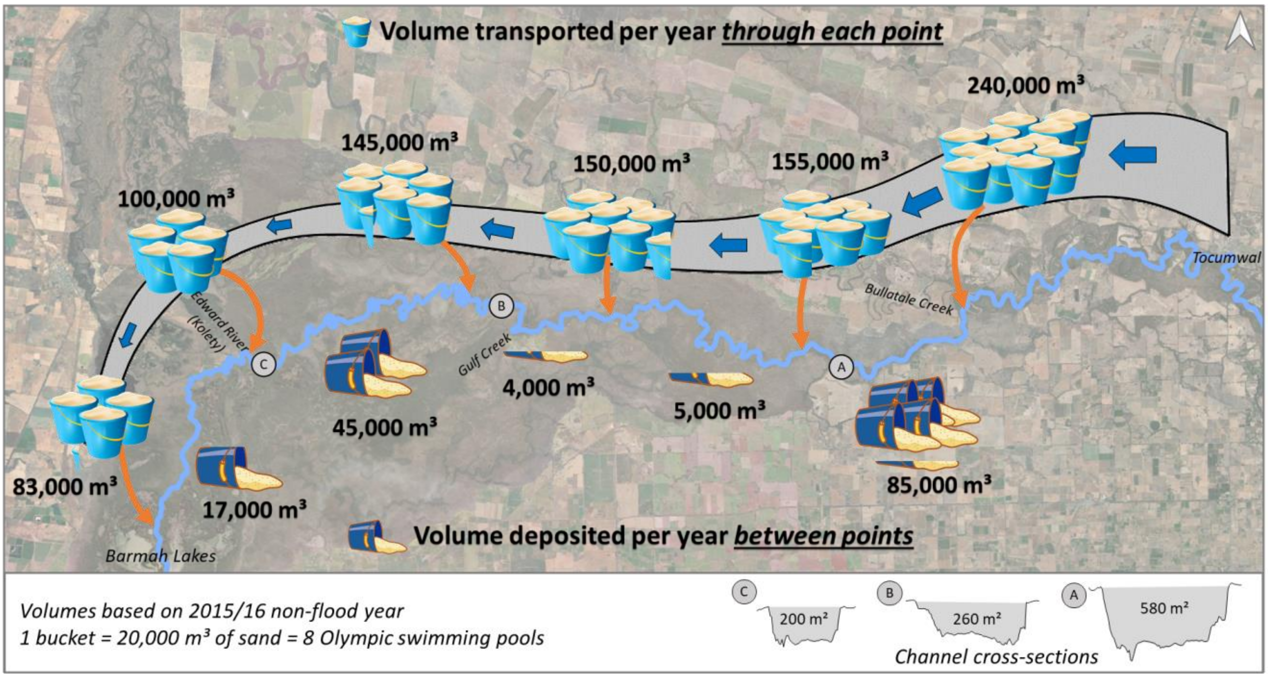


Figure 14 Barmah buckets summary of sediment transport in the Barmah-Millewa reach

2.3.4. Sediment quality

Professor Bill Maher was engaged to conduct an independent review of the heavy metal data collected as part of this project and summarised in Section 2.2.4, along with historical data (Maher, 2021). He was also asked to provide advice on a proposed way forward with respect to sampling and analysis.

Some of the key points made by Professor Maher in his report include that:

- the available sediment metal data to date indicates no gross contamination.

- the metals present are unlikely to pose an ecological threat.
- there is no need for further immediate sampling.
- sampling should be undertaken if an intervention has been agreed to and should be specific to the sediment that would be removed.

2.3.5. Historical flows analysis

An analysis of historic gauge records at selected locations in the southern connected Murray-Darling Basin was undertaken by HARC (2021) to investigate the following questions:

- Has the Barmah-Millewa reach been 'run' more or less often at or near capacity over the past 35 years, during months (January-April) when flooding of the Barmah-Millewa Forest is undesirable?
- Is there additional capacity in the Edward-Wakool system for bypassing the Barmah-Millewa reach?
- What are the historic changes to tributary inflows downstream of the Barmah-Millewa reach? These changes may be influencing how much water needs to be delivered from the upper Murray storages – through or around the Barmah-Millewa reach – to meet demands.
- What, if any, are the historic changes to tributary inflows from the Kiewa River and Ovens River to the River Murray? These changes may be influencing the volume and timing of bulk transfers of water between the upper Murray storages – through or around the Barmah-Millewa reach – to Lake Victoria (Tar-Ru).

Most relevant to this project, the analysis found that:

- Although the Barmah-Millewa reach channel capacity has reduced over time, for the months of January to April from 1985 to 2019, river levels near Barmah gauge have not been increasing. This is shown in Figure 15 which presents the proportion of time the river level at Picnic Point was at different levels, including the above the operational threshold of 2.6 m (dark blue).
- The frequency with which flows downstream of Yarrawonga have been near or above channel capacity has not increased in recent years compared with other times from 1985-2019.
- The total flow through the Edward River (Kolety) offtake and Gulpa Creek offtake from January to April (i.e., to bypass the narrowest section of the Barmah-Millewa reach) has been relatively steady since 1997. So, the reduced capacity of the Barmah-Millewa reach has not resulted in more flow being directed through the Edward River offtake and Gulpa Creek offtake.

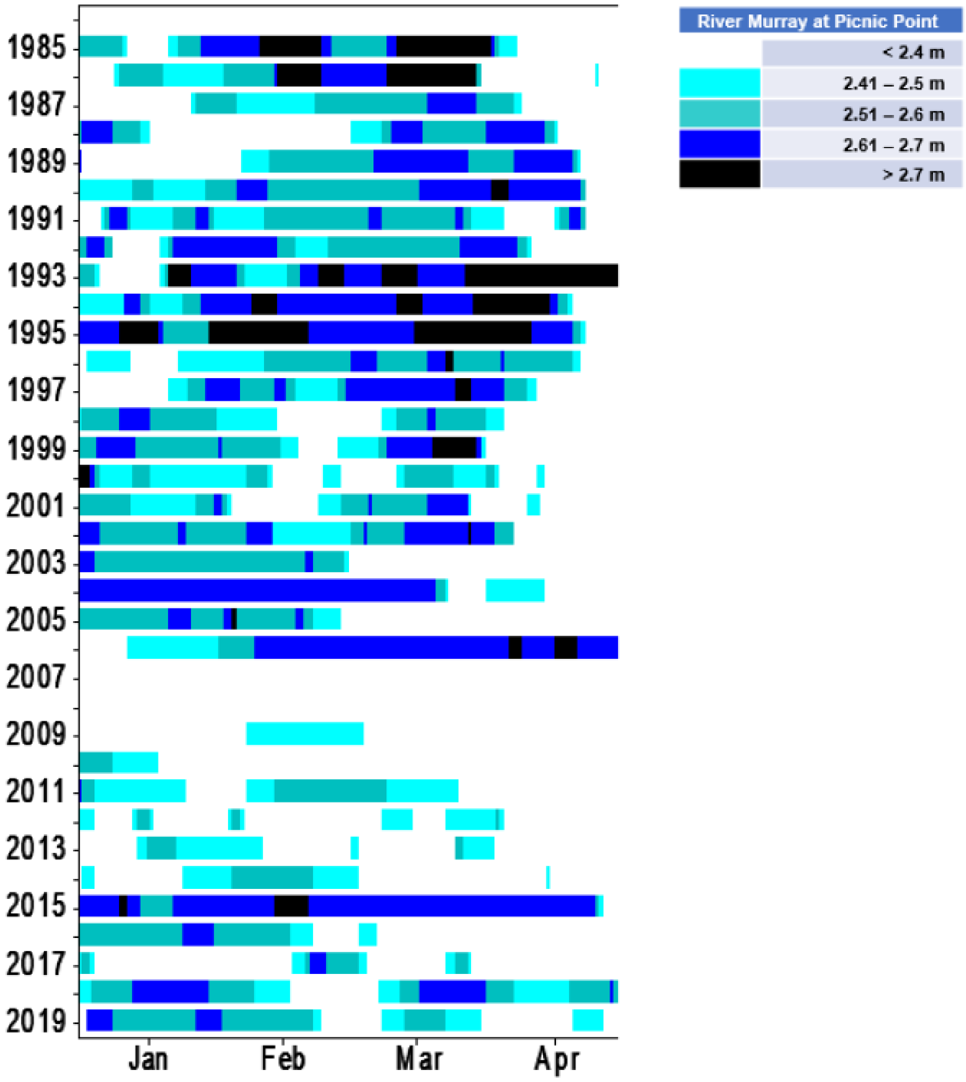


Figure 15 January to April proportion of time river levels at Picnic Point is between various water level thresholds

section three

3. **Values of the Reach**

Key values are easily recognised as being part of what we appreciate about the Barmah-Millewa reach of the River Murray and are representative of a broader range of environmental, cultural, social, and economic values that we care about.

An understanding of these values is critical to the development of the longer-term management of the waterway. It ensures that any actions or options identified to address the issue of excess sediment within the riverbed and an ongoing reduction in capacity are assessed against these values and any adverse impacts are clearly identified.

This section discusses the identification of key values based on a desktop review and targeted stakeholder consultation. While values have been grouped into the main themes (environmental, cultural, social, and economic) there is overlap and interdependence which further demonstrates their importance. These key values have informed the assessments detailed in Sections 5 & 6.

3.1. **Preliminary Desktop Review**

The purpose of the desktop review was to develop a broad understanding of existing values of the Barmah-Millewa reach as a starting point for the subsequent stakeholder engagement sessions.

3.1.1. **Environmental**

There are several key environmental values or attributes associated with both the River Murray channel and the adjacent broader Barmah-Millewa Forest and floodplain complex. The environmental value of the river channel itself is acknowledged in its designation as a Living Murray Icon site, a key environmental asset within the Basin Plan.

- The River Murray Channel Icon Site is essentially the main channel of the entire river, connecting the headwaters, floodplains and wetlands with the estuary and ocean. In the 2005 foundational report (MDBA, 2005) the main features of the River Murray Channel were defined as:
    - The River Murray holds iconic status and is the nation’s most important river.
    - It provides in-stream habitat for many aquatic plants and animals, including the Murray cod and other threatened species (e.g., trout cod, Murray hardyhead).
    - Its banks support river red gum forests, which have strong natural and First Nations cultural values and provide the aesthetic backdrop for the river and human activities associated with it.

- The following three ecological objectives have been set for the River Murray Channel. These objectives were first detailed in The River Murray Channel Icon Site Environmental Management Plan 2006–2007 (MDBC Publication No. 35/06):
    - Increase the frequency of higher-volume flows in spring, that are ecologically significant
    - Overcome barriers to migration of native fish species between the sea and Hume Dam
    - Maintain current levels of channel stability

The 2002 and updated 2013 River Murray Action Plan – Yarrawonga to Torrumbarry Weir reviewed the condition of the channel along this reach and developed action plans around specific visions for different sections. The waterway values relevant to the Barmah-Millewa reach are summarised below.

- Bullatale Creek to Edward River reach - this reach is recognised for its proximity to the Barmah-Millewa Forest, its high natural values and for its value as a conveyor of regulated flows for downstream use (RPS Aquaterra, 2013). Specific environmental values identified in this reach included:
    - Poor diversity, but generally continuous, regenerated vegetation through the Choke
    - Excellent coverage of macrophytes at high summer flow level
    - Unique stream geomorphology
    - Excellent habitat for fish at summer flow level
- Edward River to Barmah Sand Dunes reach (approx. 4.5 km downstream of the Deep Creek confluence) - this reach is recognised for its proximity to the Ramsar wetlands and red gum forest, its high natural values and for its value as a conveyor of regulated flows for downstream use (RPS Aquaterra, 2013). Specific environmental values were similar to those noted above.

More broadly, the environmental value of the Barmah-Millewa reach is closely associated with the adjacent floodplains and wetlands. A brief overview of these values is provided below.

- The Barmah Forest Ramsar site is located on the River Murray floodplain in northern Victoria (i.e., south of the main river channel) between the downstream end of Ulupna Island and Barmah Township. It predominantly consists of river red gum forests and floodplain marshes. The forest features a variety of permanent and temporary wetlands, including lakes, swamps, lagoons, and flooded forest. These wetlands provide habitat for many bird species. It was originally nominated as a "Wetland of International Importance" under the Ramsar Convention in 1982 (Hale & Butcher, 2011).
- The Barmah Forest Ramsar site is designated a National Park under the Victorian Parks and *Crown Land Legislation Amendment (River Red Gum) Act 2010* and is currently managed by Parks Victoria.

- The Millewa, Gulpa Island, Tuppal, and Moira State Forests (on the New South Wales side of the River Murray) and the Barmah Forest (on the Victorian side) form the largest continuous stand of river red gums in Australia. The floodplain and wetland systems within the Millewa Forest are areas of national and international significance, providing habitat, breeding and nursery grounds for colonial water birds and migratory species listed under international agreements, populations of rare and endangered species of fish, small mammals and birds, and endangered and vulnerable plants (NSW Government, 2017).
- The Victorian Environmental Water Holder (VEWH) notes "*The Barmah-Millewa Forest is the largest river red gum forest in Australia and the most intact freshwater floodplain system along the Murray River. The forest supports important floodplain vegetation communities including the threatened Moira grass plains and is a significant feeding and breeding site for waterbirds including bitterns, ibis, egrets, spoonbills and night herons. Significant populations of native fish, frogs and turtles also live in the forest's waterways. Barmah Forest is known to support 74 plant and animal species protected under state and national legislation*."
- CSIRO (2006) details the values attributed to the Barmah Forest vegetation at local, regional, State, Basin, National and International scales.
- The Millewa Forest lies within the NSW Central Murray Forests Ramsar site, which also include the Werai Forest and Koondrook-Perricoota Forest.
- The Barmah-Millewa Forest Environmental Water Management Plan (MDBA, 2012) provides an extensive summary of the environmental values of the Barmah-Millewa including at least 381 indigenous flora species and 221 indigenous vertebrate species. It is also known to support a range of threatened species including:
    - 6 nationally threatened flora species
    - 11 state-listed flora species
    - 13 nationally threatened fauna species
    - 44 state listed fauna species

3.1.2. Social

The River Murray through the Barmah-Millewa Forest provides many recreational opportunities and benefits for the local and broader community. Water-based recreational activities include fishing, water skiing, camping, walking, bird watching, outdoor sporting events and social gatherings. These social and recreational uses and values of the waterway, floodplain and wetland system are considered to provide many benefits, such as improved health and wellbeing, increased social cohesion, as well as boosting tourism.

A selection of studies assessing recreational and mental health values of the Barmah-Millewa reach is discussed herein.

Recreational Value

Despite the social, economic, and cultural significance of rivers, lakes, and wetlands in landscapes as typically dry as those of Australia, only a limited number of studies have addressed in detail the recreational value of its aquatic systems.

MDBA (2012) states "*Barmah–Millewa Forest receives about 100,000 visitors a day per year (Abel & O'Connell 2006). Popular activities include bike-riding, boating, bushwalking, camping, canoeing, cycling, fishing, four-wheel driving, horse-riding, orienteering, picnicking and scenic driving*".

Dyack et al (2007) reported the results of surveys of recreational users of the Barmah Forest conducted in 2006. The visitor profile from the survey results indicated that the groups visiting the Barmah Forest were often family groups, and repeat visits were common. Visitors to the River Murray participated in water activities, however, they ranked 'relaxing' highest as their reason to visit. An economic analysis, based on the survey results, found that the average non-market benefit from visitors to the Barmah Forest was $134 per adult per day, with a total non-market recreational value per adult trip of $529. From this was estimated that the total value of recreation at Barmah Forest of $13 million (25,000 x $529/adult visitor).

Hadwen et al. (2012) reviewed the recreational values of aquatic ecosystems and reported that, based on surveys undertaken with protected-area managers, tourism operators and local government representatives, inland waterbodies were disproportionately important destinations for visitors across a wide range of climate and landscape types in eastern Australia. Although they commonly occupied <5% of the area covered in their jurisdiction, aquatic systems were rated by 94% of protected-area managers are being important recreational sites. The types of activities reported as undertaken in aquatic systems were similar across protected-area managers, tourism operators and local government representatives, with bird watching, general relaxation, picnicking, hiking/bushwalking and swimming the most frequently nominated activities.

Mental-health values of natural systems

In a recent study Houghton et al (2021) noted that "*Aside from their obvious recreational importance, aquatic systems have substantial value in terms of general human wellbeing and mental health. It has been demonstrated that access to the natural world generally has significant positive impacts on mental health and wellbeing (e.g., Freeman 1978; MacKerron and Mourato 2013; Dean et al. 2018; Aerts et al. 2018). Protected areas and other examples of high-quality natural environments (e.g., nature reserves etc) have especially high mental-health value (Buckley et al. 2019). The benefits accrued of exposure to natural systems derive from phenomena as diverse as hearing bird song (Ferraro et al. 2020), to walking through old-growth woodlands or forests (Simkin et al. 2020) to being near wetlands (Maund et al. 2019)*."

Given these generalised findings, it is not unreasonable to assume that good access to high-quality natural environments along the River Murray and Barmah-Millewa Forest during periods of intense psychological stress, such as drought, could have several beneficial effects for rural populations during such times. The same could be said for the beneficial effects of such access to the broader regional population during on ongoing COVID-19 pandemic.

3.1.3. Cultural

Water resources have important cultural and spiritual values for First Nations people. Cultural and spiritual values may relate to a range of uses and issues, including spiritual relationships, language, song lines, stories, sacred places, customary use, the plants, and animals associated with water, drinking water, and recreational or commercial activities.

The following general cultural and spiritual values for water have been identified in the Australia & New Zealand Guidelines for Fresh and Marine Water Quality (ANZG, 2018) and are considered relevant to this project, Table 3.

Table 3 Cultural and spiritual values as identified in the Australia & New Zealand Water Quality Guidelines (ANZG, 2018)

Value	Indicator
'Water-Country' is healthy	Plants and animals that live in the water are healthy
	Water quality is unchanged or close to natural conditions
	Sands, silts and clays on creek and riverbeds and in lakes, estuaries and on the ocean floor are not polluted
	'Water-Country' and 'Sea-Country' looks healthy
Water quality is safe for drinking and the water is safe for sourcing food	Eating fish and other water animals is safe
	Eating water-living food plants is safe
	Water is safe for drinking
Water quality is safe for recreational and ceremonial purposes	Water quality is safe for swimming or for ceremonies where people go under water
	Water quality is safe to paddle in or go boating on
Water quality supports economic wellbeing of indigenous people	Healthy water supports tourism
	Healthy water supports farming
	Healthy water supports aquaculture
	Healthy water supports other economic uses

The Barmah-Millewa reach lies within the ancestral lands of the Yorta Yorta Nation, the Bangarang Aboriginal Corporation, and the Cummeragunja Local Aboriginal Land Council. Atkinson (2005) provides a summary of the history of the Yorta Yorta people and their connection to the Barmah-Millewa Forest. The forest and landscape are cultural values, which can be expressed through specific features, including[1]:

- Scarred trees
- Mounds and middens
- Fish trap systems
- Traditional tool working sites
- Burial sites

The Victorian Environmental Water Holder (VEWH) also notes:

- *"The wetlands throughout the forest continue to provide a constant source of nutritional foods and significant fibres for the Yorta Yorta People. It is also evident that the resources in the landscape were utilised to manufacture canoes, shields and carrying devices.*

[1] Dr Wayne Atkinson, Barmah-Millewa, Natural & Cultural Heritage: 'Keeping it for the Future', n.d. online accessed 30/08/2021 <https://waynera.files.wordpress.com/2010/09/lecbarmill04.pdf>

Flooding in the Barmah-Millewa Forest depends on flows in the Murray River. A natural narrowing of the river (commonly referred to as 'the Barmah Choke') restricts flow and causes overbank flooding when flows below Yarrawonga Weir exceed the channel's capacity. This restriction influences both the operation of Yarrawonga Weir and the upper limit of environmental flows that can be delivered to the forests. The Yorta Yorta People see this narrow part of their Dhungulla as a culturally significant creation story, and it provides ecosystem services both from a culturally and environmentally significant viewpoint. The name 'the Barmah Choke' is not a culturally appropriate name for the Yorta Yorta and is seen as a negative way to view their traditional lands and waters. Yorta Yorta People may refer to this as the 'Pama Narrows'."

An Aboriginal Waterways Assessment (AWA) was completed for the Millewa Forest, NSW in 2018 by MLDRIN[2]. Several sites along the River Murray and Millewa Forest were visited and scored as part of the assessment. All sites scored A1 (the highest score) for cultural significance. Scores for cultural values and uses for the assessed sites ranged from 63.8 % to 95.2 %, while waterway health ranged from 32.4 % to 53.6 %. It should also be noted that this AWA assessment was based on a small selection of sites and that the broader Millewa Forest and River Murray are of high cultural significance to the traditional owners (Darren Atkinson, *pers. comm*.)

A Joint Management Plan for the Barmah National Park was agreed in 2020 between the Yorta Yorta Nation Aboriginal Corporation and the Victorian Government (Yorta Yorta Traditional Owner Land Management Board, 2020). This plan sets out the vision for the park, which is 'Heal the Land, Heal the People – Healthy Country'. It states that:

"The plan recognises the important past, present and future cultural and natural values of the park both for the Yorta Yorta and the wider community. The plan includes strategies to enhance visitor experiences to ensure the park can be enjoyed by the wider community, balanced with actions that seek to provide environmental and cultural protections to improve the health and resilience of Country, particularly in times of drought and climate change"

3.1.4. **Economic**

The economic value of the River Murray channel and associated Barmah-Millewa reach can be considered in several ways, including:

- Delivery of water allocations downstream
- Through tourism and recreational activities
- Input to the local economy including property values
- Supporting social and environmental values

The economic value of these three areas is discussed in this section.

As noted in the 2020 Basin Plan Evaluation, the Murray–Darling Basin:

- is an economic and ecological powerhouse

[2] MLDRIN presentation on the Aboriginal Waterway Assessment for the Millewa Forest NSW Traditional Owners. Provided to this project by the Cummeragunja Local Aboriginal Land Council

- is home to more than 2.2 million Australians including more than 40 First Nations
- provides more than 3.6 million people with their drinking water
- generates $8 billion in tourism annually
- generates $24 billion in food and fibre
- is home to 120 waterbird species and more than 50 native fish species
- diverse habitats include 16 internationally recognised and protected wetlands

We also direct the reader to the following reports discussing the relationship between social and economic values in the Murray-Darling Basin.

- Strengthening social and economic outcomes | Murray-Darling Basin Authority (mdba.gov.au)
- 2020 Basin Plan Evaluation: reports and data | Murray-Darling Basin Authority (mdba.gov.au)
- Independent assessment of social and economic conditions in the basin (Sefton et al, 2020) - a comprehensive review of factors shaping regional and remote basin communities.

Water delivery

Water delivered through the River Murray channel and the broader Murray-Darling Basin is crucial for food and water security. These benefits come from industries including irrigated agriculture, hydro-electricity generation, tourism, and recreation as well as critical human needs such as town water supplies (stock and domestic). The Bureau of Meteorology provides a summary of the water markets via the Water Markets dashboard (http://www.bom.gov.au/water/dashboards/#/water-markets/mdb/eoi). This includes the Murray Darling Basin and details the allocations and entitlements along the River Murray along with a summary of the water trades occurring each year.

For example, over the 14-year period, 2008 to 2021, the water volume traded for the Victorian Murray (Barmah to South Australia) trading zone was 8,683,968 ML with a median price of $217.92 / ML.

Tourism & Recreational Activities

Tourism and recreation include a range of activities on or near the River Murray and its anabranches and tributaries. Boating on the open river and weir pools is popular, including house boats, paddle-steamers, canoeing, fishing, and ski boats. Camping and touring are also popular activities, as are visits to national and state parks and conservation areas. Tourists are also drawn to the wine industry, historic attractions and river-based events and festivals.

The Barmah-Millewa lies within the Victorian and NSW Murray Regional tourism areas. Recent tourism statistics for these regions (prior to 2020 which was significantly affected by COVID-19 travel restrictions) are summarised below.

The most recent Victorian Murray Region[3] Regional Tourism Strategy notes that:

[3] The Victorian Murray tourism region comprises four tourism sub-regions: Central Murray, Goulburn, Mallee and Murray East

- In 2019-20, tourism was estimated to be worth $980 million to the Murray region's economy (in direct and indirect Gross Regional Product) representing 5.9 % of the region's economy.
- Tourism generated employment of approximately 13,600 people or 8.8 % of the region's employment (direct and indirect jobs) in the Murray region.

Destination NSW December 2018-19 factsheet states that for The Murray[4] region:

- Tourism consumption was around $778 million, representing around 3.9 % of the regional economy.
- Tourism generated employment of approximately 5,000 people or 6.3 % of the region's employment (direct and indirect jobs) in this region.

Murray Regional Tourism undertakes regular online surveys to identify emerging issues or trends impacting tourism businesses and track industry performance. The 2018-19 survey was conducted online between 13 March and 31 May 2019 with 80 valid survey responses. Relevant to this project, one of the key findings was that water issues negatively impacted over half of businesses in 2018-19. This included algae, drought and negative media publicity relating to water levels. (Murray Tourism Industry Barometer, https://www.murrayregionaltourism.com.au/industry-development/murray-tourism-industry-barometer/)

New tourism initiatives include the Murray River Adventure Trail, which is a multi-sport adventure trail which extends along the length of the Murray River within the Murray tourism region in Victoria and NSW, using land and water to incorporate walking, cycling, kayaking/canoeing and other forms of water transport. It will traverse through the Barmah-Millewa reach which is an important part of the project.

Local Economy

The Barmah-Millewa reach lies within the Deniliquin Region of the Murray River Council area. Within this region agriculture forestry and fishing are the biggest contributors to the economy:

- Agriculture, Forestry and Fishing contributes 41.6 % ($25.95 million) and 55.2 % of total jobs (955 jobs).
- Tourism directly accounts for 7.9 % of total jobs (138 jobs)

Tapsuwan, Polyakov, Bark, & Nolan (2015) applied an economic valuation analysis approach to value the aesthetic and recreational benefits of proximity to the Barmah-Millewa reach, as well as the implicit valuation for in stream flows that are capitalized into nearby property prices. The results from the analysis suggest that homeowners pay premiums to live closer to the Barmah-Millewa Forest. The results also suggest that homeowners have preferences around river flows - neither low (drought) nor high (flood). The results provide estimates of the benefits of stream flows that could be used to inform policy and works related to improving environmental conditions and suggest that there are regional benefits that accrue to homeowners living near freshwater dependent ecosystems such as the Barmah-Millewa Forest.

[4] The Murray region in NSW

An economic estimate of the recreational value in monetary terms of the Barmah-Millewa reach (Dyack et al, 2006) was previously discussed in Section 4.1.2.

3.2. **Consultation Sessions**

3.2.1. **In-person workshops**

Two workshops were held at the Tocumwal Golf Club on the 19th & 20th April 2021. A key objective of these workshops was to identify and discuss key values (environmental, social, cultural, economic/operational) associated with the Barmah-Millewa reach.

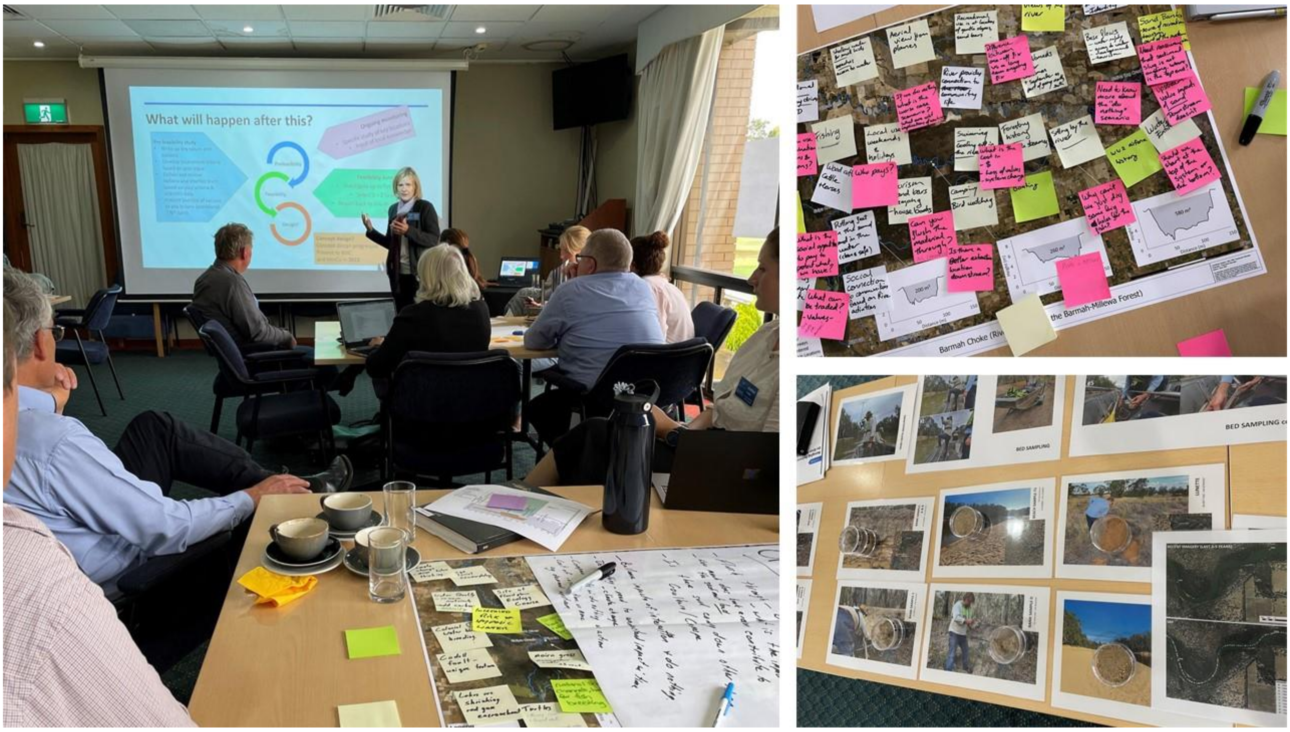


Figure 16 Snapshots from the workshops held at Tocumwal in April 2021

During each session participants were asked to identify and discuss the values of the Barmah-Millewa reach and responses were recorded by the project team. The notes and discussions from the workshops were then collated and word clouds created to identify any clear trends and outcomes under each aspect – social, economic, cultural, and environmental values. There was overlap between the values identified across the various elements, which reflects their importance to the region.

Participants were also provided with preliminary information on the sand slug issue within the Barmah-Millewa reach and canvased for their concerns on the potential implications of the sand in the river and options to manage the sand. The outcomes of these discussions are summarised in Section 3.4.

3.2.2. **Online sessions**

As a result of COVID-19 travel restrictions it was necessary to continue the consultation sessions using an online format. Online sessions were held on the:

- 7th & 8th June – to present additional data collected and analysed since the April workshops, provide initial feedback on the values information, and present additional details on the 'do nothing' option (described in detail in Section 4).
- October 2021 (8 x 2hr sessions) – to recap recent data analysis and reviews, to share further work on understanding the 'do nothing' to manage the sand option, and present 'do something' to manage the sand options for discussion. An opportunity to provide feedback on the implications for values of the different options presented. A summary of the outcomes of the online sessions is provided in Appendix C.

Between the June and October sessions, First Nations and stakeholders were provided with email updates on the progress of the project.

3.3. **What are the Values?**

A summary of the First Nations and stakeholder discussions at the April in-person workshops is provided in the following sections, along with a Word Cloud pictorial view of the main values identified. In the Word Cloud the relative size of the words reflects the number of times the value or attribute was mentioned in discussions. The Word Clouds and feedback from the workshops was presented to stakeholders at the online session in June 2021.

3.3.1. **Environmental**

The region is abundant in environmental values and stakeholders highlighted the significant range of these values. The region is prized not only for the value of individual species but also as a whole ecosystem and for the processes it supports. The region is a Ramsar listed site and the largest river red gum forest and is therefore a significant environmental value as a site. The region is prized as a biodiversity hotspot with 75 listed flora and fauna species. It is also valued as a site for colonial waterbird breeding, nesting, and feeding and for its support of native fish breeding. The ecological functioning of the river and floodplain was also highlighted as an environmental value worth protecting.

Stakeholders identified native fish species, waterbirds, and turtles as well as unique flora such as Moira grass, as key environmental values within the region. These values clearly reflect identified in the desktop review.

Figure 17 Environmental Values of the Barmah-Millewa Reach

3.3.2. Social

The Barmah-Millewa reach of the Murray River and surrounding areas provide a host of social values that are important to local communities. Recreational opportunities are among the most important values of the region for local communities. There are both active and passive opportunities for recreation in the area. Important recreational activities closely connected to the river include boating, wake boarding, fishing, swimming, camping, bird watching and bush walking. Stakeholders also indicated that other recreational opportunities in the region not directly linked to waterways, such as golfing, are still dependent on the river as it is these surrounds which attracts people to the region to engage in other recreational activities.

A sense of connection and identity are also social values highlighted by stakeholders that are important in the region. The river and natural surrounds are central to the sense of belonging and identity for people in the region. There are also the psychological and wellbeing benefits associated with access blue and green space in local communities.

Figure 18 Social Values of the Barmah-Millewa Reach

3.3.3. Cultural

For First Nations people, the entire Barmah-Millewa reach is a key cultural value. Individual sites are important, however what makes them important is the cultural context of the entire landscape. First Nations people care for Country and identity is inextricably linked with Country, which makes the entire landscape an important cultural value.

Individual cultural sites, such as camping sites, burial grounds, ceremonial grounds, and meeting places are also important for their connection and record of the past but also for ongoing cultural practices. Likewise, flora and fauna species such as those used in medicine, those used as a food source and those that are totem species are important values to maintain as a part of caring for Country and to maintain ongoing cultural practices.

Access to appropriate water is also a key cultural value for First Nations people. Access to appropriate water ensures that Country can be cared for and the flora and fauna species that are important can be maintained in a healthy condition.

Figure 19 Cultural Values of the Barmah-Millewa Reach

3.3.4. **Economic**

Stakeholders identified a variety of economic values across the region that are important to them. Key economic values are associated with the fishing, agriculture and tourism industries which rely on water resources and healthy waterways to thrive. Stakeholders reported that the fishing industry is worth up to $1.6 billion across the region, however issues such as sand infilling critical habitats and degradation of waterways due to altered hydrology are impacting on the profitability of this industry.

Increasing costs of water and constraints on the volumes of water that can be delivered through the Barmah Choke have impacted on irrigators across the region. The economic livelihoods that result from agricultural enterprises are heavily reliant on secure and affordable access to water. Successful agricultural enterprises are an important economic value for stakeholders across the region and have flow on outcomes for the viability and cohesion of small communities.

Tourism in the region was also flagged as an important economic value with tourists visiting the region for fishing, camping, golfing, and other water-based recreational opportunities. Tourists to the region stay and spend money is small businesses across the region, contributing to their economic success. The appeal of tourism in the region is heavily reliant upon the health and condition of the region's waterways and forests.

Figure 20 Economic Values of the Barmah-Millewa Reach

3.4. Issues of concern & how they have been addressed

Participants were canvassed on their concerns regarding the implications of the excess sediment in the river and the reduction in capacity. Key issues of concern as highlighted by the participants are noted below along with follow up actions to address these concerns which were completed during the project.

- The April workshop was only able to present the findings of the Streamology (2020) report and a draft version of Grove (2021). Concern was expressed by a number of participants about the lack of information on the extent of the sand slug upstream and downstream of the locations discussed and therefore what was happening across the broader river reach.
    - *This concern was acknowledged by the MDBA team. Additional sediment bedload measurements and sand sampling had been completed to address this knowledge gap and was presented to subsequent online consultation sessions. The results are included in Section 2 and throughout Sections 4 and 5.*
- Can the source of the sediment be confirmed? Have there been core samples? Has there been any chemical analysis of the sediment?
    - *The sediment sampling analysis from the bed and bank samples collected in March 2021 was not available for the workshops. However, the results were provided in the subsequent online sessions. This included sediment size data as well as sediment quality analysis (Section 2).*
    - *Additional bedload sampling and sediment volume analysis was completed by Grove (2021).*
    - *The sediment quality data was independently reviewed by Prof. Bill Maher (Section 2.2.4).*

    - *No further analysis has been proposed to further refine the source location of the excess sediment. While detailed analysis may be able to provide confirmation of the source catchment of the excess sand, this information does not change the current conditions in the river or influence potential management options.*
- During both the April and June sessions many participants expressed that they wanted more detail on the 'do nothing to manage the sand' option. Why is the sand an issue which requires management interventions?
    - *During the project additional data capture, analysis and interpretation has been completed and this has enabled a more comprehensive understanding of the implications of doing nothing to manage the sand. This is explored in detail in Section 4 of this report.*
- In the October sessions, further details were presented on the impacts of excess sand on river channels and the implications for the Barmah-Millewa reach. This included accelerated bank erosion, and loss of diversity and habitat. Queries were raised as to whether there was any existing data to show where these changes were observed or measured in the reach.
    - *After the October sessions, additional reach specific examples of change, including available data, have been incorporated into the analysis detailed in Section 4.*
- Should reducing the flow demands downstream be included as an option?
    - *Although not explicitly included within the original remit of the project, an option has now been included in the assessment of reducing downstream demands (Section 5).*

section four

4. Do Nothing to Manage the Sand

4.1. Overview

The Murray-Darling Basin Authority (MDBA) river operations currently maintain an operational threshold water level (stage) at the Picnic Point gauge of 2.6 m, which is used to define the target flow capacity through this reach. This threshold level was first used to define the Barmah-Millewa capacity in 1996 and to limit undesirable (unseasonal) flooding of the forest (HARC, 2021). The regulated capacity of the Barmah-Millewa reach is measured by the water level at Picnic Point, and the corresponding releases from Yarrawonga Weir have been declining over time, reducing from 11,500 ML/day in the 1980s to a current capacity of approximately 9,200 ML/day.

The aim of this section is to provide an overview of the current understanding of the geomorphology of the River Murray through the Barmah-Millewa reach, how the type of river system it is will impact the river flow capacity, and what the presence of the sand slug means for the reach in the future.

4.2. Barmah Conceptual Model

4.2.1. Outline

An important outcome of the recent data collections and investigations has been the reinterpretation of our understanding of the geomorphology of the River Murray through the Barmah-Millewa reach. We now know that that this reach can be classified as a "*distributive fluvial system*" (DFS), whereby it is characterised by flow *distributaries* (often called offtakes or effluents along the River Murray) as opposed to flow *tributaries* (Streamology, 2020). Other characteristics include:

- A dominant, sinuous channel, with multiple sinuous channels distributing from it.
- Downstream decrease in channel dimensions.
- Down-valley increase in channel stability (reduced meander migration) combined with an increase in potential avulsions.
- Down-valley increase in poorly drained, open water areas and this is certainly the case in this reach where a series of lakes (Moira and Barmah Lakes) have formed along the eastern edge of the Cadell Fault block.

These systems are referred to as alluvial fans (i.e., the Barmah Fan), and are fundamentally zones for sediment accumulation on the fan driven by decreasing downstream sediment transport capacity. The general pattern for a system such as the Barmah Fan is that the dominant sinuous channel progressively fills with sediment down-valley as it becomes less and less capable of transporting the sediment delivered to the fan, leading to eventual avulsion, whereby the river takes another path. The result is that the sediment that drove the avulsion is now stored in the abandoned channel. The new avulsion channel will again progressively fill with sediment until it avulses, and the cycle continues.

This is what is happening on the Barmah Fan. The downstream decrease in transport capacity is an inevitable characteristic of this type of system. However, as there has been an increase in the volume of sand delivered to the fan above natural sources, then this will serve to accelerate the process of abandonment. It is very unlikely that the excess sand (i.e., the sand slug) will simply migrate through the Barmah-Millewa reach. It is more likely that sand will continue to accumulate until the channel avulses.

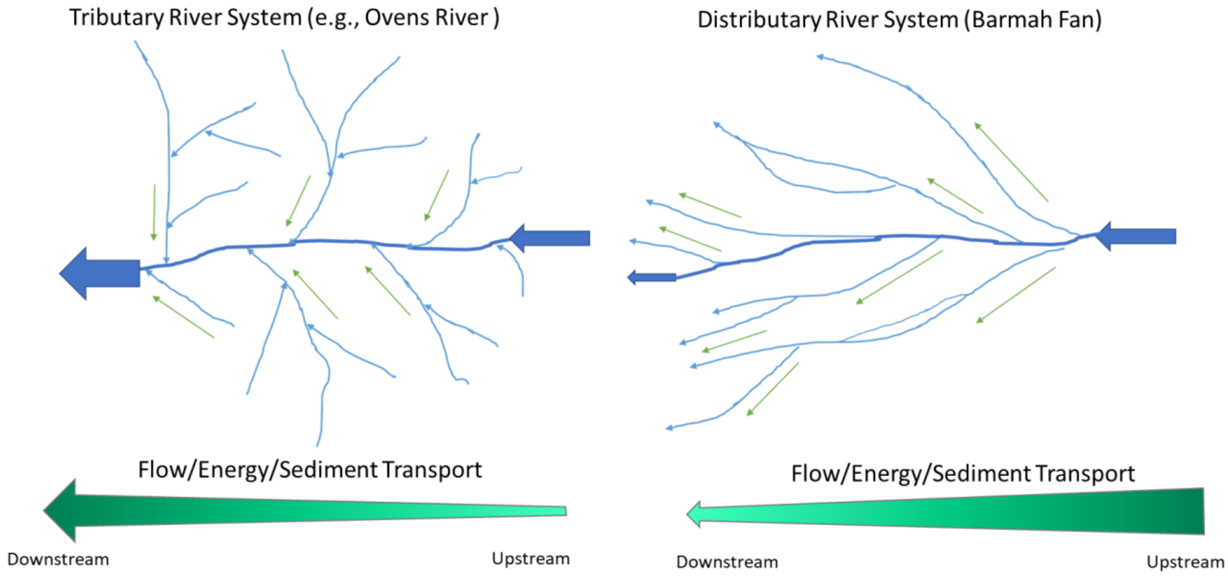


Figure 21 Differences between a Tributary and Distributary River System

4.2.2. Consequences for the Barmah-Millewa reach

The decrease in sediment transport rates and annual loads from upstream to downstream in the Barmah-Millewa reach is critical to the future flow capacity (conveyance) of the reach.

- As channel area, energy, and transport rates decline along the river's course, its ability to transport sand decreases.
- Declining transport rates downstream inevitably means that sand will aggrade the bed, and the Barmah-Millewa reach will lose flow capacity as a result. Progressively, more suspended sediment will be lost to offtakes and the floodplain. However, more sand (i.e., bedload) will remain in the main channel, aggrading the bed, displacing more water to the offtakes, triggering more deposition in a feedback loop. Eventually the feedback loop must end, with the river avulsing into a new course.

- During non-flood years estimated vertical aggradation can be as much as 5-6 cm/year in the widest upstream parts of the forest reach, compared to around 2 cm/year for the narrowest downstream sections.
- In a large flood year, the aggradation rates may be substantially higher, at 9 cm/year upstream and 4.5 cm/year in the downstream narrows.
- Bed aggradation over the last 30 years could be around 70 cm for the most downstream section of the Barmah-Millewa reach, compared to 1.9 m at the upstream end. Given that the sandy bedforms can be in the order of 1 m high and migrate slowly along the channel it may not be possible to clearly document aggradation of this magnitude in repeat cross-sectional survey data, as was evidenced in the channel cross-section analysis by Water Technology (2020). However, the analysis did show that nine of the fourteen cross-sections experienced a net loss of cross-sectional area from 1986 to 2017 (three locations could only be compared from 1986 to 2006). Interestingly, a condition assessment within the reach in 2012 (RPS Aquaterra, 2013) included a comparison of water depth measurements from 2002 to 2012 and indicated on average the river was one metre (approx.) shallower in depth.

4.3. **Effects of Excess Sand**

As discussed in the preceding section, the distributary fluvial system morphology of the River Murray through the Barmah-Millewa reach means that under undisturbed conditions the main river channel would gradually fill up with sand over time. However, the large influx of additional sediment into the Barmah-Millewa reach from sources such as gold mining and land disturbance (i.e., the sand slug) is rapidly increasing the rate of sand build-up in the river channel above the undisturbed rate.

The impacts associated with sedimentation in the channel and the excess sand present in the reach are briefly discussed below.

4.3.1. **Accelerated bank erosion**

Factors such as river regulation and vessel wash are known to contribute to bank erosion along the River Murray and their interaction can compound and amplify the level of erosion along riverbanks (MDBA, 2017). Such erosion is an issue along the Barmah-Millewa reach as noted by Grove (2021). However, in response to the increasing volume of sand within the bed of the river along this reach bank erosion is enhanced and hence channel widening could occur.

Streams with less resistant banks commonly widen in response to rapid bed aggradation which occurs because of excessive sediment inputs (i.e., sand slugs). Bartley (2001) summarises the large-scale impacts of sand slugs and found that in general channels aggrade and widen, have a change in bed material, pools infill and channel roughness decreases.

Changes that occur to the morphology of a river when there is an increase in sediment load were first described by Schumm (1969). The analysis found that an increase in sediment load (without an increase in discharge) will result in channel widening and increase in meander wavelength and channel slope and a decrease in depth and sinuosity. If there is an increase in sediment load, and a subsequent decrease in mean annual discharge, the channel depth and sinuosity will decrease, and the gradient and width to depth ratio will increase.

Jackson and Beschta (1984) outlined how increased sand delivery alters the morphologic response and roughness of channels. Based on flume studies, they found that channel widening, combined with decreased average channel depth (from sand build-up) meant that overall channel stability is reduced.

Sims and Rutherfurd (2017) documented the following examples of this process occurring:

- When mining sediments filled the Ringarooma River in Tasmania, the channel widened by between 15 and 65 % in upstream reaches (Bartley and Rutherfurd, 2005b), and by over 300 % in downstream reaches (Knighton, 1987).
- A slug of sediment into Creightons Creek in SE Australia led to a 25 % increase in channel width (Bartley and Rutherfurd, 2005a).

Grove (2021) details the work of Rutherfurd (1992) and Gippel and Lucas (2002) who found that the channel between Yarrawonga and Bullatale Creek has widened on average by 33 m between 1876 and 1981. From Bullatale Creek to Picnic Point the bankfull width increased by 3 to 15 m over the same period.

Discrete assessments of the riverbank condition through the Barmah-Millewa reach have been undertaken in 2011, 2013, 2016 and 2018 and have documented accelerated rates of bank erosion (Cardno, 2020). These assessments were qualitative based on a visual assessment of bank condition, focussing on the extent of erosion. In some surveys detail was captured on specific erosion locations, extents, and severity. The 2011 and 2013 datasets are the most comprehensive.

In the Barmah-Millewa reach the assessments have found (from Cardno, 2020):

- Erosion is especially evident on outside bends throughout the reach. On some straight planform sections, erosion is also visible along both banks of the river, indicating the manifestation of channel widening.
- Erosion of informal levees and natural silt levees is observed.

Overall, in the 2011-2013 assessments the riverbanks between Bullatale Creek and the Edward River (Kolety) confluence were described as predominantly in very good to fair condition 86 %, with 14 % in poor condition, and none in very poor condition. However, in the 2016-18 assessments the bank condition had changed to 40 % very good to fair, 47 % poor, and 13 % very poor.

The survey reach downstream commences at the Edward River (Kolety) offtake, passes through the remainder of the Barmah Choke and Barmah-Millewa Forest – including Picnic Point and Barmah Township, and concludes approximately 4.5 km downstream of the confluence of Deep Creek and the River Murray. The 2011-2013 surveys found similar results in this reach, with 13 %

of the banks rated poor condition and none very poor. The 2016 and 2018 survey results included 17 % of banks in poor condition and 7 % on very poor.

General observations from the survey results were that erosion along the Barmah-Millewa reach appeared to be increasing in extent and severity and that the erosion of informal and natural silt levees was leading to increased flooding of the adjacent forest.

While the erosion of the banks of the river through the Barmah-Millewa Forest is the result of a range of processes including river regulation, it is likely that the increasing sand within the bed of the river is accelerating the erosion processes. How the excess sand in the riverbed can accelerate bank erosion is summarised visually in Figure 22.

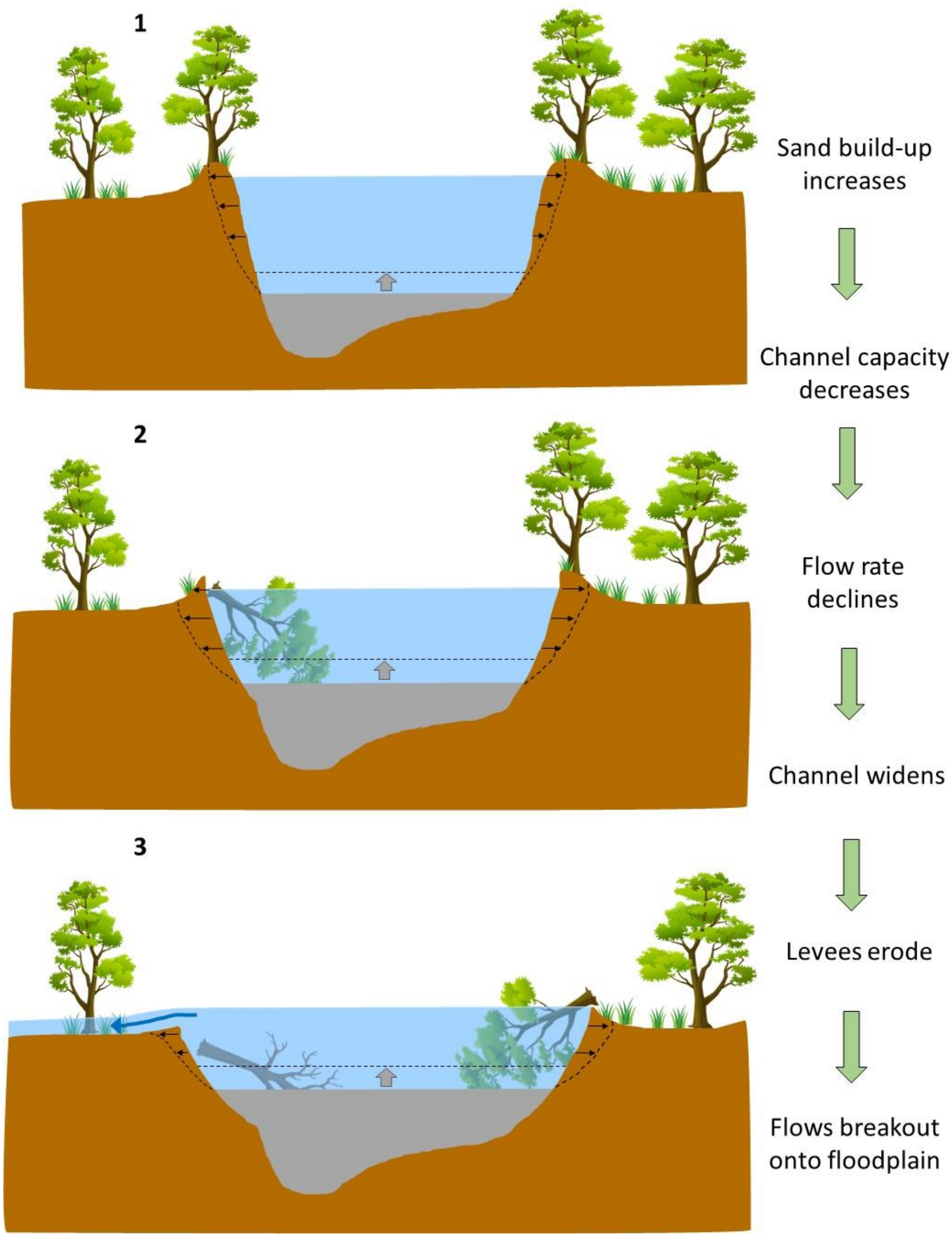


Figure 22 Schematic showing the processes of accelerated bank erosion as excess sand builds up in the bed of the river

4.3.2. Loss of river channel capacity

A major impact of sediment slugs is that they can reduce flow capacity of the channel. As shown in Figure 11, the proportion of sand in the channel compared to the total bankfull area varies from 14 % to nearly 35 % from Bullatale Creek to around 20 km downstream of the Edward River (Kolety) confluence. As sand takes up more of the cross-sectional area there is less area available to convey the flow and capacity reduces.

HARC (2021) in its review of river operations in this reach noted that the interaction between flows downstream of Yarrawonga and river levels at the Barmah Choke is complex, and it is difficult to make precise conclusions on changes in capacity of this reach over time. However, previous studies and their review of available flow and water level records suggested that:

- *In the mid-1990s, a step change occurred in the maximum regulated flow downstream of Yarrawonga, from approximately 11,000 – 11,700 ML/d to 10,500 – 10,700 ML/d. This was due to a decision by river operators to lower river levels in the Choke to reduce overbank flows in summer and the environmental damage caused by prolonged waterlogging of the Barmah-Millewa Forest.*
- *The hydraulic capacity of the Choke – as indicated by the river level at Picnic Point corresponding with regulated flow downstream of Yarrawonga – appears to have declined in the mid-2010s and trended further down in recent years.*

A reduction in capacity can increase overbank flood frequency and duration during unregulated conditions or change the flow distribution into distributary channels (also known as effluents, flood runners and breakaways) during regulated flow periods.

In the case of the Barmah-Millewa reach, the increased erosion of the informal and natural silt levels is leading to the formation of new or enlarged breakout channels, which increases flow losses into the forest and further reduces the River Murray channel capacity. Anecdotal information provided as part of the engagement process during this project suggests that there are already additional inflows to the forest, which are resulting in wetter conditions over longer periods and increasingly affect access to many parts of the forest.

4.3.3. Loss of diversity and habitat

A more varied, or more complex, riverbed suggests an environment less dominated by mobile bed sediment. Sand is preferentially deposited in pools and shallow depressions on the streambed. As sand supply increases and pools and depressions are infilled, bed relief decreases, and the channel bed is smoothed. This has been noted in the Barmah-Millewa reach where large pools on meander bends have been infilled with sediment (Section 2.2.2). Sims and Rutherfurd (2017) found that excess sediment in a river will fill pools and smother bed features such as large wood and channel vegetation. Some of the impacts of this change on habitat and biodiversity are discussed below.

Hogg and Norris (1991) investigated the impact of sediment loads from land clearing and urban development on the macroinvertebrate pool fauna of the Murrumbidgee River. They found that sediment deposition on the bed was the major cause of reduced macroinvertebrate abundance.

Lintermans (2004) noted that in the upper Murrumbidgee River “sand has filled in the majority of holes with the consequent loss of former pool/riffle sequence. Sediment addition is a major threatening process for fish, particularly species which lay demersal eggs on substrate.”

Gippel et al (2007) provide a useful summary of the relationships between geomorphic conditions and biodiversity. Key learnings included:

- Good geomorphic condition is associated with increased biological assemblages.
- Physical diversity and heterogeneity in streams correlates well with biological diversity, while streams impacted by sand slugs were less diverse than unimpacted reaches (Bartley and Rutherfurd, 2005).
- Reduced surface roughness and heterogeneity can in turn reduce species diversity, population abundance and recruitment. Primary producers such as periphyton and aquatic macrophytes are affected which is then reflected in the reduction in invertebrate and fish communities (Waters, 1995; Wood and Armitage, 1997).
- Covering the surface of coarse substrate by fine sediment deposition can lead to increased mortality of fish eggs, larvae and juveniles in gravel spawning species (Cordone and Kelley, 1961).
- Loss of pool habitat through sedimentation is also likely to have a detrimental effect on fish fauna because pools provide rearing habitat for many fish species (Waters, 1995).
- There are known strong links between the distribution and loading of large woody debris in streams and aspects of stream health (Gippel, 1995).

In a more recent discussion, Wohl (2015) also notes that:

- Enhanced sedimentation can result in lower channel and floodplain habitat diversity and stability, along with lower abundance and diversity of stream organisms.
- Excess sediment can alter water temperature, water chemistry, turbidity, and nutrient supply.
- A channel can have lower retention and resilience if sediment accumulation limits features such as riparian vegetation, hyporheic exchange, and physically complex channel boundaries.
- Excess sediment can also create effects that extend from the channel into the riparian zone and from the riparian zone into the terrestrial zone because of disruption of ecosystem subsidies such as emergent insects.

There has been a long-term fish monitoring program (2007-2021) in the Barmah-Millewa Forest Icon site (Raymond et al, 2021) which provides detailed monitoring to assess the health and status of fish communities in both permanently flowing (riverine) and semi-permanent (creeks, lakes, and wetlands) habitats. As well as fish, data has also been captured on Murray Spiny Crayfish, a rare native species. The monitoring period has encompassed extreme climatic events including periods of drought (2007 to 2010), varying flood levels and hypoxic blackwater events (2011 and 2016) and provides an important baseline dataset for assessing future changes to fish communities because of the sand build-up. It will also be important to monitor the impact of any reduction in flows through the Barmah-Millewa reach beyond the reach itself, i.e., what does a reduction in flow in the River Murray mean for fish populations upstream and downstream of the forest (Dr Zeb Tonkin, Arthur Rylah Institute, *pers comm.*).

The only habitat focussed monitoring within the Barmah-Millewa reach to date was part of condition monitoring between Yarrawonga and Torrumbarry Weir conducted in 2002 and then again in 2012 for the NSW Office of Water on behalf of the MDBA (RPS Aquaterra, 2013). Habitat data collected included snag density, canopy depth, depth of flow midstream and presence of macrophytes. Vegetation and bank condition was also surveyed. In the reach from Bullatale Creek to the Edward River (Kolety) in-stream snag density, water depth and macrophytes were low in the 2012 survey while the depth of tree canopy was good. In the reach downstream new snags were observed and many trees had recently fallen in the upper section of the reach. A comparison of the 2012 and 2002 assessments is shown in Table 4. Further monitoring is required to define the current conditions in the reach.

Table 4 Habitat condition assessment comparison between 2002 and 2012 monitoring (RPS Aquaterra, 2013)

Criteria	Bullatale Creek to Edward River (Kolety) Confluence	Edward River (Kolety) to Barmah Sand Dunes
Snag Density	Less	Same
Canopy (R)	More	More
Canopy (L)	More	More
Depth	Less	Less
Macrophytes (R)	Same	Same
Macrophytes (L)	More	Same

Note:
Same – no change
More – an improvement in condition
Less – a decrease in condition

4.3.4. **Changing the river's path**

An avulsion is the term used to describe when a river changes its course and forms a new main channel on a floodplain. It is a fundamental process on distributary alluvial fan systems like the Barmah-Millewa reach. An avulsion occurs where the bed of the river tends to naturally fill up, until it is higher than some of the effluent channels. At this point a connection between the main channel and the effluent forms and most of the flow is captured by the effluent. The process is described in Figure 23 below, where the River Murray is the 'parent' channel, and an effluent is the 'daughter' channel. Rutherfurd and Kenyon (2005) describe the Barmah-Millewa Forest as being formed by multiple successive avulsions of the Murray and Goulburn Rivers across the Riverine Plains.

The presence of the sand slug accelerates the rate of filling of the main channel in the Barmah-Millewa reach and is therefore increasing the timeframe under which an avulsion is likely to occur.

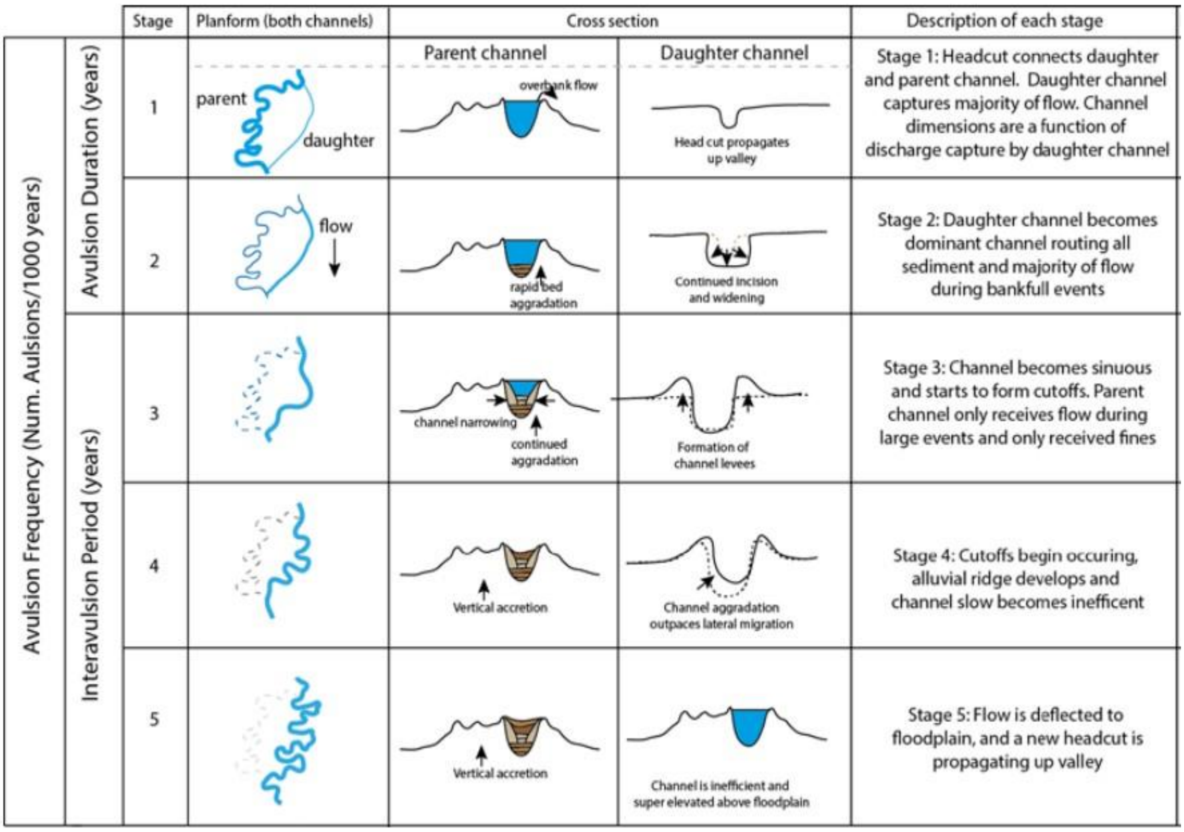


Figure 23 An adaptation of the five-stage model by Schumm et al. (1996) of avulsion development by Stout (2017).

4.4. **Past Conditions, Changes & Contributing Factors**

Grove (2021) provides a detailed summary of the past conditions and factors that may have led to the excess bed sediment along the Barmah-Millewa reach of the River Murray. He notes that there is not a single explanation, but it is highly likely to be a combination of factors. The following series of diagrams (Figure 24, Figure 25 and Figure 26) from Grove (2021) summarise the conditions and contributing factors from pre-European time to present.

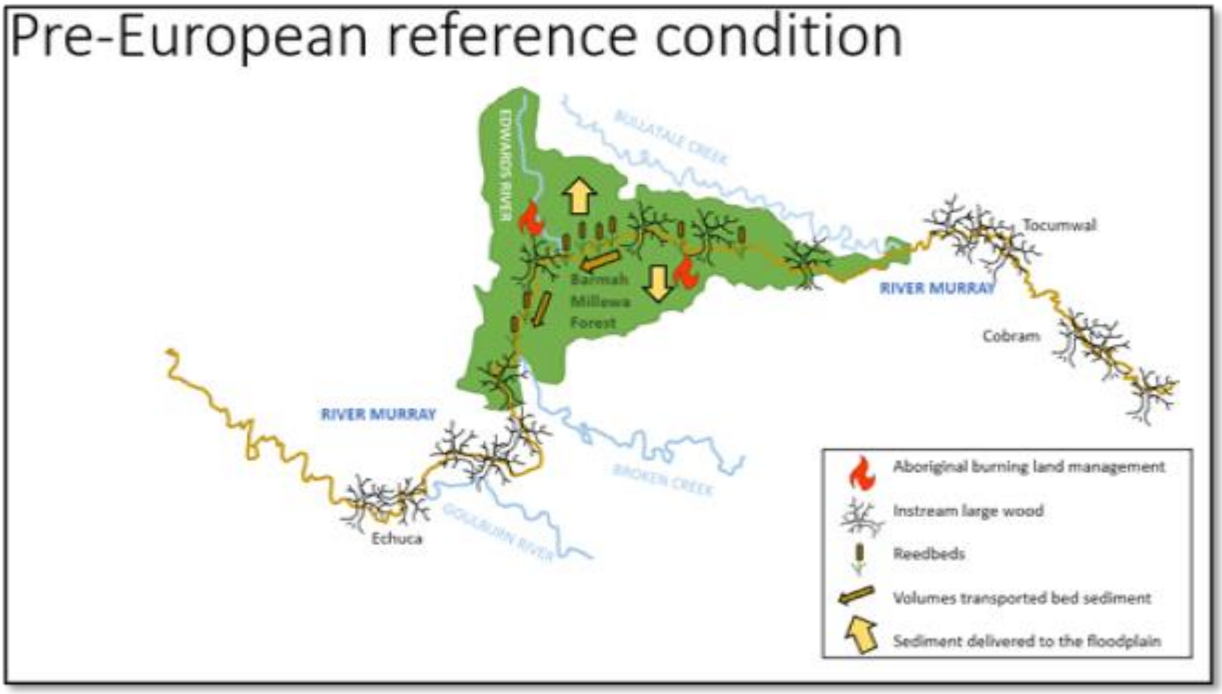


Figure 24. The pre-European reference condition of the River Murray and Barmah-Millewa Forest. The River Murray is brown to signify that it conveyed sediment, and the width of the line and arrows indicate relative volumes of sediment, the lighter colour being mainly suspended sediment. Snags were present in the channel, rushes were more extensive, sediment volumes into the reach were low and proportionally higher in suspended sediment with high losses onto the floodplain, land management was Aboriginal burning.

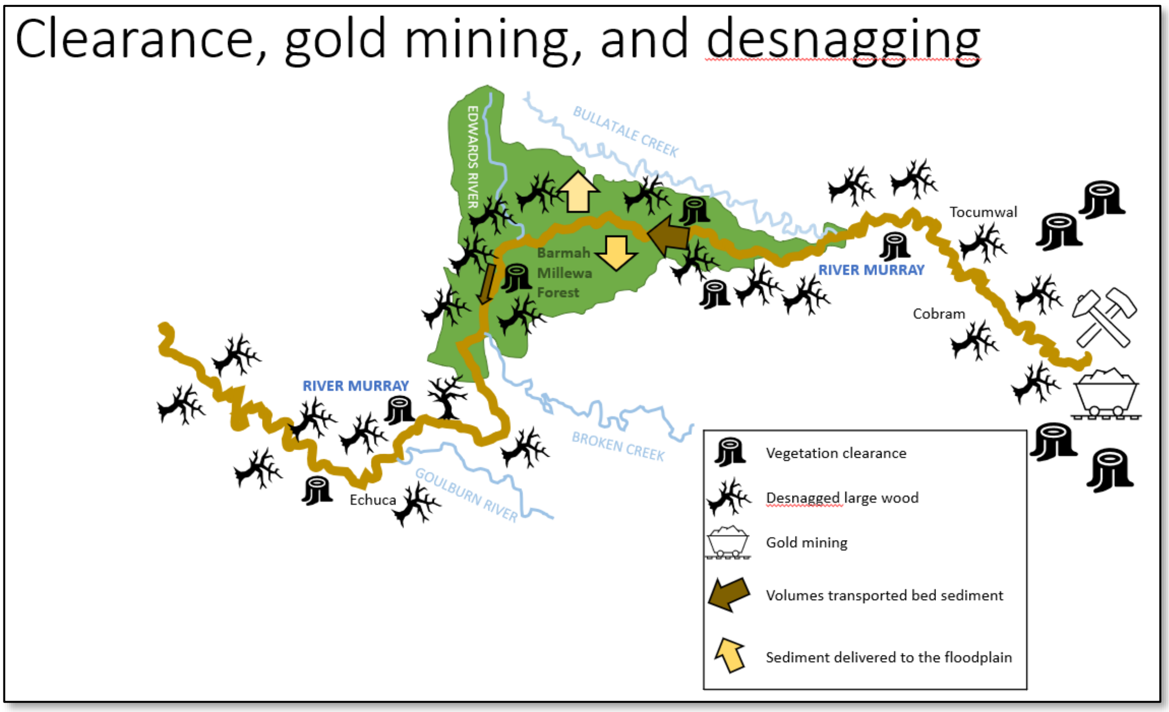


Figure 25. The pre-regulation (1850-1930) condition of the River Murray and Barmah-Millewa Forest. The River Murray is brown to signify that it conveyed sediment, and the width of the line and arrows indicate higher volumes of sediment compared to reference. Catchment sediment increases were a result of land clearance and gold mining. Desnagging was extensive as was clearance of riparian large trees. Bed sediment is coarser (darker) and accumulating in the reach as the conveyance through the Choke is low. Some sand was delivered to the floodplain and effluents.

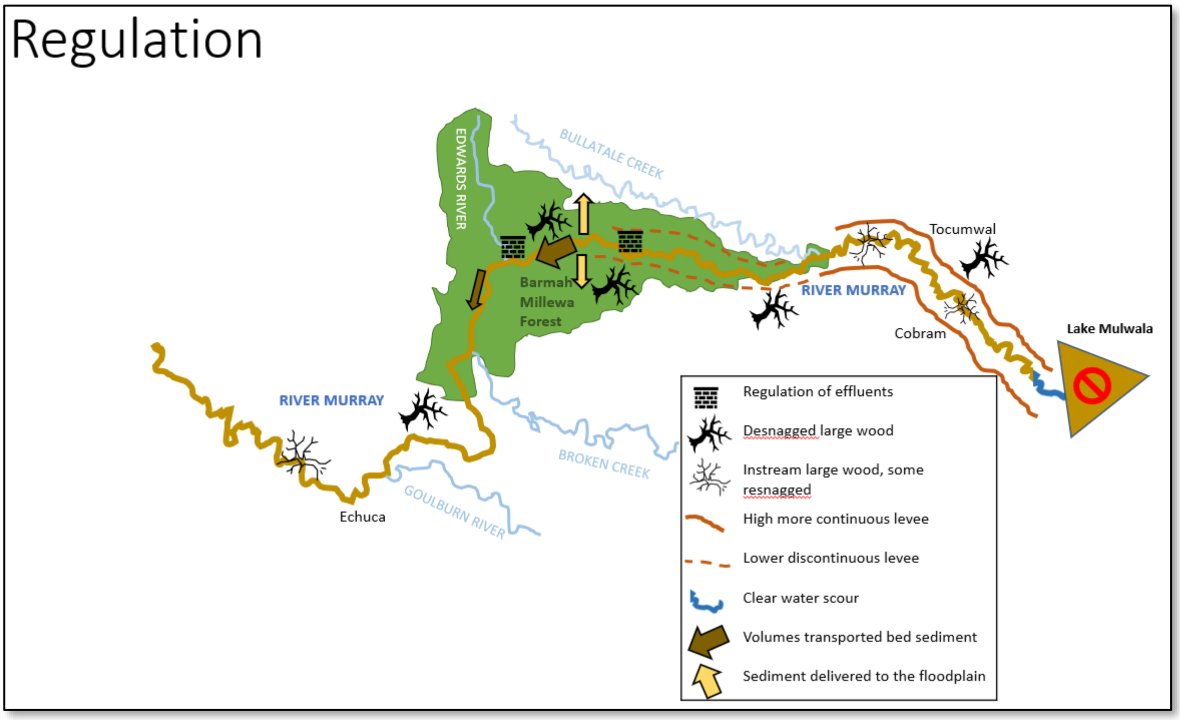
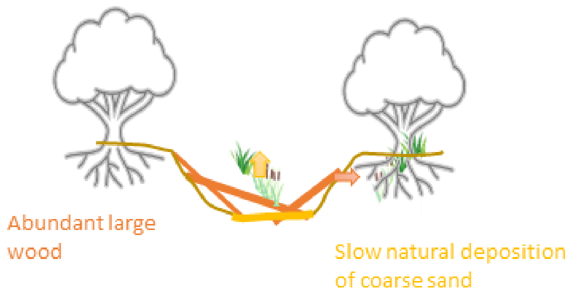


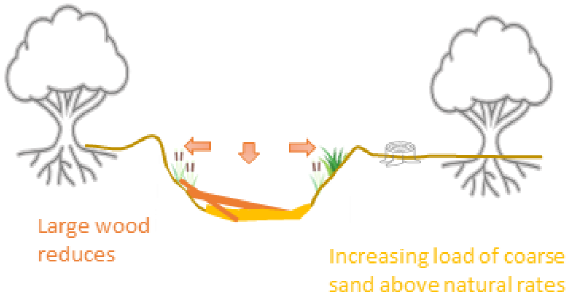
Figure 26. The regulated (post-1930) condition of the River Murray and Barmah Millewa Forest. The River Murray is brown to signify that it conveyed sediment, and the width of the line and arrows indicate higher volumes of sediment compared to reference but lower than pre-regulation. Upstream bed sediment supply was stopped by Lake Mulwala, and some clearwater scour has occurred shown in blue. Levees are shown in orange and are less significant in the Forest shown by the dashed line. Effluents are regulated shown by the walls. Desnagging has occurred as well as snagging. The arrows suggest the bed sediment has accumulated further downstream because of upstream supply exceeding downstream transport capacity.

Figure 27 and Figure 28 attempt to also show the past conditions and factors contributing to change on a cross-sectional scale. For each period considered, a short summary of the conditions and changes occurring is provided.



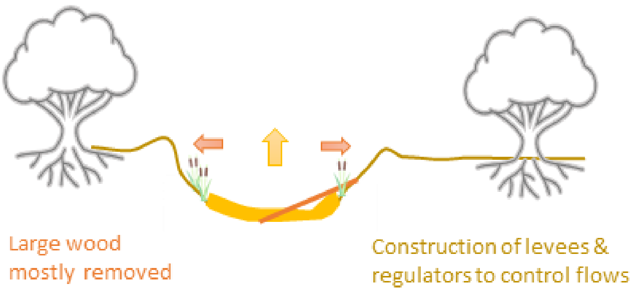
- Limited coarse sandy bed load
- Predominantly clay bed and banks
- Slow natural deposition of coarse sand on riverbed
- Minor channel migration (erosion)
- Clear water during low flows
- Connected effluent (distributary) channels deliver flows into the forest
- Deep pools, complex habitat and biological diversity

Pre-European (before 1840)



- High suspended (fine) sediment load due to land disturbance (land clearance, gold mining) during low flows
- High coarse sediment loads from upstream southern tributaries
- Increased load of coarse sand entering the River Murray
- De-snagging of the river begins, including cutting down riparian trees to reduce potential wood load & for paddle steamer fuel
- Slight widening and deepening due to desnagging and first flood levees

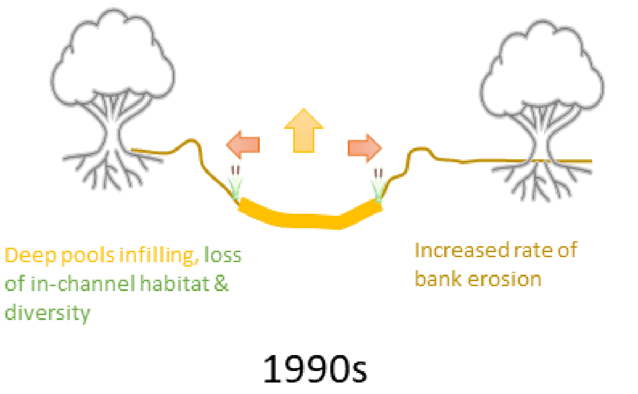
Gold and Gully Period (1850 – 1938)



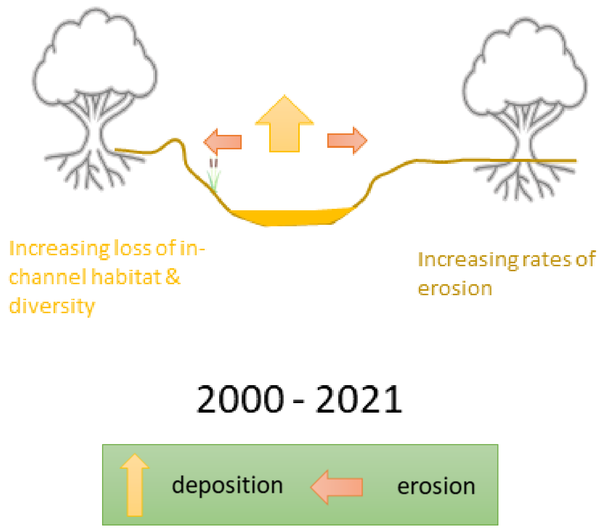
- Higher suspended (fine) sediment loads from the catchment replaced by loads from bank erosion
- Further catchment derived coarse sediment supply limited by catchment dams, but particularly by construction of Yarrawonga Weir in 1938
- Coarse sands already in the river upstream now moving downstream
- Some infilling of deep pools by the coarse sand commences
- De-snagging continues
- Limited bank erosion in this reach, but increased bank erosion upstream, particularly below Yarrawonga Weir.
- Regulators installed on offtake (distributary) channels & levees to reduce outflows
- Increase in unseasonal, regulated bankfull irrigation flows (1970s)

Regulation Period (1930 – 1990)

Figure 27 Timeline of channel change in the River Murray through the Barmah-Millewa reach from pre-European to 1990 (specifically Bullatale Creek to Picnic Point). The arrow size reflects the relative scale of the erosion or deposition.



- De-snagging ceases
- Caps on diversions (1996)
- Peak flows reduced from 11,700 ML/d to 10,500 ML/d to limit overbank flows & waterlogging
- Coarse sediment supply from upstream reach is increasing and likely reducing the channel capacity through deposition.
- Increased rates of bank erosion through regulated flow regime (e.g., notching), boat wakes etc
- Deep pools filling in and in-channel habitat & biological diversity reducing (e.g., aquatic macrophytes, macroinvertebrates and fish communities impacted)



- Continued loss of channel capacity, with peak regulated flows around 9,200 ML/d by 2020.
- Noticeable increase in coarse sand into and within the reach reducing sediment transport capacity
- Continued bank erosion due to existing processes and probably enhanced by increasing sand deposition
- Erosion of levees and potential for increased unseasonal flooding
- Deep pools filled in by coarse sand
- Rates of sedimentation along the reach increase well above natural rates
- Continued loss of habitat and aquatic diversity

Figure 28 Timeline of channel change in the River Murray through the Barmah-Millewa reach from 1990 to present (specifically Bullatale Creek to Picnic Point). The arrow size reflects the relative scale of the erosion or deposition

4.5. **Future Trajectory Scenarios**

Given the changes observed over time along the Barmah-Millewa reach, and the presence of a large volume of excess sand in the bed of the river, what can we expect to see over the next 10 to 30 years?

The work by Grove (2021) estimated that there is a very large sediment store of coarse sand in the reach of the River Murray between Yarrawonga and Picnic Point. The total volume of sediment has been estimated to be in excess of 20 million m^3. He concluded that over the next 10 years and beyond:

- The sediment will continue to move downstream, and in the absence of major floods it is unlikely that any significant quantity will be lifted out of the channel and onto the floodplain or point bars for storage.
- Sediment stores have started to decline in the upstream sections of the reach, as the sediment moves downstream, and Yarrawonga Weir has cut-off sediment supply from further upstream.
- The sediment store in the upstream section of the reach will continue to decline, but this will happen very slowly.
- Over the next ten years the riverbed is likely to lower over 10s of kilometres in the upper sections of the reach, but it is not expected to lower through to Bullatale Creek for many decades.
- If sediment transport into the Barmah-Millewa reach continues to exceed the capacity to transport sediment out, then there is likely to be a build-up of sediment near to Picnic Point.
- Without management of the sediment, there will be continued fluctuations in bed levels, with more extended periods of reduced capacity to deliver water through the Barmah-Millewa reach, for several decades.
- In the worst-case scenario, aggradation could cause sediments to build-up in the channel through the Barmah-Millewa Forest to a point where an avulsion creates a new channel on the floodplain to bypass some or all the reach.

As discussed in Section 4.2.3, the excess sand in river channels tends to encourage widening of the channel by increasing the shear stress on the banks, as well as causing the loss of in-channel habitat and biodiversity. The combination of widening (bank erosion) and reduced channel capacity has the effect of increasing flows into effluents (also known as breakaways) and therefore increasing the movement of water from the main River Murray channel to the floodplains and wetlands. This occurs, first, by reducing conveyance in the channel, pushing more flow into effluents; and second, by eroding natural and artificial levees, which drops the sill height for water to flow into those effluents. Pushing more water onto the floodplain has secondary effects, including the potential to exacerbate unseasonal flooding of the Barmah-Millewa Forest which has many consequences for the management of the forest. There is also the potential for increased deposition of finer sediments on the floodplain and in the Lakes. The loss of water to the forest also further reduces delivery of water through the River Murray system.

The following two future trajectory scenarios for the Barmah-Millewa reach have been developed to explore what the river conditions might be over the next 10 to 50 years assuming two different river operational conditions; a water level based scenario, and a flow capacity based scenario. The purpose of these scenarios is to assist in understanding any potential impacts to the values of the Barmah-Millewa reach if no specific sand management activities are undertaken.

4.5.1. **Level based**

A future scenario based around maintaining the existing River Murray operational threshold water level at the Picnic Point gauge of 2.6 m assumes:

a. As the river is being operated to a target water level threshold at Picnic Point, the water level gradient of the river upstream of Picnic Point at peak operational flow will be maintained at current levels, and therefore any reduction in flow capacity reflects the increased build-up of sand in the riverbed or losses to the forest from breakouts.

b. Any reduction in flow capacity can be matched by reduced flow releases from Yarrawonga, otherwise the operational threshold at Picnic Point will be exceeded. Timing and duration of flows may also be amended.

c. Where the rate of bank erosion is enhanced by the build-up of sand in the riverbed or other factors there is the potential for new breakaways to form where the erosion connects the river to a floodplain breakaway feature. There is also the risk of erosion lowering the crest of levees which would direct flows away from the main channel.

d. The silty eroded material is readily transported along breakaways and over eroded banks to be deposited in the wetlands and floodplains of the Barmah-Millewa Forest.

A breakaway developing from the main river channel is shown in Figure 29.

Figure 29 Example of a site in the Barmah-Millewa reach where flows into the adjacent forest along an effluent channel are increasing under regulated conditions. Image was captured by Professor Ian Rutherfurd in 2021.

For the Yarrawonga to Torrumbarry Interim River Works Program (2022-2027), analysis has been undertaken to identify locations like the site in Figure 29, where there is a developing connection between the river channel and the floodplain, or locations where such a connection could occur with further bank erosion (Streamology, 2021). An example of a location where erosion is likely to form a new connection is shown in Figure 30.

Figure 30 Example of a section of levee that has eroded, making breakaway flows onto the adjacent low floodplain possible during high water levels. The same location captured in photo (A) is depicted in an oblique DEM view (B) (Streamology, 2021)

To manage the increasing erosion of the riverbanks and enhanced unseasonal loss of water through activation of new or enlarged existing effluents, a program of bank protection works will be required. Examples of existing bank protection works along this reach are provided in Figure 31 and Figure 32.

Figure 31 Example of existing bank protection works at a small regulating structure on the Barmah-Millewa reach upstream of the Edward River confluence. Image was captured by Professor Ian Rutherfurd in 2021.

Figure 32 Example of existing bank protection works (sheet piling) on the Barmah-Millewa reach upstream of the Edward River confluence. Image was captured by Professor Ian Rutherfurd in 2021.

4.5.2. **Flow based**

A future scenario based around maintaining the current flow capacity 9,200 ML/d at Yarrawonga Weir assumes that:

a. As the river is being operated to a target flow capacity of 9,200 ML/d, the water level gradient along the entire reach at peak operational flow will increase above current levels, which will reflect the increased build-up of sand in the riverbed.

b. Any increase in water levels will result in more unseasonal inundation of the Barmah-Millewa reach as levees are overtopped and breakaway flows increase. Timing and duration of flows into the forest may also change.

c. There will be increasing loss of flow into the forest which may not re-enter the river downstream and therefore reduces the flow capacity.

d. Like the level-based trajectory, where the rate of bank erosion is enhanced by the build-up of sand in the riverbed or other factors there is the potential for new breakaways to form where the erosion connects the river to a floodplain breakaway feature. There is also the risk of erosion lowering the crest of levees which would direct flows away from the main channel.

To manage the increasing water levels, the resultant increased flow into effluent channels, erosion of the banks, and increased unseasonal loss of water through activation of new or enlarged existing effluents and general overbank flows, a program of levee building and bank protection works will be required. Any levees will need to be designed and constructed in accordance with the relevant State requirements, e.g., Levee Management Guidelines (2015).

An effluent channel that could become more actively engaged under higher regulated flow condition is shown in Figure 33 and Figure 34.

Figure 33 Example of an effluent channel which could become more regularly connected to the river if regulated water levels are increased. Image was captured by Professor Ian Rutherfurd in 2021.

Figure 34 Another example of an effluent channel which could become more regularly connected to the river if regulated water levels are increased. Image was captured by Professor Ian Rutherfurd in 2021.

section five

5. Do Something to Manage the Sand

5.1. Approach

5.1.1. Overview

The purpose of this section is to present a high-level multi-criteria analysis (MCA) of options to manage the excess sand in the Barmah-Millewa reach. The approach is summarised in Figure 35.

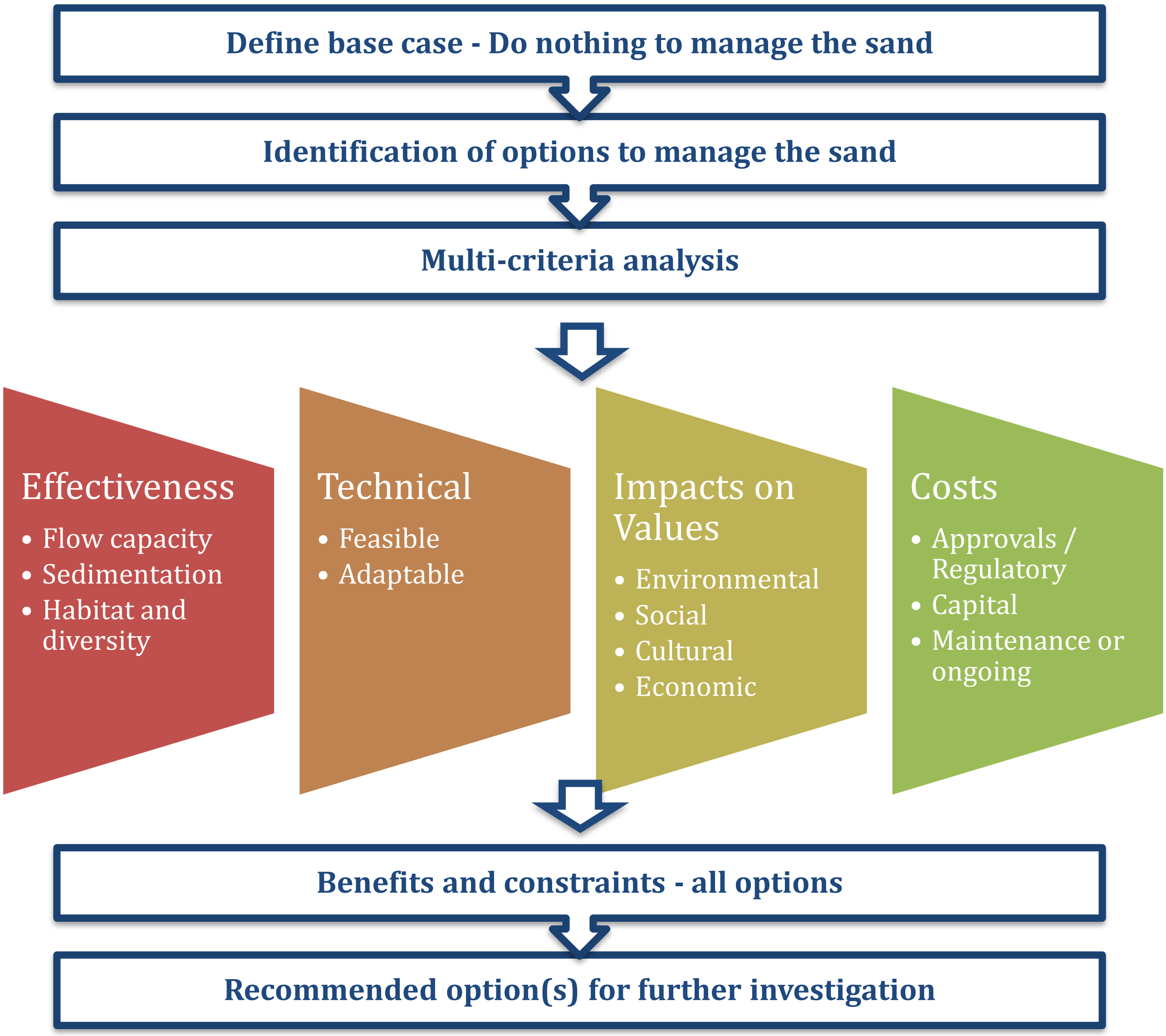


Figure 35 Overview of options assessment approach

The base case against which all the options are compared – the 'do nothing to manage the sand', was described in detail in Section 4 and is also included in the assessment detailed in this section. Throughout the project the feedback from stakeholders reiterated this as the starting point for any comparison. From the base case, several options to management the sand have been identified and these are each detailed further in Section 5.2.

In line with the project scope, the focus of the MCA is on options that could:

- Stop further loss of channel capacity
- Possibly reinstate channel capacity

However, given the enhanced understanding of the issue developed through the project and concerns raised by First Nations people and stakeholders it has become clear that concerns regarding capacity through the reach cannot be separated from other aspects such as bank erosion, ecological degradation, and the loss of values especially cultural values. To accommodate these aspects, the options are evaluated based on their effectiveness at addressing the main issues of concern, the feasibility of implementing the option (where relevant), the impact on values, and finally cost. Descriptions of these criteria are provided in Section 5.1.2. The benefits and constraints of each option can then be readily identified based on how they meet these different criteria.

The analysis outcomes assist in understanding what potential options are available and in developing a short-list of options that warrant further investigation.

5.1.2. **Evaluation criteria**

A simple traffic light approach to the criteria has been applied using the criteria in Table 5. If an evaluation criterion is not relevant the option is left uncoloured.

Feedback received during the consultation sessions in October highlighted that the environmental impacts could be further divided in specific impacts on the channel, banks, and the floodplain and that some impacts are short term only while others are more long term. Comments on these aspects have therefore been included in the final analysis and discussion is provided within the given option.

Table 5 MCA evaluation criteria

Criteria				
Effectiveness	Flow capacity	Increases current flow capacity	No change to current flow capacity	Reduction in current flow capacity
	Sedimentation	Reduces sedimentation within the reach	No reduction in sedimentation rate	Increasing sedimentation
	Habitat & Biodiversity	Improves habitat & biodiversity	No change to habitat and biodiversity	Reduces habitat and biodviersity
Technical	Technically Feasible	Feasible using accepted techniques	Feasible but with contraints	Not feasible using accepted techniques
	Flexibility (reversible/adaptable)	Can be easily adapted	Is reversible or adaptable but at considerable cost/effort	May be irreversible once implemented, but limits alternative options
Impacts on Values	Environmental	May positively impact the environment	No net change	May negatively impact the environment
	Social	Acceptable to community & stakeholders	Likely to be acceptable to some (but not all)	Unlikely to be acceptable the community & stakeholders
	Cultural	Acceptable to the Traditional Owners	Likely to be acceptable to some (but not all)	Unlikely to be acceptable to Traditional Owners
	Economic	Aceptable to the communities and/or businesses	Likely to be acceptable to some (but not all)	Unlikely to be acceptable to communities and/or businesses
Costs	Regulatory Requirements	Low level or no approvals required	Some appprovals required, moderate planning requirements	Significant regulatory requirements. Further investigations required
	Capital Investment	Low cost (< $5M)	Moderate cost ($5M - $50M)	High cost (>$50M)
	Ongoing & Maintenance Costs	Usually not required (< 5k pa)	Usually not but likely under medium to long term (<100k pa)	On-going, required to maintain function

5.2. **What are the Options?**

The options to manage the sand were based on four broad sand management categories (after Sims and Rutherfurd, 2017) plus two additional categories focussed on modifying how or if water passes through the Barmah-Millewa reach:

- Flushing the sand through
- Storing the sand
- Controlling the input of sand
- Physically removing the sand
- Moving the water around
- Reducing downstream demands

All seven options, including the base case, are described in Table 6. Options have been assessed individually against the MCA criteria; however, a suite of options may be required to best address sand management within the reach.

Table 6 Overview of options assessed

Category	Description
Do nothing to manage the sand	Base case - current trajectory (Section 4)
Flush the sediment through the system	Options that encourage the increased transport of sediment through the system. This could comprise: - Implementing changes to the flow regime to enhance sediment transport through the reach. - Increasing overbank flows to move coarse sediment onto the floodplain for storage.
Storing the sediment	Trapping the excess sediment in the channel, which protects downstream reaches from high sediment loads. Includes: - Use of in-channel structures to stabilise and trap sediment in the reach and limit further transport downstream. - Use of in-channel structures to stabilise and trap sediments upstream of the reach and limit further transport into the forest section.
Controlling sediment inputs	Options that reduce or eliminate sediment supply at the source. Most of the coarse sand in the reach is derived from historic sources. The only contemporary source of sand is from bank or bar erosion. Therefore, the only option to control sources of sand is bank protection works to mitigate bank erosion.
Physically removing the sand	Options that physically remove some or all the sediment from the bed of the channel. This option has been generalised for this assessment as the where, how, and how often require further investigation.
Moving the water around	Options to use the existing irrigation networks or channels to transfer water around the reach to reduce the loss of flow into the forest and unseasonal flooding or to supply peak demands. This will be assessed in detail through the Barmah Optimisation Feasibility Study that is being managed by the MDBA on behalf of the governments of SA, Vic, NSW, and Commonwealth.
Reduce downstream flow demand	Options that reduce the long-term flow demand downstream of the reach. This could be through new policies or modifications to existing policies and operational rules or a downstream reduction in water entitlements that enable the River Murray system to be managed within the on-going reduction in capacity of the Barmah-Millewa reach without on-ground works.

For this high-level assessment, there has been some preliminary assessment of where, how, or how often an option may be required however, these aspects will require a more detailed analysis in the next stage of the project. There is also opportunity for complementary measures such as habitat restoration or enhancement as part of any option or suite of options however these have not been investigated in detail for this project.

5.3. **Options Analysis**

The following section summarises each option and presents the outcomes of the MCA. Each option has been assessed against the evaluation criteria in Table 5 using available data, information, and analysis; the results of the values assessment (Section 3); the knowledge gained through the developing the base case; and additional option specific desktop assessments.

As the project has developed it has become clear that:

- The base case (do nothing to manage the sand) will have considerable negative outcomes to environmental, social, cultural, and economic values throughout the reach. Flow capacity will continue to decline as sedimentation increases, resulting in on-going loss of habitat including enhanced bank erosion and unseasonal flooding of the forest within the Barmah-Millewa reach.
- There is no single option that is effective in addressing the reduction in flow capacity, increasing sedimentation, and loss of habitat and diversity in the Barmah-Millewa reach. A combination of options is likely going to be necessary, including both short-term and long-term actions.

5.3.1. Do nothing to manage the sand (base case)

The evaluation results for the base case, i.e., do nothing to manage the sand, are presented below. These ratings are based on the detailed analysis described in Section 4.

Evaluation Criteria		Do nothing to manage the sand
Effectiveness	Flow capacity	
	Sedimentation	
	Habitat & Diversity	
Technical	Technically Feasible	
	Flexibility	
Impacts on Values	Environmental	
	Social	
	Cultural	
	Economic	
Costs	Regulatory requirements	
	Capital Investment	
	Ongoing & Maintenance costs	

As evidenced by other sand affected river systems, if nothing is done to manage the excess sand in the Barmah-Millewa reach, there will be an ongoing and accelerating loss of capacity due to sand build-up in the channel. The sand will continue to fill in deep pools and smother habitat such as woody debris changing the entire riverine environment. This has significant impacts for a broad range of native fish and other aquatic species. Accelerated bank erosion will continue with the loss of informal and natural levees, leading to increased unseasonal flooding of the forest and floodplain.

Impacts on values

Environmental - increased unseasonal flooding and smothering of floodplain vegetation by finer sediment eroded from the banks and levees will see a loss of flora and fauna species, negatively impacting significant existing environmental values.

Social – increased flooding limits access for recreation throughout the forest, and potentially negatively impacts camp sites and tracks. Loss of fish habitat reduces recreational fishing opportunities, while changes to flora and fauna may negatively impact bird watching and bush walking.

Cultural - bank erosion exposes and damages cultural sites such as middens. There will also be a loss of trees, and changes to flora and fauna species which could negatively impact on many cultural practices.

Economic - the loss of capacity and ability to delivery downstream flow requirements has negative economic impacts.

There may be a range of negative regulatory impacts associated with the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act), the Water Act 2007 and NSW or Victorian land and water planning legislation as well as International Agreements such as the Ramsar convention.

5.3.2. Flushing the sediment through

Flushing excess sediment through a river reach aims to enhance the sediment transport processes to move the sediment through faster than under natural conditions. In regulated rivers this could be achieved by increasing flow rates or targeted flow releases or in unregulated systems by concentrating flows (for example, confining the flows to a narrow cross-section to increase the velocity and hence sediment transport) (Sims and Rutherfurd, 2017).

The Barmah-Millewa reach has a natural surplus of sediment, meaning more comes in that can be moved out. Over time the riverbed would fill with sediment naturally, however, there was not a large volume of sand supply in the river under natural conditions so the rate of change would have been very low. Streamology (2020) showed that even in flood years this deficit occurs, and in fact flood years result in higher rates of sediment build-up as more sand can be efficiently delivered to the reach, but the rate of transport out does not increase.

There is also a significant volume of sand both in the Barmah-Millewa reach (~8 million m^3) and the upstream reach as far as Yarrawonga (~12 million m^3). This means there is a continuing excess supply of sediment into the reach. Initial calculations suggest that even if all supply of sediment into the reach could be stopped at Bullatale Creek, it could take > 100 years to flush the existing excess sediment through the reach. During this time the capacity of the reach would continue to reduce as the sand continued to build up in the narrowest sections, downstream.

Flushing the sediment through is not technically feasible and therefore cannot be effective in addressing the main issues of flow capacity, sedimentation, and loss of habitat and diversity.

Evaluation Criteria		Flushing through Sediment
Effectiveness	Flow capacity	
	Sedimentation	
	Habitat & Diversity	
Technical	Technically Feasible	
	Flexibility	
Impacts on Values	Environmental	
	Social	
	Cultural	
	Economic	
Costs	Regulatory requirements	
	Capital Investment	
	Ongoing & Maintenance costs	

5.3.3. Storing the sediment

In rivers affected by excess sediment, in-stream structures such as check dams or revegetation of bars or benches can be used to trap and store the material. This protects downstream reaches from the effects of the excess sediment. An example of this approach is the Genoa River in East Gippsland, where revegetation was used to stabilise stream banks and trap large ‘sand slugs’ washed into the river following floods (Sims and Rutherfurd, 2017).

This approach will not work in the Barmah-Millewa reach. The volumes of sand are large and there is excess material from Yarrawonga to as far downstream as Barmah township. Trapping sand in specific locations will therefore exacerbate the current flow, sediment, and habitat issues. Any revegetation of bars on channel bends will have the same effect. It is also not possible to revegetate instream bars as the flow regime with high summer flows does not allow in-stream vegetation to establish.

Storing the sediment is not technically feasible and therefore cannot be effective in addressing the main issues of flow capacity, sedimentation, and loss of habitat and diversity.

Evaluation Criteria		Storing Sediment in the Channel
Effectiveness	Flow capacity	
	Sedimentation	
	Habitat & Diversity	
Technical	Technically Feasible	
	Flexibility	
Impacts on Values	Environmental	
	Social	
	Cultural	
	Economic	
Costs	Regulatory requirements	
	Capital Investment	
	Ongoing & Maintenance costs	

5.3.4. Controlling sediment inputs

Reducing or stopping the supply of excess sediment to a river can accelerate recovery by allowing the material already in the river to migrate downstream. The idea is to reduce the size of the pulse of sediment (the sand slug).

Evaluation Criteria		Source Control
Effectiveness	Flow capacity	
	Sedimentation	
	Habitat & Diversity	
Technical	Technically Feasible	
	Flexibility	
Impacts on Values	Environmental	
	Social	
	Cultural	
	Economic	
Costs	Regulatory requirements	
	Capital Investment	
	Ongoing & Maintenance costs	

The dominant sources of the coarse sand in the Barmah-Millewa reach are from historic gold mining and land use change. The only current sources of material are from bank and bar erosion, but the additional volumes are low in comparison to what is already in the channel. Preventing new sand entering the river will not limit the continued movement of sediment into the Barmah-Millewa reach from the upstream reaches, the associated loss of capacity or ongoing loss of habitat and diversity.

However, the use of bank protection works to limit ongoing erosion and the formation of new breakaway channels into the forest could potentially reduce the rate of these changes and some environmental impacts in the short-term. These types of river management works have standard approaches and have been undertaken previously in the region; for example, the Hume to Yarrawonga reach of the River Murray has had a River Works Program in operation from 2004 to 2020. This program has delivered physical bank stability and erosion control works and provided support to landholders to undertake various works that improve streamside vegetation and reduce bank erosion.

Depending on how bank works are designed and implemented, including the materials used, there may be opportunity to provide short-term improvements to environmental, social, and cultural values. For example, the use of log revetments rather than rock beaching for bank protection combined with revegetation works.

Within the Barmah-Millewa reach there may be the need to obtain approvals and permits depending upon the location and scale of the bank works and to allow access to the site for construction.

The Interim River Works Program (2022-2027) will provide indicative cost estimates for bank protection works in this reach. Based on similar program, capital costs are within the low range, but there will be increasing ongoing and maintenance costs beyond the life of the project.

5.3.5. **Physically removing the sand**

Physically removing the sand from the channel aims to directly increase the flow area within the channel cross-section and interrupt the downstream movement of sand. This can be achieved using various techniques.

Evaluation Criteria		Physical Interventions
Effectiveness	Flow capacity	
	Sedimentation	
	Habitat & Diversity	
Technical	Technically Feasible	
	Flexibility	
Impacts on Values	Environmental	
	Social	
	Cultural	
	Economic	
Costs	Regulatory requirements	
	Capital Investment	
	Ongoing & Maintenance costs	

At a high-level, this option could be effective in maintaining or increasing the channel capacity, reducing sedimentation, and improving or maintaining habitat and diversity of the channel form. How effective it can be, will need to be evaluated in the next phase of the project.

There are a range of techniques for physically removing the sand, ranging from excavators to 'sand shifters'. A common approach is hydraulic dredging which utilises pumps and water flow to suck sediment from the riverbed. The sand-water slurry is then pumped to a stockpile site on land. Alternatively, a 'sand shifter' arrangement uses pressurised water which is pumped through an array of nozzles installed on the riverbed to create a sand slurry which is then pumped on land. An initial feasibility assessment confirmed several techniques could be applied within the Barmah-Millewa reach. It is important to note that due to the large volumes and extent of the sand, any extraction is likely to be ongoing and not a one-off. It is not a short-term solution.

There could be negative impacts on values associated with extraction of sediment from the riverbed such as closure of areas of the river for recreation while works are underway, or the removal of vegetation to install pipes and pumps to move the sand. However, provided these impacts can be managed through design and monitoring, the reduction in sedimentation will help reinstate or maintain capacity, aid reducing the rates of bank erosion, and in re-establishing channel diversity and habitat.

There are likely to be significant regulatory requirements, including Statement of Environmental Effects, and a range of approvals which need a range of further studies to be completed (GHD, 2014), see Appendix D.

Costs will vary depending on the details of the option but are likely to be moderate to high. There may be opportunity to offset costs through beneficial use of the extracted sand. Commercial extraction has been used as a management tool for excess sand on the Glenelg River in Victoria for the past two decades.

5.3.6. Moving water around

There is a project currently underway to investigate the feasibility of moving water around the Barmah-Millewa reach using existing irrigation infrastructure. The intent of this option is to mitigate against any potential shortfalls to downstream demands resulting from capacity through the Barmah-Millewa reach reducing further. It has been assumed for the purposes of this assessment that the any works to achieve this movement of water around the reach are feasible.

This could assist in maintaining the delivery of water to meet downstream demands. However, it will not be effective in managing the sand in the reach, its continued build-up, and the resultant adverse impacts on environmental, social, cultural, and economic values. There is also the question as to whether transferring water to other constructed and natural waterways may adversely impact those systems through increased bank erosion, or changes to the flow regime for native fish and other species.

There will still be a need to provide high flows in the Barmah-Millewa reach in winter-spring-early summer to meet ecological requirements but lowering summer flows by passing water around the reach may reduce stress on the riverbanks.

While by itself, moving the water around does not meet the objectives of this project, it may have a role in a suite of solutions through allowing more variability in the flow regime through this reach.

Evaluation Criteria		Moving water around
Effectiveness	Flow capacity	
	Sedimentation	
	Habitat & Diversity	
Technical	Technically Feasible	
	Flexibility	
Impacts on Values	Environmental	
	Social	
	Cultural	
	Economic	
Costs	Regulatory requirements	
	Capital Investment	
	Ongoing & Maintenance costs	

5.3.7. Reducing regulated flows

Reducing regulated flows would require new policies or modifications to existing policies and operational rules or a permanent reduction in downstream demand to enable the River Murray System to be managed to accommodate a declining capacity through the Barmah-Millewa reach. This was previously investigated by SKM (2011) where policy options to manage capacity within the reach at that time were assessed. The result was the implementation of the Barmah Choke trading rule. The effect of a continually declining capacity was not considered.

While it is recognised that this could be effective in managing flow capacity constraints, the sedimentation will continue in this reach with the associated adverse impacts on banks, floodplain and wetland flora and fauna as well as social and cultural values.

While by itself, reducing downstream flow demands does not meet the objectives of this project, it may have a role in a suite of solutions through reducing the long-term stressors on the river channel.

This option has not been assessed in detail as it is outside the scope of works, however it has been included at the request of several stakeholders who raised it for consideration during the consultation sessions. There will likely be further limited investigation into this option which will consider the reasons for development downstream of the Barmah-Millewa reach, including drivers such as water markets, climatic conditions, soils and landuse constraints. The focus will be on understanding what the disincentives are to development upstream.

Evaluation Criteria		Reducing regulated flows
Effectiveness	Flow capacity	
	Sedimentation	
	Habitat & Diversity	
Technical	Technically Feasible	
	Flexibility	
Impacts on Values	Environmental	
	Social	
	Cultural	
	Economic	
Costs	Regulatory requirements	
	Capital Investment	
	Ongoing & Maintenance costs	

5.4. A Combination of Options

The options analysis has clearly shown that there is no single option that can effectively manage the reduction in flow capacity, increasing sedimentation, and loss of habitat and diversity in the Barmah-Millewa reach, both in the short or long-term.

Three options, namely controlling sediment inputs through targeted bank protection, physically removing sand, and moving water around the reach to reduce summer and autumn flows look to provide the most benefits. It is recommended that these options be progressed to the next stage, noting that they all require further investigation to determine how, where and when these options could be applied. An overview of the pros and cons of these options is presented in Table 7.

Table 7 Summary of the pros and cons of selected sand management options

Option	Pros	Cons
Controlling new sediment inputs (targeted bank protection)	Can mitigate against the accelerating bank erosion and risk of new flow connections forming from the river channel to the floodplain and leading to unseasonal flooding.	Does not address the main driver, namely the increasing sedimentation and loss of flow capacity
	The design of bank works could include revegetation and works to improve habitat features.	There will be continued negative or unacceptable impacts on some values in the reach
	Agencies have existing experience in the type of works required and can apply known techniques	Ongoing works and maintenance will be required
Physically removing sand	Effective in addressing the main drivers, namely the increasing sedimentation and loss of flow capacity	Design and approvals requirements are likely to be significant and costly
	Technically feasible, with several techniques that may be applicable	Implementation costs are likely to be moderate to high and the works will be long-term
Moving water around the reach	May be effective in reducing the flow stress on the reach during the summer-autumn period and reduce bank erosion during these periods	Does not address the main driver, namely the increasing sedimentation and loss of flow capacity
	Likely to be technically feasible	There will be continued negative or unacceptable impacts on some values in the reach
		Could shift the adverse outcomes to other rivers or reaches
		Likely to be high cost and may require substantial approvals

section six

6. **Summary and Recommendations**

6.1. **The Issue**

The natural narrowing of the River Murray through the Barmah-Millewa reach has always presented a control on the flow capacity of the river. The restriction provides an operational challenge for the MDBA as it attempts to manage delivery of water from upstream to downstream of the reach to meet peak irrigation demands.

The regulated capacity of the Barmah-Millewa reach as measured by the water level at Picnic Point, and the corresponding releases from Yarrawonga Weir have been declining over time, reducing from 11,500 ML/day in the 1980s to a current capacity of approximately 9,200 ML/day.

In conjunction with the loss of capacity, ongoing degradation of riverbanks has been occurring throughout the broader Yarrawonga to Torrumbarry reach of the River Murray due to regulated flow patterns and exacerbated by other factors such as vessel wash and deterioration of riparian vegetation. Recent investigations (Streamology, 2020; Grove, 2021) identified that the presence of excessive deposits of coarse sand in the river channel downstream of Yarrawonga Weir is most likely to be the major contributing factor to the loss of capacity and contributes to the acceleration of the rates of bank erosion, and channel degradation through loss of diversity and habitat.

6.2. **Investigation Approach**

The Murray-Darling Basin Authority (MDBA) has been directed by the Basins Officials Committee (BOC) to investigate what can be done to stop further loss of channel capacity and possibly reinstate capacity through the Barmah-Millewa reach of the River Murray.

Given the enhanced understanding of the issue developed through this project and concerns raised by First Nations and stakeholders during the engagement process, it has become clear that concerns regarding capacity through the reach cannot be separated from other aspects such as bank erosion, ecological degradation, and the loss of values especially cultural values.

The scope of this project has therefore been to develop a comprehensive understanding of several aspects, including:

- The processes leading to the accumulation of sand in the reach,
- The extent and volume of excess sand,
- The resultant implications for flow capacity as well as environmental, social, cultural, and economic values if nothing is done to manage the sand, and

- The potential options for managing the sand.

This has involved the capture and analysis of new data, desktop review, and First Nations and stakeholder consultation to understand the values of the reach. Technical evaluation and interpretation of the data and information has provided a thorough and detailed understanding of current conditions and future trajectories. Additional desktop assessments have explored specific sand management options.

Engagement with First Nations people and stakeholders has been ongoing throughout the project, to provide updates on the progress of work as well as canvas their input in defining the values of the reach and how predicted changes to the river may impact them.

6.3. **Main Outcomes**

The data collected and analysed has shown that there is in excess of 20 million m^3 of coarse sand in the bed of the River Murray Channel between Yarrawonga and Picnic Point, which is referred to as the 'sand slug'. Much of this sand was most likely mobilised through land use practices and mining in the 1800s, whereby large volumes of sediment were deposited into catchment waterways upstream. The sand then slowly migrated downstream and is currently building up in the Barmah-Millewa reach.

The build-up of sand is a result of the nature of the River Murray in this reach. Water tends to flow out of the main channel, through creeks and flood runners, instead of into it. Less water flowing down the main channel means less ability to transport the sand downstream, causing it to accumulate. While sediment build-up is therefore a natural process, the bed of the river would normally only contain small quantities of sand and the process would be very slow. With the presence of the large volumes of sand from the sand slug in the river, this process is now happening much faster.

The result is the loss of flow capacity, the acceleration of bank erosion processes, and the filling in of deep pools reducing diversity and habitat. The acceleration of bank erosion is also leading to the loss of levees on the riverbanks, which causes trees to fall in, the damage and loss of cultural sites such as middens, and the creation of new flow connections into the floodplain and wetlands. These new flow connections enhance unseasonal flooding, and the fine silts eroded from the banks smother vegetation in these areas. These changes will adversely affect values in the reach, such as the changes in the condition of the Ramsar wetlands, the loss of access to camping sites and recreational areas, damage to cultural sites or loss of cultural practices, reduced visitation and tourism and the associated economic benefits. Doing nothing to manage the sand therefore has a range of unacceptable outcomes.

A range of options to manage the sand have been investigated. For each option, their effectiveness in managing the issues of concern, their technical feasibility, impacts on values, and costs were assessed. Options that have been ruled out include:

- Flushing the sediment through, and

- Storing the sediment.

Neither option is technically feasible for this reach and therefore cannot be effective in addressing the main issues of flow capacity, sedimentation, and loss of habitat and diversity.

The remaining options are technically feasible but variable in their effectiveness. No single option has been identified that addresses all the issues of concern. Instead, a range of solutions is likely to be required which could include:

- Protection of priority sections of riverbank through on-ground works,
- The physical removal of sand in targeted areas, and
- Moving water around the reach to reduce summer and autumn flow rates.

6.4. Recommendations for Next Steps

Based on the outcomes of this investigation is it recommended that the project be progressed to the next stage – Options Development.

Several feasible options have been identified, namely:

- Protection of priority sections of riverbank through on-ground works,
- The physical removal of sand in targeted areas, and
- Moving water around the reach to reduce summer and autumn flow rates.

Each of these options need to be investigated further to determine how, where and when they could or should be applied. Each option also needs to be considered in conjunction with the others to develop a preferred package of options.

A range of studies are likely to be required in Stage 2 to confirm the effectiveness, costs, and risks associated with each option individually, and as a package of options. These will be scoped and confirmed prior to commencement of any works. Examples of the studies to be considered include:

- Further investigation of sand movement in the reach, including additional information on the downstream extent of sand, its rate of movement, and sediment quality analysis at any identified extraction locations.
- Feasibility assessment of sand removal techniques and their potential effectiveness, identification of suitable locations for works, costs, and associated frequency of works.
- Beneficial uses study to identify opportunities for reuse of sand removed.
- Scoping studies to review approvals requirements and identification of associated technical work, including cultural heritage due diligence and possible study designs for baseline environmental and social values monitoring and evaluation.

Targeted bank protection and the feasibility of moving water around the reach are being investigated as part of the interim river works program, and Barmah Optimisation Feasibility Study respectively. Any outcomes and learnings from these studies will be incorporated into the Stage 2 assessment.

As with Stage 1, all options will continue to be assessed against criteria that consider the social, cultural, environmental, and economic implications of any actions. Continued engagement with stakeholders including Traditional Owners and the community will an integral part of all studies.

section seven

7. **References**

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Appendix A: Bedload Thickness Map

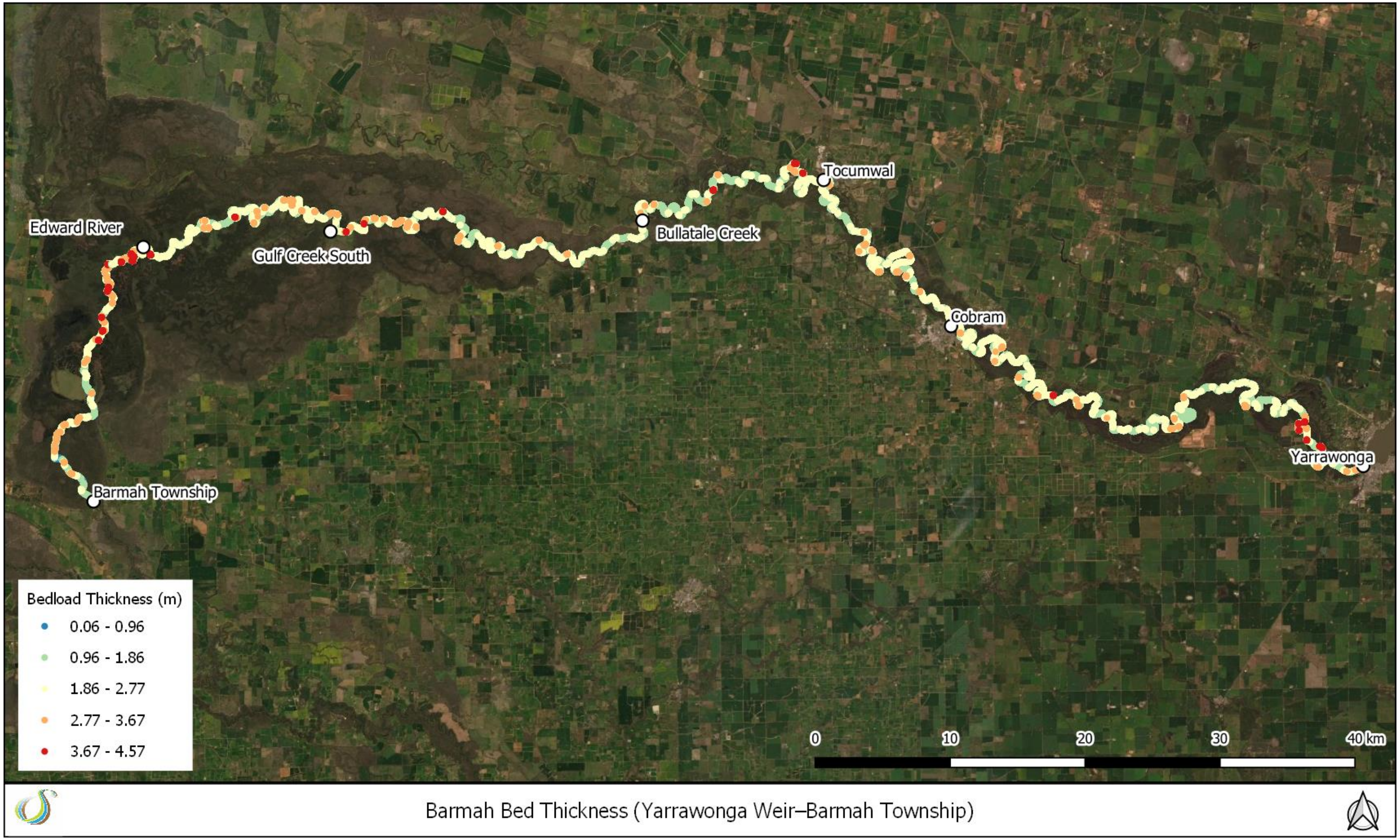

Figure 36. Map showing bedload sediment thickness (original data) from Yarrawonga to Barmah township. Note that the rendering order emphasizes areas of thicker sediment over thinner points.

Appendix B: Heavy Metal Analysis Results

RESULTS OF SOIL ANALYSIS

14 samples supplied by Water Technology on 20/04/2021. Lab Job No. K8594.
Samples submitted by Tom Atkin. Your Job: 14 Soil. Additional elements requested on 19/08/2021. Original job number K5909
40 Rowan Street WANGARATTA VIC 3677

SAMPLE ID	Job No.	Silver (mg/kg)	Arsenic (mg/kg)	Lead (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Copper (mg/kg)	Manganese (mg/kg)	Nickel (mg/kg)	Selenium (mg/kg)	Zinc (mg/kg)	Mercury (mg/kg)	Iron (mg/kg)	Aluminium (mg/kg)
	Method	*1:3 Nitric/HCl digest - APHA 3125 ICPMS*	*1:3 Nitric/HCl digest - APHA 3125 ICPMS*	*1:3 Nitric/HCl digest - APHA 3125 ICPMS*	*1:3 Nitric/HCl digest - APHA 3125 ICPMS*	*1:3 Nitric/HCl digest - APHA 3125 ICPMS*	*1:3 Nitric/HCl digest - APHA 3125 ICPMS*	*1:3 Nitric/HCl digest - APHA 3125 ICPMS*	*1:3 Nitric/HCl digest - APHA 3125 ICPMS*	*1:3 Nitric/HCl digest - APHA 3125 ICPMS*	*1:3 Nitric/HCl digest - APHA 3125 ICPMS*	*1:3 Nitric/HCl digest - APHA 3125 ICPMS*	*1:3 Nitric/HCl digest - APHA 3125 ICPMS*	*1:3 Nitric/HCl digest - APHA 3125 ICPMS*
Bed 001	*K8594/1*	<1	4.51	2.86	<0.5	2.65	5.66	89.4	2.41	<2	6.78	<0.1	3,574	1,176
Bed 002	*K8594/2*	<1	4.64	2.88	<0.5	2.17	5.40	92.2	2.21	<2	7.97	<0.1	3,856	1,360
Bed 003	*K8594/3*	<1	4.10	2.65	<0.5	1.57	2.63	106	1.92	<2	5.75	<0.1	2,980	985
Bed 004	*K8594/4*	<1	3.88	2.39	<0.5	1.74	2.85	105	1.63	<2	4.91	<0.1	3,018	889
Bed 005	*K8594/5*	<1	3.72	2.51	<0.5	2.16	3.62	117	1.97	<2	6.39	<0.1	3,213	1,224
Bed 006	*K8594/6*	<1	2.93	2.12	<0.5	1.78	1.97	70.7	1.86	<2	5.10	<0.1	2,700	1,096
Bed 007	*K8594/7*	<1	7.56	14.1	<0.5	24.1	38.2	125	13.4	<2	32.6	<0.1	21,922	14,743
Bed 008	*K8594/8*	<1	5.29	3.49	<0.5	2.40	3.48	181	2.55	<2	7.54	<0.1	4,301	1,346
Bed 009	*K8594/9*	<1	5.07	3.66	<0.5	2.29	3.80	200	2.89	<2	7.73	<0.1	4,618	1,386
Bed 010	*K8594/10*	<1	6.61	12.5	<0.5	21.4	13.3	278	19.2	<2	47.2	<0.1	19,192	15,344
Bed 011	*K8594/11*	<1	5.85	3.57	<0.5	2.48	2.09	91.7	2.34	<2	6.36	<0.1	4,432	1,450
Beach - T1	*K8594/12*	<1	2.57	2.45	<0.5	2.24	1.98	64.9	2.14	<2	6.74	<0.1	3,259	1,409
Beach - KP2	*K8594/13*	<1	4.33	2.55	<0.5	1.82	1.47	111	1.67	<2	5.39	<0.1	3,388	1,144
Beach - KP3	*K8594/14*	<1	5.56	3.11	<0.5	2.05	1.78	130	1.82	<2	7.57	<0.1	4,254	1,296

SAMPLE ID	Lithium (mg/kg)	Beryllium (mg/kg)	Boron (mg/kg)	Silicon (mg/kg)	Vanadium (mg/kg)	Cobalt (mg/kg)	Strontium (mg/kg)	Molybdenum (mg/kg)	Antimony (mg/kg)	Barium (mg/kg)	Thallium (mg/kg)	Bismuth (mg/kg)	Thorium (mg/kg)	Uranium (mg/kg)
	1:3 Nitric/HCl digest - APHA 3125 ICPMS	*1:3 Nitric/HCl digest - APHA 3125 ICPMS*	*1:3 Nitric/HCl digest - APHA 3125 ICPMS*	*1:3 Nitric/HCl digest - APHA 3125 ICPMS*	*1:3 Nitric/HCl digest - APHA 3125 ICPMS*	*1:3 Nitric/HCl digest - APHA 3125 ICPMS*	*1:3 Nitric/HCl digest - APHA 3125 ICPMS*	*1:3 Nitric/HCl digest - APHA 3125 ICPMS*	*1:3 Nitric/HCl digest - APHA 3125 ICPMS*	*1:3 Nitric/HCl digest - APHA 3125 ICPMS*	*1:3 Nitric/HCl digest - APHA 3125 ICPMS*	*1:3 Nitric/HCl digest - APHA 3125 ICPMS*	*1:3 Nitric/HCl digest - APHA 3125 ICPMS*	*1:3 Nitric/HCl digest - APHA 3125 ICPMS*
Bed 001	1.49	<0.5	<5	1,312	4.45	2.04	2.35	<0.5	<1	12.5	<0.5	<0.5	1.24	0.343
Bed 002	1.67	<0.5	<5	1,267	4.26	2.09	2.07	<0.5	<1	14.7	<0.5	<0.5	1.20	0.363
Bed 003	1.24	<0.5	<5	1,517	3.76	2.00	1.42	<0.5	<1	16.2	<0.5	<0.5	1.63	0.323
Bed 004	1.12	<0.5	<5	1,280	3.57	1.77	1.46	<0.5	<1	12.2	<0.5	<0.5	0.756	0.295
Bed 005	1.63	<0.5	<5	1,703	4.16	1.73	1.63	<0.5	<1	13.8	<0.5	<0.5	0.941	0.356
Bed 006	1.46	<0.5	<5	1,442	3.55	1.39	1.47	<0.5	<1	11.2	<0.5	<0.5	0.888	0.327
Bed 007	7.94	0.897	<5	3,651	33.5	5.97	14.7	<0.5	<1	92.8	<0.5	<0.5	5.09	1.11
Bed 008	1.44	<0.5	<5	1,832	5.47	2.71	2.08	<0.5	<1	22.3	<0.5	<0.5	1.60	0.410
Bed 009	1.40	<0.5	<5	1,891	6.27	2.89	2.45	<0.5	<1	21.4	<0.5	<0.5	1.46	0.512
Bed 010	16.6	1.17	<5	2,791	23.7	11.4	18.1	<0.5	<1	123	<0.5	<0.5	8.44	1.37
Bed 011	1.66	<0.5	<5	1,809	5.39	2.75	2.22	<0.5	<1	15.5	<0.5	<0.5	2.95	0.441
Beach - T1	1.70	<0.5	<5	1,332	3.82	1.78	2.34	<0.5	<1	12.8	<0.5	<0.5	1.87	0.352
Beach - KP2	1.29	<0.5	<5	1,477	3.60	1.78	1.69	<0.5	<1	14.8	<0.5	<0.5	1.11	0.329
Beach - KP3	1.47	<0.5	<5	1,879	4.57	2.11	1.97	<0.5	<1	16.3	<0.5	<0.5	1.25	0.365

Notes:

1. ppm = mg/Kg dried sample
2. All results as dry weight DW - samples were dried at 40oC for 24-48hrs prior to crushing and analysis.
3. Methods from Rayment and Lyons, Soil Chemical Methods - Australasia
4. Metals analysed by ICP-MS (Inductively Coupled Plasma - Mass Spectrometry)
5. Analysis conducted between sample arrival date and reporting date.
6. ** NATA accreditation does not cover the performance of this service.
7. .. Denotes not requested.
8. This report is not to be reproduced except in full.
9. All services undertaken by EAL are covered by the EAL Laboratory Services Terms and Conditions (refer SCU.edu.au/eal/t&cs or on request).
10. Results relate only to the samples tested.
11. This report was issued on 23/08/2021.

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checked:...............
Graham Lancaster

Appendix C: Online Consultation Summary

Barmah–Millewa Sediment Investigation

Community Engagement Online Workshops, October 2021

In October 2021, eight online workshops were held with a broad range of community groups including Traditional Owners, state agencies, local governments, tourism, environmental and water advocacy groups, irrigators and water corporations. Several additional sessions are scheduled to meet requests by specific organisations.

The workshops, led by MDBA and Streamology, provided a project update, discussed the impacts of no intervention, presented preliminary management options, and received feedback on the assessment of those options, including impacts to values the community had previously identified.

Below is a high-level overview of community feedback received:

1. There is a desire to see agencies/jurisdictions/groups working together to protect the river and values for future generations.
2. The river is not only important for transporting water for irrigation purposes, but it also has high value culturally, socially, environmentally and economically.
3. There is a recognition of the high complexity and difficulty of the project, and the associated projected timelines.
4. There needs to be a consistent and coordinated approach between all levels of government, different managing partners and projects within this reach.

Impacts

5. Community members are most concerned about the following impacts from the excess sediment in the Barmah-Millewa reach:
    a. Bank erosion
        i. Slumping and acceleration of erosion by boat wash
        ii. Loss of culturally significant sites (e.g. middens, burial sites, birthing trees)
        iii. Loss of natural levees
            1. Silt building up on the Barmah-Millewa forest floor and floodplain, and in the Barmah Lakes
            2. Want to see water maintained in the channel and not outside when not desired
    b. Ecological degradation

Office locations – *First Nations Country*
Adelaide – *Kaurna* | **Canberra** – *Ngunnawal* | **Goondiwindi** – *Bigambul* | **Griffith** – *Wiradjuri*
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   c. Potential impacts to regulator operations
   d. Point bar changes
      i. Anecdotal evidence of point bars growing in recent years
      ii. Preferential erosion of adjacent riverbanks (e.g. Wopperana Beach d/s Tocumwal)
      iii. Don't want to see impacts to social and economic values at these beaches

<u>'Do nothing' to manage the sand</u>

6. Majority of community members do not accept a 'do nothing' approach.
7. Adverse impacts to cultural, social, environmental and economic values are unacceptable to most community members, and these impacts are currently seen in the Barmah-Millewa reach.
8. If nothing is done, it will affect current communities and future generations.
9. Heard commentary that this would be a 'disaster environmentally'.
10. High concern about the associated loss in hydraulic diversity and in-channel habitat.
11. Sand deposition has implications to re-snagging programs.

<u>'Do something' to manage the sand</u>

12. Most community members accept and understand that the way forward is likely to be a suite of solutions complementing one another.
13. There are concerns over significant costs of management options.
14. The community wants to see a solution that takes into account:
    a. The environment and ecology of both in-channel and adjacent landscapes (i.e. floodplain),
    b. Long-term versus short-term impacts with consideration to the rejuvenation of the system,
    c. The long-term nature of the issue and associated solution (i.e. not do works that are soon negated by the effects of the excess sand); and
    d. A holistic approach to land and water management (e.g. bank protection, soil degradation prevention).
15. Bank protection:
    a. Community expressed high interest in targeted bank protection works to be part of the solution
    b. This was seen to be a priority and needed to be implemented 'sooner rather than later'.
16. Moving water around the Choke:
    a. There is concern that this option is likely to move the problem to other tributaries and cause ecological and environmental degradation.
    b. Associated with this project, the community wants consideration to:
       i. Reducing the volume of water going through the Barmah Choke; and
       ii. Possible long-term net upstream trade of water, and/or reduce use downstream.

17. Sand removal:
    a. Community member wish to see sand stop building up.
    b. Concerned about:
        i. Environmental impact, including to animals, during works
        ii. Water quality downstream of disturbed sediment due to turbidity plume
        iii. Logistics including where it would be removed, where would it be stored, the number of trucks on roads as a result and potential access points.
    c. Some community members suggested looking at places where sand accumulation is highest, including downstream of Picnic Point and infilled scour holes through the Barmah-Millewa reach.
    d. A small footprint option is most preferable.
    e. Community members wanted assurance it would be a long-term impactful solution.
    f. Numerous community groups asked if the sand could be sold as a commodity to offset management costs.
    g. Community vocalised their surprise to see the lack of options that have the potential to be a meaningful solution.
    h. Although sand removal does not align with all community values, it is considered by many as the better solution than to 'do nothing'.

Traditional Owners

18. High concern by Traditional Owners of the impacts to cultural and environmental values.
19. Anecdotal evidence that Traditional Owners in Deniliquin want to see sand removed from cod holes.
20. Anecdotal evidence from third parties suggest some Traditional Owners are unlikely to support management works.
21. High interest in ongoing engagement and collaboration in this project including:
    a. Monitoring programs,
    b. Determining baseline ecological values; and
    c. Employment opportunities.
22. Traditional Owners - Bangerang Aboriginal Corporation & Cummeragunja Local Aboriginal Land Council:
    a. Do not accept the 'do nothing' scenario.
    b. Wish to see something done to manage the sand.
    c. They see addressing bank erosion as a benefit.
    d. They see opportunities in the solutions presented.
    e. They think the majority of Aboriginal people want to care for the environment and Country.
23. Traditional Owners - Yorta Yorta:
    a. Presentation to Elders is to be advised by Yorta Yorta members.
    b. There are concerns that a decision has been made and 'do nothing' scenario is no longer being considered.

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c. There is concern about the use of the term 'natural processes' (in regard to erosion, bed aggrading mechanisms and sand movement with flows) and that it may be a justification for the current regulated river conditions and associated impacts.
d. The issue of the excess sand in the river compounds long held concerns for the river and regulation practices.
e. There is an interest to fully understand how the sand accelerates bank erosion.
f. Do not agree with the language used as it suggests the sand and associated impacts are an 'emergency'.
g. Request to be more involved in the project.

<u>Outstanding questions</u>

24. These include:
    a. Will the solution be a one-off measure, or a long-term management?
    b. How can we stop the sand moving downwards and counteract any sand removal efforts?
    c. How far does the sand extend past Barmah township?
    d. Can the coarse sand be confidently linked to gold mining (i.e. fingerprinting)?
    e. Is all the coarse sand free from gross contamination?
        i. Noting community is largely satisfied with preliminary testing with results of no significant contamination recorded and support a method of targeted testing, this will occur prior to any potential sand removal.
    f. Can the sand be sold as a commodity to counter costs associated with the project?
    g. How will flow rates and water levels change following management options, will these increase, and will there be further damage associated?
    h. What is the impact to the tributaries (e.g. Edward-Kolety, Bullatale)?
        i. Is there sand building up in these rivers?
        ii. Can things be done to reduce the significant erosion seen in these rivers and impact to culturally significant sites (e.g. middens, burial sites)?
        iii. Will the solution to the sand in the Barmah-Millewa reach transfer issues to adjacent waterways?
    i. If the river is to change course, when and where might that be?

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Appendix D: Regulatory Requirements

The following list of likely regulatory requirements for works requiring the physical removal of sand from the reach. It is based on available information from projects with similar scope or in similar locations (DPI, 2013; GHD, 2014) and includes Federal and State legislation. These requirements will be reviewed for applicability of the options assessed.

Legislation	Activity
Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)	Assess whether the activity will have a significant impact on a nationally listed vulnerable species.
Environmental Planning and Assessment Act, 1979 (EP&A Act) and Environmental Planning and Assessment Regulation 2000 (EP&A Reg)	Environmental Impact Statement required as the activity is classed a "designated development" as it is not part of works identified in a river, land or water management plan and extraction volumes are greater than 1,000m3)
Threatened Species Conservation Act 1995	Assessment of the potential risk of harm to threatened species
Protection of the Environment Operations Act 1997	Pollution Licence required if extraction of more than 30,000m3 per year of extractive materials.
Fisheries Management Act 1994	Part 7 Permit not required for a Public Authority, but notice must be given to the Minister and matters raised considered. Various issues required to be assessed to allow for comment. Includes works to install instream structures.
Water Management Act 2000	Public Authorities are exempt from requiring a Controlled Activity Approval (CAA), although concurrence from DPI Office of Water required. A Controlled Activity Approval is required if the operation is a commercial exercise
National Parks and Wildlife Act	Includes indigenous heritage items or places which are protected under the Act
Crown Lands Act 1989	Extractive Industries Licence required if operation is a commercial exercise or used by local government. If not a commercial exercise, then a Letter of Authority is required. Initial application and annual rent cost. Licence preferentially linked to extractor rather than CMA.
Native Vegetation Act 2003	If vegetation to be removed, a property management plan (PVP) is required to allow assessment and approval.
Noxious Weeds Act 1993	Weed Management Plan (WMP) required for areas affected by noxious weeds.
SEPP Infrastructure 2007	Works being carried out for environmental benefit (management) by, or on behalf of a public authority are exempt
SEPP Mining and Petroleum and Extractive Industries 2007	This SEPP attempts to standardise the approach throughout NSW to the assessment and approval of mining activities under Part 4 of the EP&A Act. Under Regulation 7 of this SEPP, development permissible with consent includes mining and extractive industries in any part of a waterway of the State that is not in an environmental conservation zone.

Environmental Effects Act 1978	Potential long-term change to the ecological character of a wetland listed under the Ramsar Convention or in 'A Directory of Important Wetlands in Australia' Potential extensive or major effects on the health or biodiversity of aquatic, estuarine or marine ecosystems, over the long term.
Planning and Environment Act 1987 Planning Permit Public Land Managers Consent	Applicant to request permission from public land manager to apply for a planning permit for works on public land A planning permit application is then submitted with supporting documentation including an: • Offset strategy • Threatened species management plan Local Council refers applications and plans to appropriate authorities for advice
Aboriginal Heritage Act 2006 Cultural Heritage Management Plan	A CHMP is required when a listed high impact activity will cause significant ground disturbance and is in an area of cultural heritage sensitivity as defined by the Aboriginal Heritage Regulations 2007 (Part 2, Division 5).
Water Act 1989 Works on waterways permit	Application for a licence to construct and operate works on a waterway
National Parks Act 1975 Section 27 consent	Approval for a public authority to carry out its functions in a national park
Flora and Fauna Guarantee Act 1988 Protected flora license of permit	Application for approval to remove protected flora within public land for non-commercial purposes. Will need to include targeted surveys for threatened/protected species considered likely to be present at the site and impacted by proposed works.