Macquarie River debris rafts

Expert opinion: hydro-geomorphology

Prepared for NSW Environment Protection Authority

January 2023

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1 Report overview

Several large debris rafts have formed in the Macquarie River downstream of Warren (the debris rafts or rafts). It is understood that some rafts originally formed during the 2016 floods and have continued to evolve during recent flooding that occurred in the second half of 2022. The rafts comprise organic and anthropogenic materials and are of concern to the adjoining landholders and the local community.

The NSW Environment Protection Authority (EPA), acting on behalf of the Environmental Services Functional Area, have activated an Incident Management Team (IMT) to assist with clean-up response and recovery from the recent flooding in NSW. The IMT is working to establish a response plan for the rafts. To assist with guiding the response, the EPA have engaged EMM Consulting (EMM) to provide an expert opinion on the following questions:

1. Whether the rafts have potential to block or restrict flow of the Macquarie River and to what extent.
2. Whether the rafts could cause the river to change its course.
3. Whether there could be damage/scouring of the riverbank levees, and to what extent.
4. How the rafts might move or change with further flooding in the Macquarie River.

EMM and the EPA visited the site on 19 December 2022 where we were shown around by adjoining landowners, local community members and a representative from Ozfish.

This report provides opinions on the above questions. The opinions are informed by:

- information and descriptions provided by adjoining landowners, local community members and Ozfish during the site visit;
- site observations (on 19 December 2022);
- a downstream river reach survey conducted by Ozfish on 4 January 2023;
- information provided by the EPA, including the images and videos collected by the State Emergency Service (SES) during several aerial surveys that were conducted during and shortly after the 2022 floods; and
- analysis of stream gauge data, aerial and satellite imagery and LiDAR survey levels.

Chapter 2 provides a description of the rafts including known chronology and physical characteristics. Chapter 3 provides a summary of other relevant information that has been used to inform our opinions. Chapter 4 provides opinions on the above questions.

Key photographs and figures are provided in the main report. Supplementary figures are provided in Appendix A and supplementary photographs and imagery are provided in Appendix B.

2 Description of rafts

This chapter describes the known chronology and physical characteristics of the rafts. The descriptions are informed by relevant information from the following sources:

- local community (based on descriptions during the site visit);
- SES aerial surveys that were flown on 15 and 27 October and 4 December 2022;
- EMM site observations during the 19 December 2022 site visit;
- Ozfish site observations during the 19 December 2022 site visit and a further survey of the downstream river reach that was conducted on 4 January 2023; and
- publicly available aerial and satellite imagery (multiple sources).

This chapter is structured as follows:

- Section 2.1 describes the location of the rafts and establishes terminology;
- Section 2.2 describes the known chronology of the rafts;
- Section 2.3 describes the physical characteristics of the rafts; and
- Section 2.4 provides key conclusions that are relevant to this report scope.

It is noted that further information on the Macquarie River geomorphology, river and floodplain characteristics and flooding regimes is provided in Chapter 3.

2.1 Raft locations and terminology

Numerous large debris rafts have been identified in the Macquarie River reach between Warren and Marebone Weir. Some of the rafts are known to be mobile and are slowly moving and changing form. However, at least one raft appears to be fixed, in that it hasn't moved during the recent 2022 floods. Section 2.3 describes the physical characteristics of seven major rafts that have been identified from an aerial survey conducted by the SES on 4 December 2022 and a survey of the downstream river reach that was conducted by Ozfish on 4 January 2023. These rafts are referred to as Rafts 1 to 7 (from upstream to downstream). Raft 1 is located approximately 26 km downstream of Warren and Raft 7 is located approximately the same distance (26 km) upstream of Marebone Wier.

It is understood that there is at least one additional major raft located near Warren and numerous smaller rafts that do not fully span the channel along the river reach.

The location of the seven rafts (in December 2022 and January 2023) are shown in Figure 2.1. Figure 2.1 also notes the location of the following river features that are relevant to this report scope:

- Bulla Bulla Creek - is an anabranch to the Macquarie River, which receives inflows from the river during certain flow conditions. It re-joins the Macquarie River approximately 7 km to the north-west of its inlet.
- Channel breakout – refers to a location where significant riverbank erosion occurred in 2016/7 when a debris raft formed. Water spills out onto the adjoining floodplain when the river flow is near bank full (discussed further in Chapter 3).

The river reach between Warren and Marebone Wier is referred to as the Investigation Area in this report. Figure A.1 (Appendix A) shows the location of the Investigation Area within the greater Macquarie River basin.

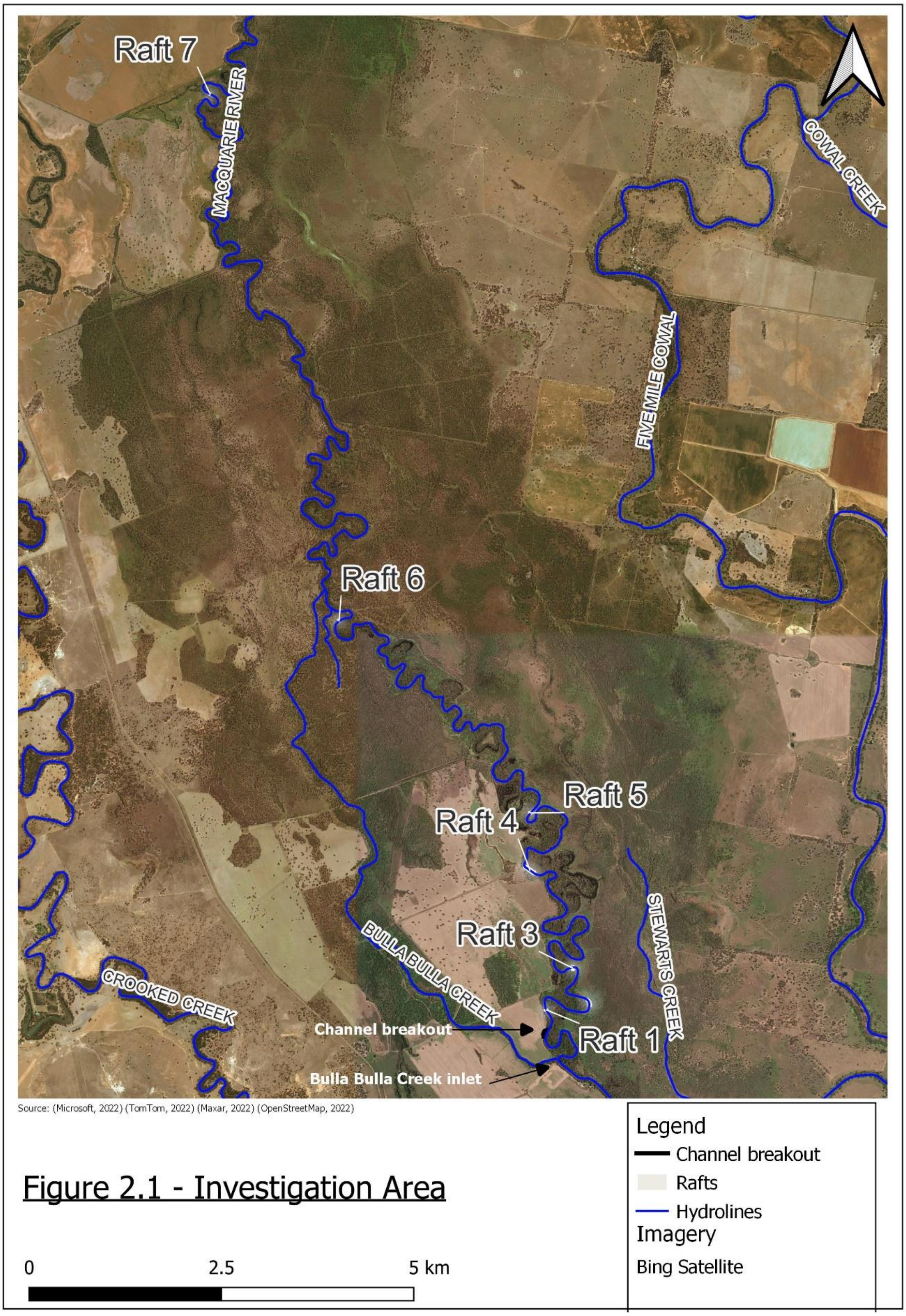


Figure 2.1 Investigation Area

2.2 Known chronology of the rafts

It is understood that some rafts originally formed during the 2016 floods and have continued to evolve during recent flooding that occurred in December 2021 and the second half of 2022. This section describes the known chronology of the rafts using information provided by the local community and the EPA, available aerial and satellite imagery and site observations on 19 December 2022.

It is noted that the effectiveness of satellite imagery is dependant of cloud cover, the angle of the image and vegetation cover. It is possible to identify the location of some rafts and surface water from the images. However, the imagery is not sufficiently reliable to be used to prove that a raft is not present at a particular location. Accordingly, satellite imagery has only been used to confirm the presence of a raft or surface water when it is clearly evident in the image.

2.2.1 2016 floods

i Flood description

The Macquarie River flooded in September and October 2016. The flood peak occurred in late September with a peak river height of 5.1 m recorded at the Warren Weir gauge (421004 - located upstream of Warren). The flood lasted approximately 30 days and was the largest flood since 1991 (based on the Warren Weir gauge record). The gauged river height and discharge for this event is shown in Figure A.2 (Appendix A).

ii Known chronology of rafts

1. A raft formed near the township of Warren. Due to the raft's proximity to the town's levees and hospital a decision was made to intervene. It is understood that Warren Shire Council successfully broke-up the raft using a long reach excavator. The debris were allowed to flow downstream.

2. A raft formed downstream of the Bulla Bulla Creek inlet. Satellite imagery from 20 October 2016 (near the end of peak flooding) indicates that the raft initially formed approximately 800 m downstream of the Bulla Bulla Creek inlet (see Figure B.3 – Appendix B). Satellite imagery from 19 December 2016 (see Figure B.4 – Appendix B) indicates the raft moved to the channel breakout location after the 2016 flood subsided. Satellite imagery from mid-2017 indicates that the riverbank erosion occurred or at least started sometime between 27 July 2017 and 25 September 2017 (see Figure B.5 – Appendix B). Comparison of aerial imagery from 28 November 2015 (Figure B.1 – Appendix B) and 24 September 2018 (Figure B.6 –Appendix B) confirms that the river bank erosion occurred sometime between November 2015 and September 2018.

3. Local community members advised that a second raft formed near the December 2022 Raft 4 location. The presence of this raft cannot be confirmed via satellite imagery. However, comparison of aerial imagery from 28 November 2015 (Figure B.2 – Appendix B) and 24 September 2018 (Figure B.7 – Appendix B) confirms that a raft formed at this location sometime between November 2015 and September 2018.

2.2.2 2017 to 2021 period

i Streamflow conditions

One of the worst droughts on record occurred in 2018-19 which resulted in the Macquarie River ceasing to flow for extended periods of time. Wetter conditions and streamflow in the Macquarie River returned in early 2020 and a flood of similar magnitude to the 2016 event occurred in December 2021.

ii Known chronology of rafts

Local community members advised that:

- Raft 4 stayed in place for the entire period. It is noted that this raft becomes apparent at its December 2022 location in most satellite imagery from September 2021.

- The raft at the channel breakout location stayed in place during the drought but moved downstream by approximately 500 m in 2020 when streamflow returned to the Macquarie River.

2.2.3 2022 floods

i Flood description

Significant flooding in the Macquarie River occurred in the second half of 2022. Initial floods occurred in July, August and September. The August and September floods were of similar magnitude to the 2016 or December 2021 floods. A larger flood occurred in October and November. This flood peaked at 5.5 m at the Warren Weir gauge (421004) and lasted for approximately 50 days. It was the largest flood since the 1955 and 56 floods (based on the Warren Weir gauge record). The gauged river height and discharge for this event is shown in Figure A.4 (Appendix A).

ii Known chronology of rafts

1. Prior to flooding, remnant rafts from the 2016 flood were identified at the Raft 4 location and downstream of the channel breakout.

2. During the August and September floods, a new raft formed approximately halfway between Warren and the Bulla Bulla Creek inlet. This raft was surveyed by Fire and Rescue NSW (FRNSW) on 19 September 2022. FRNSW calculated that the raft covered an area of approximately 2,000 m^2. It is understood that this raft moved downstream in October 2022. An aerial image of this raft is provided in Figure B.8 (Appendix B).

3. On 15 October 2022, the SES undertook an arial survey of the river reach downstream of the Bulla Bulla Creek inlet. This survey was undertaken near the flood peak. Two large rafts and several smaller rafts were identified. One of the large rafts was located approximately 500 m downstream of the breakout location (see Figure B.9 and Figure B.10 – Appendix B). The second was Raft 4, which was at its December 2022 location.

4. On 27 October 2022, the SES undertook another aerial survey. From the images provided it appears that the two main rafts were relatively unchanged from the 15 October 2022 survey. Some additional rafts were also identified downstream of Raft 4.

5. Satellite imagery from 29 October and 18 November 2022 indicates that the upstream raft from the 15 October survey had broken up into three smaller rafts during this period. Relevant images are provided as Figure B.11 and Figure B.12 (Appendix B).

6. On 4 December 2022 (after peak flooding had subsided), the SES undertook another aerial survey. This survey confirmed that the upstream raft from the 15 October survey had broken up into three smaller rafts (referred to as Rafts 1, 2 and 3 in this report). The Raft 4 location was unchanged.

7. On 19 December 2022, EMM undertook a site inspection. Rafts 1 to 4 appeared to be relatively unchanged from the 4 December 2022 survey locations.

8. On 4 January 2023, Ozfish undertook a survey of the river reach downstream of Raft 4. Rafts 5, 6 and 7 were identified by this survey.

Figure 2.2 shows the locations of Rafts 1 to 4 from the October 15 and December 4 surveys. Section 2.3 provides further details on Rafts 1 to 7 (based on site observations on 19 December 2022 and 4 January 2023).

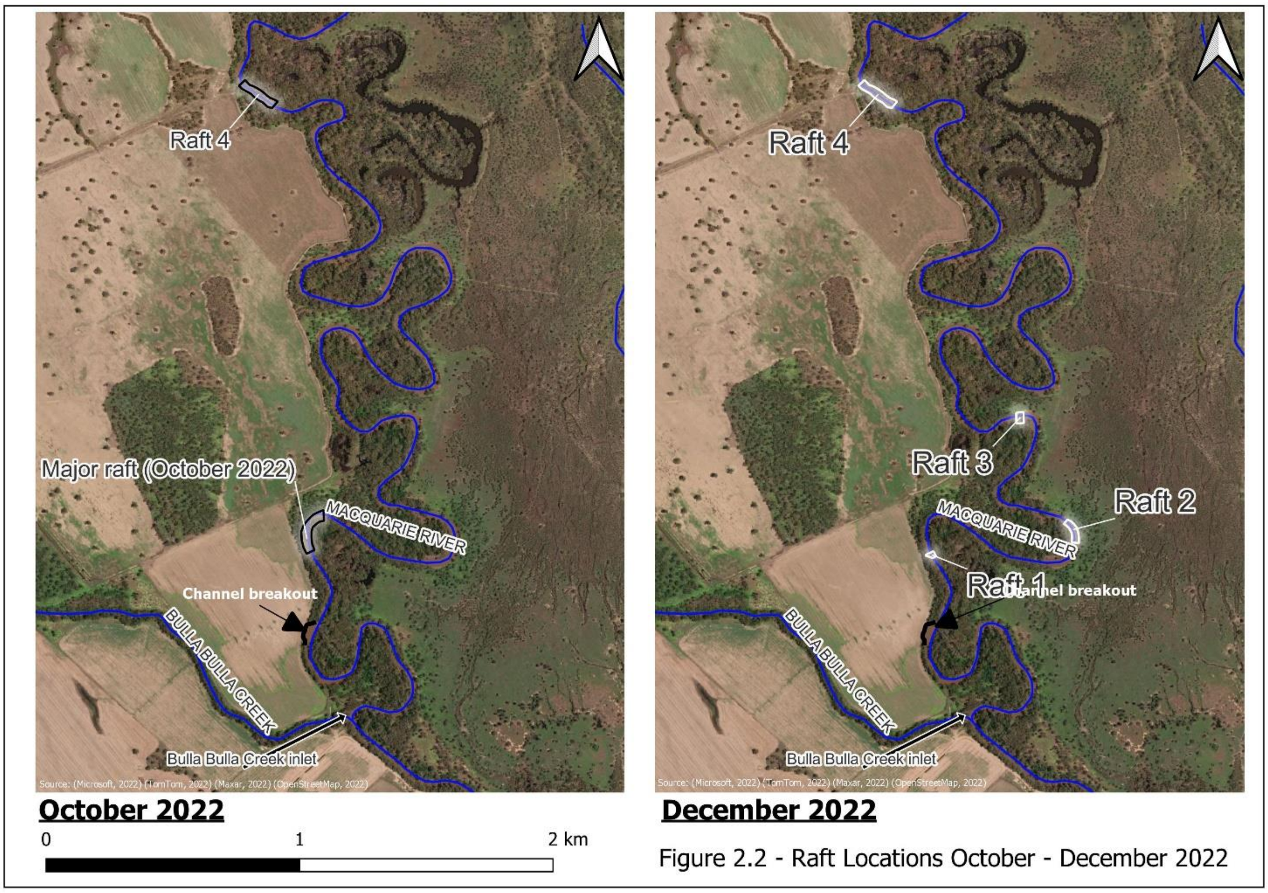


Figure 2.2 Raft locations October to December 2022

2.3 Description of rafts

This section provides a description of the physical characteristics of Rafts 1 to 7. The location of all rafts are indicated in Figure 2.1. Figure 2.2 shows Rafts 1 to 4 only. The descriptions are primarily based on site observations made by EMM and OzFish on 19 December 2022 and OzFish on 4 January 2023.

On 19 December 2022, the river water levels were approximately 1.5 to 2.0 m below top-of-bank and the gauged flow at the Warren Weir gauge (421004) was 5,754 ML/day.

On 4 January 2023, the river water level (estimated from photographs) was approximately 3 m below top-of-bank and the gauged flow at the Warren Weir gauge (421004) was 2,820 ML/day.

2.3.1 Raft 1

Raft 1 is located approximately 300 m downstream of the channel breakout location. It is interpreted to be a remnant from a larger raft that was observed at this location (and immediately downstream) during the 15 October 2022 SES aerial survey (see Section 2.2.3). The raft was approximately 20 m long and comprised mostly small to medium woody debris with some anthropogenic material including plastic bottles, tyres, a 44-gallon drum and a fridge. The raft appeared to be buoyant and had settled with the falling river levels. There was no significant visible change in river water levels upstream and downstream of the raft, indicating there was no significant blockage of river flows on 19 December 2022.

Photograph 2.1 shows Raft 1 looking downstream.

Photograph 2.1 Raft 1 looking downstream (19 December 2022)

2.3.2 Raft 2

Raft 2 is located approximately 800 m downstream of Raft 1. It is interpreted that this raft formed sometime between 29 October and 18 November 2022 when the larger raft that was observed at the Raft 1 location during the 15 October 2022 SES aerial survey (see Section 2.2.3) broke up. The raft was approximately 100 m long on 4 December 2022 (measured from an aerial image – see Photograph 2.2).

EMM did not inspect this raft. However, Ozfish provided several images which indicate the raft is similar in composition to Raft 1 and had reduced in size and moved approximately 100 m downstream since 4 December 2022. Photograph 2.3 and Photograph 2.4 are two of the images provided by Ozfish.

Photograph 2.2 Aerial image of Raft 2 (4 December 2022)

Image source: SES

Photograph 2.3 Raft 2 – looking upstream (19 December 2022)

Image source: Ozfish

Photograph 2.4 Raft 2 – typical composition of debris (19 December 2022)

Image source: Ozfish

2.3.3 Raft 3

Raft 3 is located approximately 800 m downstream of Raft 2. It was not identified in the 4 December 2022 SES survey and as noted in Section 2.3.2, Raft 2 had moved 100 m downstream and reduced in size between 3 and 21 December. Hence, it is interpreted that Raft 3 formed between 4 and 21 December 2022 from Raft 2 material.

Raft 3 is estimated to be 30 m long and was similar in composition to Raft 1. Photograph 2.5 shows Raft 3 looking upstream.

Photograph 2.5 Raft 3 looking upstream (19 December 2022)

2.3.4 Raft 4

Raft 4 is understood to have formed during the 2016 floods. The raft was approximately 200 m long on 4 December 2022. Comparison of images taken from aerial surveys on 15 October and 4 December 2022 indicate that the raft did not materially change during the 2022 floods, with the upstream end of the raft extending by only a small amount (see Photograph 2.6).

During the 19 December 2022 site inspection, the upstream portion of the raft (see Photograph 2.7) appeared to be similar to Rafts 1 to 3 (ie comprised predominantly of small to medium woody debris with some anthropogenic waste). The downstream portion (see Photograph 2.8) had more large woody debris, appeared to be more intertwined and to extend further at depth then the upstream portion. Vegetation had also established on the surface of the downstream portion of the raft (see Photograph 2.6 and Photograph 2.8), indicating that it had not broken up for some time.

Water was observed to be flowing under the raft and upwelling currents were visible in the river downstream of the raft. There was no significant visible change in river water levels upstream and downstream of the raft, indicating there was no significant blockage of river flows on 19 December 2022.

During the site inspection, there was evidence that recent out-of-channel flows occurred around the western flank of the raft through an area that comprises a shallow billabong. Water inundation of this area is also evident in Photograph 2.6 (15 December 2022 image).

Comparison of photos of the raft taken on 15 October and 19 December 2022 confirm that the raft has settled with the falling river levels (the peak flood mark is evident on some trees in Photograph 2.8), indicating that it is buoyant.

Photograph 2.6 Aerial images of upstream portion of Raft 4 from 15 October 2022 (left) and 4 December 2022 (right)

Photograph 2.7 Raft 4 – upstream portion of the raft (19 December 2022)

Photograph 2.8 Raft 4 – downstream portion of raft, looking upstream (19 December 2022)

2.3.5 Raft 5

Raft 5 was identified by an Ozfish survey conducted on 4 January 2023. The raft was located approximately 1,800 m downstream of Raft 4. It was not identified in any of the SES aerial surveys and is not detected in satellite imagery. Hence, it is not clear when it formed. Ozfish estimated that the raft is 30 to 40 m long.

Photograph 2.9 was provided by Ozfish and shows Raft 5 looking downstream. From the photograph, Raft 5 appears to be similar in composition to Raft 1 (ie predominantly small to medium woody debris with some anthropogenic waste) and likely formed at this location due to the large tree that has fallen into the channel from the left bank. It is also noted that the river levels had receded substantially between 19 December 2022 and 4 January 2023.

Photograph 2.9 Raft 5 looking downstream (4 January 2023)

Image source: Ozfish

2.3.6 Raft 6

Raft 6 was identified by an Ozfish survey conducted on 4 January 2023. The raft was located several kilometres downstream of Raft 5. It was not identified in any of the SES aerial surveys and is not detected in satellite imagery. Hence, it is not clear when it formed. Ozfish estimated that the raft is 20 m long.

Photograph 2.10 was provided by Ozfish and shows Raft 6 looking downstream. From the photograph, Raft 6 appears to be smaller than the other rafts, but similar in composition to Raft 1 (ie predominantly small to medium woody debris with some anthropogenic waste). It likely formed at this location due to the large tree that has fallen into the channel from the right bank.

Photograph 2.10 Raft 6 looking downstream (4 January 2023)

Image source: Ozfish

2.3.7 Raft 7

Raft 7 was identified by an Ozfish downstream survey conducted on 4 January 2023. The raft was located several kilometres downstream of Raft 6. Rafts at or near this location were previously identified in the 27 October 2022 SES aerial survey. Ozfish estimated the raft to be 30 to 40 m long.

Photograph 2.11 and Photograph 2.12 were provided by Ozfish and show Raft 7 looking downstream and upstream respectively. From the photographs, Raft 7 appears to have formed behind the large tree that has fallen into the channel from the right bank. Parts of the raft do not appear to have settled with the falling river levels indicating they are not fully buoyant. Similar to Raft 4, vegetation, has also established on the surface of the downstream part of the raft. It is possible that this raft could further develop overtime.

Photograph 2.11 Raft 7 looking downstream (4 January 2023)

Image source: Ozfish

Photograph 2.12 Raft 7 looking upstream (4 January 2023)

Image source: Ozfish

2.4 Key conclusions

The key conclusions relevant to this report scope are:

- Most of the rafts comprise small to medium woody debris and some anthropogenic wastes. These rafts appear to be buoyant and mobile but move slowly. The depth of underwater debris is unknown but is expected to be predominantly less than 1 m below the surface.
- Raft 4 and Raft 7 contained larger woody debris and appeared to be more intertwined. It is likely that these rafts extend further at depth in places than the rafts that comprise small to medium woody debris, however the depth below water is unknown. These rafts appear to be buoyant at high river stages but may become perched as the river levels drop (as evidenced by parts of Raft 7).
- Rafts 2 and 3 have been proven to be mobile but are moving slowly despite significant flooding.
- Raft 4 has been proven to be fixed (from at least September 2021 to December 2022, but likely longer). It is possible that it will increase in length if debris from Rafts 1 to 3 accumulate at the upstream end.
- Rafts 5, 6 and 7 have formed behind fallen trees and have potential to develop further as more debris get washed down the river.

3 Other relevant information

This chapter provides a summary of information that has been used to inform the opinions provided in Chapter 4. It includes descriptions of the Macquarie River geomorphology (Section 3.1) and floodplain characteristics (Section 3.2) and descriptions of river and floodplain flows during the 2022 floods (Section 3.3) and analysis of river bank erosion (Section 3.4). The descriptions and analysis in this chapter focus on the river reach between the Bulla Bulla Creek inlet and Raft 4 as this is where the main rafts have occurred and was the area inspected by EMM during the 19 December 2022 site visit.

3.1 Macquarie River geomorphology overview

The Macquarie River is a western flowing river that is part of the greater Barwon-Darling system. Its headwater catchments are on the western slopes of the Great Dividing Range and provide most of the discharge to the river. The upper reaches of the river and its tributaries are typically in bedrock confined valleys and are gaining streams. Downstream of Narromine (approximately 150 km upstream of the Investigation Area) the river transitions to a semi-arid alluvial floodplain where it begins to form anabranches within a widening floodplain. It becomes a losing stream due primarily to high stage losses to anabranches, the lack of tributary inflows and losses to shallow groundwater systems (Ralph 2009).

Downstream of Warren the floodplain width expands further and floodplain wetlands begin to occur on both sides of the channel. The river channel progressively reduces in size and capacity and generally increases in sinuosity. This trend continues to beyond Marebone Wier where the Macquarie River channel eventually breaks-down into a series of distributed channels and floodplain marshes in the Macquarie Marshes (Ralph 2009).

Figure 3.1 is reproduced from Ralph 2009 and shows the changes to the Macquarie River channel between Dubbo and the end of the river system. Similar figures that show changes to streamflow, stream power, channel area, floodplain width and sinuosity over the same river reach are provided in Figure A.5 and Figure A.6 (Appendix A). This information shows that between Warren and Marebone the Macquarie River channel progressively becomes smaller, with Ralph 2009 estimating the bank-full channel area to be 261 m^2 at Carvel (just downstream of Warren) and 92 m^2 at Marebone (see Figure 3.1) and that large and small flood discharge rates reduce by a similar amount (see Figure A.5). This diminishing channel trend occurs as the flood discharges conveyed in the channel reduce over the river reach due to losses to floodplain wetlands and anabranches.

The key conclusion relevant to this report scope is that the ability of the river to flush floating debris progressively reduces between Warren and Marebone.

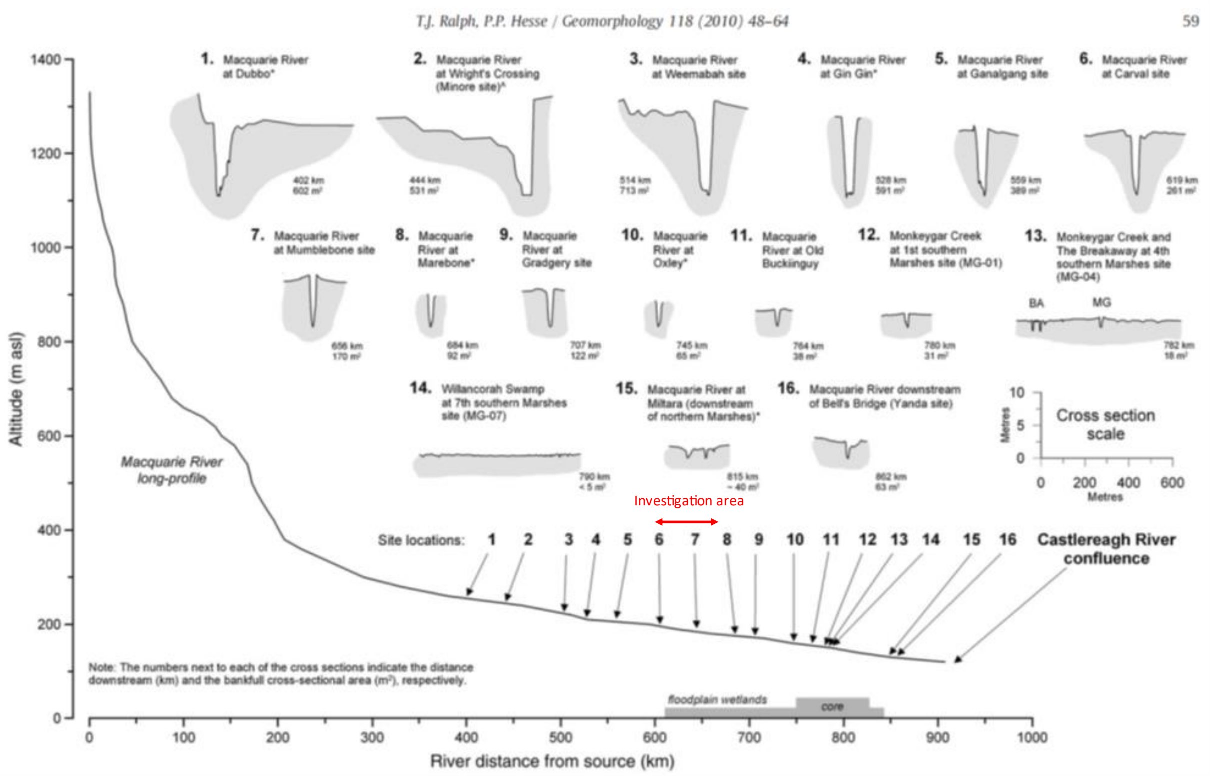


Figure 3.1 **Change to the Macquarie River channel along river reach**

Figure source: (Ralph 2009)

3.2 River and floodplain features

This section describes the key features of the Macquarie River, Bulla Bulla Creek and the adjoining floodplain near Rafts 1 to 4. A 1 m resolution Digital Elevation Model (DEM) created by Geoscience Australia from a 2014 LiDAR survey is used to describe key levels and geometries of the channels and floodplain. It is noted that this LiDAR was flown prior to the 2016 and 2022 floods, hence recent features such as the channel breakout are not captured in the data.

The following figures have been prepared to explain key features relevant to this report scope:

- Figure 3.2 shows floodplain levels;
- Figure 3.3 compares channel cross-section of the Macquarie River (referred to as Mac River 1) and Bulla Bulla Creek. The cross-section locations are indicated in Figure 3.2; and
- Figure 3.4 is a long-section of the Macquarie River channel, from Raft 4 to the Bulla Bulla Creek inlet.

Key features are described following the figures.

It is noted that the channel breakout is discussed in detail in Section 3.4.1. A figure that shows the Mac River 2 cross-section is provided in this section.

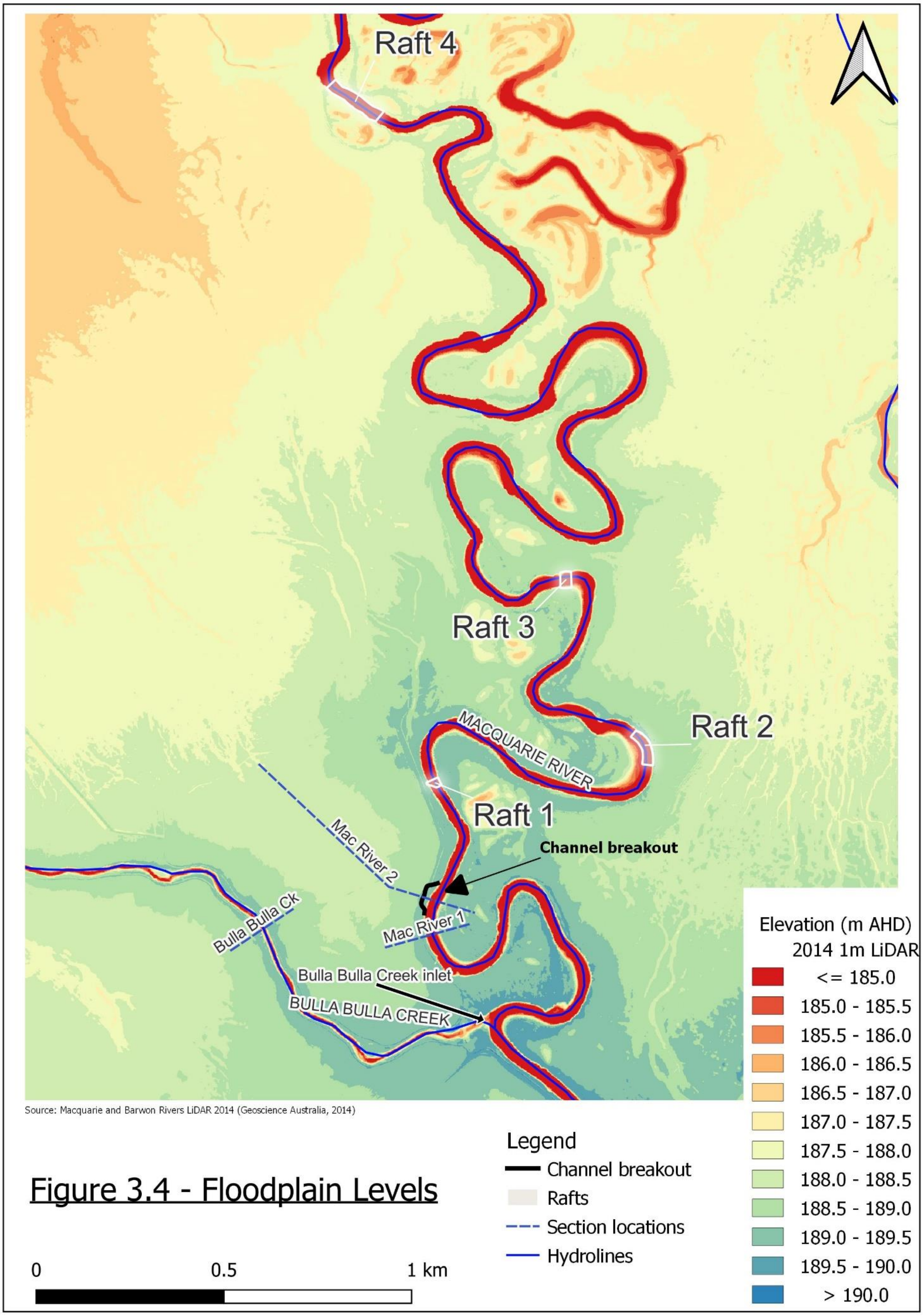


Figure 3.2 Floodplain levels

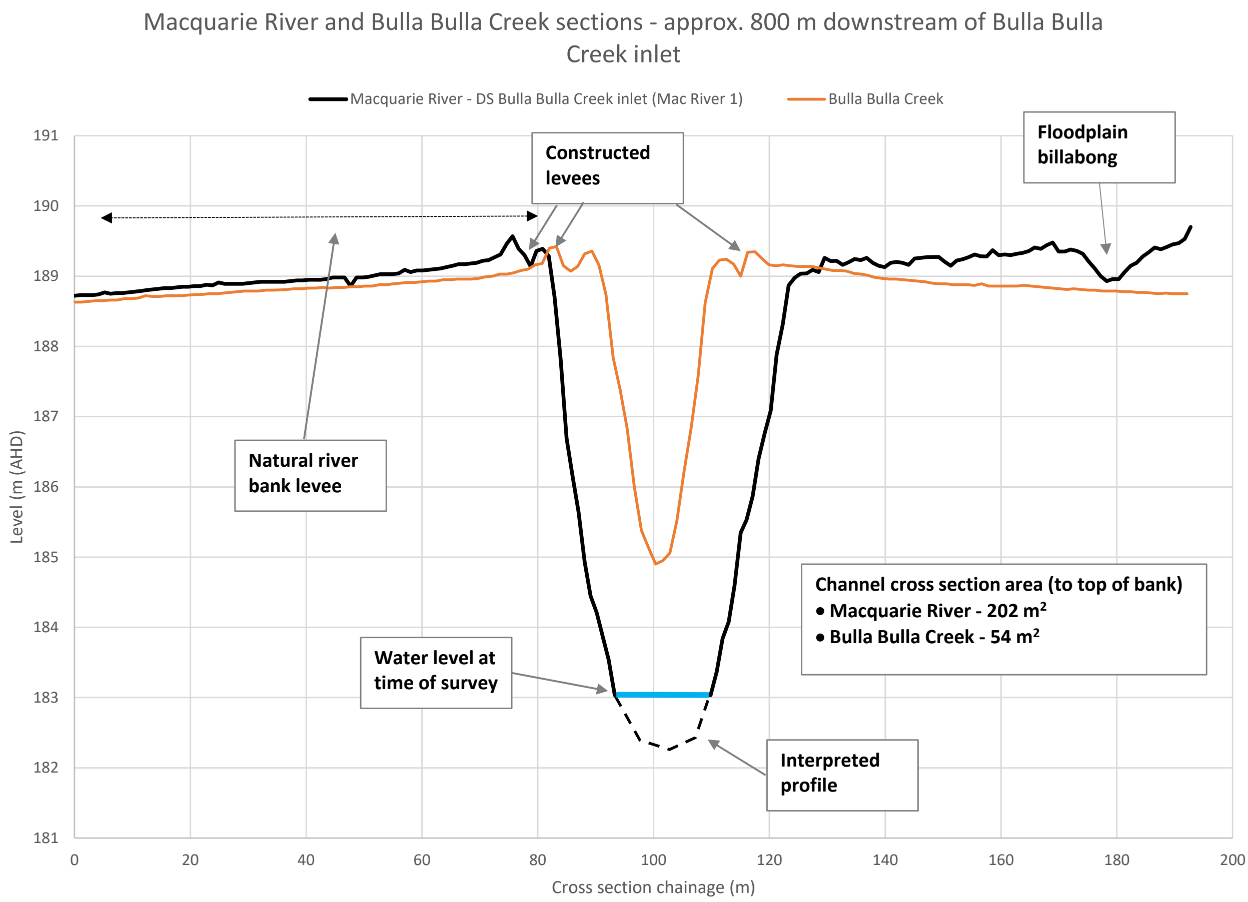


Figure 3.3 **Bulla Bulla Creek and Macquarie River channel sections**

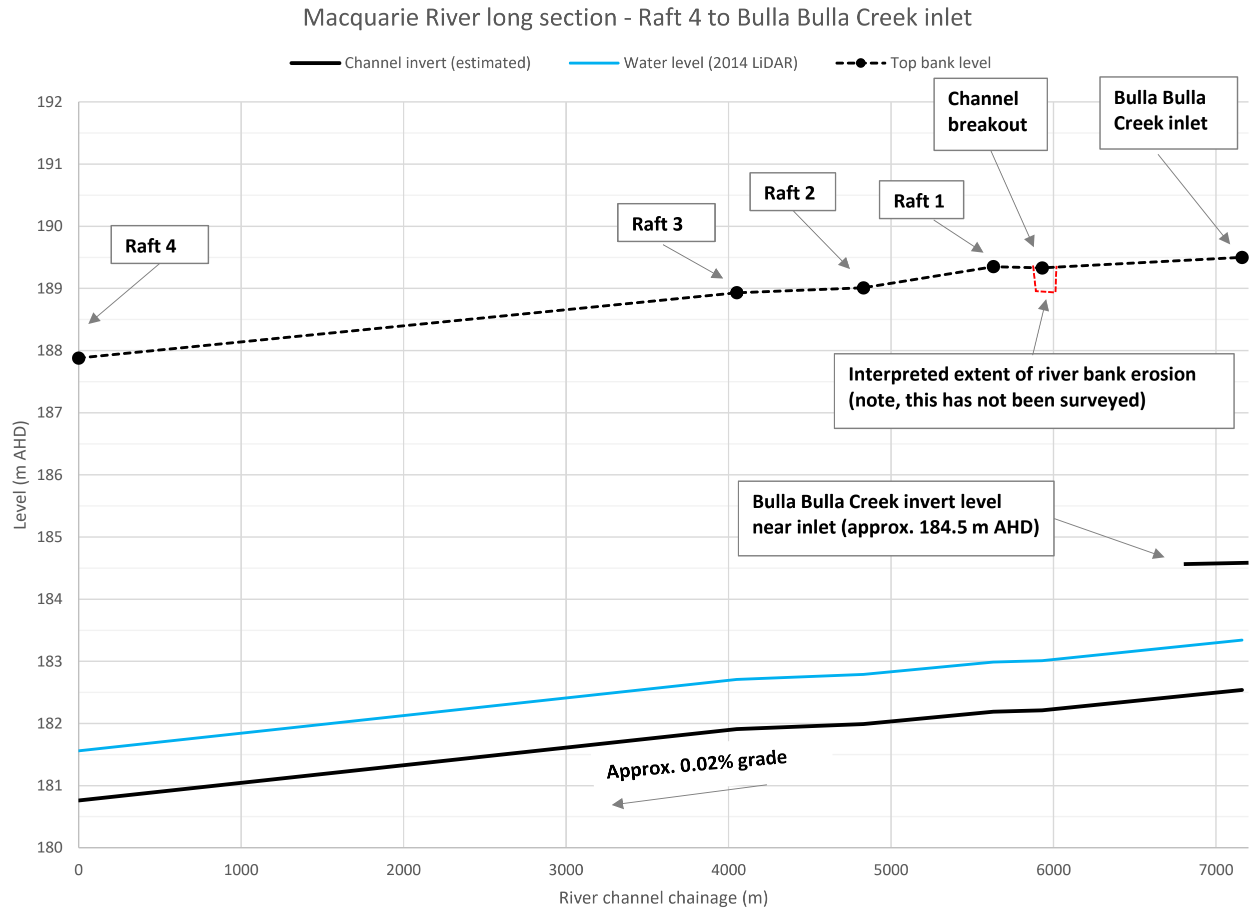


Figure 3.4 Macquarie River long section – Raft 4 to Bulla Bulla Creek inlet

Key features relevant to this report scope are:

- The Macquarie River and Bulla Bulla Creek have natural riverbank levees which have formed overtime by sediment accretion processes. These levees typically occur adjacent to the channel and floodplain billabongs (which are collectively referred to as the river corridor in this report). Due to these levees, the river channel top-of-bank is typically around 0.5 to 1.0 m higher than the adjoining floodplain. This means that when the river is flowing at bank full, the water in the channels (and greater river corridor) is perched relative to the floodplain and any overflows from the channel will spill to the floodplain and will generally not re-enter the channel. Examples of natural riverbank levees are noted in Figure 3.3.

- Constructed levees that are approximately 0.3 to 0.5 m higher than the natural riverbank levees have been established along the interface between most paddocks and the river corridor. Constructed levees are evident in the Macquarie River (left bank only) and Bulla Bulla Creek cross-sections in Figure 3.3.

- The Bulla Bulla Creek channel invert is approximately 2 m higher than the adjoining Macquarie River channel invert. This means that flows in Bulla Bulla Creek occurs when the water depth in the Macquarie River channel exceeds 2 m at the inlet.

- The Macquarie River channel area (to top-of-bank) is approximately four times larger than the Bulla Bulla Creek channel area (see Figure 3.3). This means that when the river is flowing at bank full, the Macquarie River Channel has approximately four times the capacity of Bulla Bulla Creek. However, this ratio could be impacted by the partial channel blockage caused by the debris rafts.

- Figure 3.4 shows the longitudinal profile of the Macquarie River between Raft 4 and the Bulla Bulla Creek inlet. The figure includes the interpreted channel invert, river water level (at the time of survey) and top-of-bank all which grade at approximately 0.02% (1 m of fall for every 5 km of river reach). The interpreted extent of riverbank erosion (or scour profile) at the channel breakout location is also shown. The following conclusions can be made from this figure:

  - The top-of-bank levels at Raft 1, 2 and 3 locations are similar to or higher than the interpreted scour profile at the channel breakout (discussed in Section 3.4.1). Therefore, any backwater affects from partial blockage of the channel at Raft 1, 2 or 3 locations would likely result in more water spilling at the channel breakout location (only when the river is flowing at near bank-full). When the river is flowing below bank-full, it is possible that any significant backwater affect would result in additional flows into Bulla Bulla Creek.

  - The top-of-bank level at the Raft 4 location (187.9 m AHD) is approximately 1.0 m lower than the interpreted scour profile at the channel breakout (188.9 m AHD). This means that any backwater affect from a partial channel blockage at Raft 4 would not be relieved by increased overflows at the channel breakout, rather increased out-of-channel flows near the Raft 4 location would occur.

3.3 River and floodplain flows

This section presents satellite and aerial images to describe flooding regimes within the Investigation Area. Key conclusions relevant to this report scope are provided at the end of the section.

3.3.1 Satellite imagery

A review of satellite imagery from the 2021 and 2022 identified that out-of-channel flooding (of varying magnitudes) occurred in early December 2021, intermittently in August and September 2022 and near continuously in October and November 2022. This flooding sequence aligns with the recorded streamflow at the Warren Weir gauge (421004) (see Figure A.4 – Appendix A).

Satellite imagery from 18 November 2022 is the clearest imagery from the October/November 2022 flood (the largest magnitude flood) and is provided in this report. Figure 3.5 shows the river reach between the Bulla Bulla Creek inlet and Raft 4. Figure 3.6 is a larger scale image that shows the river reach between the Bulla Bulla Creek inlet and Raft 6. The images are presented using the false colour style which distinguishes surface water using a blue-green colour. These images show that:

- Floodwaters spilled from the channel onto the adjoining western floodplain at the channel breakout location. Overflows at the channel breakout are also evident in imagery from the December 2021 and August and September 2022 floods and appear to occur when the streamflow at the Warren Weir gauge (421004) exceeds 12,000 ML/day.

- There is no evidence of channel overflows to the floodplain occurring at any of the raft locations.

- Floodwaters that spill from the channel breakout accumulate on the western floodplain which overflows to Bulla Bulla Creek. Bulla Bulla Creek re-joins the Macquarie River Channel downstream of Raft 6 (indicated in Figure 3.6) and would return some water to the Macquarie River Channel. However, Bulla Bulla Creek appears to overflow to floodplain areas to the north-west (evident in Figure 3.6 only). This water does not appear to re-enter the Macquarie River Channel. It is noted that this flooding regime is consistent with descriptions provided by local community members during the site visit.

Figure 3.5 Satellite imagery – Rafts 1 to 4 (18 November 2022)

Source: Digital Earth Australia

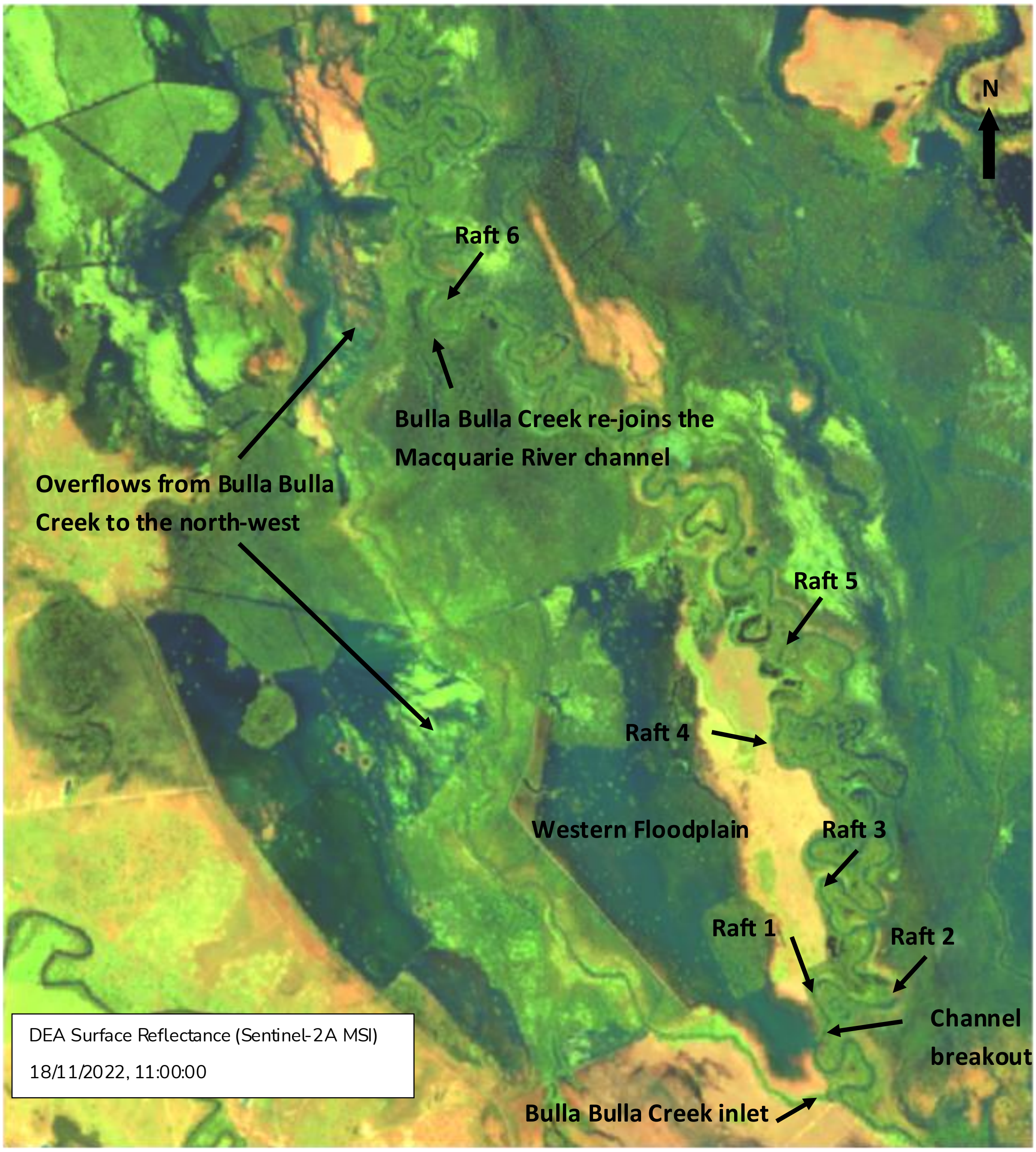


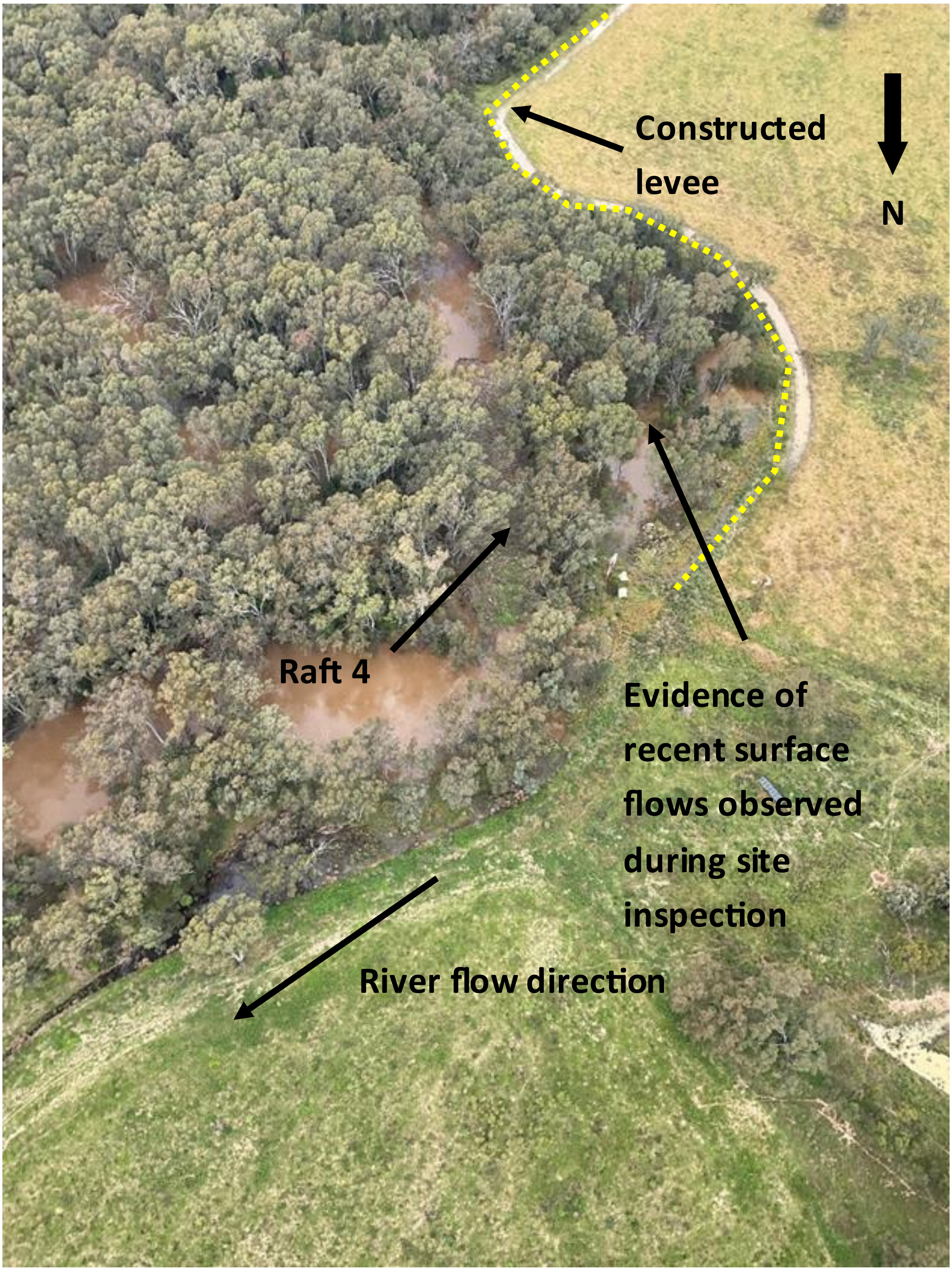
Figure 3.6 Satellite imagery – Rafts 1 to 6 (18 November 2022)

Source: Digital Earth Australia

3.3.2 Aerial photographs

The SES undertook an aerial survey on 27 October 2022. Photographs captured during this survey can be used to validate the 18 November 2022 satellite imagery that is presented in Figure 3.5 and Figure 3.6.

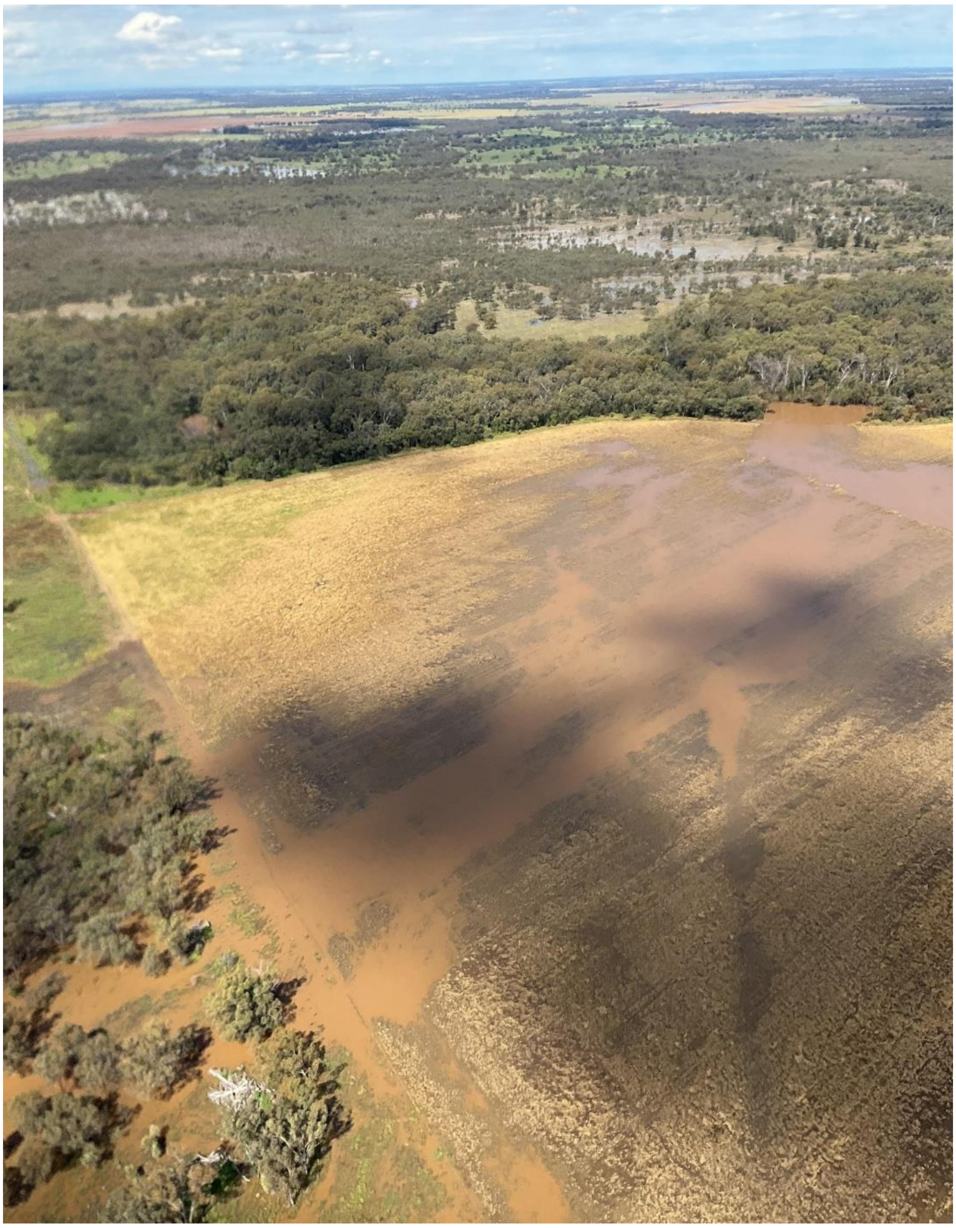
Photograph 3.1 is of the Raft 4 location, looking upstream. This image shows that out-of-channel flows occurred around Raft 4 on both sides the channel (but within the river corridor), which aligns with site observations that recent out-of-channel flows occurred around the western flank of the raft through an area that comprises a shallow billabong (see Section 2.3.4). The photograph shows that out-of-channel flows were maintained within the river corridor (which refers to the channel and adjoining billabongs) and there is no evidence of overflows to the adjoining floodplain area. The constructed levee (indicated in the photograph) may have contained the out-of-channel flows to the river corridor. The extent of this levee is also evident in Figure 3.2.



Photograph 3.1 Aerial image of Raft 4 – 27 October 2022

Image source: SES

Photograph 3.2 shows floodwaters spilling from the river channel at the channel breakout.



Photograph 3.2 Aerial image of Channel breakout – 27 October 2022

Image source: SES

3.3.3 Key conclusions

The key conclusions relevant to this report scope are:

- Overflows from the river channel at the channel breakout occurred in early December 2021, intermittently in August and September 2022 and near continuously in October and November 2022. It is interpreted that these overflows occur when the streamflow at the Warren Weir gauge (421004) exceeds 12,000 ML/day. As described in Section 3.2, backwater affects from the partial blockages of the channel at Raft 1, 2 or 3 locations would likely have resulted in more water spilling at the channel breakout then would have otherwise occurred.

- There is no evidence of overflows from the channel to the floodplain occurring at any of the raft locations. Overflows at the channel breakout would have reduced channel flows at the downstream raft locations, which would have reduced the risk of additional overflows of the riverbank levees occurring.

- During flood conditions some of the water that enters Bulla Bulla Creek and overflows at the channel breakout flows to the north-west and does not re-enter the Macquarie River channel. The portion of water lost vs returned is unknown but is expected to be variable at different river stages and significant during flood conditions. Any partial blockages of the channel due to debris rafts have potential to increase overflows at the channel breakout and flows into Bulla Bulla Creek and could therefore increase losses from the Macquarie River channel.

3.4 Evidence of river levee and bank erosion

Significant riverbank erosion occurred in 2016/17 when a debris raft formed at the channel breakout. Active riverbank erosion was also observed at several locations between the Bulla Bulla Creek inlet and Raft 4 during the 19 December 2022 site inspection. This section reviews available information to establish the likely extent of river levee and bank erosion attributable to the debris rafts. It includes a description of the channel breakout (Section 3.4.1) and other riverbank erosion (Section 3.4.2). Conclusions relevant to this report scope are made at the end of each section.

3.4.1 Channel breakout

The riverbank erosion at the channel breakout is approximately 70 m long and 15 to 20 m wide. The erosion has removed the highest part of the riverbank levee which means that water spills from the channel to the western floodplain when the river is flowing at or near bank full. This occurred during the December 2021 flood and the recent 2022 floods (discussed in Section 3.3).

The following sections describe the interpreted chronology of the erosion, the channel and floodplain levels and observations during the 19 December 2022 site inspection. Key conclusions relevant to this report scope are provided at the end of the section.

i Interpreted chronology

Section 2.2 established that:

1. a large debris raft initially formed downstream of the channel breakout location in October 2016, during the 2016 floods;

2. the raft moved to the channel breakout location in late 2016, after the 2016 flood subsided;

3. the riverbank erosion occurred or at least started sometime between 27 July 2017 and 25 September 2017. There were no flood events in 2017 (see Figure A.3 – Appendix A); and

4. floodwaters spilled from the channel during the December 2021 flood and recent 2022 floods (Section 3.3).

Photograph 3.3 and Photograph 3.4 were provided by a local community member and show the channel breakout in 2019 (during drought conditions). The riverbank erosion is clearly evident in Photograph 3.3 and the remnant debris from the raft are evident in both photographs.

Photograph 3.3 Channel breakout (looking downstream) – 2019

Image source: local community member

Photograph 3.4 Channel breakout (looking upstream) – 2019

Image source: local community member

ii River and floodplain characteristics

The channel breakout is located on the outside of a meander. Prior to the breakout occurring the channel bank was sparsely vegetated by a single row of trees growing on the bank. The natural riverbank levee had been enhanced by a constructed levee and a road and paddock were located within 5 m of the top of riverbank (see Figure B.1 – Appendix B).

Figure 3.7 is a cross-section of the river and floodplain at the channel breakout location (the cross-section alignment is indicated in Figure 3.2). The cross-section was sourced from the 2014 LiDAR survey (described in Section 3.2). An interpreted erosion profile is also shown. This profile has been estimated based on images and site observations.

Figure 3.7 shows that:

- the western floodplain is approximately 1.5 m lower than the top-of-bank (prior to erosion occurring);
- the erosion has removed the highest part of the riverbank levee which allows water to spill from the channel when the river is flowing at or near bank full; and
- the western floodplain would need to scour significantly for breakout flows to occur during lower river stages.

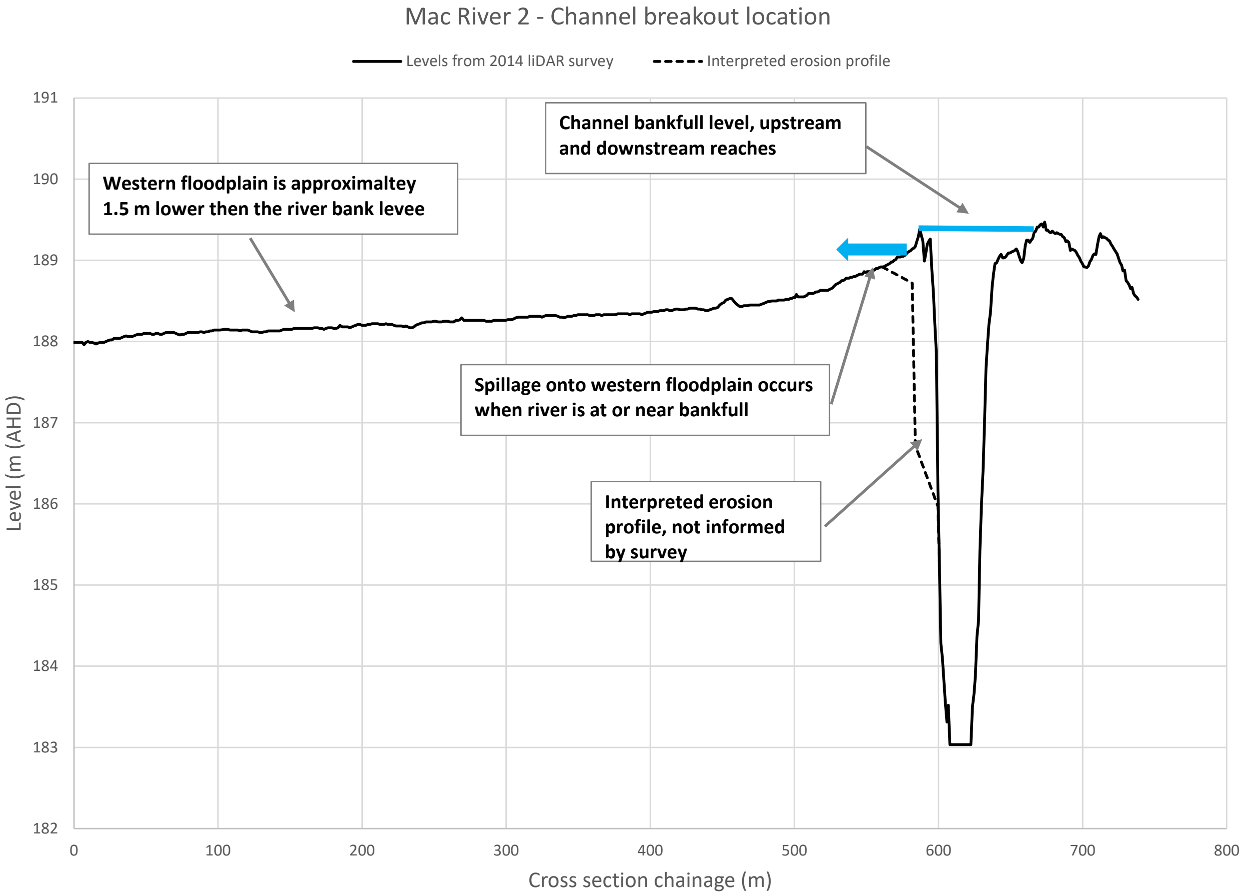


Figure 3.7 River and floodplain section – channel breakout

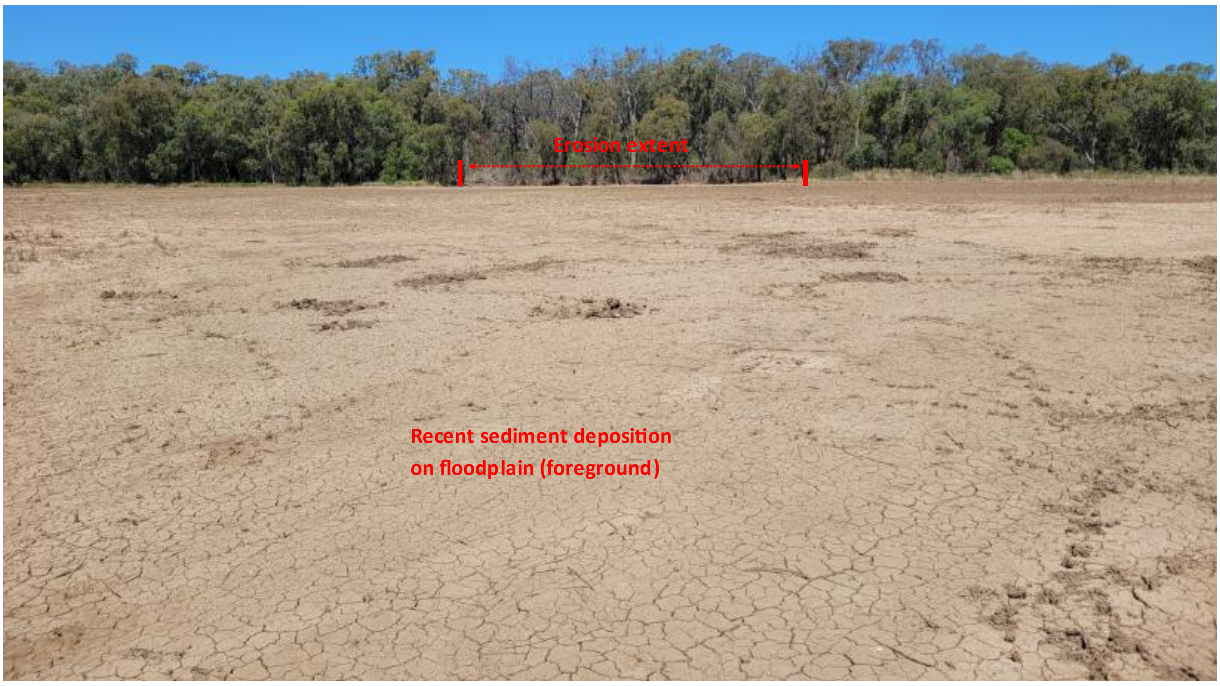
iii Site observations

The channel breakout and the adjoining floodplain to the west was inspected by EMM on 19 December 2022. Key observations were:

- the river water level was approximately 1.5 m below the overflow level;
- based on comparison of photographs from 2019, there was no clear evidence that the riverbank erosion had increased or worsened during the 2022 floods; and
- there was no evidence of scour or erosion on the western floodplain. Rather, deposition of silt or mud (approximately 0.1 m thick) was observed in areas were out-of-channel flow occurred.

Photograph 3.5 shows the channel breakout location, looking downstream. Photograph 3.6 was taken from the western floodplain looking towards the channel breakout. The extent of the riverbank erosion and recent deposition on the floodplain are evident in the photograph.

Photograph 3.5 Channel breakout – looking downstream (19 December 2022)



Photograph 3.6 Channel breakout – looking to the east from the western floodplain (19 December 2022)

iv Conclusion

The key conclusions relevant to this report scope are:

- The riverbank erosion is interpreted to have occurred in mid-2017, during a period when the river was not in flood. It is likely that the erosion was initiated by bank slumping which can occur when the lower or middle portions of the riverbank are scoured leaving the upper portion of the bank unsupported and prone to collapse. It is likely that this scour occurred due to the partial channel blockage caused by the debris raft as it settled with the falling river. The minimal riverbank vegetation at this location may have also been a contributing factor.

- There is no evidence that the erosion increased during the 2022 floods, despite breakout flows occurring for extended periods of time during the December 2021 flood and recent 2022 floods.

- The western floodplain would need to scour significantly for breakout flows to occur during lower river stages, which would be a mechanism that could lead to the river channel changing course. There was no evidence of scour on the floodplain, rather deposition of silt or mud (approximately 0.1 m thick) was observed in areas where out-of-channel flow occurred. This indicates that the natural riverbank levee is slowly reforming and over time (and many flood cycles) the channel breakout will be repaired.

3.4.2 Other riverbank erosion

i Description

Riverbank erosion is a natural process that leads to the channel planform (or alignment) gradually changing over time. The rate of erosion at a specific location can be exacerbated in areas where riverbank vegetation is sparse or non-existent or if a partial blockage in the river channel occurs due to a fallen tree or a debris raft. Partial blockages can deflect more water flow against an eroding bank which can increase erosion rates. Actively eroding riverbanks typically occur on the outer bank of a meander and are generally characterised by a near vertical, sparsely vegetated or unvegetated bank. In some areas exposed roots of trees can indicate the extent of recent erosion.

During the 19 December 2022 site inspection recent or active riverbank erosion was observed at several locations between the Bulla Bulla Creek inlet and Raft 4. Actively eroding riverbanks were observed near Rafts 2 (see Photograph 3.7) and 3 only (see Photograph 3.8) but not at any of the other raft locations.

Photograph 3.7 Active riverbank erosion at Raft 2 (19 December 2022)

Image source: Ozfish

Photograph 3.8 Active riverbank erosion at Raft 3 (19 December 2022)

Image source: Ozfish

ii Evidence of new riverbank erosion attributed to debris rafts

Observed areas of riverbank erosion during the 19 December 2022 site inspection were compared to areas of exposed riverbanks that are evident in high resolution imagery from 2013. This analysis concluded that all of the actively eroding riverbanks between Bulla Bulla Creek inlet and Raft 4 (including the sections near Rafts 2 and 3) were present in 2013. No new areas of riverbank erosion were identified.

iii Conclusion

The key conclusion relevant to this report scope is that aside from erosion at the channel breakout location, there is no evidence of new riverbank erosion that can be attributed directly to the debris rafts.

It is noted that:

- The 19 December 2022 site inspection was undertaken when the river water levels were approximately 1.5 to 2 m below top-of-bank. Hence, the middle and lower portions of the riverbank were not inspected.

- Debris rafts may exacerbate erosion rates in areas where there is an actively eroding riverbank prior to the raft forming. However, this cannot be reliably assessed from available information.

4 Expert opinions

This chapter provides opinions on the four questions noted in Chapter 1. For each question, a summary of relevant information from Chapters 2 and 3 is provided along with the opinion for each question.

4.1 Question 1

i Question

Whether the rafts have potential to block or restrict flow of the Macquarie River and to what extent?

ii Summary of relevant information

- Rafts 1 to 4 were inspected on 19 December 2022. At the time of inspection, the river water levels were approximately 1.5 to 2.0 m below top-of-bank and the gauged flow at the Warren Weir gauge (421004) was 5,754 ML/day. At each of the rafts there was no significant visible change in river water levels upstream and downstream of the raft, indicating there was no significant blockage of river flows at the time of inspection (see Section 2.3).

- Rafts 5 to 7 were identified by Ozfish on 4 January 2023 during a canoe survey of the river reach between Raft 4 and Marebone Wier. On 4 January 2023, the river water level (estimated from photographs) was approximately 3 m below top-of-bank and the gauged flow at the Warren Weir gauge (421004) was 2,820 ML/day. From the photographs provided by Ozfish, at each of the rafts there was no significant visible change in river water levels upstream and downstream of the raft, indicating there was no significant blockage of river flows at the time of inspection (see Section 2.3).

- Analysis of satellite and ariel imagery (see Section 3.3) established that:

  - Overflows from the river channel to the floodplain at the channel breakout occurred in early December 2021, intermittently in August and September 2022 and near continuously in October and November 2022. It is interpreted that these overflows occurred when the streamflow at the Warren Weir gauge (421004) exceeded 12,000 ML/day. As described in Section 3.2, backwater affects from the partial blockages of the channel at Rafts 1, 2 and 3 would likely have resulted in more water spilling at the channel breakout then would have otherwise occurred.

  - There is no evidence of overflows from the channel to the floodplain occurring at any of the raft locations during the December 2021 or recent 2022 floods. There is evidence that out-of-channel flows occurred at Raft 4. These flows were contained within the river corridor (which includes the river channel and any adjoining billabongs) and would have re-entered the channel downstream of the raft. It is possible that similar out-of-channel flows occurred at other raft locations.

iii Opinion

The debris rafts form partial blockages of the Macquarie River channel. The magnitude of the blockages would vary:

- for each raft based on the length of the raft and the depth below water of the debris;

- temporally as rafts move and change; and

- temporally due to changes in river flow and levels.

For the debris rafts to restrict river flow in the Macquarie River, the blockages (either from an individual raft or from multiple rafts) would need to result in either overflows from the channel to the floodplain or increased flows into a river anabranch, such as Bulla Bulla Creek. There was no evidence of any significant flow restriction during the 19 December 2022 site inspection, when the river water levels were approximately 1.5 to 2.0 m below top-of-bank and the gauged flow at the Warren Weir gauge (421004) was 5,754 ML/day.

Overflows from the river channel at the channel breakout occurred in early December 2021, intermittently in August and September 2022 and near continuously in October and November 2022. It is interpreted that these overflows occurred when the streamflow at the Warren Weir gauge (421004) exceeded 12,000 ML/day and backwater affects from the partial blockages of the channel at Rafts 1, 2 or 3 would likely have resulted in more water spilling at the channel breakout then would have otherwise occurred.

In conclusion, the debris rafts (in their December 2022 form) are assessed to only restrict flow in the Macquarie River channel during flood conditions when the river is flowing at or near bank full. Survey and hydraulic modelling would be required to assess the magnitude of the flow restriction.

4.2 Question 2

i Question

Whether the rafts could cause the river to change its course.

ii Summary of relevant information

- The Macquarie River flooded in September and October 2016. This flood was the largest flood since 1991. The initial debris rafts formed in the Macquarie River during this event (see Section 2.2.1).

- Significant flooding in the Macquarie River occurred in December 2021 and the second half of 2022. The December 2021 flood and initial floods that occurred in August and September 2022 were of similar magnitude to the 2016 flood. A larger flood occurred in October and November 2022. This flood lasted for approximately 50 days and was the largest flood since the 1955/56 floods (based on the Warren Weir gauge record). Numerous debris rafts were present in the Macquarie River downstream of the Bulla Bulla Creek inlet during these floods (see Section 2.2.3).

- The riverbank erosion at the channel breakout location is interpreted to have occurred in mid-2017, during a period when the river was not in flood (see Section 3.4.1). Overflows at the channel breakout occurred in early December 2021, intermittently in August and September 2022 and near continuously in October and November 2022 (see Section 3.3.3). There is no evidence that the riverbank erosion increased during the 2022 floods, despite breakout flows occurring for extended periods of time. There was also no evidence of scour on the floodplain adjacent to the channel breakout. Rather deposition of silt or mud (approximately 0.1 m thick) was observed in areas where out-of-channel flow occurred. This indicates that the natural riverbank levee is slowly reforming and over time (and many flood cycles) the channel breakout will be repaired (see Section 3.4.1).

- There is no evidence that overflows from the channel to the floodplain occurred at any of the raft locations during the 2022 floods (see Section 3.3.3).

iii Opinion

The following sections describe the processes that could lead to the river changing course, risks based on the debris rafts in their recent and current form and risks for potential future scenarios that may occur overtime.

a Description of processes

The debris rafts partially block the river channel which can lead to out-of-channel flows occurring during flood conditions. Out-of-channel flows can erode the landform and overtime create a new channel that water flows in. For the river to change course a new or existing channel would need to develop to have a similar depth and geometry to the Macquarie River channel, which is approximately 40 m wide and 7 m deep (see Figure 3.3) in the Investigation Area. There are three processes by which this could occur, these are described below.

Process 1 - Meander cutoff

If out-of-channel flows occur within the river corridor it is possible that a new channel could develop within the corridor that bypasses the blocked portion of the existing channel. This would be similar to a meander cutoff process that occurs naturally within the Macquarie River corridor due to the lateral migration of the channel. If this were to occur, it would be of little consequence as the Macquarie River would still flow through the river corridor and the abandoned channel would become a billabong overtime. Figure 4.1 shows the meander cutoff process.

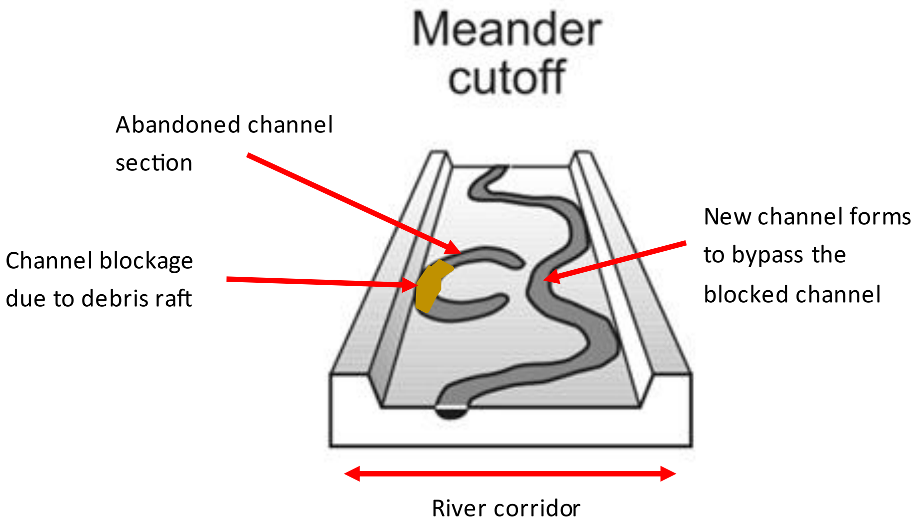


Figure 4.1 Meander cutoff process

Background image source: River Styles

Process 2 – Expansion of an anabranch channel

Bulla Bulla Creek is an anabranch to the Macquarie River. It receives inflows from the river during certain flow conditions and re-joins the Macquarie River approximately 7 km to the north-west of its inlet. A significant blockage in the Macquarie River channel immediately downstream of the Bulla Bulla Creek inlet would result in more water flowing into Bulla Bulla Creek then would otherwise occur. It is possible that this additional flow could cause the creek to enlarge, and over time become the main channel. For this to occur the creek channel would need to scour significantly to become approximately twice as wide and 3 m deeper than the current channel (see Figure 3.3 – which compares cross-sections of the Macquarie River and Bulla Bulla Creek channels).

Process 3 – Development of a distributary channel

If overflows from the channel to the floodplain occur, it is possible that a new channel that takes water away from the main river channel could develop. In most instances, these new channels are shallow and only receive water during flood conditions and are referred to as distributary channels or breakaways. A distributary channel would likely transfer water from the main channel to a floodplain wetland or a low point on the floodplain. The floodplain wetlands on the Macquarie River floodplain (within the Investigation Area) are nearly always lower than the Macquarie River top-of-bank but several meters higher than the Macquarie River channel invert, as shown in Figure 3.7 which shows a cross-section of the Macquarie River channel and the adjoining western floodplain. Accordingly, the floodplain wetland levels will control or limit the depth of distributary channels, in that the channel will not develop to a level that is below the wetland level.

For a distributary channel to become a main channel a new channel would need to form downgradient of the receiving wetland that returns water to the Macquarie River (or another regional creek). If this channel were to develop through the wetland the distributary channel could then develop further to become the main channel.

b Risks due to debris rafts in their recent and current form – based on available evidence

Significant flooding in the Macquarie River occurred in December 2021 and the second half of 2022. During these floods:

- A large raft was located at the Raft 1 location, approximately 1,400 m downstream of the Bulla Bulla Creek inlet. Blockages due to this raft may have created a backwater affect at the Bulla Bulla Creek inlet, which would have resulted in more water flowing into the creek then would have otherwise occurred. There is no evidence of significant riverbank erosion in Bulla Bulla Creek which would indicate that it is enlarging.

- Overflows from the channel to floodplain occurred for extended periods of time at the channel breakout location. There is no evidence that the riverbank erosion significantly increased, or that a distributary channel is forming in the adjoining floodplain. Rather deposition of silt or mud (approximately 0.1 m thick) was observed in areas where out-of-channel flow occurred. This indicates that the natural riverbank levee is slowly reforming and over time (and many flood cycles) the channel breakout will be repaired.

- There is evidence that out-of-channel flows occurred around Raft 4. These flows were maintained within the river channel corridor and there is no evidence of overflows to the adjoining floodplain area or significant scour within the river corridor that would indicate a new channel was forming via the meander cutoff process. It is possible that similar out-of-channel flows occurred at other rafts.

In conclusion, there is no known evidence that the debris rafts in their recent and current form are causing the Macquarie River to change its course, despite significant flooding.

c Potential future risks

The following scenarios may occur overtime as the rafts continue to change during future wet and dry cycles:

- **Scenario 1** - **Raft 4 further develops** - Rafts 1, 2 and 3 are interpreted to be mobile and are slowly moving downstream (see Section 2.4). If these rafts combine with Raft 4 the magnitude of blockage at Raft 4 could increase and the absence of any rafts immediately downstream of the channel breakout would likely reduce the amount of water that overflows from the channel, meaning that more channel flow would arrive at the Raft 4 location during flood conditions. The combination of these changes would increase the magnitude of out-of-channel flows at the Raft 4 location.

- **Scenario 2 – A more significant blockage develops** - a more significant blockage could occur at any of the current or future raft locations if say a bank collapses and several large trees fall into the channel. A more significant blockage would increase the likelihood and magnitude of out-of-channel flows.

- **Scenario 3** – **A new channel breakout forms** – the channel breakout is interpreted to have formed due to bank slumping in mid-2017, during a period when the river was not in flood (see Section 3.4.1). It is possible that similar breakouts could occur at new locations in the future.

If any of the above scenarios were to occur, it is possible that during the next flood, out-of-channel flows will occur at new locations and /or at increased magnitudes. Possible outcomes are:

- No significant erosion occurs due to the out-of-channel flows (as per the recent period) – possible for all scenarios.

- A new channel forms within in the river corridor via the meander cutoff process - possible for Scenarios 1 and 2 only.

- A distributary channel forms due to overflows from the channel to floodplain occurring at a new location - possible for all scenarios.

For all scenarios, it is unlikely that the flow regime in Bulla Bulla Creek will change as the rafts are progressively moving downstream of the creek inlet.

4.3 Question 3

i Question

Whether there could be damage/scouring of the riverbank levees, and to what extent.

ii Summary of relevant information

- Riverbank erosion at the channel breakout is interpreted to have occurred in mid-2017, during a period when the river was not in flood. It is likely that the erosion was initiated by bank slumping which can occur when the lower or middle portions of the riverbank are scoured leaving the upper portion of the bank unsupported and prone to collapse. It is likely that this scour occurred due to the partial channel blockage caused by the debris raft as it settled with the falling river. The minimal riverbank vegetation at this location may have also been a contributing factor (Section 3.4.1).

- During the 19 December 2022 site inspection recent or active riverbank erosion was observed at several locations between the Bulla Bulla Creek inlet and Raft 4. Actively eroding riverbanks were observed near Rafts 2 and 3 but not at any of the other raft locations. Observed areas of riverbank erosion during the 19 December 2022 site inspection were compared to areas of exposed riverbanks that are evident in high resolution imagery from 2013. This analysis concluded that all of the actively eroding riverbanks between Bulla Bulla Creek inlet and Raft 4 (including the sections near Rafts 2 and 3) were present in 2013. No new areas of riverbank erosion were identified (Section 3.4.2).

It is noted that:

- The 19 December 2022 site inspection was undertaken when the river water levels were approximately 1.5 to 2 m below top-of-bank. Hence, the middle and lower portions of the riverbank were not inspected.

- Debris rafts may exacerbate erosion rates in areas where there is an actively eroding riverbank prior to the raft forming. However, this cannot be reliably assessed from available information.

iii Opinion

From the evidence presented in this report it is concluded that:

- During flood conditions when the channel is flowing at or near bankfull, debris rafts do not significantly increase the risk of riverbank erosion occurring. The reasons for this are:

- the rafts generally span the full channel width and therefore do not deflect flow against a bank on one side of the river; and

- the rafts form a partial blockage of the channel which would likely result in out-of-channel flows occurring to either the river corridor or the floodplain at a location that is upstream of the raft. This reduces the channel flow passing the raft and therefore reduces erosion risks at the raft location.

- The risk of erosion increases as the river levels drop. The reasons for this are:

  - the channel blockage may increase in magnitude (ie as a percentage of the total flow area across the channel) as the river levels drop; and

  - out-of-channel flows do not occur so all of the river flow needs to pass under the raft, at a velocity that is likely materially higher than in other parts of the river that are not affected by a raft. This increases the erosion risk to the middle and lower portions of the riverbank.

There are exceptions to the above conclusions. In particular, in river reaches where the flow is confined by constructed levees (ie through a township) a debris raft would increase the risk of erosion to the riverbank and constructed levees during flood conditions if out-of-channel flow upstream of the raft cannot occur due to confinement of the river flow by the levees.

In conclusion, debris rafts have potential to cause significant erosion of the riverbank and riverbank levees. Based on available evidence, the erosion is most likely to occur after a flood due to bank slumping processes. It is likely that the erosion risk is higher:

- for rafts that are not moving and have debris that extend further in depth. Raft 4 is an example of a such a raft;

- on the outside of channel meanders as the riverbanks are naturally steeper and less stable; and

- for river reaches that have minimal riverbank vegetation, which stabilises the channel bank.

It is noted that the channel breakout location had elevated risks based on each of the above factors.

The erosion that has occurred at the channel breakout (see descriptions in Section 3.4.1) is an example of the magnitude or extent of erosion that can occur.

4.4 Question 4

i Question

How the rafts might move or change with further flooding in the Macquarie River.

ii Summary of relevant information

- Between Warren and Marebone Wier, the Macquarie River channel progressively becomes smaller, with the bank-full channel area estimated to be 261 m^2 at Carvel (just downstream of Warren) and 92 m^2 at Marebone and that large and small flood discharge rates reduce by a similar amount. This diminishing channel trend occurs as the flood discharges conveyed in the channel reduce over the river reach due to losses to floodplain wetlands and anabranches. This means that the ability of the river to flush floating debris progressively reduces between Warren and Marebone (see Section 3.1).

- A summary of interpreted chronology of Rafts 1 to 3: During the 2016 flood, a large raft formed downstream of the Bulla Bulla Creek inlet. The raft moved further downstream to the channel breakout location after flooding subsided. The debris from the raft remained at the channel breakout location during the 2018/19 drought before moving downstream by approximately 500 m in 2020 when streamflow returned to the Macquarie River. A large raft formed at this location and remained fixed during the December 2021 flood and the initial part of the 2022 floods. This raft broke up into three smaller rafts (Raft 1, 2 and 3) during the 2nd half of the October/November 2022 flood. These rafts comprise small to medium woody debris and some anthropogenic wastes. They appeared to be buoyant and mobile but move slowly. (see Chapter 2).

- Raft 4 is understood to have also formed during the 2016 flood. It has been fixed in its current (4 December 2022) location since at least September 2021, but possibly for longer. The downstream part of the raft contained larger woody debris and appeared to be more intertwined than Rafts 1, 2 and 3. It was observed to be buoyant at high river stages but may become perched as the river levels drop. The raft did not materially change during the 2022 floods, with the upstream end of the raft extending by only a small amount. It is possible that Rafts 1 to 3 will eventually accumulate at the upstream end of Raft 4, making the raft longer (see Chapter 2).

- The chronology of Rafts 5, 6 and 7 is unknown. However, all of the rafts have formed behind fallen trees and have potential to develop further as more debris get washed down the river.

iii Opinion

Debris rafts initially formed in the Macquarie River channel downstream of Bulla Bulla Creek during the 2016 floods. From the information presented in this report it is interpreted that most of the debris from the 2016 flood and the additional debris that have washed down the river during the 2022 floods have accumulated in the 7 km river reach that is between Bulla Bulla Creek and Raft 4. It is likely that some debris have moved out of this river reach via out-of-channel flows around Raft 4 and have moved further downstream, possibly forming Rafts 5, 6 and 7.

Raft 4 is interpreted to be fixed and may grow in length if additional debris from Rafts 1, 2 and 3 accumulate at the upstream end. It is possible that Raft 4 may move in the future if rising and falling river levels are able to dislodge some of the debris overtime. If it does move or change, evidence from other large rafts that have moved suggests that the debris will form a new raft immediately downstream.

Downstream of Raft 4 the Macquarie River channel becomes progressively narrower and several trees have fallen into the river at the Raft 5, 6 and 7 locations. It is therefore likely that Rafts 5, 6 and 7 could further develop or new rafts could form downstream of Raft 4 if more debris get washed down the river.

It is concluded that without intervention, the debris rafts will continue to evolve and move slowly downstream but are likely to stay within the Macquarie River channel at or near the current raft locations until the woody debris break-down.

References

Ralp et all 2009, Downstream hydrogeomorphic changes along the Macquarie River, southern eastern Australia, leading to channel breakdown and floodplain wetlands.

Appendix A
Figures

A.1 Location diagram

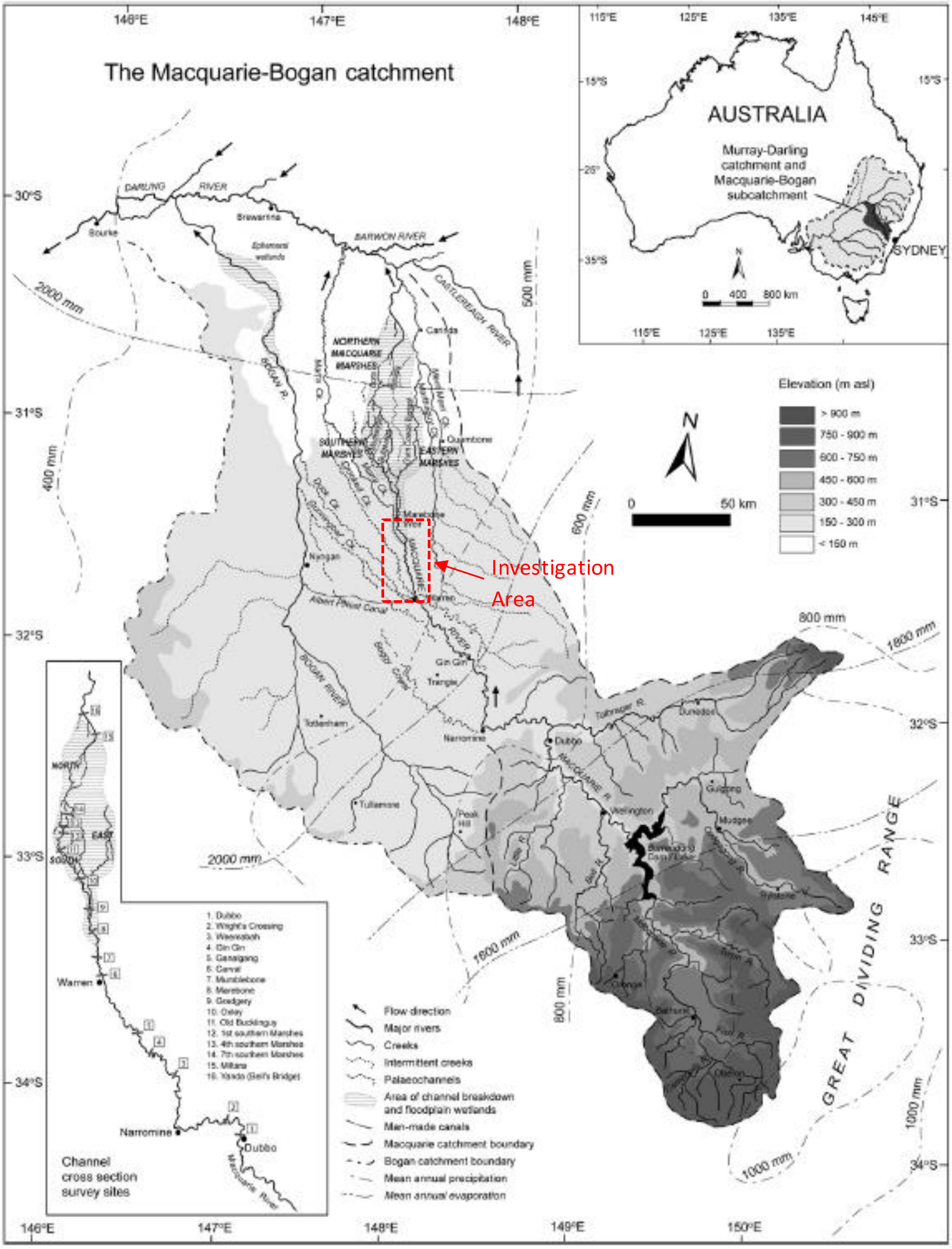


Figure A.1 Location of the Investigation Area

Image source: (Ralph 2009)

A.2 Stream gauge data

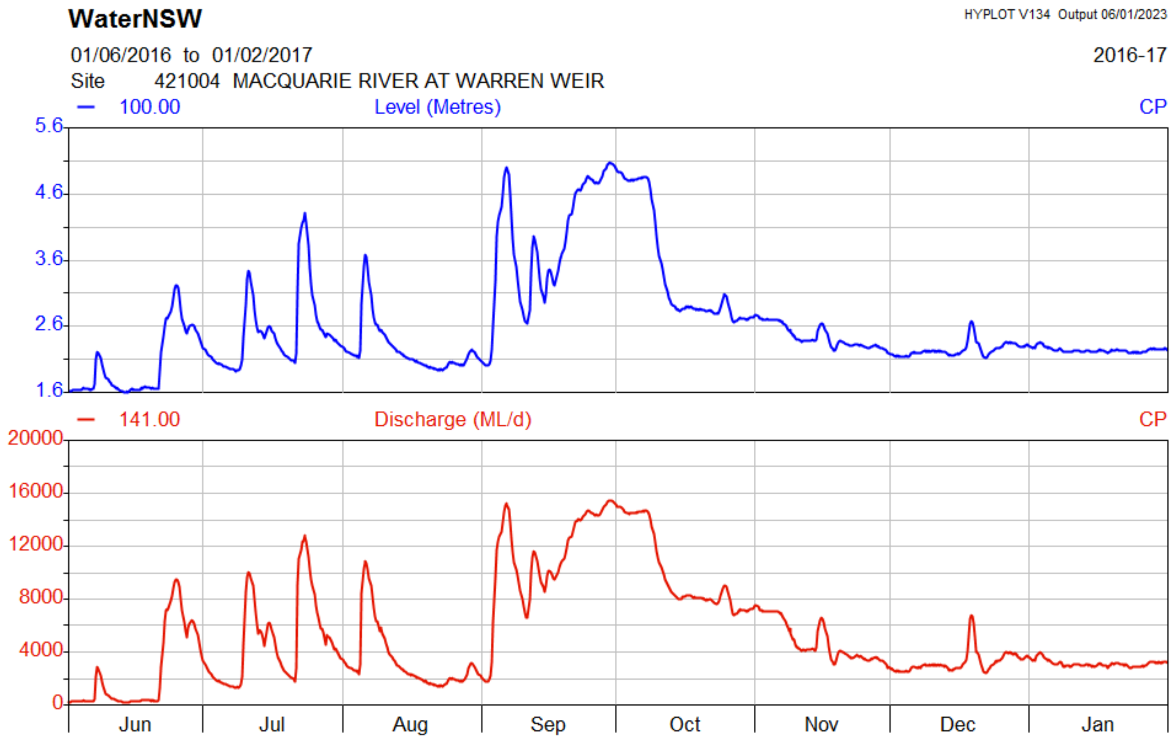


Figure A.2 Warren Weir gauge record – 2016 floods

Source: WaterNSW real time data portal.

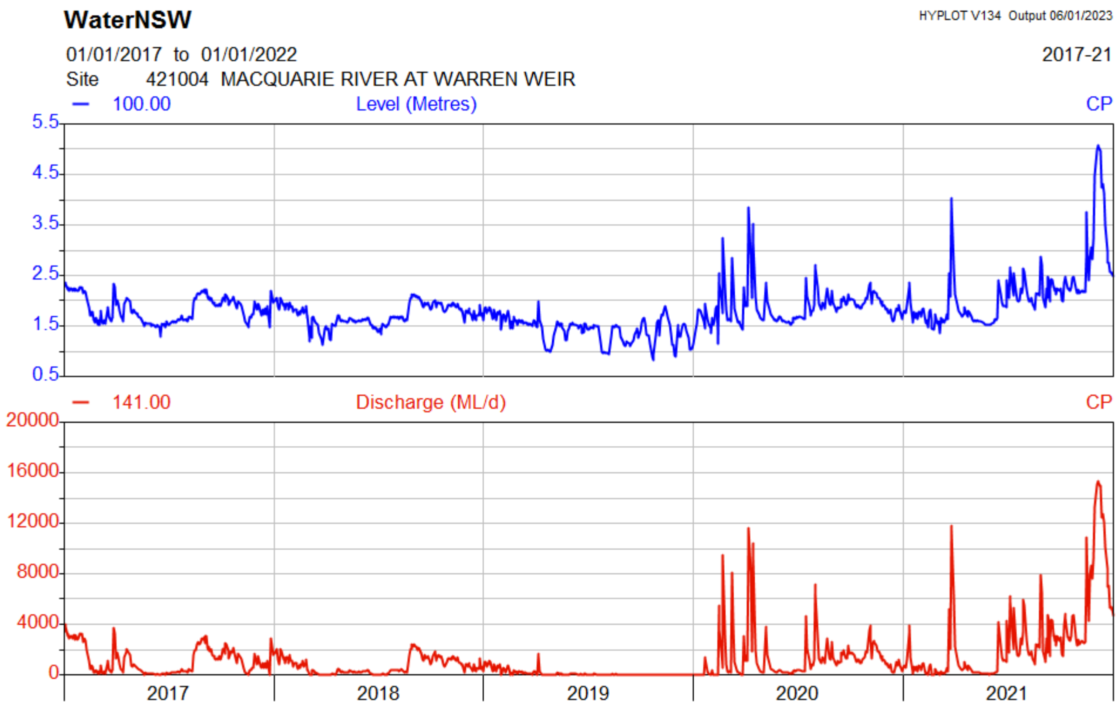


Figure A.3 Warren Weir gauge record – 2017 to 2021

Source: WaterNSW real time data portal.

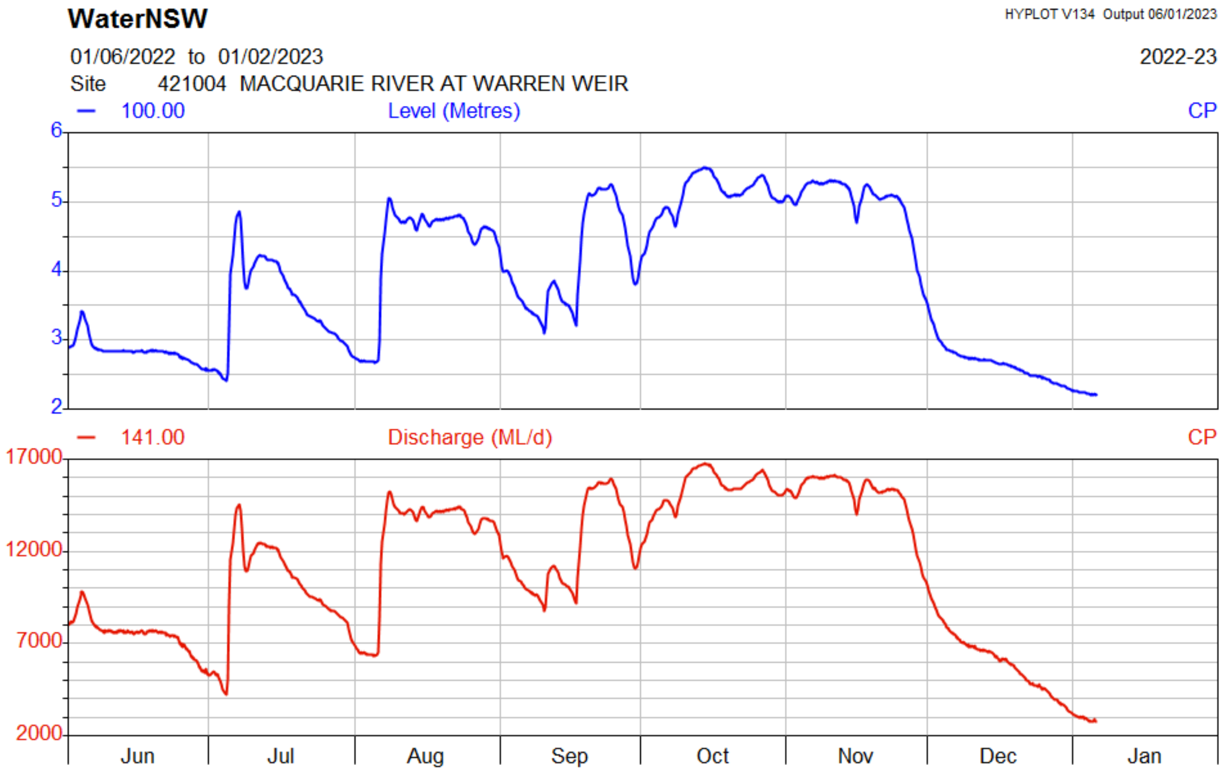


Figure A.4 Warren Weir gauge record – 2022 floods

Source: WaterNSW real time data portal.

A.3 Geomorphology related figures

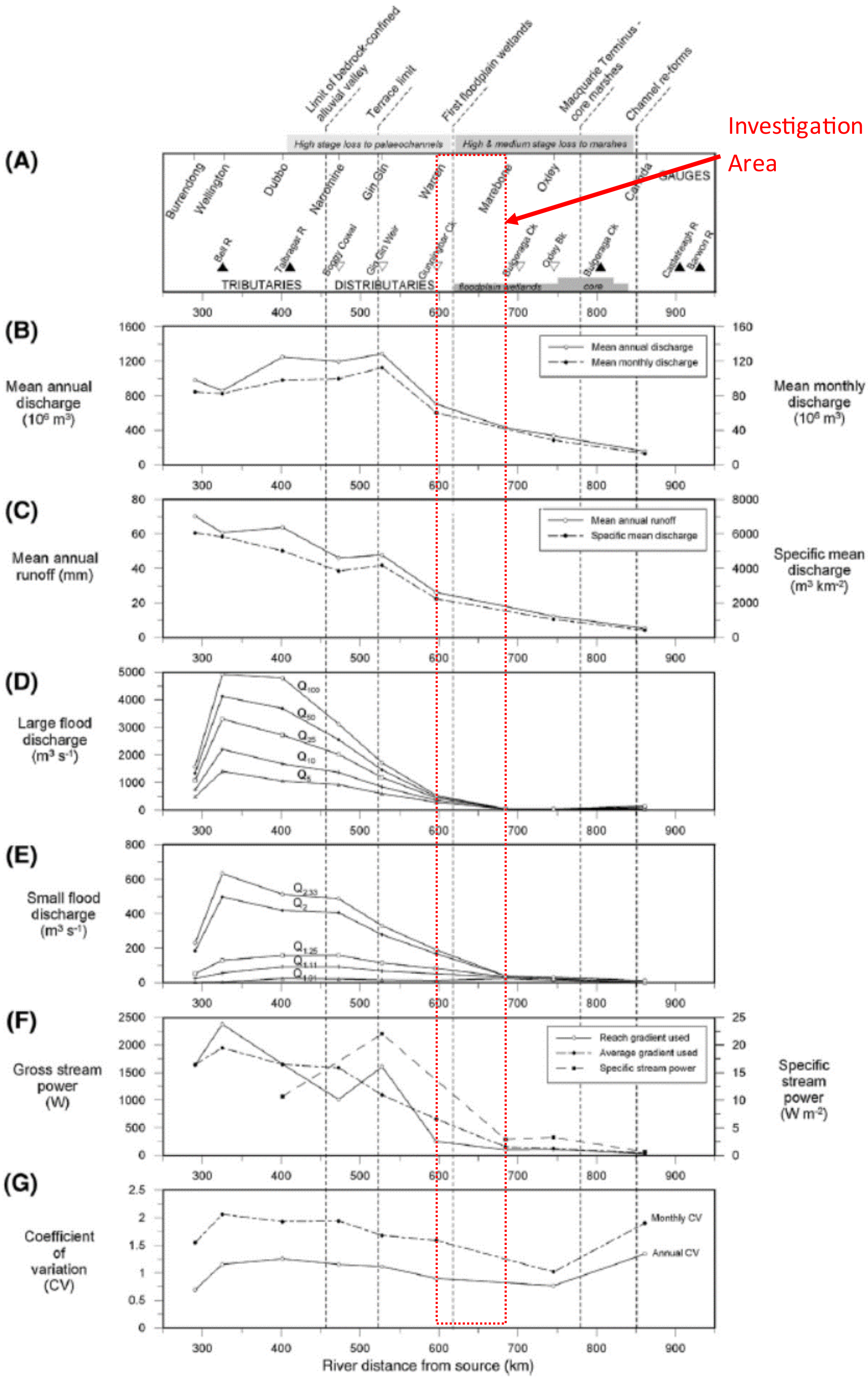


Figure A.5 Changes to discharge and stream power along the Macquarie River

Figure source: (Ralph 2009)

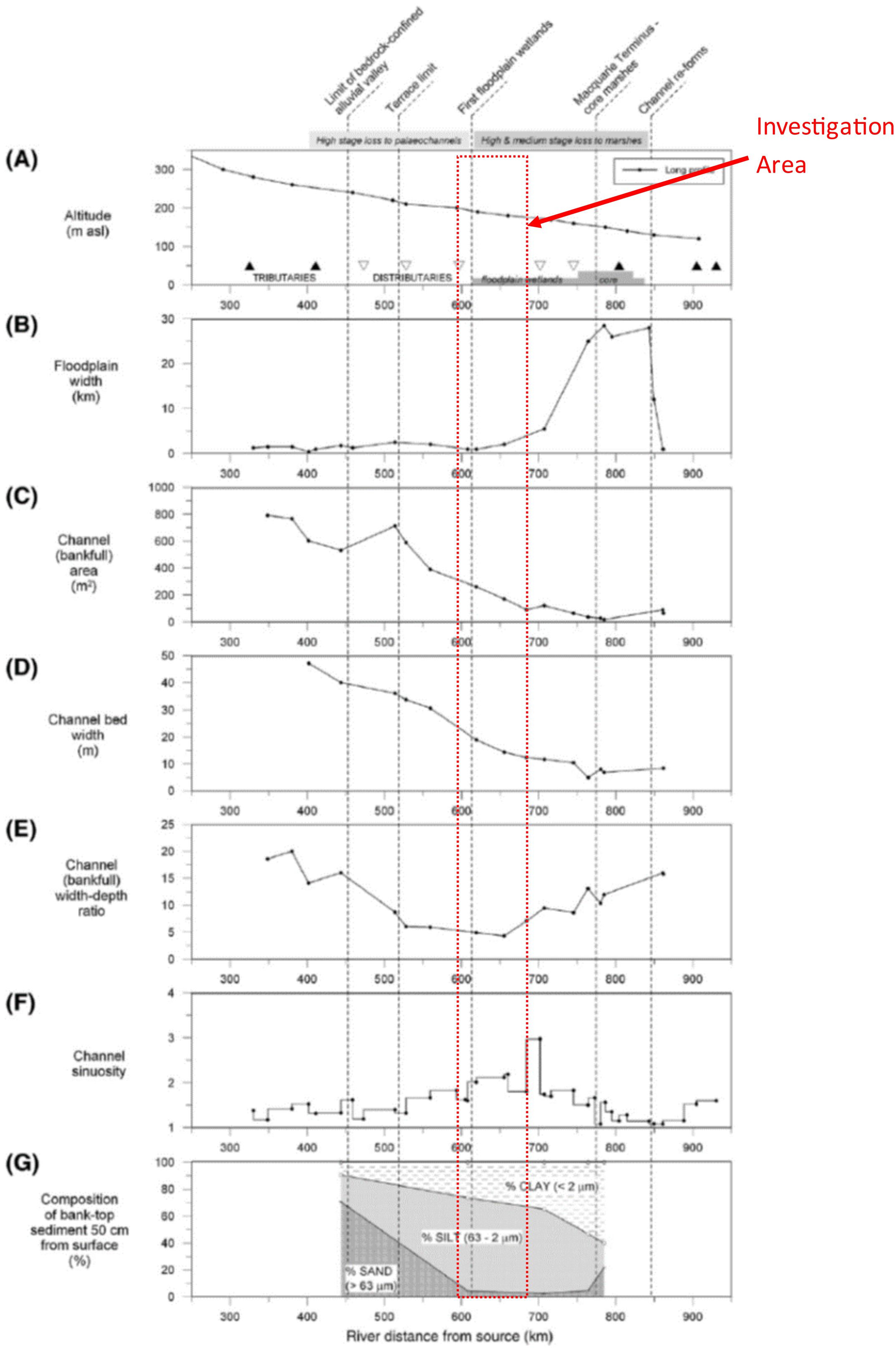


Figure A.6 Channel and floodplain changes along the Macquarie River

Figure source: (Ralph 2009)

Appendix B
Aerial images and photographs

B.1 2015 imagery

Figure B.1 Channel breakout location – November 2015

Figure B.2 Raft 4 location – November 2015

B.2 2016 imagery

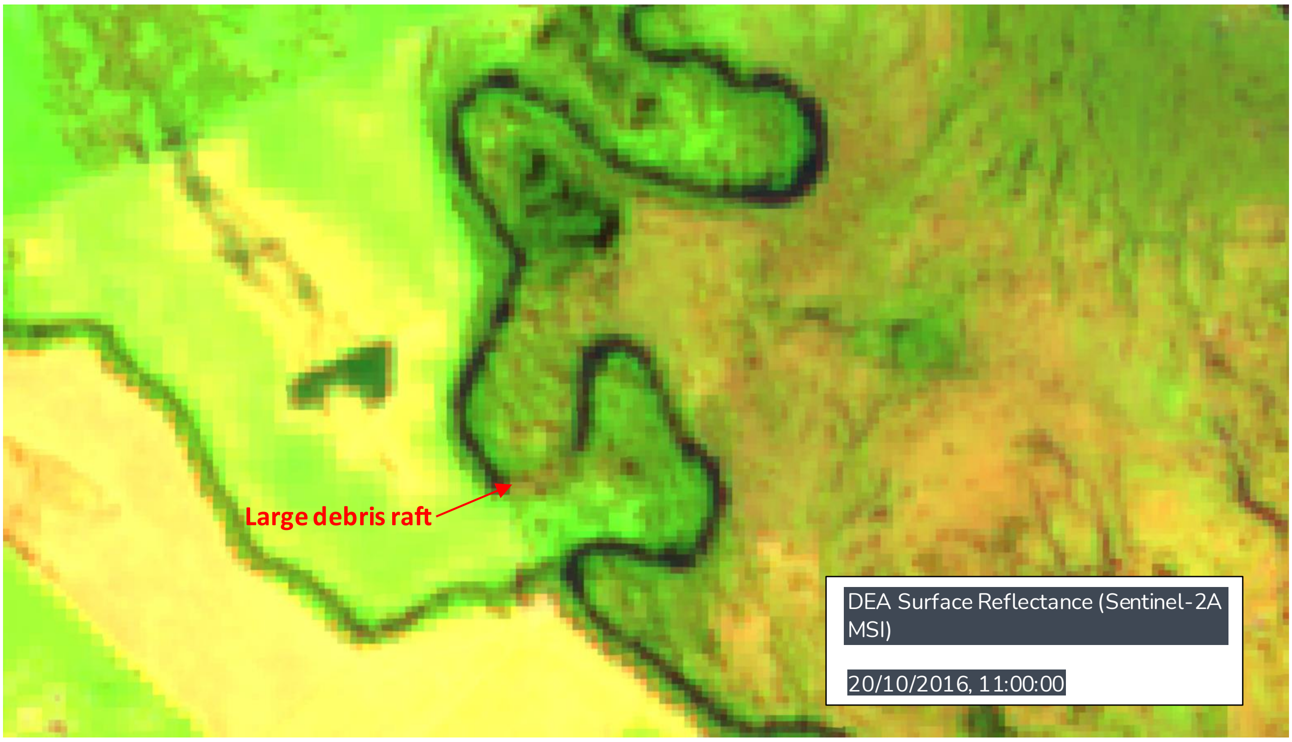


Figure B.3 Satellite imagery – 20 October 2016

Source: Digital Earth Australia

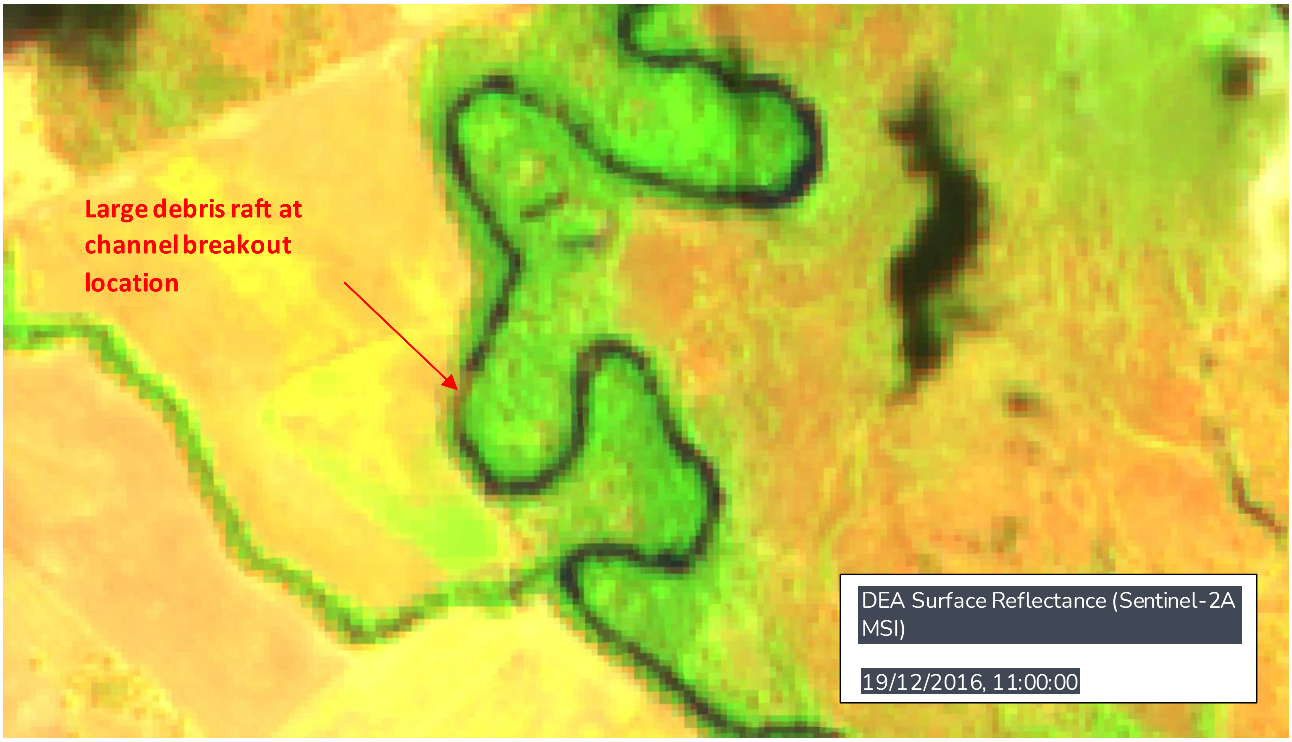
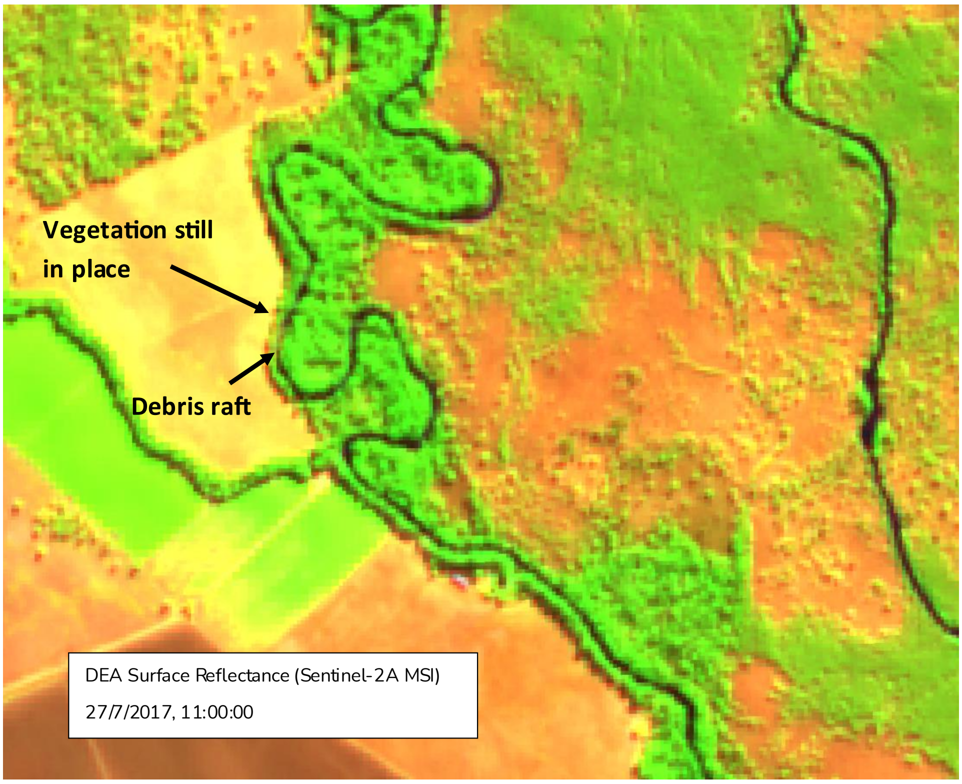


Figure B.4 Satellite imagery – 19 December 2016

Source: Digital Earth Australia

B.3 2017 imagery



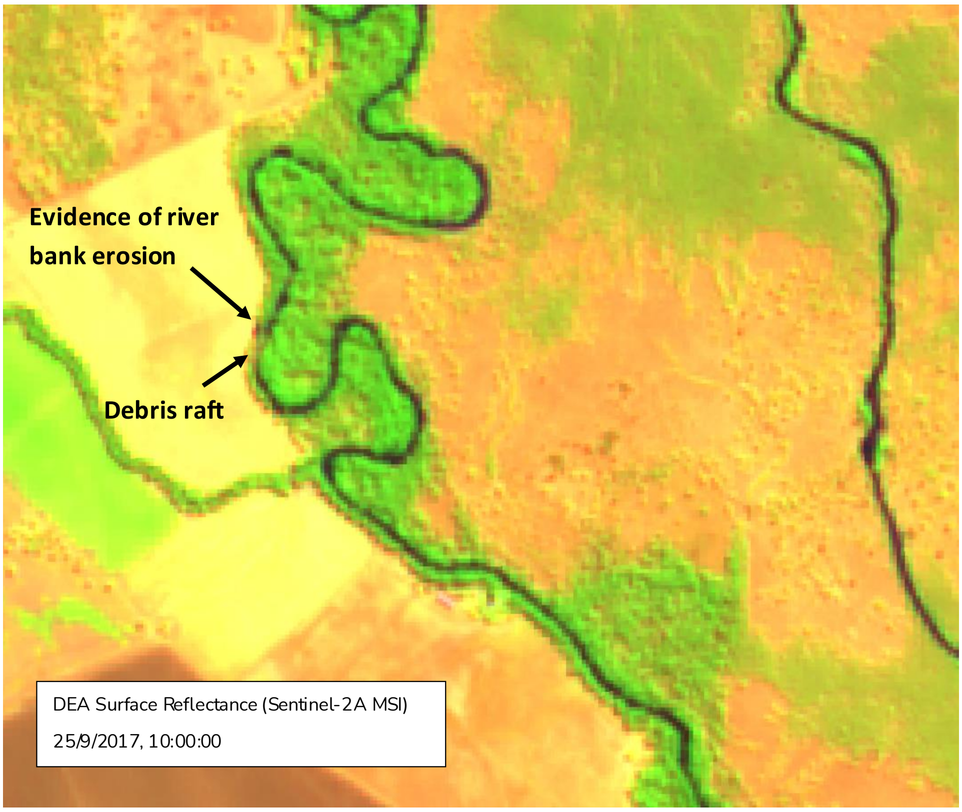


Figure B.5 Satellite imagery – mid-2017

Source: Digital Earth Australia

B.4 2018 imagery

Figure B.6 Channel breakout location – September 2018

Source: Google Earth

Figure B.7 Raft 4 location – September 2018

Source: Google Earth

B.5 2022 imagery

Figure B.8 Raft located downstream of Warren – 19 September 2022

Source: Fire and Rescue NSW report

Figure B.9 large raft downstream of channel breakout – around 15 October 2022

Source: SES

Figure B.10 Aerial images of the large raft downstream of channel breakout – 15 October 2022

Source: SES

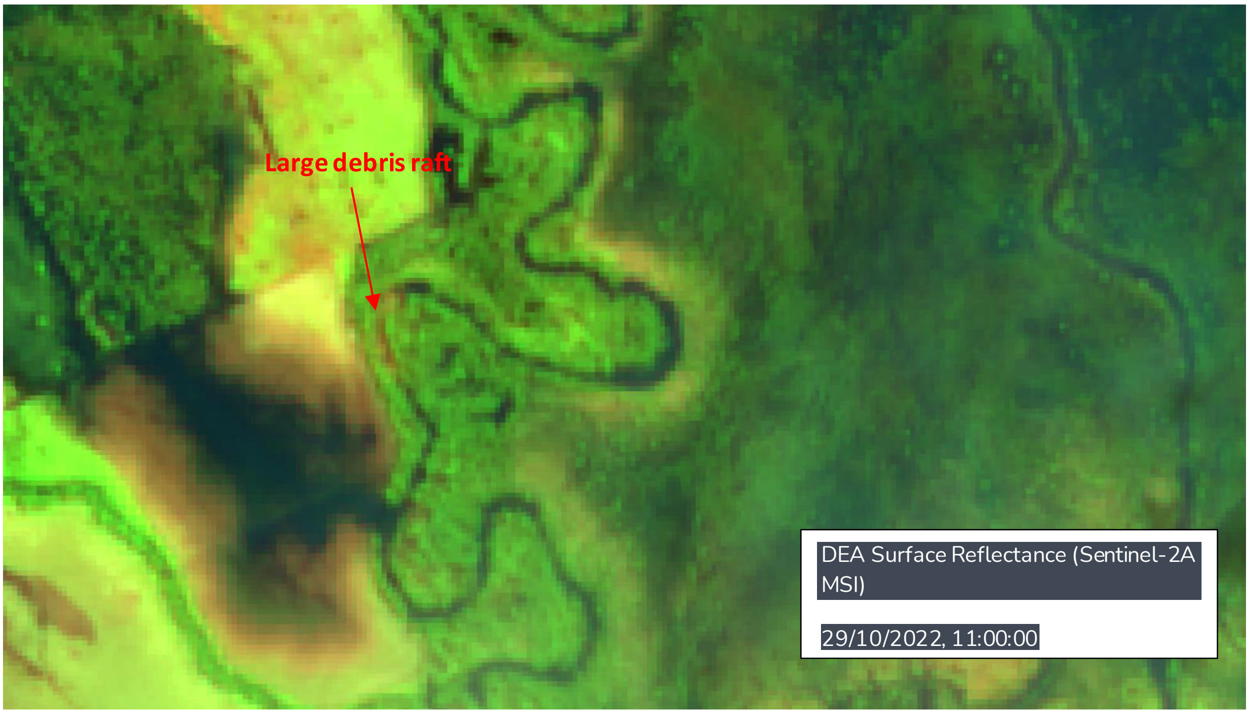


Figure B.11 Satellite imagery – 29 October 2022

Source: Digital Earth Australia

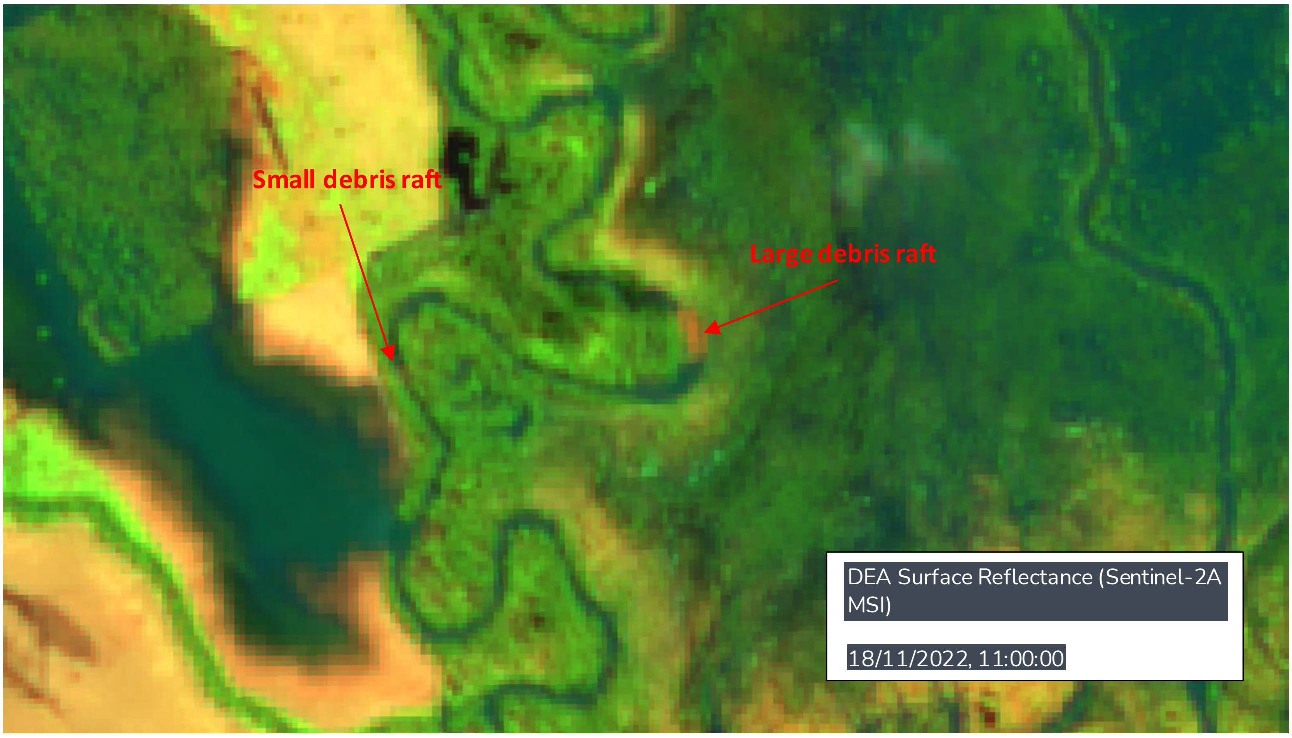


Figure B.12 Satellite imagery – 18 November 2022

Source: Digital Earth Australia

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