Annex to Terara Shoalhaven Sand – Application for Extension of Dredge Area Supplementary Information – Geomorphology

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Terara Shoalhaven Sand

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			Name/Position	Signature
Final	27 February 2023	Reviewed	Chris Gippel Director Geomorphologist	

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1 Introduction

On 19 April 2022 Shoalhaven City Council provided a request for information (RFI) to Terara Shoalhaven Sand in relation to the Environmental Impact Statement (EIS) for Regional Application - Extension of Dredge Area, to Western End and Northern Side of Pig Island, on the Bed of the Shoalhaven River, Adjacent to Lots 1 and 2 DP 1184790 below MHWM (RA21/1000).

Fluvial Systems was commissioned to respond to items in the RFI relevant to geomorphology. The responses were documented in Gippel (2022).

On 7 October 2022 Justin Lamerton, Shoalhaven City Council, assessed the report and provided written comments in a Planning Environment & Development Group Internal referral. The relevant paragraphs are provided below:

> ***"Bank Erosion / Scour Impacts upon Levee Banks and other Infrastructure:***
>
> *The River Stability Bank Erosion & Flow Paths Report[1] concludes that erosion along both banks of the Lower Shoalhaven River south of Nowra Bridge is ongoing and widespread. The assessment included a desktop assessment of previous studies, site inspections and analysis of flood modelling results.*
>
> *According to the assessment, bank erosion and instabilities are likely associated with long term major channel realignment downstream of Nowra. Furthermore, wind- and boat-wake generated wave actions, tidal oscillation, groundwater seepage, rapid water drawdown, flood events and tidal flows were identified as mechanisms associated with bank erosion. The Martens report identified no indications that historic or current dredging operations may impact erosion and bank instability, but did not specifically indicate this has not or could not be a contributing factor for bank instability.*
>
> *The Martens report indicated from visual site investigations that "dredging operations do not appear to have had any effect on bank stability as evidenced by the tidal and sub-tidal bench which extended away from the southern bank along the length of the inspected area" and "no significant detrimental impacts are anticipated". It is unknown however whether the elevation of the tidal and sub-tidal bench has lowered as a result of adjacent dredge operations.*
>
> *It is noted that recent visual audit reports have identified at least five locations in which there are earthen levee slips in the location of the current dredge extent. These have all been caused by undercutting of steep banks, leading to tension cracks and then earthen slips.*
>
> *Whilst the geomorphology analysis has identified numerous likely contributing factors for bank erosion, given the highly dynamic environment it is possible that dredge operations may be a contributing factor to previous and future bank and levee damage. Hence there is still some concern that existing dredge operations area and proposed dredge expansion area could potentially contribute to increased bank instability which could impact the structural integrity of the Riverview Road and Terara flood levees.*
>
> *If the dredge extent is to increase this would require frequent monitoring (including bathymetric survey) and adaptive management conditions to prevent any adverse impacts on bank and levee structural integrity due to fluvial geomorphology changes…*
>
> *The Martens report recommends a monitoring program to be implemented for the northern bank of Burraga Island, where higher flow velocity increased may be experienced. Given the importance of the Riverview Rd and Terara levees in protecting life and property in a flood event, it is considered that a monitoring program would also be required along the southern bank, in addition to frequent bathymetric survey as noted above.*

[1] Foster, N. 2022. Response to Shoalhaven City Council request for further information – EIS related to expansion of sand extraction operations at Terara Shoalhaven Sand, Terara, NSW. Martens & Associates Pty Ltd, Hornsby.

It is however noted that the provided additional information, including the River Stability Bank Erosion & Flow Paths Report and the Geomorphology Supplementary Information, are to a great extent relying on existing studies and a desktop assessment approach. Neither study includes a detailed fluvial geomorphology assessment to determine the short- and long-term impacts on nearby levees and infrastructure as a result of the proposed expanded dredging area.

The geomorphic assessments have focused on river bank stability in the vicinity of the proposed expanded dredge area in response to Councils RFI. It is however unclear as to what potential long-term impacts the dredging may have on other infrastructure upstream of the proposed expanded dredge area, including but not limited to wharfs and pontoon structures adjacent Wharf Rd and the bridges. Dredge operations in a river bed can potentially result in the development of a head cut that would propagate upstream depending on shear stress and stream power impacts on in-situ riverbed material. Bed lowering has the potential to steepen batters which would contribute to erosion, tension cracks and potential earthen levee failures. It is noted that the Terara Shoalhaven Sand – Application for Extension of Dredge Area Supplementary Information – Geomorphology (Fluvial Systems Pty Ltd, 2022) report notes that "there is no data or published research available that would enable an assessment to be made on the impact of deep dredge holes on the location and depth of nearby channels". The frequency and extent of historic bathymetric survey is also not that comprehensive.

The fluvial geomorphology assessment should also assess and comment on the potential impact of changes in riverbed profile on the structural integrity of existing structures constructed within the river over time. If long-term changes in riverbed levels in the vicinity of the Princes Hwy bridge was possible then TfNSW would become a key stakeholder in this DA.

The geomorphology conclusions have been drawn based on flood level and velocity results for design event floods only and it is noted that shear stress and stream power are key hydraulic model outputs when assessing the potential impact of proposed instream works on geomorphology processes. Clarification is sought as to whether these hydraulic model outputs have been considered as part of the fluvial geomorphology assessment."

On 15 February 2023, Mark Stone, Shoalhaven City Council, provided Justin Lamerton, via email, a high level summary of the information required from the applicant, which included the following paragraphs relevant to geomorphology:

*"**Geomorphology Investigation***

- *Geomorphology investigation which assesses the potential geomorphology impacts that may result from the proposed dredging operations / changes in riverbed profile on the structural integrity of existing structures (upstream, adjacent to and downstream of the proposed dredge extent) constructed within the river. This shall consider updated hydraulic model outputs such as shear stress and/or stream power.*
- *Details of an ongoing monitoring and adaptive management strategy in the event that potential adverse impacts occur. This could identify what monitoring is needed (i.e. bathymetric survey, levee inspections etc) and the frequency, quantitative limits on allowable changes in bed level in critical locations and management actions to be implemented in the event that any impact to levees or other infrastructure is identified throughout the ongoing monitoring."*

This report addresses the above requests for further information and clarification of geomorphic matters relevant to RA21/1000.

2 Methodology

2.1 Determination of historical channel stability

The assessment of historical stability of the bed of the Shoalhaven River upstream of, downstream of, and in the vicinity of the proposed extension of the dredge area near Pig Island was based on review of the extensive analysis of Carvalho (2018, pp. 58-60), who compared bathymetric surveys undertaken in 1981 and 2006 from Long Reach to O'Keefes Point.

The assessment of historical stability of the banks of the Shoalhaven River upstream of, downstream of, and in the vicinity of the proposed extension of the dredge area near Pig Island was based primarily on a review of the extensive analysis of Carvalho (2018, pp. 68-75), who used visual assessment to map erosion presence and type, armouring presence and type, and presence of erosion of armouring of the Shoalhaven River from Barrington Reach to the river mouth. Another key source of information was the River Stability Assessment undertaken by Martens (2019) to support the EIS for RA21/1000. The work of Carvalho (2018) was included with other relevant reports in the review by Martens in their response to the request by Council for further information (Foster, 2022).

2.2 Modelled bed shear stress distributions and risk of bank erosion

A review by Florsheim et al. (2008) found that bank erosion is an important component of the natural disturbance regime of river systems and is integral to long-term geomorphic evolution of fluvial systems and to ecological sustainability. Bank erosion at a rate within the natural range is therefore a desirable attribute of rivers (Florsheim et al., 2008). However, erosion at a rate exceeding the natural range, as might be associated with disturbed river banks with degraded riparian vegetative cover, can be associated with reduced river health. Any bank erosion is usually considered undesirable in areas where farmland or infrastructure such as houses, roads, railways or bridges are built in close proximity to the river bank. Also, are at risk of eroding at a rate outside the natural range.

Bed shear stress is a hydraulic variable that provides an index of fluid force per unit area on the stream bed, which has been related to bed sediment mobilization and transport, as well as bank stability. Maximum permissible bed shear stress refers to the threshold shear stress required to mobilise sediments or soils. Tables of maximum permissible bed shear stress appear in many channel design, engineering and hydraulics publications (e.g. Chow, 1981; Chang, 1988), and they are all based on values given by the U.S. Bureau of Reclamation (Lane, 1952; Carter, 1953). The values for 'clear water' flow, meaning water with concentrations of suspended solids <1,000 mg/L (Ritzema, 1994) suggest that unconsolidated sandy soils have a maximum permissible bed shear stress of around 2 N/m^2 while silts and clays resist bed shear stress up to around 12 N/m^2. A rule of thumb derived from the standard Shields equation is that the critical bed shear stress required to move a particle (N/m^2) is approximately the same as the particles diameter in millimetres (Gordon et al., 2004, p. 194). Thus, sand-sized bed material, which is up to 2 mm diameter (Gordon et al., 2004, p. 116), can be mobilised by flows when bed shear stress exceeds 2 N/m^2. Clay-silt (mud) sized bed material would be expected to mobilise when bed shear stress exceeds around 12.5 N/m^2.

When soil is covered by vegetation, as might be the case for some channel banks and floodplain surfaces, its resistance to scour is considerably enhanced. A critical shear stress in the range 100 – 200 N/m^2 is a reasonable guide to the shear stress required to remove typical native or pasture grass cover, or tree cover, found on floodplains and riparian zones (Blackham, 2006). Well vegetated channel banks with high silt-clay content would also be expected to be relatively stable under shear stress values less than 200 N/m^2.

The distribution of bed shear stress was modelled using TUFLOW at 25 × 25 m cells, were provided by Martens & Associates Pty Ltd. The modelled floods were average recurrence interval (ARI) 10 yr, 100 yr, 200 yr, 500 yr and PMF (probable maximum flood) events. Two scenarios were run, Existing conditions, with the model recalibrated to better match Council's updated flood study, and Proposed, conditions, including the mounds and the smaller pit.

Of primary interest was the distribution of shear stress in the vicinity of the river banks, which were determined to comprise a levee and sloping bank face up to around 60 m wide. The crests of the levees along the left and right banks from Nowra Creek (upstream of Princes Highway Bridge) to the upstream end of Numbaa Island were identified, and 60 m wide buffers drawn on the river side of the levee crests. The downstream distribution of maximum bed shear stress on the banks was mapped at 5 m intervals by extracting the maximum value of the bed shear stress pixels intersected by 5 metre-spaced transects perpendicular to the thalweg and passing through the 60 m wide buffer. The modelled bed shear stress values were compared with the above maximum permissible thresholds for stability.

3 Review of channel stability

3.1 Bed stability

Carvalho's (2018) comparison of Shoalhaven River bathymetric surveys taken in 1981 and 2006 indicated that the river bed from Long Reach to upstream of O'Keefes Point aggraded approximately 2,000,000 m^3, while downstream of O'Keefs Point the river bed scoured approximately 1,600,000 m^3. Upstream of O'Keefes Point, areas of bed scour occurred on the north of Pig and Numbaa Islands. Upstream of Nowra, scour occurred in some pools, while others indicated deposition. Despite these changes, pools, and the shallow areas between pools, were in the same positions in both surveys, as the distribution of bedforms is controlled by the pattern of hydraulics, which is determined by the meander pattern. The Shoalhaven River has been dredged to facilitate navigation since the 1860s. Active mining for coarse river sand within the Shoalhaven River in the vicinity of Terara and Pig Island has been ongoing since the late-1960s or early-1970s. There is no evidence in the data or literature of a migrating head cut forming in the bed of the Shoalhaven River in response to dredging operations. Rather, limited repeat survey data suggests that infilling, or partial infilling, of dredge holes has occurred (Gippel, 2022). This suggests that a head cut is not currently a threat to the integrity of Nowra Bridge. Also, Nowra Bridge was constructed at a point on the river where the bed is composed of sand (Figure 2). In this situation it would be standard engineering practice to assume bed scour around piers and abutments during flood events, and this would be taken into account in the design.

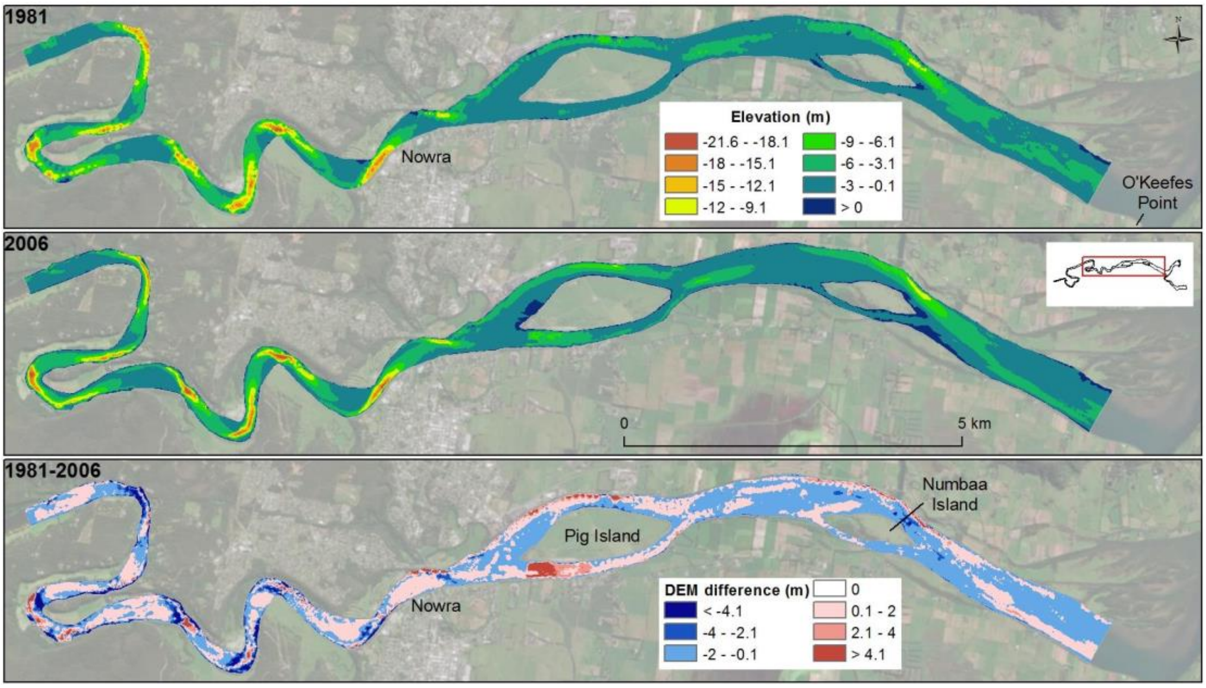

Figure 1. Bathymetric variation in the Shoalhaven estuary between Long Reach and O'Keefes Point in 1981 and 2006. In the lower map, red polygons indicate areas where erosion occurred whereas blue polygons indicate areas of accretion over time. Source: Figure 4.3 from Carvalho (2018, p. 60).

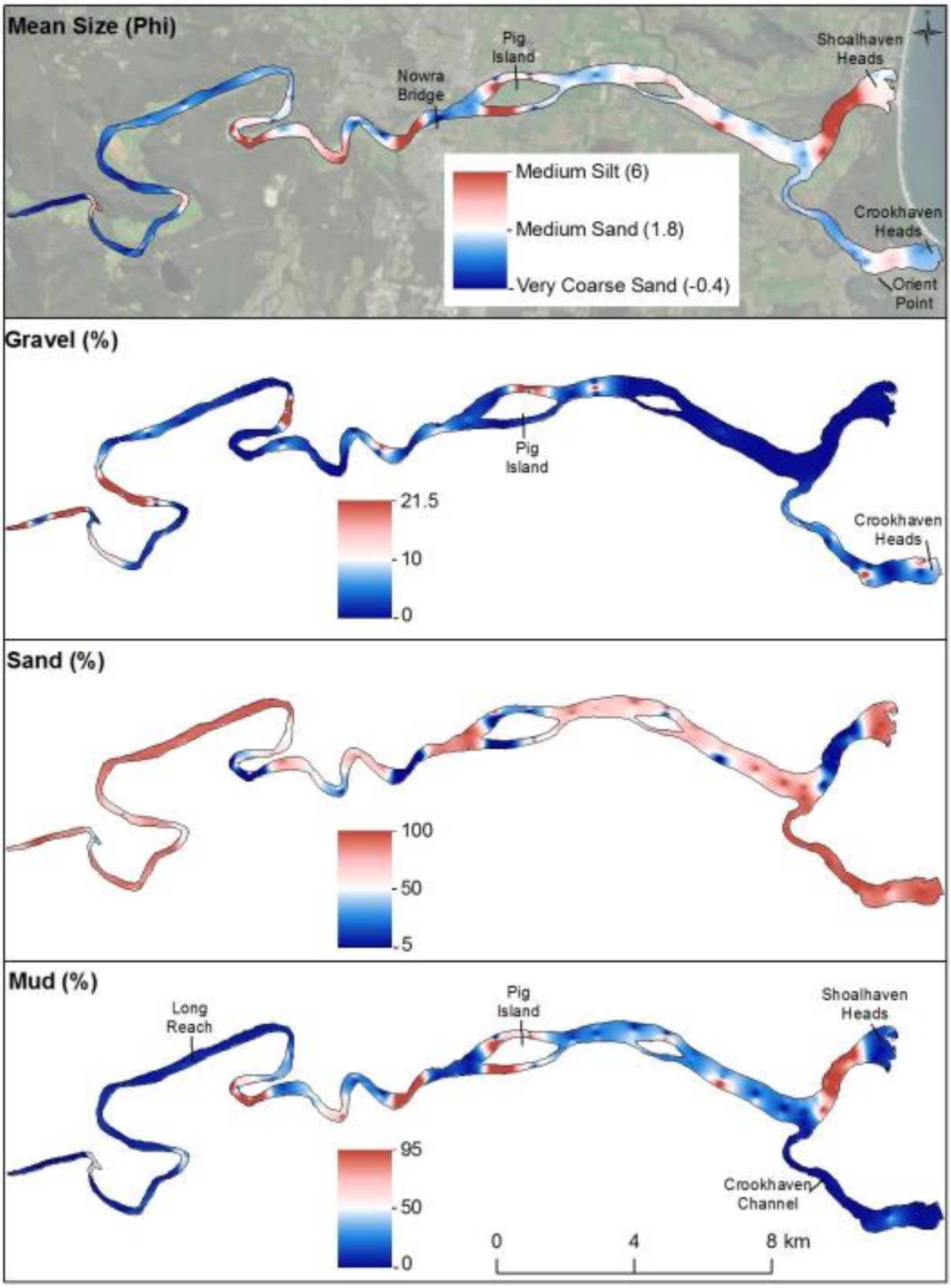

Figure 2. Mean grain size and percentage of gravel, sand and mud content in estuarine samples. Source: Figure 4.13 from Carvalho (2018, p. 76).

3.2 Bank stability

On the basis of analysis of aerial imagery from 1949, 1970, 1984, 2012 and 2021, Gippel (2022) found that there was little change apparent in the shorelines of Pig Island and the Shoalhaven River in the vicinity of Pig Island between 1949 and 2021, despite this area being recognised as having a bank erosion problem. This result is not incompatible with local, perceived problematic, bank erosion, especially close to an urban area where bank erosion is often viewed negatively. Gippel (2022) summarised that since 1949 there have been no major changes to bank positions in the Pig Island area despite construction of Tallowa Dam (in 1976), several large floods, and regular sand extraction since the late-1960s or early 1970s. This is in contrast to the apparently high level of geomorphic instability of this reach during the floods of 1860 and 1870.

Erosion of stream banks can be one, or a combination, of:

- Fluvial scour: removal of bank materials by flowing water, also called hydraulically-induced failure
- Mass failure: sections of the bank material fail and fall into the channel under gravity
- Subaerial erosion: caused by raindrop impact or surface runoff

Imanshoar et al. (2012) provided illustrations of some main mechanisms of bank erosion (Figure 3). The three types of fluvial scour (hydraulically-induced) failure were illustrated by O'Neill and Kuhns (1994) (Figure 4).

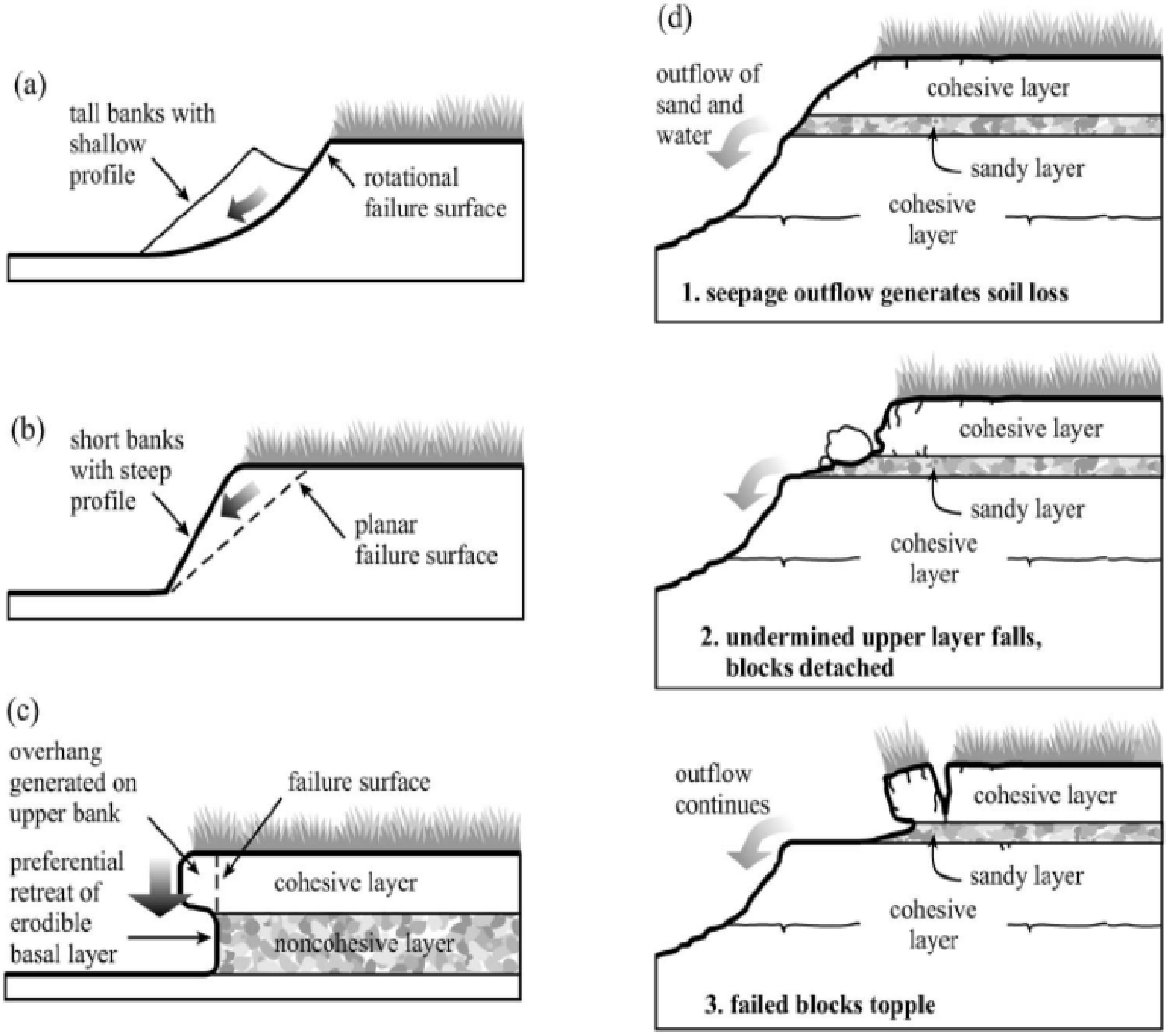

Figure 3. Bank failure mechanism: (a) Rotational; (b) Planar; (c) Cantilever and (d) Piping or sapping. Source: Imanshoar et al. (2012).

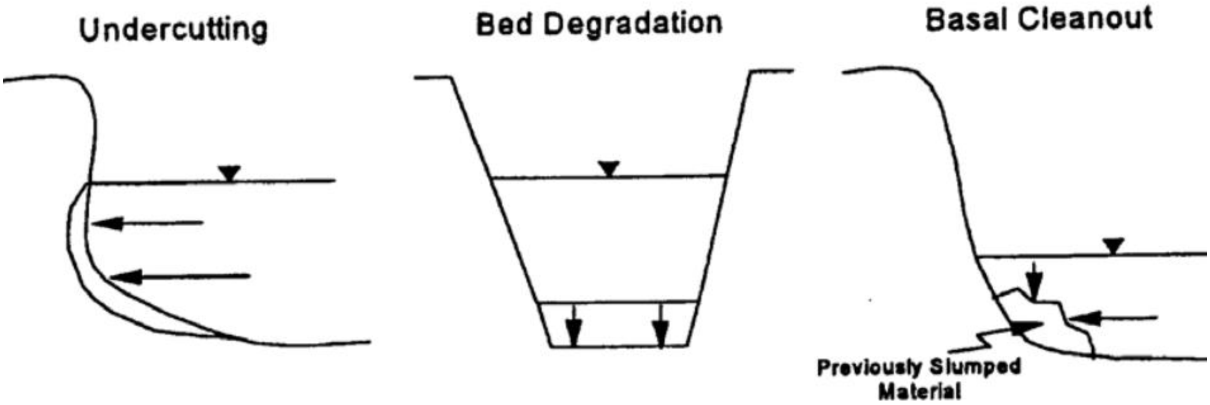

Figure 4. Hydraulic failure mechanisms. Source: O'Neill and Kuhns (1994).

Carvalho (2018, p. 69) reported that evidence of erosion was observed in most of the reaches on both banks of the estuarine river channel (Figure 5). Evidence of erosion was not observed in only 14 (7.2%) out of 193 reaches. Evidence suggested that shallow and planar erosion were the two most common erosive mechanisms as they occurred in 79 (40.1%) and 57 (29.5%) of the reaches, respectively. Evidence of rotational failure and failure of composition was also observed. It appears that Carvalho (2018) classified most of observed bank erosion as mass failure rather than fluvial scour.

Most of the reaches surveyed by Carvalho (2018) (105 of the 193 reaches) had no natural and/or artificial armouring, whereas 88 (45.6%) of the reaches had armouring along their extent (Figure 5). Armouring types were identified as natural (bedrock) and engineered (revetment), with several reaches where both were present. Erosion behind the revetment was also found in 34 (17.6 %) reaches. Carvalho (2018) found the banks in the vicinity of Nowra Bridge were not eroded, as they were protected by revetment (Figure 5). It is common practice to fortify river banks with revetment for some distance upstream and downstream of bridges, due to higher risk of erosion due to confinement of the flow causing increased shear stress, and desire to protect the asset. Carvalho (2018) reported that the revetment in the area of the bridge was not degraded by erosion (Figure 5).

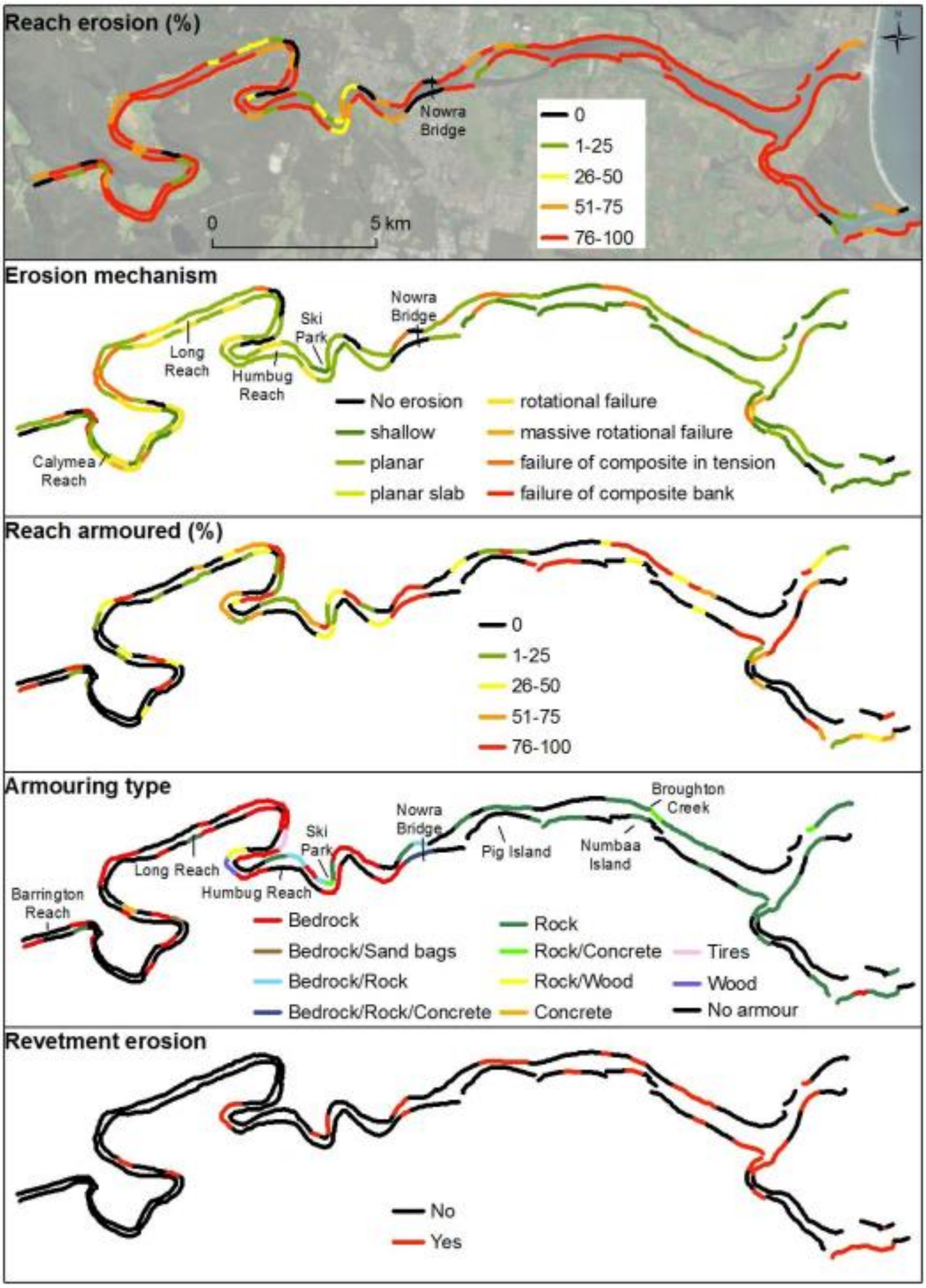

Figure 5. Bank erosion in the Shoalhaven estuary based on field observation datasheet surveys conducted in 2015. Maps from top to bottom indicate percent erosion in each of the 193 reaches (each of 500 m length); erosion mechanism; percentage of the reach that is armoured; type of natural and/or engineered bank armouring; and the existence of erosion behind the artificial armouring (revetment). Source: Figure 4.9 in Carvalho (2018, p. 70).

4 Modelled bed shear stress

4.1 Modelled reach

Within the reach selected for analysis, the crests of the left and right bank levees were of different lengths, the left being 8038 m and the right being 7341 m (Figure 6). Thus, the downstream chainages of features such as Nowra Bridge and Pig Island differ somewhat between left and right banks.

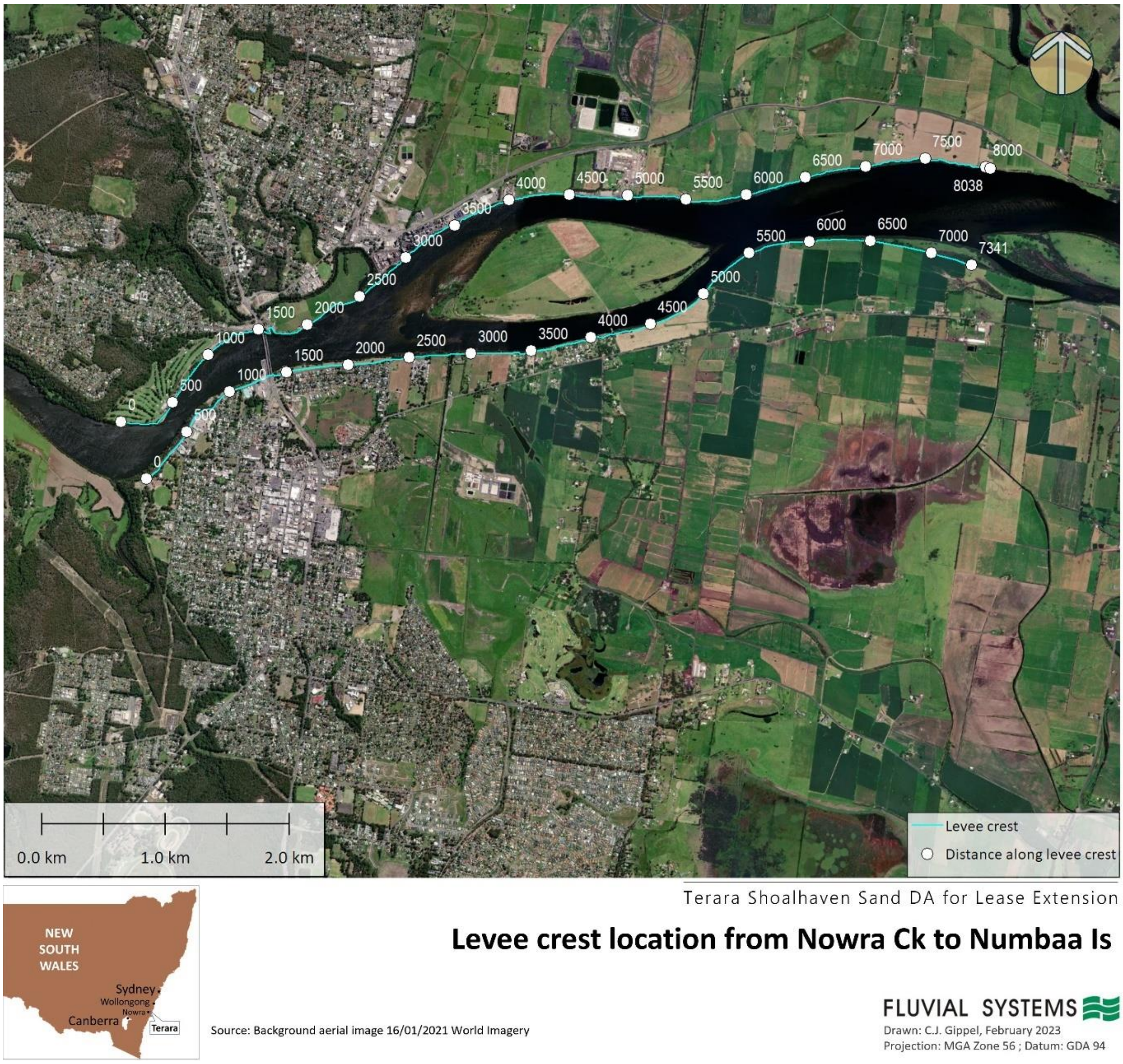

Figure 6. Levee crest location showing chainage downstream from Nowra Creek. Left/right bank is from perspective of looking downstream.

4.2 Existing and proposed conditions

Under Existing conditions, the right bank had particularly high bed shear stress in the vicinity of Nowra Bridge, on both right (Figure 7) and left banks (Figure 8). These conditions are highly erosive to unprotected banks, but in these areas the banks are protected by revetments (Figure 5). Elsewhere, bed shear stress on the right and left banks exceeds 200 N/m^2 under large flood conditions in some locations, more so on the left bank. Bed shear stress is less than 100 N/m^2 along most of the lengths of the banks (except in the vicinity of Nowra

Bridge) for the 10 year ARI event, and it can be assumed to be lower than this for smaller events. Thus, the 10 year ARI event, and smaller events, would pose a low-moderate risk of fluvial scour of the banks under fully vegetated conditions, but the risk of erosion would be high in places where the vegetation is degraded. Large floods would be expected to cause fluvial scour, even on well vegetated banks and levees. This result is consistent with the observations of evidence of active erosion made by Carvalho (2018) and Martens (2019).

4.3 Existing and Proposed conditions difference

The differences in bank bed shear stress between Existing and Proposed conditions were mostly small and inconsequential. In some locations the proposed conditions created lower bed shear stress and in other locations, higher bed shear stress. Special attention should be made to monitor banks in the locations with predicted elevated bed shear stress on the banks.

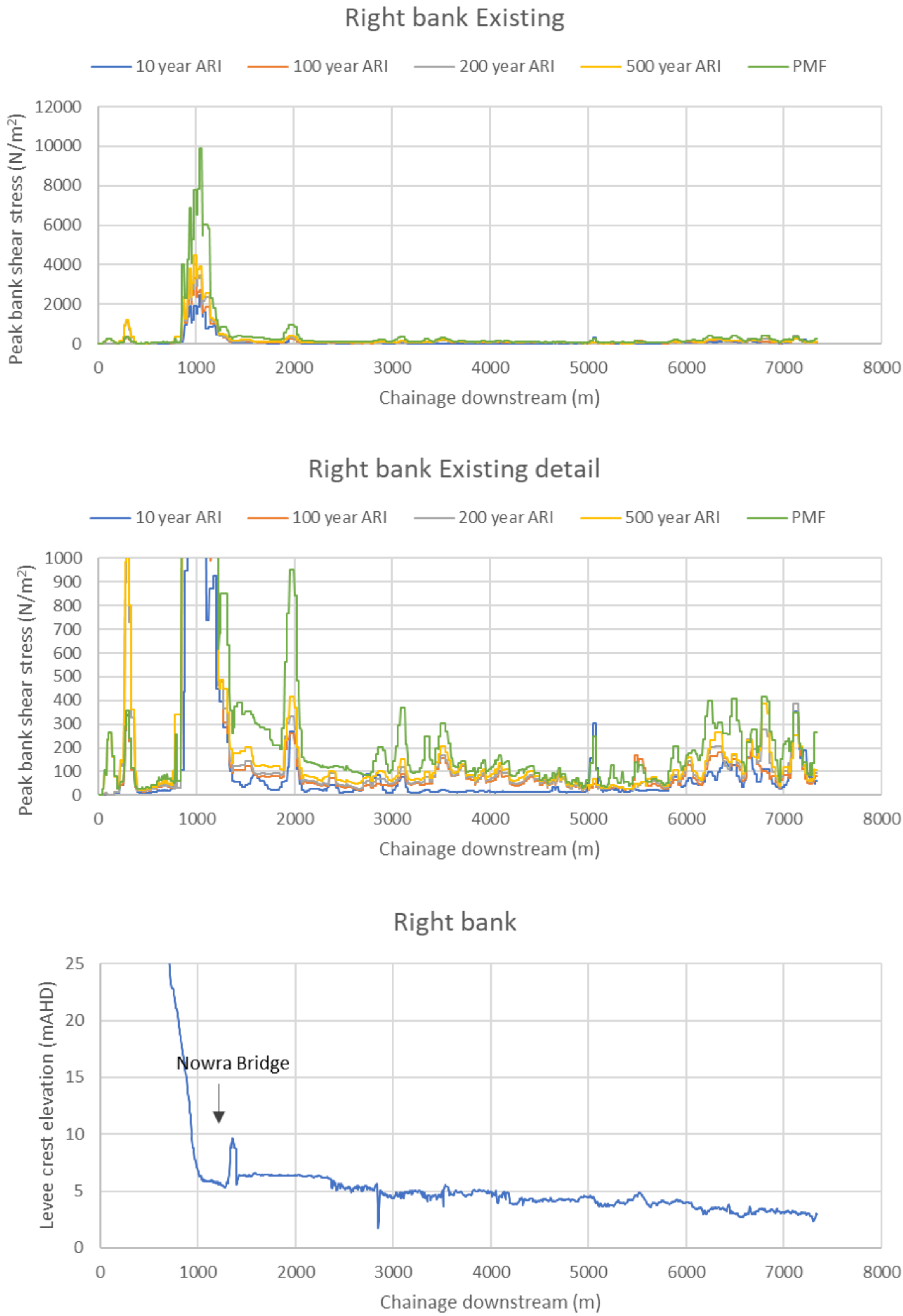

Figure 7. Peak bed shear stress, Existing conditions, in the right bank zone from the levee crest to 60 m within the channel. Bank crest elevation shown for reference. Levee begins at 1000 m chainage.

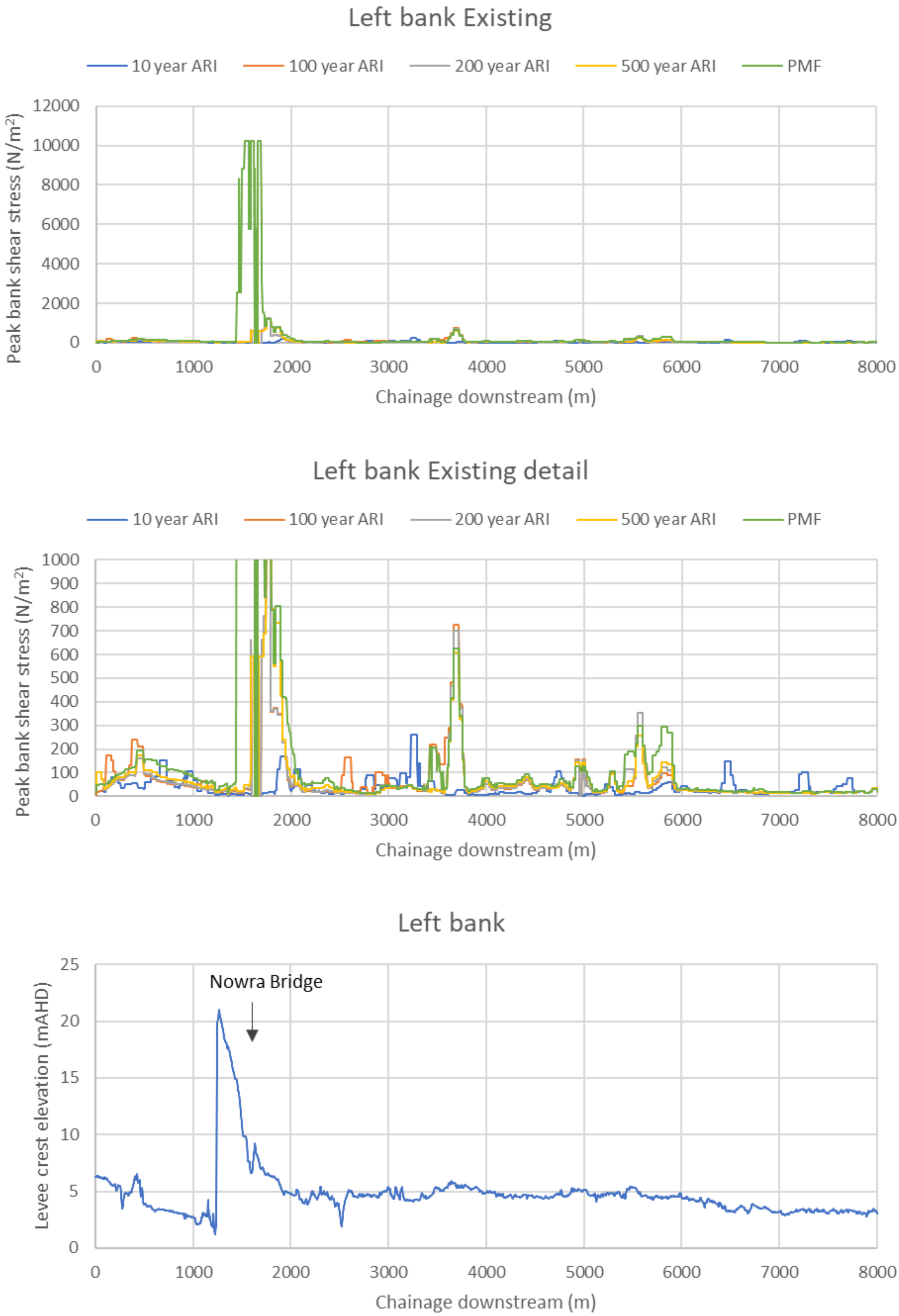

Figure 8. Peak bed shear stress, Existing conditions, in the left bank zone from the levee crest to 60 m within the channel. Bank crest elevation shown for reference.

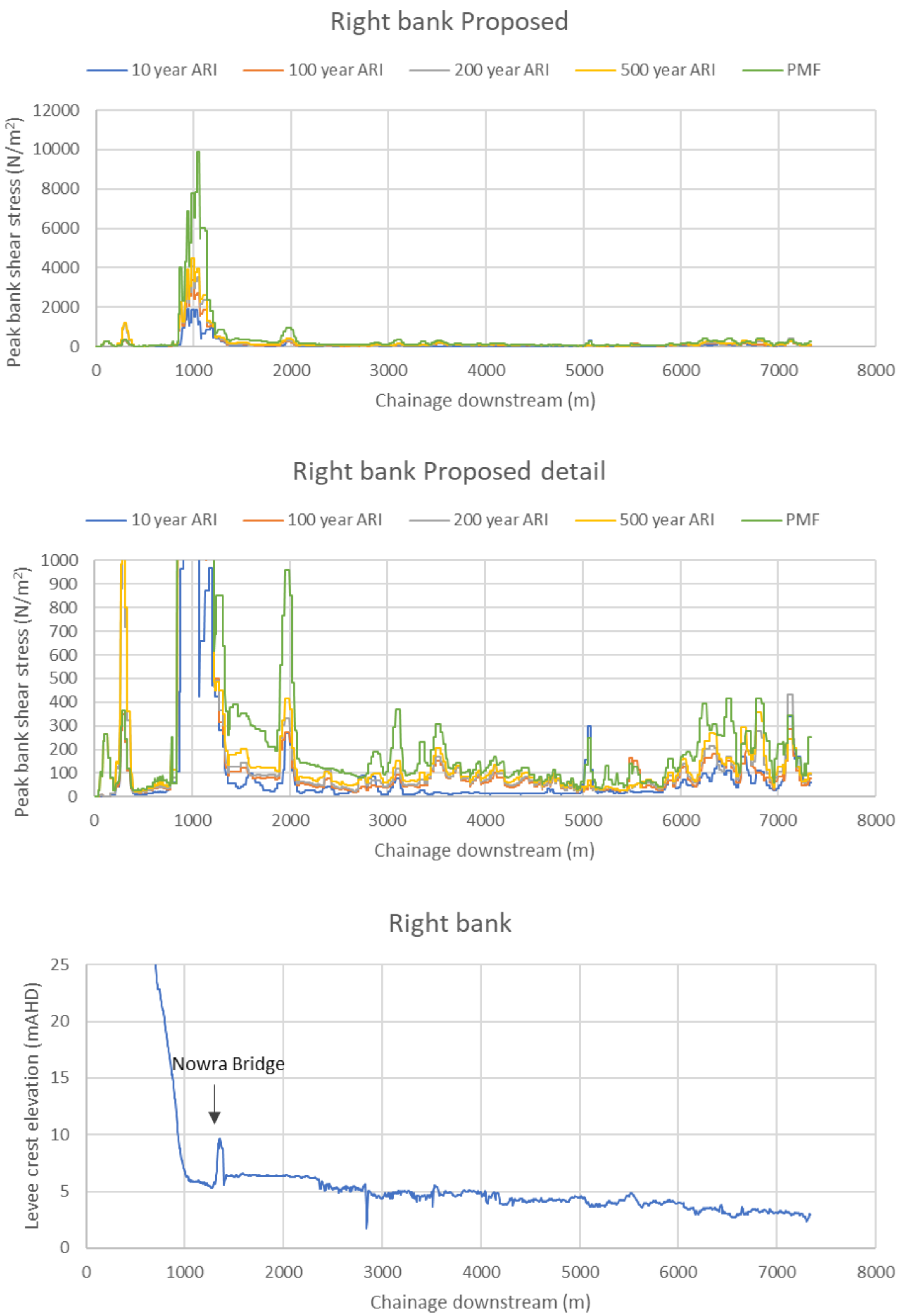

Figure 9. Peak bed shear stress, Proposed conditions, in the right bank zone from the levee crest to 60 m within the channel. Bank crest elevation shown for reference. Levee begins at 1000 m chainage.

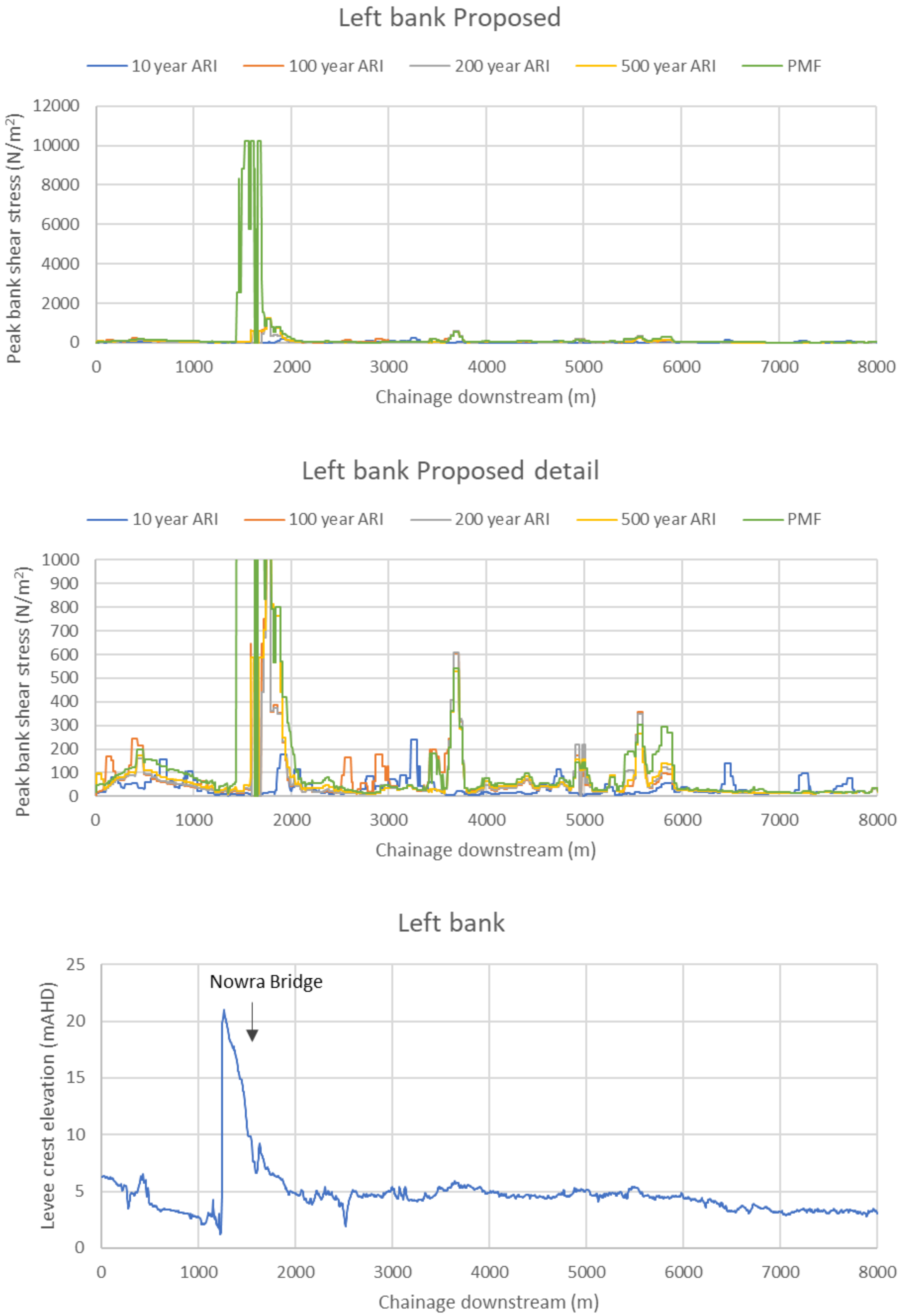

Figure 10. Peak bed shear stress, Proposed conditions, in the left bank zone from the levee crest to 60 m within the channel. Bank crest elevation shown for reference.

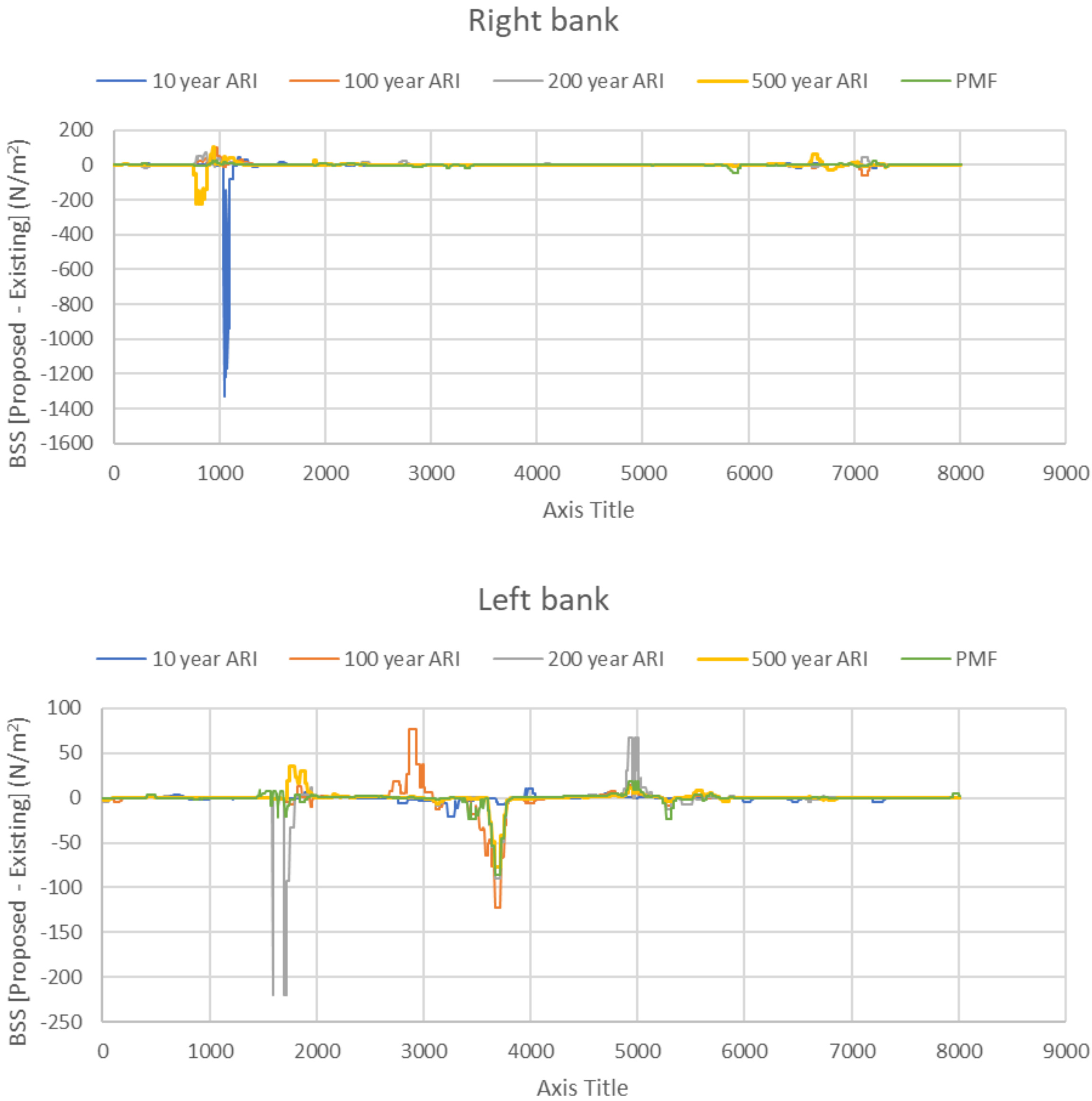

Figure 11. Difference in peak bed shear stress, Proposed conditions minus Existing conditions, in the right and left bank zones from the levee crests to 60 m within the channel.

5 Potential geomorphological impacts that may result from the proposed dredging operations

This report agrees with Foster (2022) that bank erosion and bed instabilities are likely associated with long term major channel realignment downstream of Nowra. Furthermore, wind- and boat-wake generated wave actions, tidal oscillation, groundwater seepage, rapid water drawdown, flood events and tidal flows are all potential agents in causing bank erosion and bed scour or deposition. It would be very difficult to isolate the individual contributions of each of these factors on bed and bank morphological instabilities. Similarly, it would be difficult to isolate the impacts of dredging operations on bed and bank morphological instabilities.

This report agrees with findings of Carvalho (2018), Martens (2019) and others that the lower Shoalhaven River has extensive evidence of active bank erosion, although the relative contributions of fluvial scour, mass failure or subaerial erosion processes to erosion have not been established. The degree of bank erosion is minor compared to erosion observed in historical times in the lower estuary due to establishment of Berrys Canal and under extreme flood conditions near Pig Island (Gippel, 2022). The assessment of the distribution of bed shear stress on the banks undertaken by this report established that under flood conditions the banks experience conditions that are conducive to erosion. As a consequence, infrastructure on the banks that is not protected by revetment is at risk of damage, independent of dredging operations. Under the Proposed conditions, some areas of the banks could experience elevated bed shear stress under flood conditions, while other areas could experience reduced bed shear stress. Nowra Bridge abutments are protected by revetments and are not at risk of bank erosion.

Recent visual audit reports by Council have identified at least five locations in which there are earthen levee slips in the location of the current dredge extent. These have all apparently been caused by undercutting of steep banks, leading to tension cracks and then earthen slips. Whether the dredging itself was responsible for undercutting the banks, or whether this was related to high shear stress and/or degraded vegetation cover is not known. The available knowledge and literature does not link dredging operations to bank failure, but it is important to ensure that operations are undertaken in such a manner that this is avoided. There is no evidence that dredging operations have caused initiation of a head cut in the bed of the Shoalhaven River. The pattern of bedforms of the river are controlled by the interaction of hydraulics and planform morphology. Under current conditions, the risk of a head cut would be low.

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