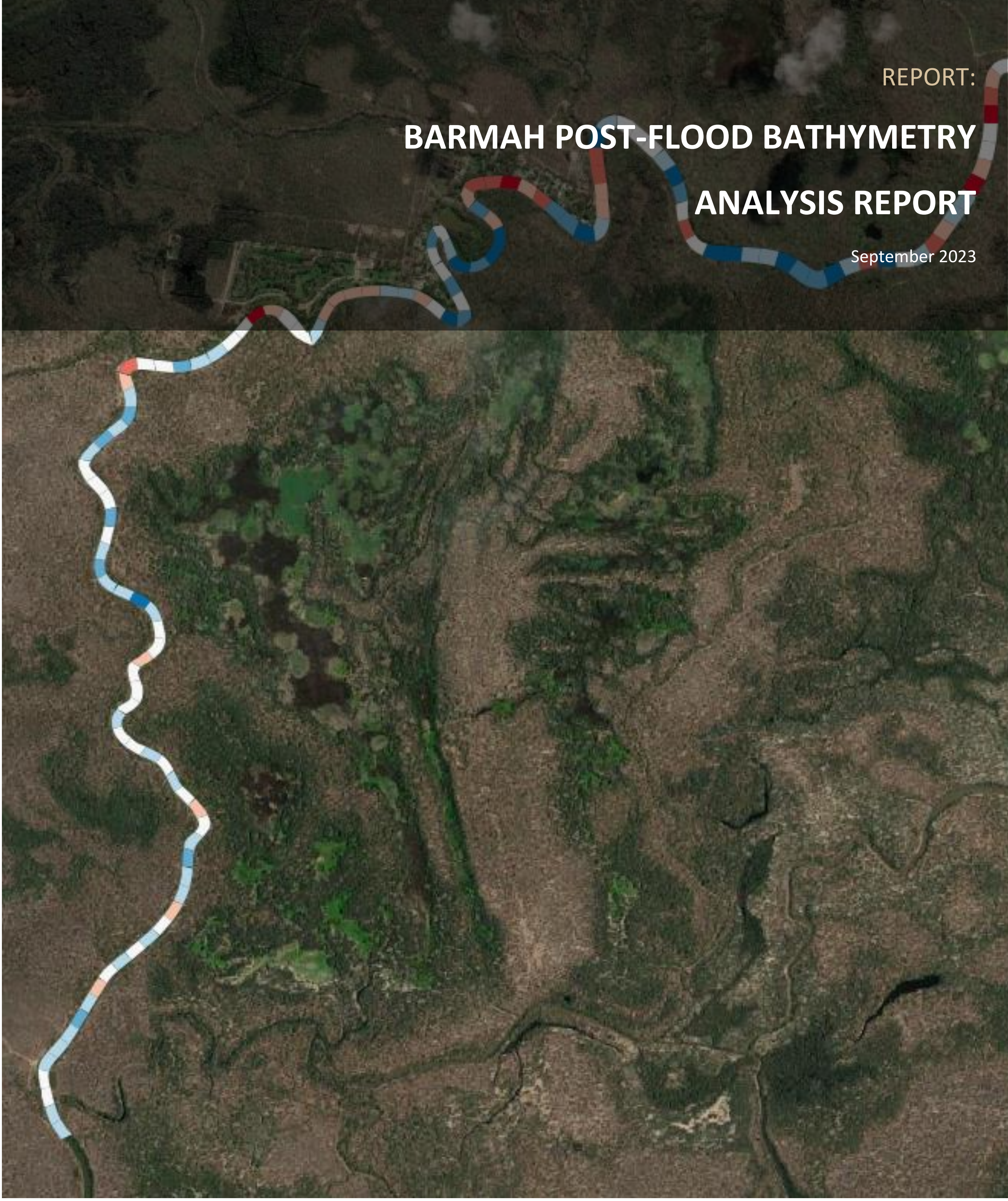
REPORT:

# BARMAH POST-FLOOD BATHYMETRY ANALYSIS REPORT

September 2023



Report for the Murray Darling Basin Authority

streamology
waterway science and management

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# Glossary & Acronyms

| | |
|---|---|
| **Aggradation** | Increase in elevation (e.g., of a riverbed) due to the deposition of sediment carried by a river, stream, or current |
| **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 |
| **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** | 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. |
| **Flow** | See Discharge |
| **Flow Gauging** | The measurement of discharge (i.e., the volume of water) flowing past a specific point in a waterway at a given time. |
| **Morphology** | In geography and related disciplines, morphology is synonymous for the physical form (or shape) of landforms, including rivers |
| **Offtake** | See effluent |
| **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 |

# Acknowledgement of Country

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'*

# Contents

# 1 Introduction

## 1.1 Background

The Barmah-Millewa reach is a section of the River Murray that 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 Murray-Darling Basin Authority (MDBA) in managing delivery of water from upstream to downstream of the reach to meet peak and total system water demands downstream.

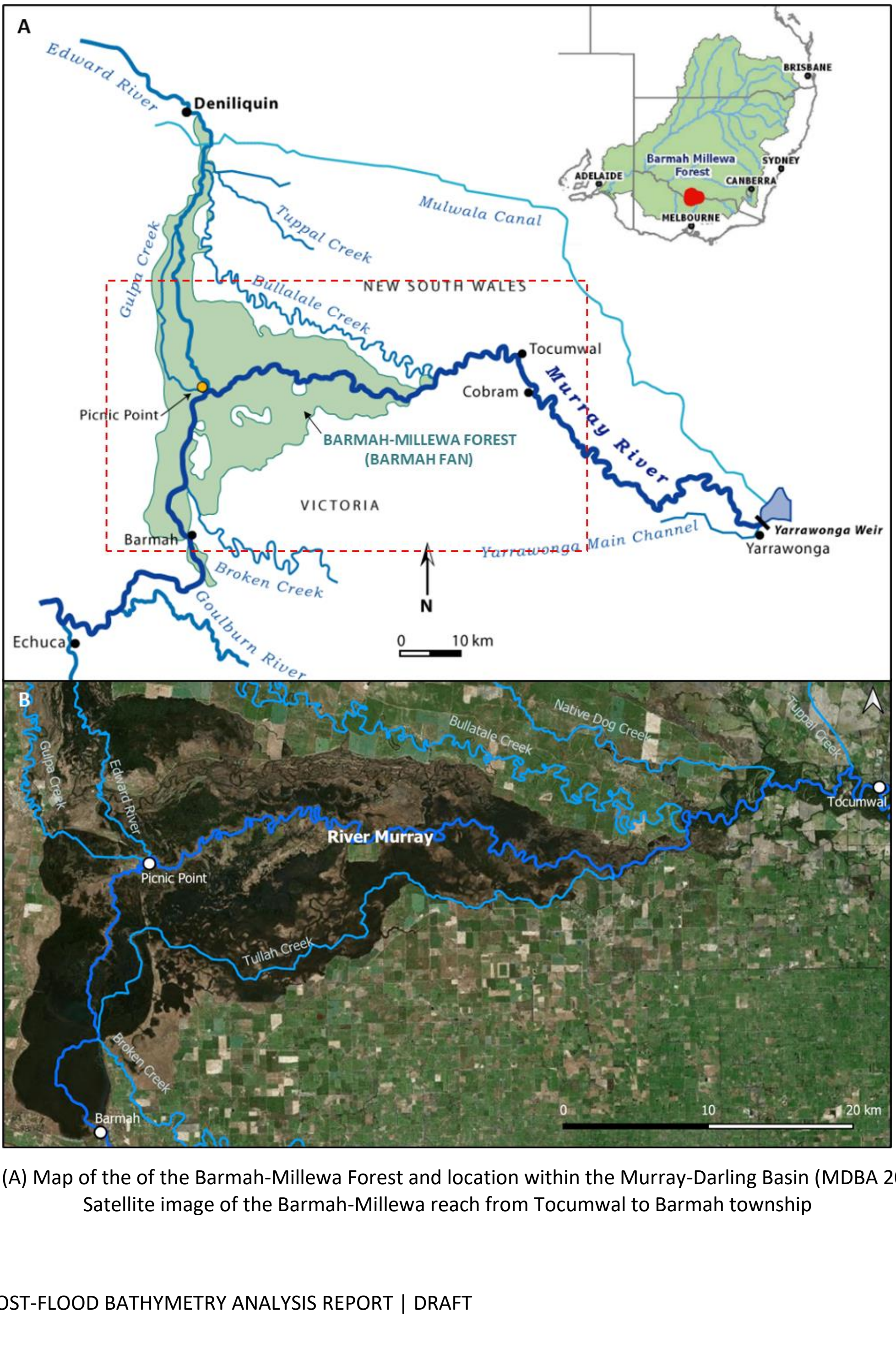



Figure 1 (A) Map of the of the Barmah-Millewa Forest and location within the Murray-Darling Basin (MDBA 2008). (B) Satellite image of the Barmah-Millewa reach from Tocumwal to Barmah township

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 more than 11,000 ML/day in the late 1980s to capacity of approximately 9,200 ML/day in 2021, and which has been further reduced following the October 2022 flood event.

Studies by Streamology in 2020 and 2021 identified that much of this reduction in capacity can be attributed to the estimated presence of more than 20 million $m^3$ of coarse sand on the bed of the River Murray channel between Yarrawonga Weir and Picnic Point, which is sometimes also referred to as a ‘sand slug’. This accumulated sand on the riverbed is now known to extend downstream as far as Echuca (Streamology, 2022). Much of this sand was most likely mobilised through land use changes and gold mining in the 1800s, whereby large volumes of sediment were deposited into catchment waterways upstream. Various lines of evidence now indicate that this sand has slowly migrated downstream and is currently building up in the Barmah-Millewa reach.

## 1.2 Scope of this project

An important means of monitoring the sand movement in the Barmah-Millewa reach of the River Murray is through repeat measurements of riverbed level. An increase in the thickness of the sand layer on the riverbed raises the bed level while a decrease in the thickness of sand causes a lowering in the level of the bed relative to an earlier benchmark measurement. The sand also moves along the riverbed in the form of “dunes” which means the level varies up and down depending on where and how fast each dune is moving. Figure 2 shows the dunes at one point in time as indicated by the lighter and darker shades of brown in the river channel.

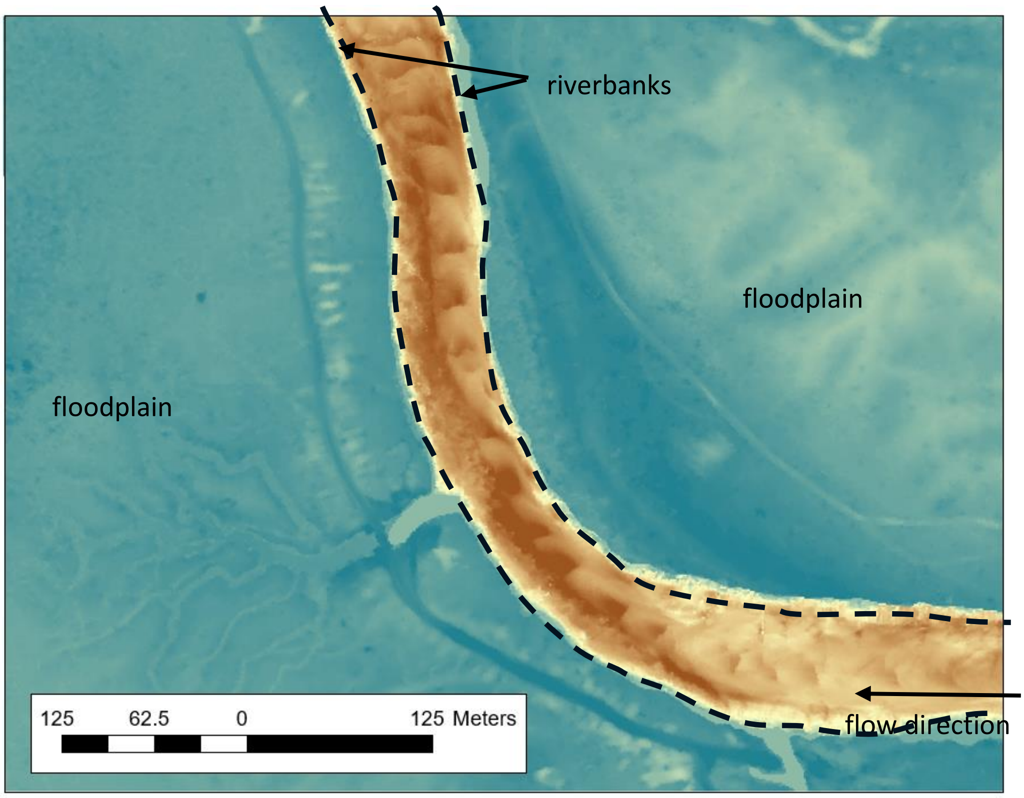



Figure 2 A view of the sand dunes (in brown) along the riverbed in the Barmah-Millewa reach (Streamology, 2020)

Comparing bed level measurements covering the entire riverbed (known as bathymetric data, or bathymetry) from one date to another allows us to track patterns of sand movement in detail. This method is effective in the Barmah-Millewa reach as the overall large amount of sand and the small size of the channel mean changes in bed level can be measured and monitored over time. It is important to capture these changes as the movement of sand can have a large impact on the bank condition of the river through bank erosion, the riverine environment, and the flow capacity of this part of the river.

The presence of accumulated sand was first identified by analysis of riverbed level data captured between August 2018 and February 2019 and detailed in Streamology (2020 & 2021). Repeat bed level data for some areas was captured in February 2022, and then again in early 2023.

The very high flows that occur during floods, like those starting in October 2022, can carry large volumes of sand and substantially alter how sand is distributed within the reach. Floods have the potential to cause a relatively large amount of bed level change compared to more moderate flows (even those occurring over longer time periods). A key objective of this study was therefore to assess how the 2022 floods changed the amount and distribution of sand in the Barmah-Millewa reach and determine how any changes align with existing knowledge of sediment transport processes in the reach.

The focus of the study is on three key questions:

1. How has the bed level changed (from 2018 to 2023) within the River Murray main channel (particularly at key locations like Picnic Point and Morgan's Beach[1])?
2. Has the 2022 flood resulted in a decrease, increase, or no change in the estimated total amount of sand in the reach?
3. How do any changes align with our understanding of sediment transport processes in the reach?

A summary of the approach used for the study is provided in the next section, with the remainder of the report structured around the above questions.

[1] Only bathymetric data from Picnic Point was available at the time of writing.

## 2 Study approach

The main technique used for the study is the comparison of measurements of riverbed level captured before (February 2022) and after (February 2023) the floods. The two sets of bed level (or bathymetry) data cover around 15 km of the River Murray main channel, beginning 5 km upstream of Picnic Point and extending a further 10 km downstream (Figure 3). The datasets represent the elevation, or level, of the bed in metres above the Australian Height Datum (m AHD) for every square metre of the bed.

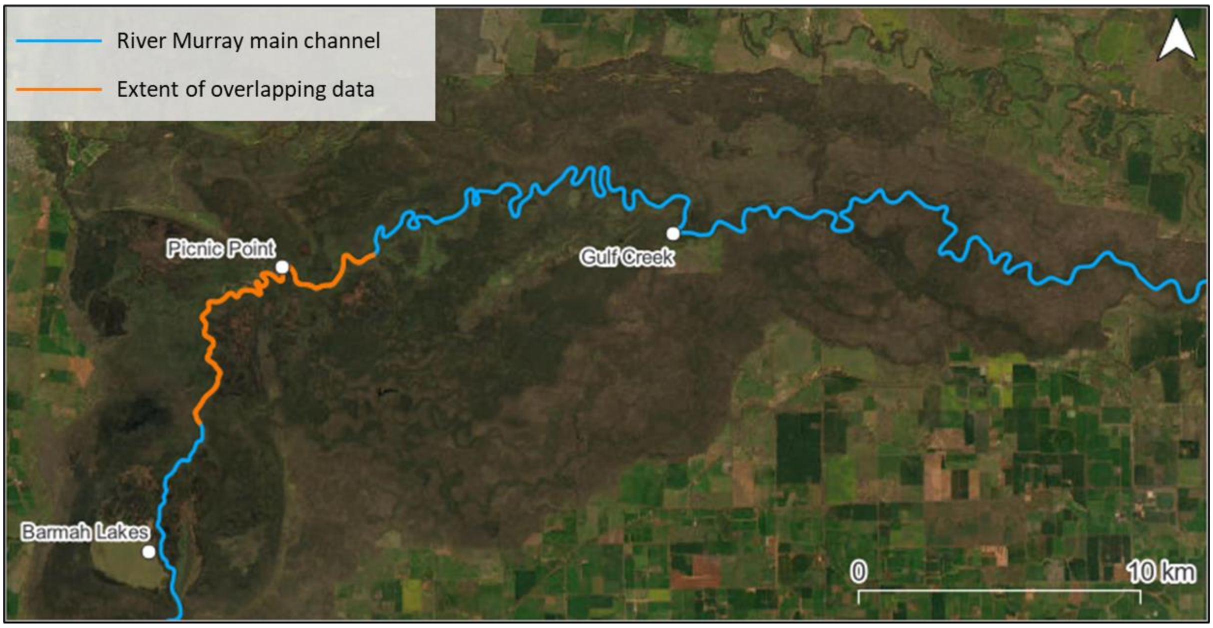



Figure 3 Exent of bed level survey where data before and after the October 2022 flood event is available (in orange)

Subtracting the dataset of elevations after the flood from those recorded before, provides a map of bed level changes covering the whole riverbed along the reach. A decrease in the amount of sand shows up as negative values, whereas an increase in the amount of sand appears as positive values. In the example in Figure 4, sand thickness decreases are shown using red tones, and sand thickness increases with blue.

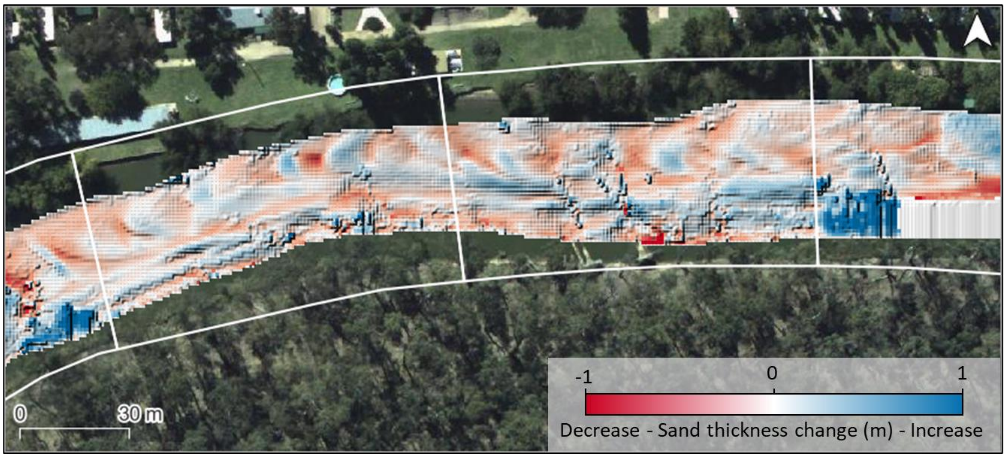



Figure 4. Example map of a small section of riverbed, showing the pattern of sand thickness decrease (red) and increase (blue) that was recorded before and after the floods.

These results are examined in detail to reveal the patterns of sand movement that occur in different parts of the riverbed (e.g., decrease in one place, increase in another). Also, by grouping the results into 100-metre-long sections of river (i.e., the white boxes in Figure 4) and averaging the measurements within each, it is possible to generalise the amount of change to reveal the larger-scale patterns along the reach. The measurements of bed level change can also be used to calculate the estimated volume of sand (in cubic metres) removed or added in different sections and the net change.

The measured changes in sand thickness and estimated volume between 2022 and 2023 are put in the larger context of sand movement in the Barmah-Millewa reach by comparing to changes that occurred in the preceding three years using earlier data captured in late 2018/early 2019. The survey dates for the three different datasets are depicted in Figure 5 along with the record of flows that occurred over time.

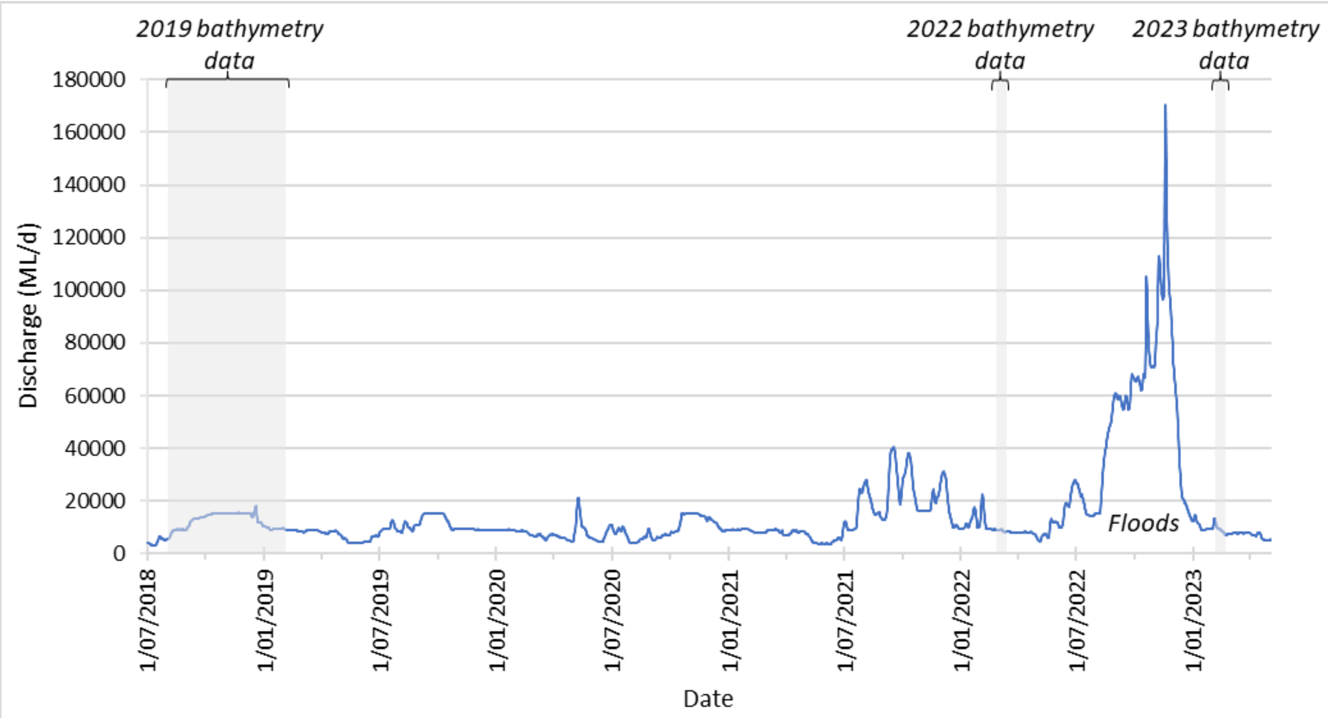



Figure 5. Hydrograph of River Murray flows (Tocumwal gauge) showing timings of the surveys used to capture the bathymetry data for this study.

# 3 Findings

## 3.1 Question 1 — Bed level change

The first question examined in the study is:

> How has the bed level changed from 2018 to 2023 within the River Murray main channel (particularly at key locations Picnic Point and Morgan's Beach)?

Measured level changes show the riverbed in the reach is dynamic, with highly varied change detected throughout. Sand has moved over time, which appears as changes to the bedforms in the channel. Change includes migration of large waves (or dunes) of sand along the bed, increases or decreases in the size of sandbars, and deepening or infilling of scour holes (see Figure 6 for examples).

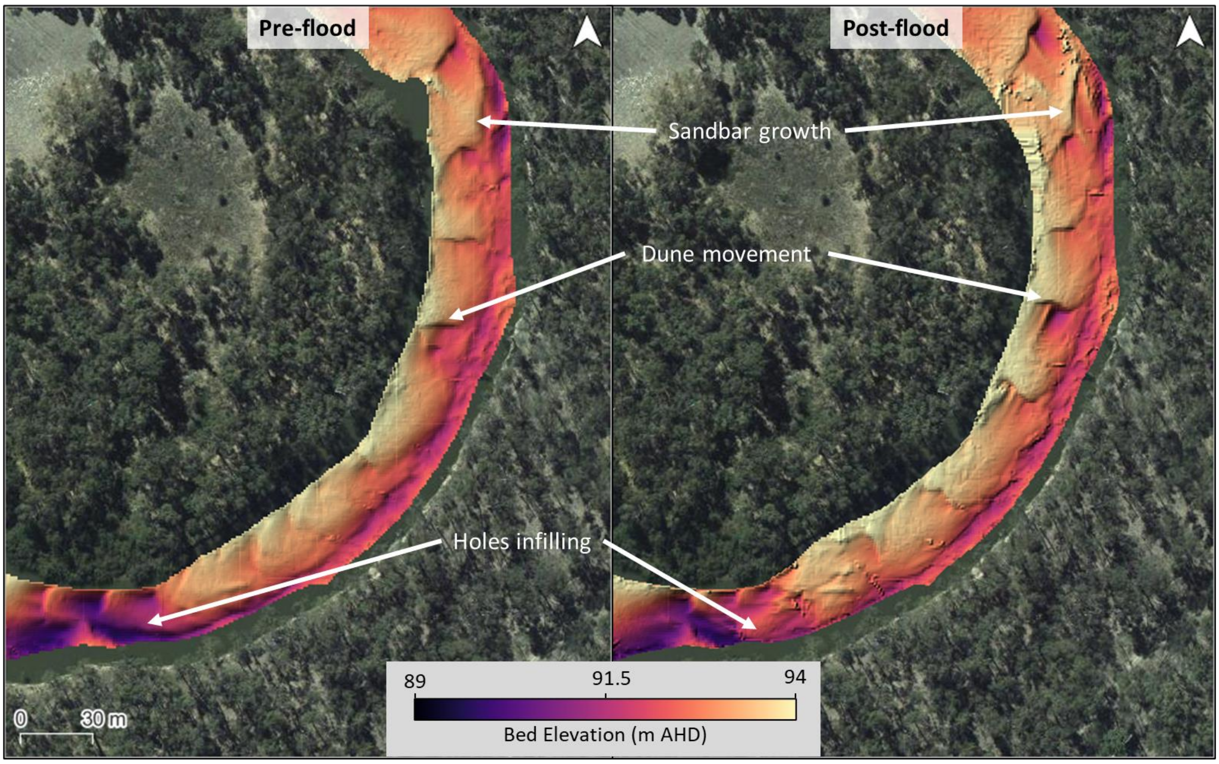



Figure 6. Bed elevation maps from pre- and post-flood showing changes to bedforms.

Example maps illustrating some of the different patterns of change over the two periods are provided in Figure 7 and Figure 8, below. In the first example (Figure 7), the area near the Edward River (Kolety) offtake was dominated by sand thickness increases during the 2019-22 (non-flood) period, which appears as more blue than red in the left map. For the 2022-23 (flood) period, the same area experienced more of a balance between sand thickness decreases and increases, which shows as a mixture of red and blue in the righthand map.

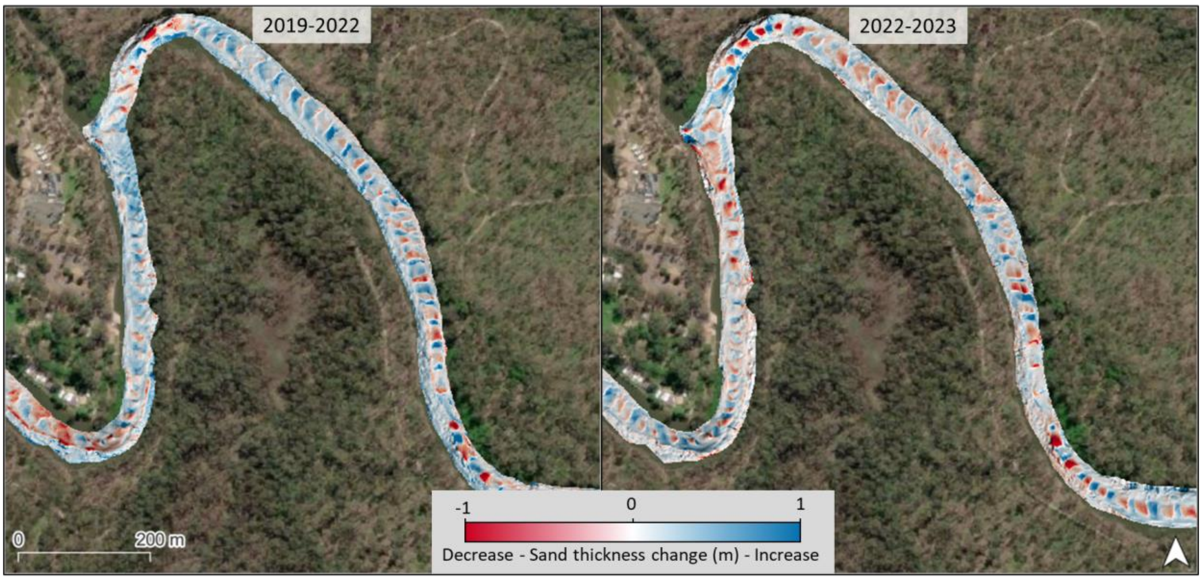



Figure 7. Maps of sand thickness change near the Edward River (Kolety) offtake showing the patterns of sand thickness increase and decrease that have occurred over two different periods.

In contrast, much of the reach downstream of Gulpa Creek was dominated by sand thickness increases during the 2022-23 (flood) period, as opposed to sand thickness decreases during 2019-22. Figure 8 includes example maps of this area.

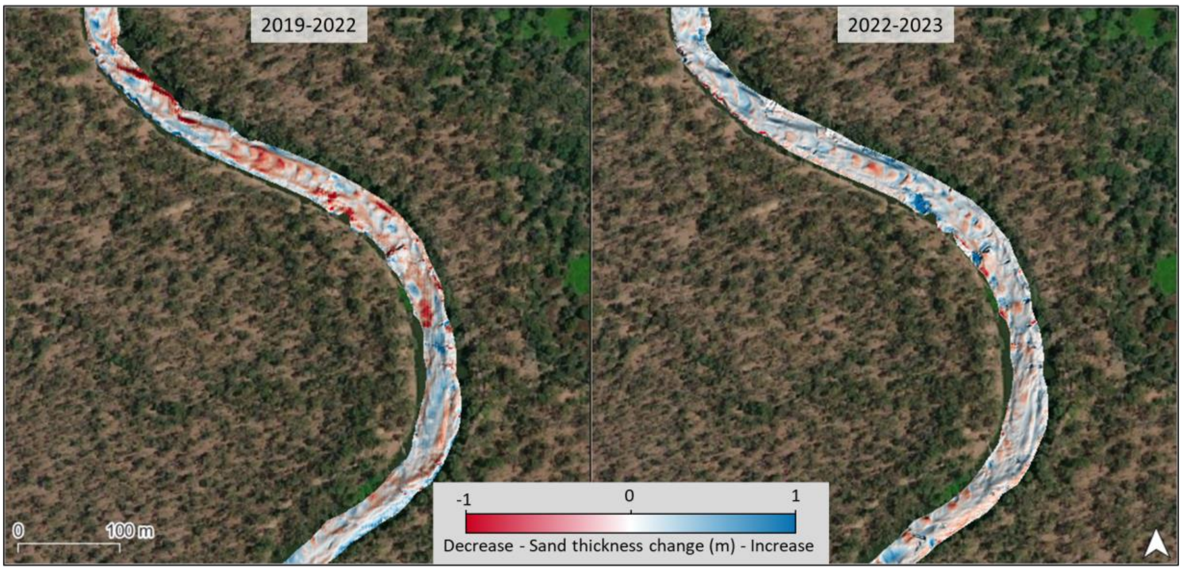



Figure 8. Maps of sand thickness change downstream of Gulpa Creek, showing the patterns of increase and decrease that have occurred over two different periods.

The larger scale assessment of bed level change is determined by averaging the measured changes from scans conducted in 2022 compared to 2023 for every 100-metre-long section of riverbed (Figure 9). The top panel shows the average bed change in each section in map form, with red sections indicating overall lowering of the bed (sand thickness decrease) and blue an overall increase of the bed level (sand thickness increase). The same sequence of average changes is also plotted against the downstream distance as a line plot in the bottom panel. Key observations to draw from Figure 9 include:

- Measured change is spatially variable, even when averaged by 100-metre sections.
- Overall, the reach is dominated by sand thickness increases, as indicated by several blue segments in the map and the line plot being above zero for most of its length.
- There are three main parts of the reach where sand thickness decreases are dominant, with one centred on Boals Creek, one around Gulpa Creek, and another downstream of Gulpa Creek.

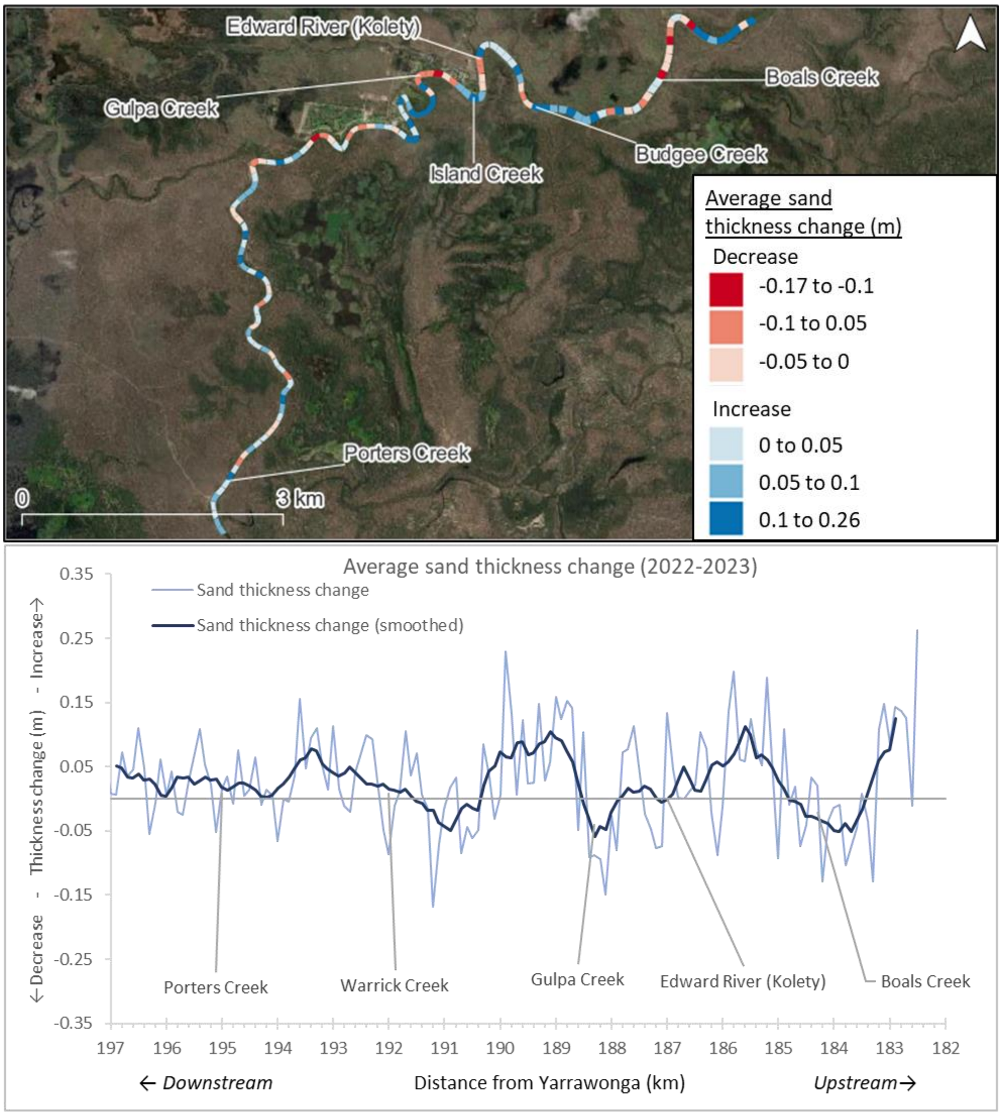



Figure 9. Average sand thickness change (2022-23) for every 100 m long section of riverbed showing in maps form (top) and as a line graph (bottom). Light blue line depicts average values for every 100 m section of riverbed, which has been further smoothed using an 800 m moving window filter to create the dark blue line.

The changes observed from results before and after the flood can also be compared with those occurring over the three years prior (2019-2022) in Figure 10. Key differences in the patterns of sand movement between these two periods include:

- The upstream two thirds of the reach were dominated by sand thickness increases during the 2019-2022 period, while changes in the 2022-23 (flood) year were more varied.
- The downstream third of the reach was dominated by sand thickness decreases during the 2019-2022 period, while sand thickness increases dominated over the 2022-23 (flood) year.

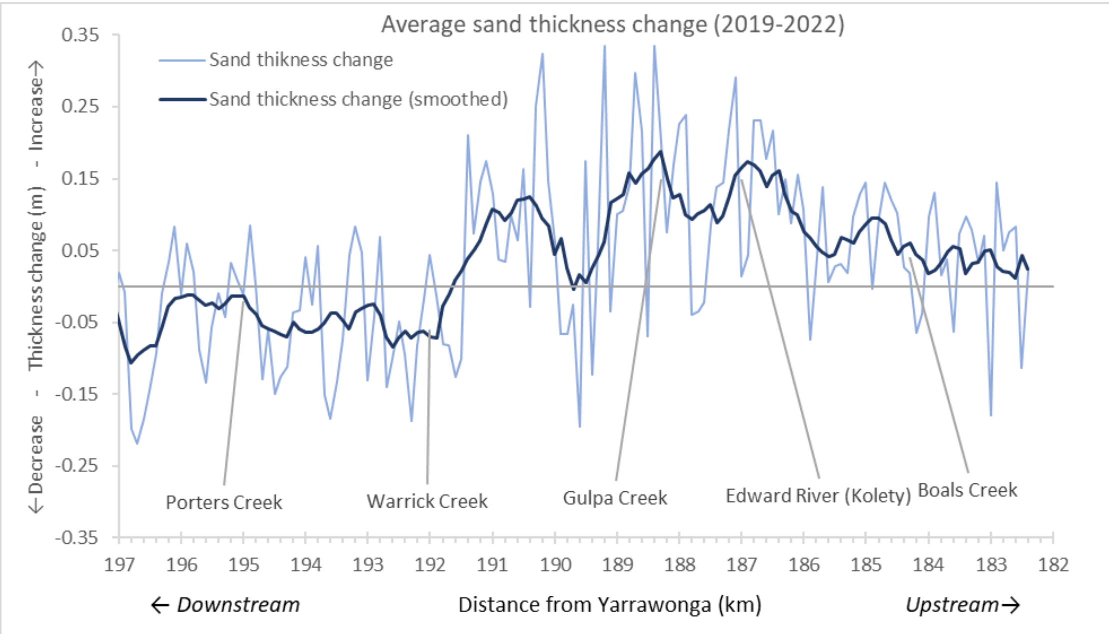



Figure 10. Average sand thickness change (2019-22) for every 100 m long section of riverbed. Light blue line depicts average values for every 100 m section of riverbed, which has been further smoothed using an 800 m moving window filter to create the dark blue line.

While the bed level changes are variable, the differing patterns of change along the reach over the 2019-22 (non-flood) period compared to the 2022-23 (flood) year indicates a wholesale movement of sand from upstream to downstream.

## 3.2 Question 2 – Sand volume change

The second question addressed by the study is:

| |
|---|
| Has the 2022 flood resulted in a decrease, increase, or no change in the estimated total amount of sand in the reach? |

While the bed level changes in the section above may appear small (i.e., mostly within ±15 cm), this is due to the averaging process which supresses extremes in change. A better appreciation of the scale of change is gained by examining the volume of sand these changes represent across the reach. The estimated total volumes of sand removed or added (i.e., all negative and positive measurements summed separately) and net change (i.e., gross increases minus gross decreases) occurring over the two time periods are listed in Table 1, below. Key things to note include:

- Total net sand volume change for the reach was positive with a net increase (more sand added than removed) for both periods.
- For the one-year period of 2022-23 (flood year), there was an estimated 16,600 m³ of sand added to the 15 km reach (a volume equivalent to 6.6 Olympic sized swimming pools).
- During the preceding three years (2019-22), 23,000 m³ of sand (9.2 Olympic sized swimming pools) was estimated to have been added to the reach.
- While the gross increase in estimated sand volume was lower for the 2022-23 period, compared to 2019-22, so was the gross decrease.

Table 1. Summary of total sand volume changes along the 15 km reach, for two time periods.

| Period | Gross Decrease (m³) | Gross Increase (m³) | Net Change (m³) |
|---|---|---|---|
| 2019-22 (non-flood) - 3 years | -71,700 | 94,800 | 23,000 |
| 2022-23 (flood) - 1 year | -64,000 | 80,600 | 16,600 |

A more detailed view of the estimated sand volume changes along the reach is provided in the bar chart in Figure 11 for the 2022-23 flood year. Each bar denotes the net volume of sand for every 100-metre-long section of riverbed that was either added (blue) or removed (red). The overall dominance of sand increases along the 15 km reach is indicated by the greater number and larger size of blue bars relative to red bars.

For comparison, the net sand volume change for the prior 2019-22 period is plotted in Figure 12. This shows that in the three years prior to the flood year there was mostly an increase in sand volumes upstream of Warwick Creek while decreases in sand volume tended to dominate downstream.

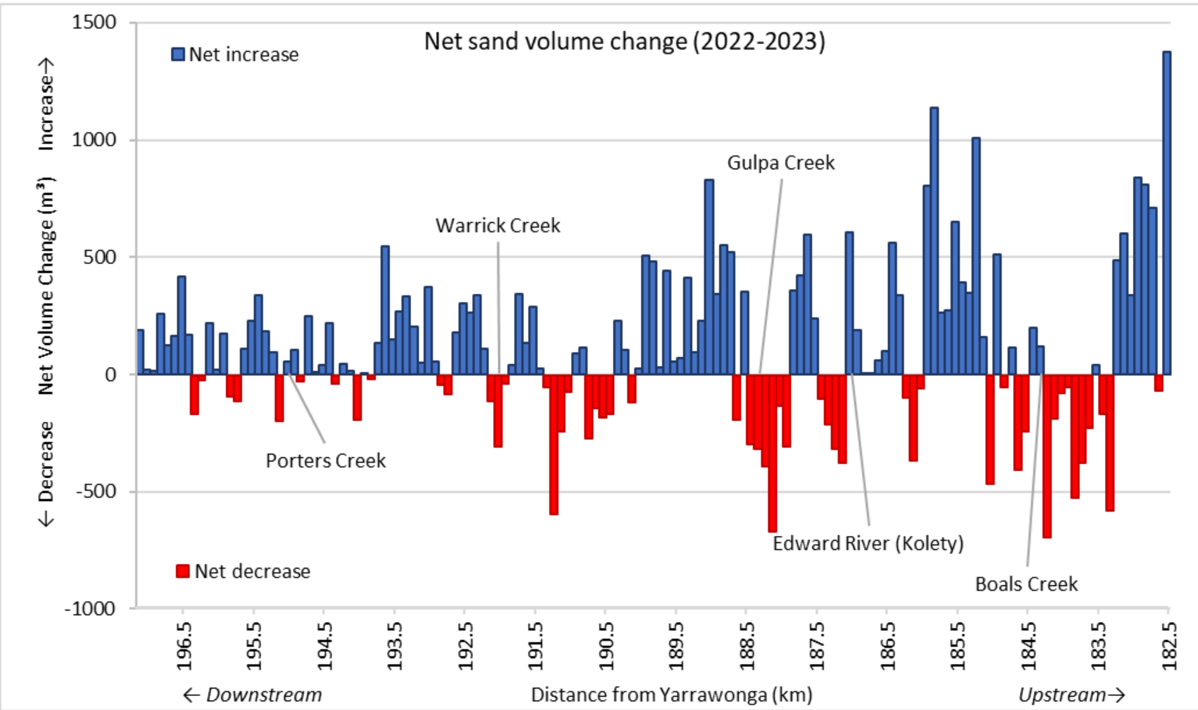



Figure 11. Bar chart showing net sand volume change (increases minus decreases) for every 100-metre-long section of riverbed for the 2022-23 period.

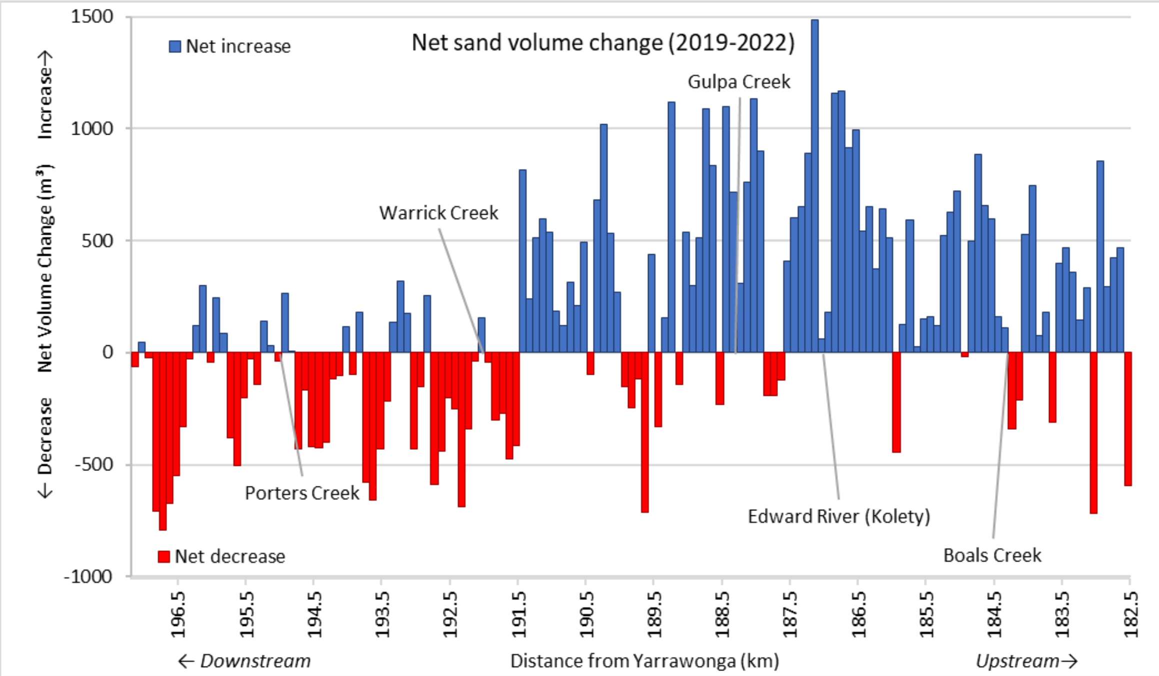



Figure 12. Bar chart showing net sand volume change (increases minus decreases) for every 100-metre-long section of riverbed for the 2019-22 period.

By comparing the bed level in 2019 (the earliest data available) with 2023 (the most recent data) we can see the estimated total volume of sand that has been added or removed from the reach over the study period. The total volume change is shown in Figure 13, below. The overall pattern is like the 2019-2022 period, but with the reach upstream of Warrick Creek even more dominated by deposition.

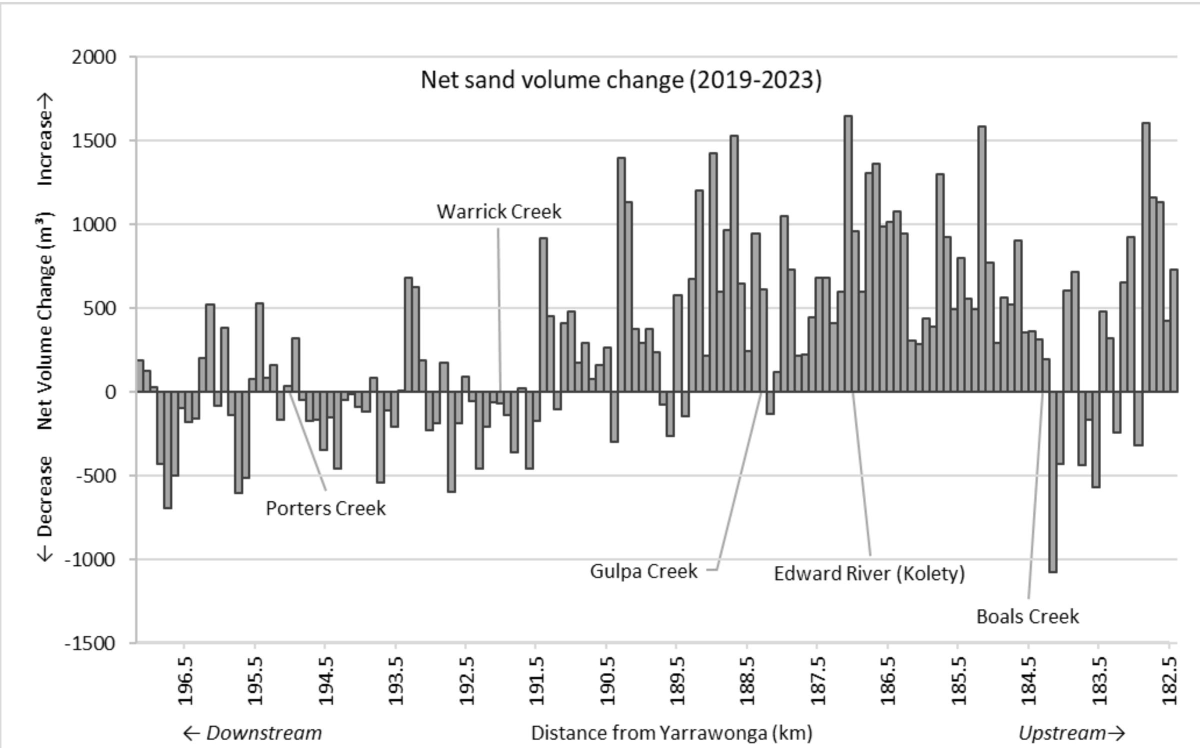



Figure 13. Bar chart showing net sand volume change for every 100 m of riverbed for the entire 2019-2023 period (cumulative result of both 2019-2022 and 2022-2023 periods combined).

Modelling detailed in Streamology (2022) has indicated the *sub-reach* most important for impacts on the overall flow capacity of the Barmah-Millewa reach (if sand thickness change) is the 11 km from Gulpa Creek downstream to Cutting Creek. Nine kilometres of this sub-reach are captured in the data for this study. Total changes in sand volume for this sub-reach are provided in Table 2, including for both the flood period (2022-23) and the preceding three years (2019-22). Key differences in this sub-reach include:

- The total net volume of sand added to the 9 km sub-reach because of the 2022-23 (flood) year was almost 14 times the amount for previous three years (2019-22).
- There was an approximate 9,000 m³ net increase in the volume of sand estimated to be in the sub-reach during the 2022-23 (flood) year.
- The net change in sand volume largely balanced during the 2019-22 period (i.e., a similar amount of sand was added as was removed).

Table 2. Summary of the estimated total sand volume changes along key reach downstream of Gulpa Creek, for two time periods.

| Period | Gross Decrease (m³) | Gross Increase (m³) | Net Change (m³) |
|---|---|---|---|
| 2019-22 (non-flood) - 3 years | -44,400 | 45,000 | 660 |
| 2022-23 (flood) - 1 year | -29,700 | 38,800 | 9,000 |

The second most important sub-reach for impacts on flow capacity is the 4 km section from Boals Creek downstream to Gulpa Creek (all of which is captured in the data). Total sand volume changes for this reach are provided in Table 3. Key things to note about the changes in this sub-reach are:

- There was a large amount of sand (~19,300 m³) added to this sub-reach during the 2019-22 (non-flood) period.
- There was also a net increase in sand in the sub-reach over the 2022-23 (flood) year, however the net amount was much less (at 5,300 m³) than for the preceding three years.

Table 3. Summary of the estimated total sand volume changes along key reach between of Boals Creek and Gulpa Creek, for two time periods.

| Period | Gross Decrease (m³) | Gross Increase (m³) | Net Change (m³) |
|---|---|---|---|
| 2019-22 (non-flood) - 3 years | -16,000 | 35,300 | 19,300 |
| 2022-23 (flood) - 1 year | -20,700 | 26,000 | 5,300 |

Like the overall pattern of bed level change, the volume of sand deposited in these two sub-reaches over the 2019-22 and 2022-23 periods indicates a general large-scale movement of sand from upstream to downstream.

## 3.3 Question 3 – Sediment transport processes

The third question addressed by the study is:

> How do any changes align with our understanding of sediment transport processes in the reach?

We are interested in how any measured changes in bed level during the flood and prior period help to explain observed impacts on flow capacity and health of the reach, in the context of existing findings from modelling of sediment transport in the reach.

### 3.3.1 Existing modelling results

Previous reports (Streamology 2020, 2021) have shown that there is a clear decrease in energy and transport rates downstream through the Barmah-Millewa reach. This decrease acts as a fundamental control, reducing sediment transport rates downstream even under high upstream flows.

Streamology (2020) calculated that 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 flood, to over 500,000 $m^3$/year during a major flood. Compare this with downstream where transport rates are lowest, annual sediment loads ranged from 70,000 – 80,000 $m^3$/year with loads during a flood year greater than non-flood years but still significantly reduced compared to upstream.

Then in Streamology (2021) it was estimated that during non-flood years, the average increase in sand thickness of as much as 5-6 cm/year in the widest parts of the Barmah-Millewa reach could occur, compared to 2.4 cm/year for the narrowest downstream section. In a large flood year, the rate of increase in sand thickness may be substantially higher, estimated at 9 cm/year upstream and 4.5 cm/year in the narrow downstream section (i.e., downstream of Gulpa Creek and Picnic Point). Using just the non-flood rate of sand thickness increase of 2.4 cm/year and applying it to a typical cross-section in the narrowest downstream part of the reach results in a predicted 8% reduction in channel capacity (from 198 to 182 $m^2$) over 10 years (depicted in Figure 14).

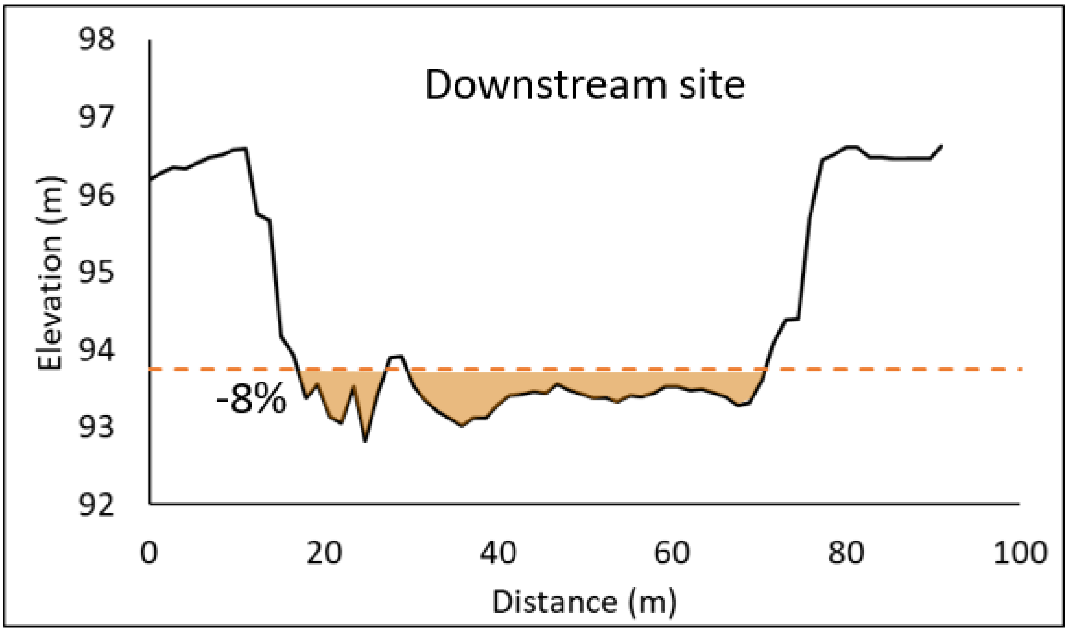



Figure 14. Previous analysis of predicted channel cross-section change over 10 years based on modelling, for a narrow downstream part of the reach (original area 198 $m^2$).

### 3.3.2 Effects on capacity

In Streamology (2022) an assessment of hydraulic capacity was undertaken for exploring Barmah-Millewa sand removal options. This included an assessment of a limited 'Do Nothing' scenario, which estimated an 8% decrease in channel cross-sectional area from sand accumulating and increasing in thickness over 10 non-flood years (Figure 14, above). The model was run for a steady state flow of 9,100 ML/d with the cross-sections in the model reduced by 8% to simulate the predicted conditions 10 years from now. The area of each cross-section was reduced over a 9,250 m length of channel around Picnic Point (Figure 15) in order the test potential effects on water level and flow. It is important to note, however, that increases in bed level (and hence reductions in channel cross-sectional area) could extend across a much greater extent and would likely be more variable (as shown in the various bathymetric survey results).

The modelling found that if the sand thickness increases occurred (the 8% decrease in channel cross-sectional area scenario) the resultant water level increase was around 83 mm at Gulpa Creek. This equated to a decrease in flow capacity of 14% which was around 1,070 ML/d. The reduction in capacity resulting from sediment accumulation occurs because this section is narrow and is the most sensitive to change in cross-sectional area of all the sections of the Barmah-Millewa reach.

A non-flood year average rate of sand thickness increases was assumed within the scenario, which is lower than occurs in a flood year. As the original analysis and the recent survey results show, in a flood year the average rate of increased sand thickness can be more than twice the non-flood year meaning that if a flood occurs this would reduce the time it takes to reduce the channel capacity through sedimentation by 8%.

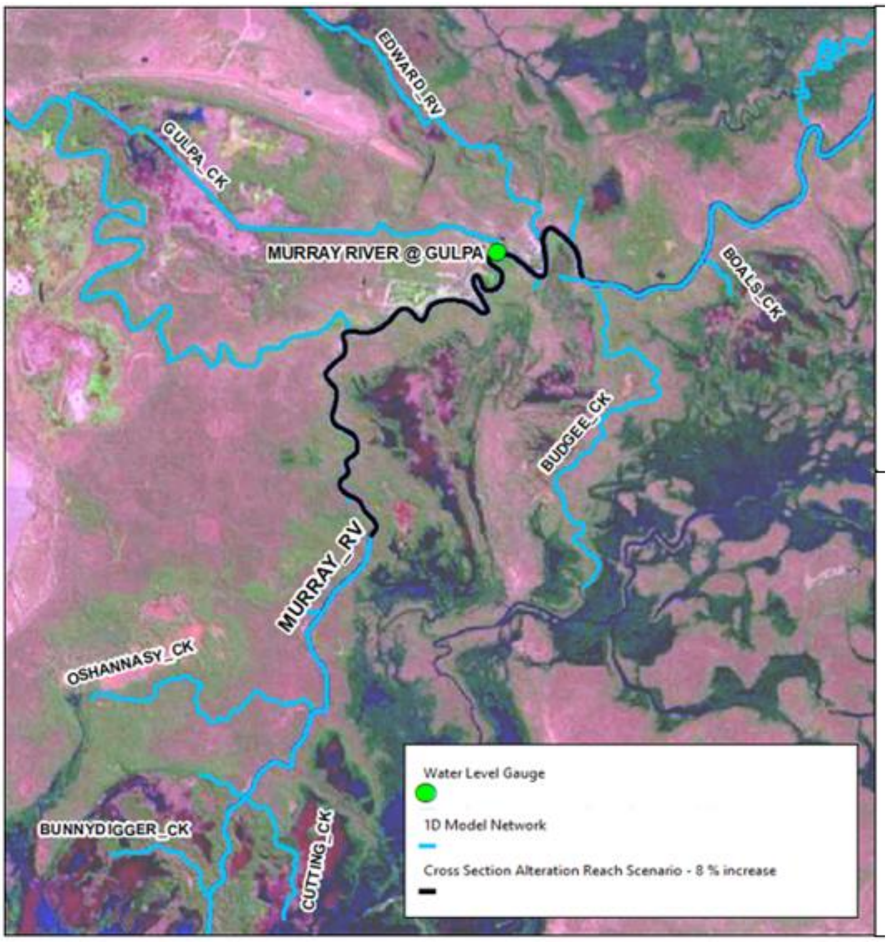



Figure 15. Modelled extent of sediment deposition (assumes an 8% reduction in channel cross-sectional area, equivalent to approximately 10 years of non-flood sand thickness increases)

### 3.3.3 Post-flood observations of flow capacity change

Recent estimates of flow rates by flow gauging through the Barmah-Millewa reach in the wake of the 2022 flood[2] suggest the flow capacity has reduced following the flood year to 8,300 ML/d to maintain a water level of around 2.6m at Picnic Point under regulated flow conditions (i.e., with the forest regulators closed). The results of the bathymetric change analysis in the current study provides some insights as to the reasons for this change.

Because flow capacity in the Barmah-Millewa reach is estimated using water levels recorded near Picnic Point (Murray River @ Gulpa gauge), any changes in bed level directly downstream of this point can have a disproportionate impact on the flow capacity of the reach overall. Some of the largest bed level increases measured over the 2022-23 flood period were detected immediately downstream of Gulpa Creek (see maps, Figure 16).

This sub-reach saw the growth and movement of large waves (or dunes) of sand, increases in the size of sandbars, and infilling of scour holes. While sand thickness decreases still occurred in pockets downstream of Gulpa Creek, sand thickness increases were dominant for at least 1.5 km downstream. In some places the bed level increased by 1 m (dark blue areas on the left panel on Figure 16) , and when averaged over 100-metre-long segments, the mean bed level was raised by 10–26 cm in nine of 17 segments downstream of the gauge at Gulpa Creek (dark blue sections in the right panel of Figure 16).

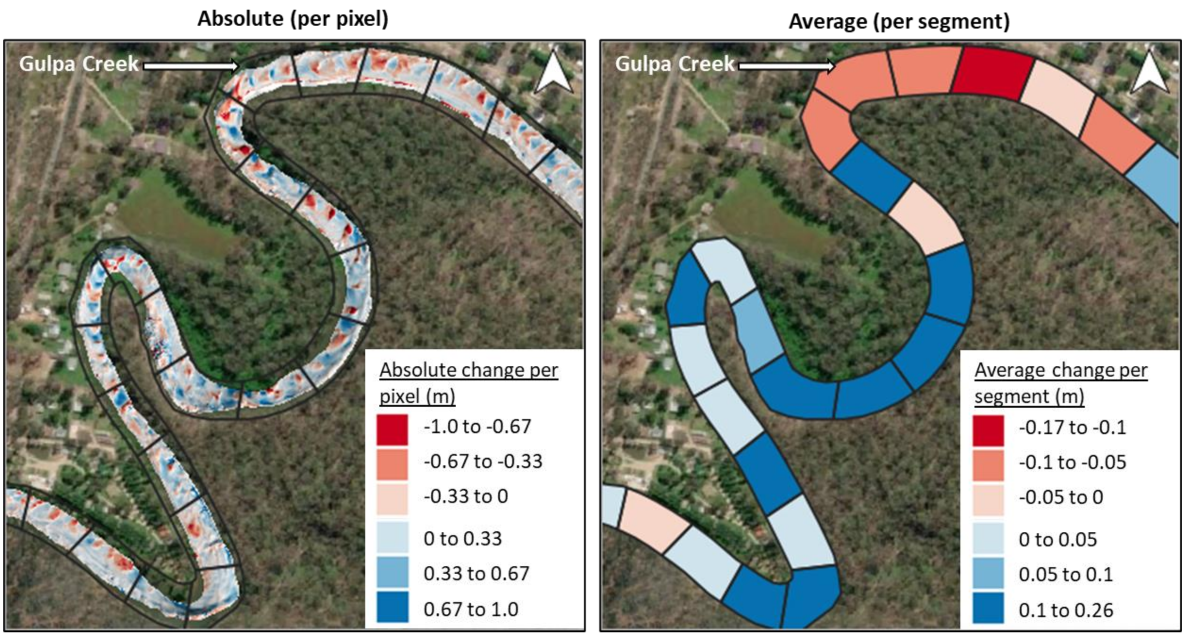



Figure 16. Maps showing the absolute (left) and average (right) sand thickness increase that occurred in the area downstream of Gulpa Creek over the 2022-23 flood period. Red shades denote sand thickness decreases, blue shades denote increases.

Another view of the average bed level increase downstream of the gauge at Gulpa Creek is provided by the bar chart in Figure 17. The dominance of sand thickness increases in the sub-reach most likely to impact flow capacity is illustrated by the mean positive bed level changes for most of the 1.6 km on the left of the chart. Such a large and consistent increase in bed level (relative to more varied areas)

[2] See media release: [Murray River water storages high but dry condition planning is underway | Murray–Darling Basin Authority (mdba.gov.au)]

in this area assists in understanding the observed impacts of the recent flood year on flow capacity (i.e., a reduction in flow capacity).

While the overall average rates of change in bed level along the surveyed reach give a lower rate of sediment accumulation than previously predicted for a flood year (4.5 cm/year predicted for downstream of Gulpa Creek), the data in Figure 17 show that in several segments of the channel, the accumulation was well in excess of this value. The highly variable nature of sediment movement, the availability of supply from upstream, and the response to both flood and non-flood conditions make it difficult to validate the modelled prediction. However, the results do clearly show that during flood years, if there is a good supply of sediment it can readily be transported along the reach, and the transport rate upstream can exceed the transport rate out of the reach – in agreement with the model predictions.

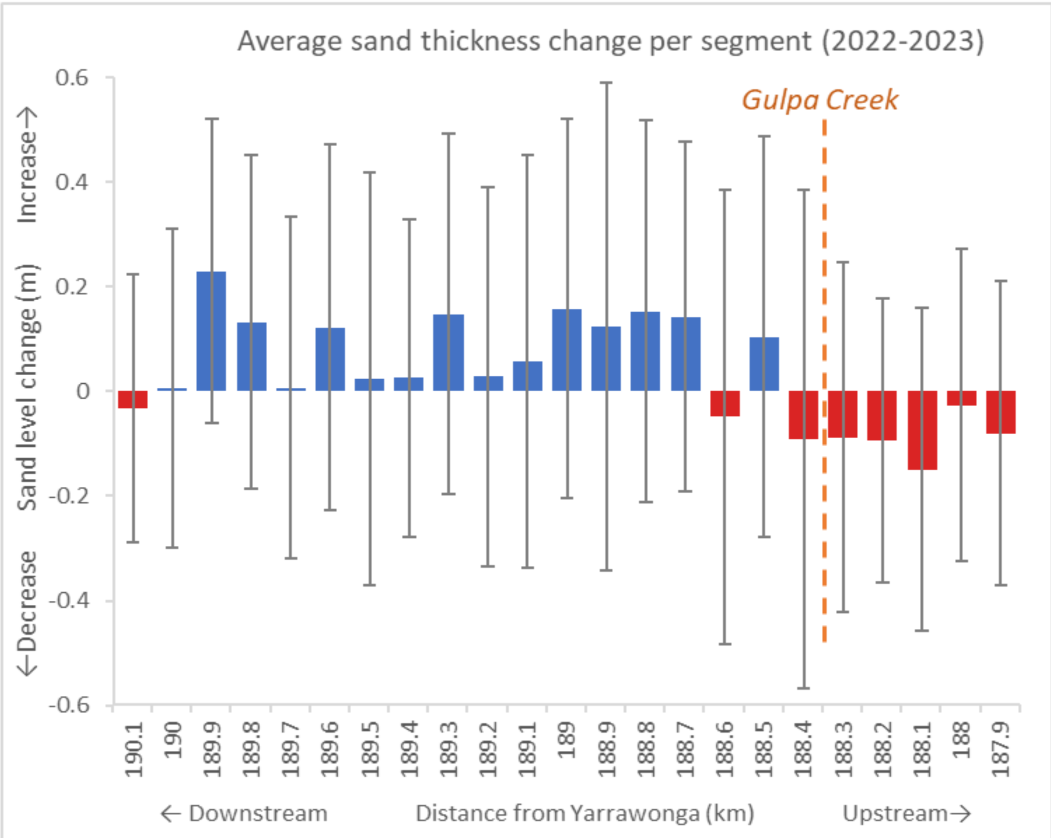



Figure 17. Bar chart of average bed level change per 100-metre-long segment showing the bed level increase that occurred in the area downstream of Gulpa Creek over the 2022-23 flood period. Red denotes sand thickness decreases, blue denotes increases.

# 4 Conclusions

Changes to the flow capacity through the Barmah-Millewa reach of the River Murray since the late 1980s can in part be attributed to the presence of an estimated amount of more than 20 million $m^3$ of coarse sand on the bed of the river between Yarrawonga Weir and Echuca. Previous studies have found that much of this sand was most likely mobilised through land use changes and gold mining in the 1800s, whereby large volumes of sediment were deposited into catchment waterways upstream. Various lines of evidence now indicate that this sand has slowly migrated downstream and is currently building up in the Barmah-Millewa reach.

The presence of the accumulated sand was first identified by analysis of riverbed level data captured between August 2018 and February 2019 and detailed in Streamology (2020 & 2021). Repeat bed level data for some areas was captured in February 2022, and then again in early 2023. These repeat riverbed level datasets are an important means of monitoring the sand movement in the Barmah-Millewa reach. An increase in the thickness of the sand layer on the riverbed raises the bed level while a decrease in the thickness of sand causes a lowering in the level of the bed. The sand also moves along the riverbed in the form of "dunes" which means the level varies up and down depending on where and how fast each dune is moving.

Floods can carry large volumes of sand from upstream into the Barmah-Millewa reach compared to more moderate flows and so the key objective of this study was to assess how the 2022 floods changed the amount and distribution of sand in the Barmah-Millewa reach and determine how any changes align with existing knowledge of sediment transport processes in the reach.

The focus of this study was to answer three key questions relating to changes in bed levels and sand volumes because of the October 2022 flood event. The questions and outcomes are summarised below:

**1. How has the bed level changed within the River Murray main channel (particularly at key locations like Picnic Point)?**

The repeat bed level analysis results show that sand has moved over time, through changes to the bedforms in the channel. Change includes migration of large waves (or dunes) of sand along the bed, increases or decreases in the size of sandbars, and deepening or infilling of scour holes. While the bed level changes are variable, the differing patterns of change along the reach assessed over the 2019-22 (non-flood) period compared to the 2022-23 (flood) year indicates a wholesale movement of sand from upstream to downstream.

**2. Has the flood resulted in a decrease, increase, or no change in the total amount of sand in the reach?**

Overall, the total net sand volume change for the reach was positive with a net increase (more sand added than removed) for the 2019-22 and 2022-23 periods. However, for the 2022-23 (flood year), there was an estimated 16,600 $m^3$ of sand added to the 15 km reach (a volume equivalent to 6.6 Olympic sized swimming pools), compared to an estimated 23,000 $m^3$ of sand (9.2 Olympic sized swimming pools) was added to the reach during the preceding three years (2019-22). This means that twice as much sand was added to the reach during the flood year compared to each non-flood year.

Like the overall pattern of bed level change, overall, the estimated volume of sand deposited over the 2019-22 and 2022-23 periods indicates a general large-scale movement of sand from upstream to downstream with a net increase across the reach.

### 3. How do these changes align with our understanding of sediment transport processes in the reach?

Previous modelling of the effects of the bed level increases on flow capacity indicated that the sub-reach of the river downstream of Gulpa Creek, near Picnic Point, is particularly sensitive to change. Some of the largest bed level increases measured over the 2022-23 flood period were detected immediately downstream of Gulpa Creek.

While the overall average rates of change in bed level along the surveyed reach give a lower rate of sediment accumulation than previously predicted for a flood year (4.5 cm/year predicted for downstream of Gulpa Creek), the results show that in several segments of the channel much more sand accumulated. The highly variable nature of sediment movement, the availability of supply from upstream, and the response to both flood and non-flood conditions make it difficult to validate the previously modelled prediction. However, the results do clearly show that during flood years, if there is a good supply of sediment it can readily be transported along the reach, and the transport rate upstream can exceed the transport rate out of the reach – in agreement with the model predictions.

The bed level increases over the flood year align with the latest flow gauging which measured a reduction in the flow capacity through the Barmah-Millewa to 8,300 ML/d under regulated flow conditions (i.e., with the forest regulators closed), when a water level of around 2.6 m is maintained at Picnic Point. The results of the bed level change analysis in the current study provides some insights as to the reasons for this change (i.e., large increase in sand immediately downstream of Gulpa Creek).

# 5 References

HARC. (2021). Historical flows in the southern connected Murray-Darling Basin. Report prepared for the Murray-Darling Basin Authority

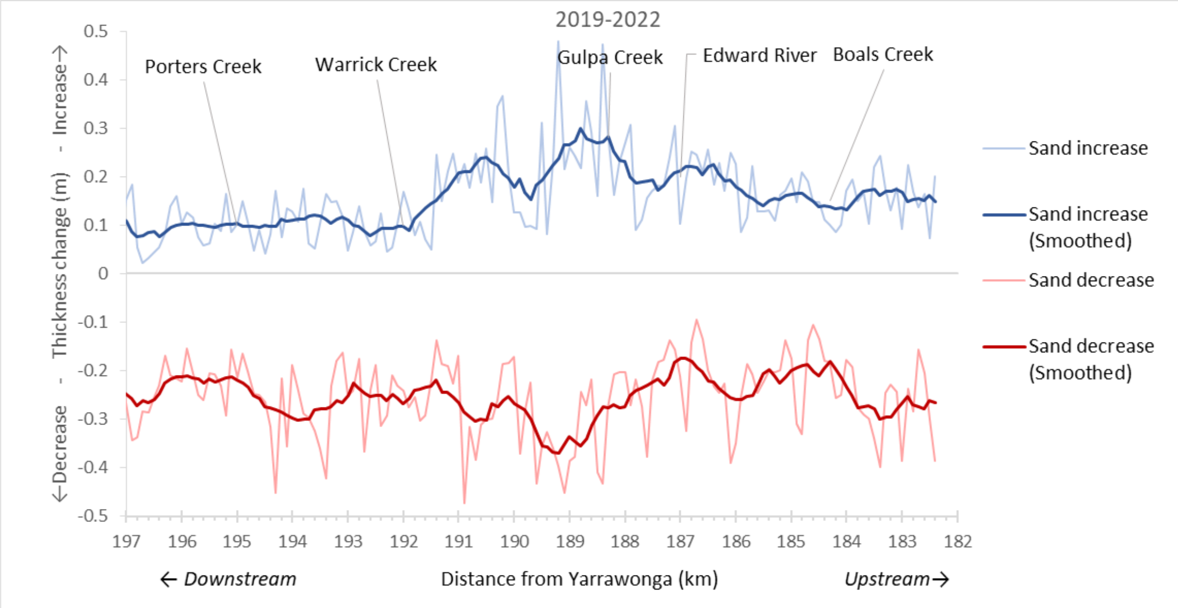
Streamology. (2020). Barmah Choke Sediment Transport Investigation. Report prepared for the Murray-Darling Basin Authority.

Streamology. (2021). Options for Managing the Capacity of the Barmah-Millewa Reach of the River Murray – Preliminary Investigations. Report prepared for the Murray-Darling Basin Authority.

Streamology. (2022), Options for Managing Sediment in the Barmah-Millewa Reach of the River Murray – Stage 2 Options Assessment, Report prepared for the Murray-Darling Basin Authority

## Appendix

Additional supporting information is provided here.



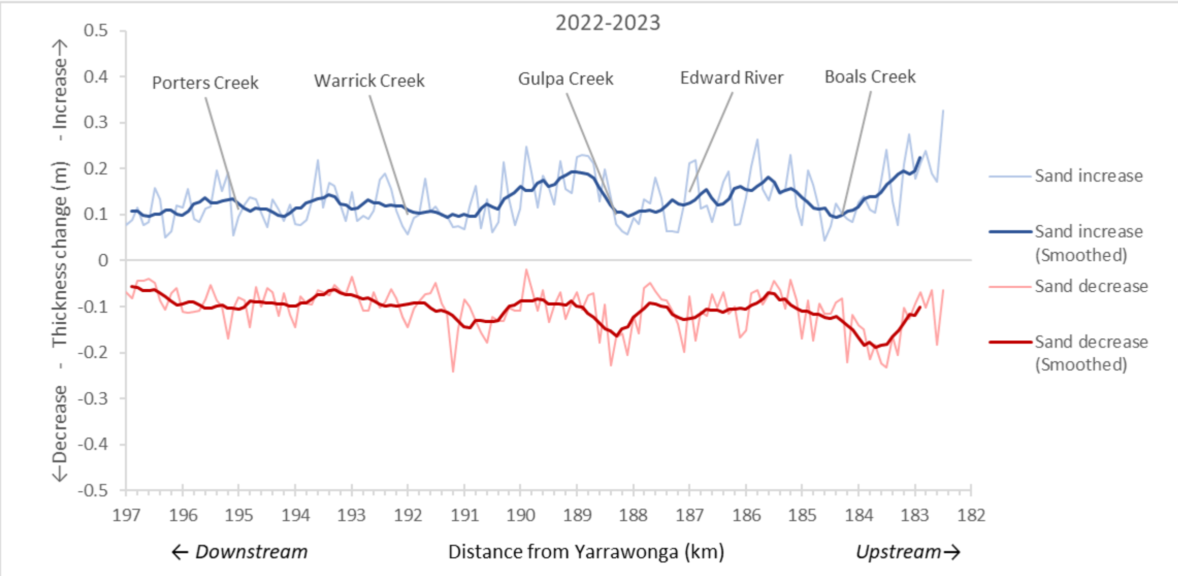
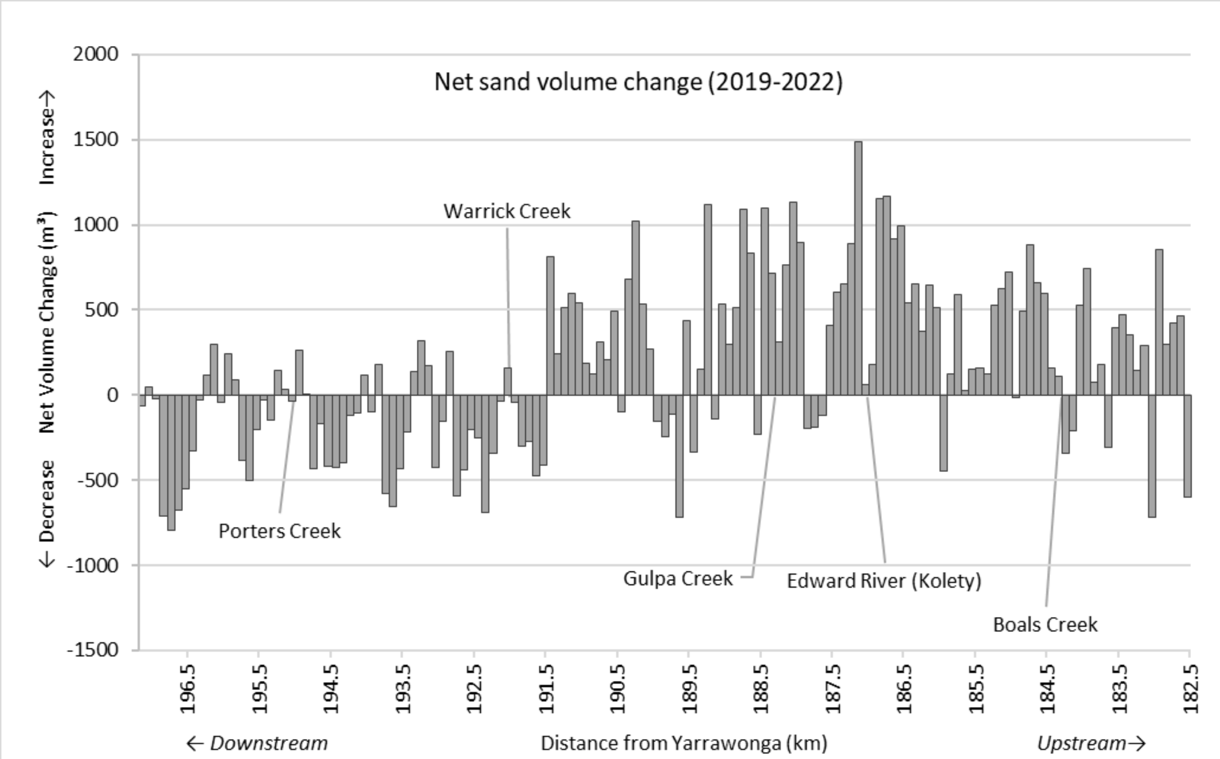




Figure 18. Line plots showing estimated average sand thickness increase, separated into decrease (red lines) and increase (blue lines), for every 100 m of riverbed for 2019-2022 (top) and 2022-2023 (bottom). Light blue/red lines depict average values for every 100 m section of riverbed, which have been further smoothed using an 800 m moving window filter to create the dark blue/red lines.



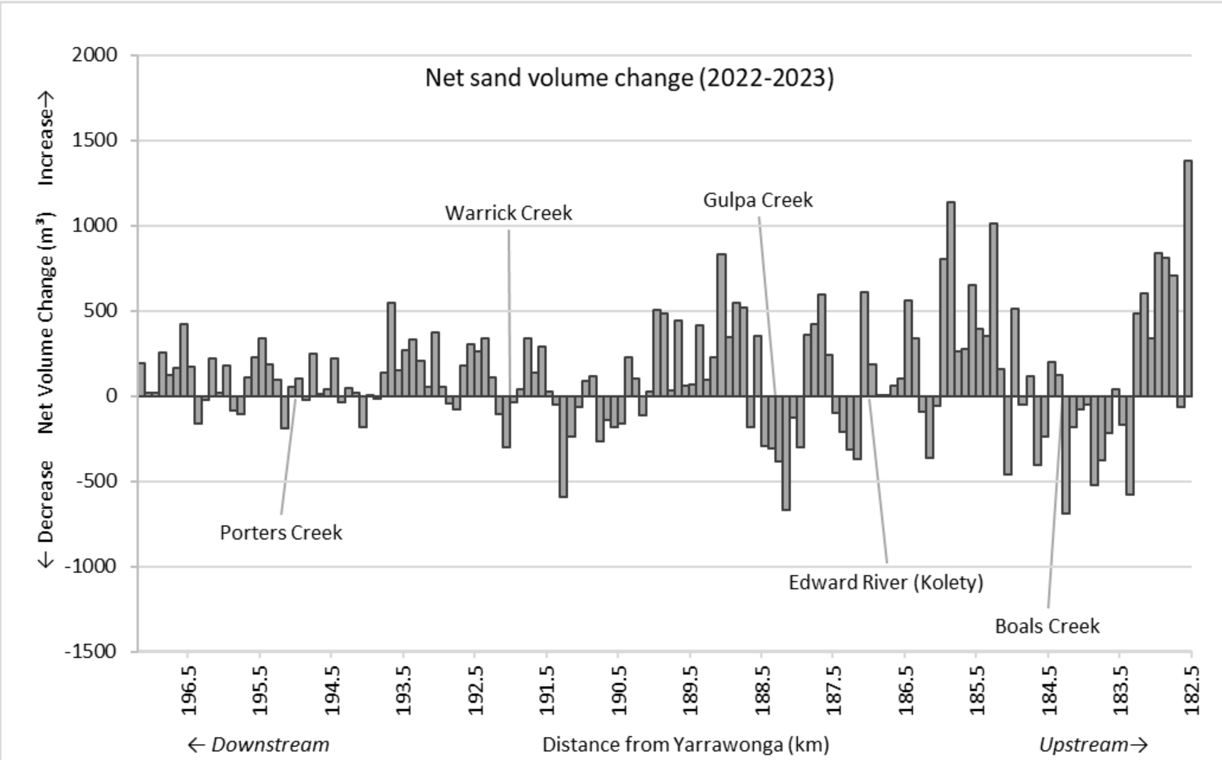




Figure 19. Bar charts showing estimated net sand volume change for every 100 m of riverbed for two time periods.

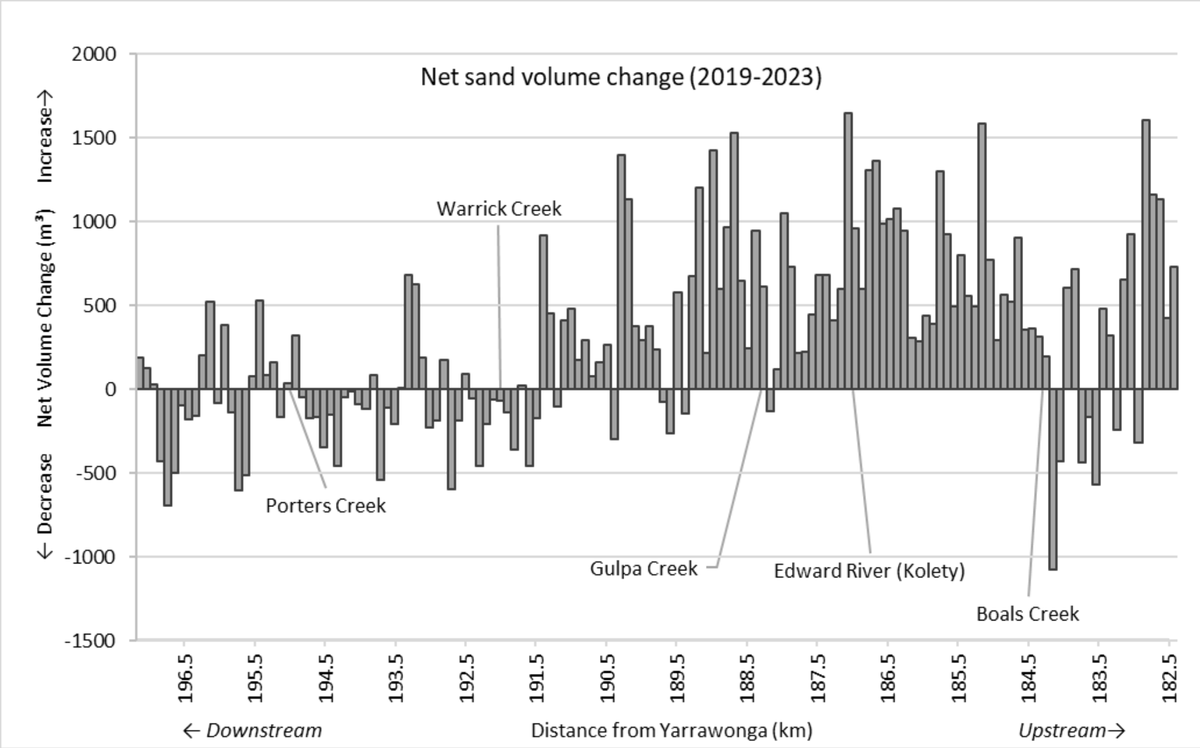
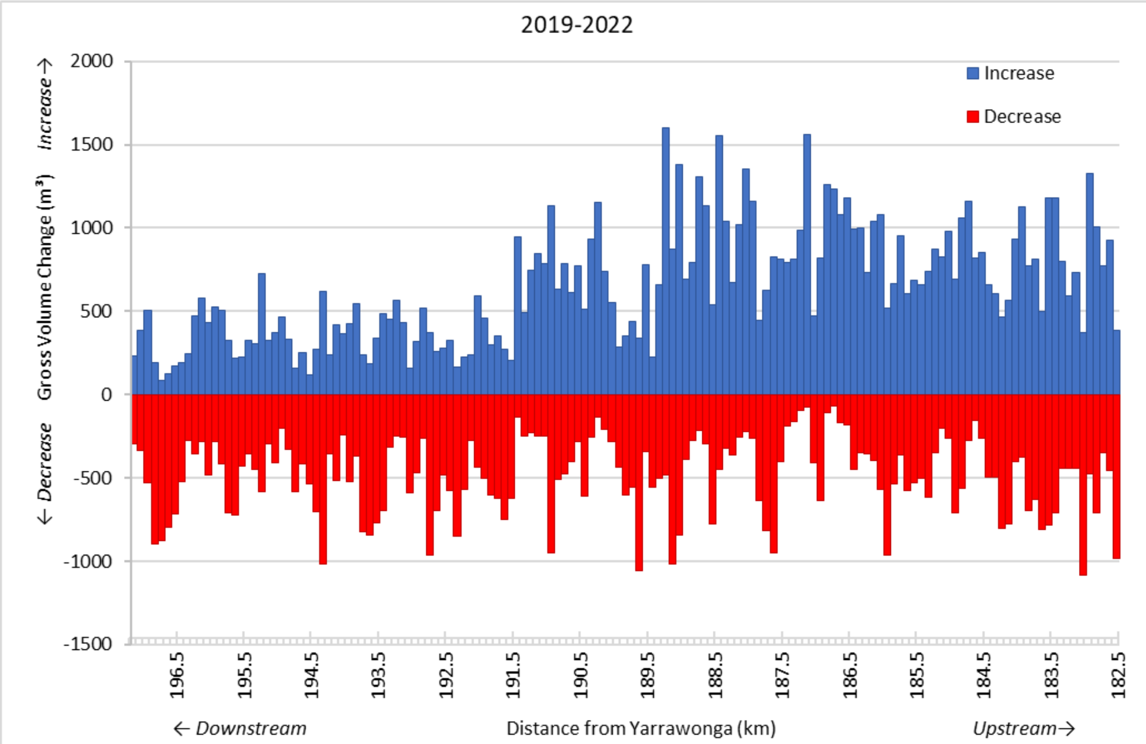



Figure 20. Bar chart showing estimated net sand volume change for every 100 m of riverbed for the entire 2019-2023 period (cumulative result of both 2019-2022 and 2022-2023 periods combined).



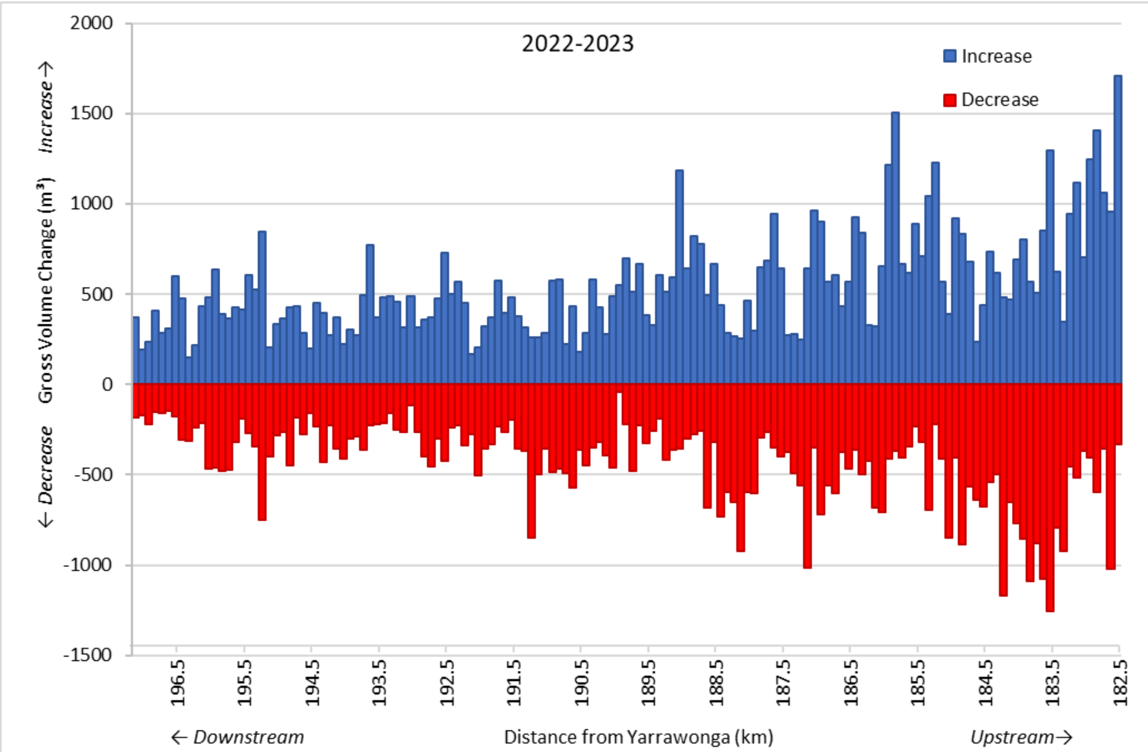




Figure 21. Bar charts showing estimated gross sand volume change for every 100 m of riverbed for two time periods.