martens

Contact
Jeff Fulton
Our Ref
P1806743JC05V01
Pages
16s

29 September 2022

Shoalhaven City Council
Attn: Justin Lamerton
By email

Dear Justin,

RE: RESPONSE TO SHOALHAVEN CITY COUNCIL REQUEST FOR FURTHER INFORMATION – EIS RELATED TO EXPANSION OF SAND EXTRACTION OPERATIONS AT TERARA SHOALHAVEN SAND, TERARA, NSW

1 Introduction

Martens and Associates ('**MA**') have prepared this letter on behalf of Terara Shoalhaven Sand (the '**Proponent**') to address a Request for Further Information ('**RFI**') by Shoalhaven City Council ('**Council**') at Terara Sands, Terara NSW (the '**Site**').

This letter includes the following information to address Council's RFI comments 9a & b:

- Summary of bank erosion and instability documented in previous reports and literature for the lower Shoalhaven River.
- Findings of the Terara Flood Study and associated reports.
- Findings of a MA bank inspection of instability identified in Council's RFI.
- Commentary on flow paths and possible bank erosion.

This letter should be read in conjunction with the information previously provided in the MA report River Stability *Assessment: Proposed Expansion of Sand Extraction Operations at Terara Shoalhaven Sand, Pig Island, Terara, NSW* (March 2019, Ref: P1806743JR01V01), hereafter referred to as the MA **River Stability Report**.

2 Council RFI Comments

The comments provided in the RFI by Council in relation to the MA River Stability Report are as follows:

9. Bank Erosion / Scouring Impacts upon Levee Bank

a) The report identifies from a river bank photographic survey that "recent dredging operations do not appear to have had any material effect on bank stability" and that "No significant detrimental impacts are anticipated from the proposed dredging extraction works on the river banks or the bank *protection works, based on the historically stable bank position and the ongoing success of the existing bank protection works".*

It is noted that the existing Terara flood levee has experienced slumping and bank instability immediately adjacent to the existing dredge operation extents, including some current damage identified during a visual audit in 2020 which is yet to be repaired.

There are concerns that the existing dredge operations area and proposed dredge expansion area could potentially result in increased bank instability which could impact the structural integrity of the Riverview Road and Terara flood levees. It is not considered that this report has adequately addressed the concerns raised by Council.

b) There are concerns around the proposed dredge footprint and how this could impact on flow paths within the river, and possibly exacerbate bank erosion.

3 Response to RFI Comment 9(a)

3.1 Review of Documented Bank Erosion and Instability of the Lower Shoalhaven River

Further to the information provided in the MA River Stability Report, a number of sources have previously documented a long-standing history of bank erosion and bank instability along the lower Shoalhaven River. These sources are identified as:

- Carvalho, R.C. (2017) *Sediment budget of the Shoalhaven coastal compartment. unpublished PhD thesis, University of Wollongong*.
- Patterson Britton & Partners (2004) *Shoalhaven River Foreshore Definition Study*.
- Unwelt (Australia) Pty Ltd (2006) *Shoalhaven River Estuary Management Plan*.
- Webb, McKeown & Associates Pty Ltd (2002) *Terara Village Floodplain Management Study*.
- Webb, McKeown & Associates Pty Ltd (2008) *Lower Shoalhaven River Floodplain Risk Management Study.*

A summary of the pertinent findings of each of the above reports are presented in Table 1.

Table 1: Summary of documented bank erosion and instability

Study	Documented Bank Erosion and Instability
Carvalho PhD Thesis (2017)	As part of a PhD study examining sediment delivery behaviour and dynamics of the lower Shoalhaven River, Carvalho (2017) conducted an estuarine bank erosion assessment throughout the 50 km extent of the Shoalhaven River estuary in 2015. The assessment recorded the existence and extent of erosion, mechanisms, and bank armouring and type, along 500 m reach segments of bank. Bank erosion was observed in most of the reaches on both flanks of the estuary, and bank erosion assessment findings were as follows: • Erosion was not identified in only 14 (**7.2 %**) out of 193 reaches. • 13 (**6.7 %**) reaches had erosion for less than 25 % of the reach's extent; 8 (**4.1%**) between 26 and 50 %; 19 (**9.8 %**) between 51 and 75 %; and 139 (**72 %**) reaches had erosion along >greater than 75% of the reach's extent.

Study	Documented Bank Erosion and Instability
	Carvalho (2017) concluded that bank erosion experienced throughout the estuary was occurring in similar places to historical estuary trends, downstream from the Nowra Bridge, as was observed previously by PWD (1988).
Patterson Britton & Partners (2004) *Shoalhaven River Foreshore Definition Study*	The 2004 Shoalhaven River Foreshore Definition Study, prepared by Patterson Britton & Partners (PBP) discussed the findings of the NSW Department of Public Works (DPW) study in 1977, which expected that siltation (i.e. sediment deposition), bank erosion, and meander development would continue along the lower Shoalhaven River for the foreseeable future. PBP stated that the DPW study considered active bank scour (including during flood events), resulting in bank undercutting and subsequent bank slumping, was the main process responsible for bank instability in the lower Shoalhaven River estuary. PBP also noted that the 1977 DPW study considered that bank slumping, associated with groundwater seepage, was also a driver of bank instability. DPW attributed sloughing of silty, clayey bank material as a result of tidally induced seepage forces. PBP also indicate that the 1977 PWD study also considered that wind generated wave action contributed as a mechanism for bank erosion mechanism by was affecting all bank instability areas to some degree, with straight and wide reaches of the Shoalhaven River thought to be well suited to the development of substantial wind waves. PBP also reported that a second 1988 study by PWD identified that bank erosion was found to be affecting about 60% of the river banks of the lower Shoalhaven River, but could not establish the fundamental reasons why channel morphology in the vicinity of Terara and Nowra had changed since European settlement. The study did, however, identify bank erosion mechanisms related principally to flood scour, tidal scour, and wind waves, which had been compounded by the removal of riparian vegetation from the banks of Shoalhaven River. The scour and slumping was partly associated with a tendency for meander development in the river, with PWD indicating that northward channel migration was evident. PWD asserted that this was natural river migration, that is, not caused by anthropogenic influences. The 1988 PWD study also noted that bank protection works had ameliorated rates of bank erosion along some sections of bank, but continued bank undercutting had resulted in the loss of some bank protection works. The 1988 PWD study concluded that rates of riverbank erosion were not slowing, except locally where some bank protection works had been employed, and that further understanding of the existing processes of erosion and development of a management strategy that would be required that will combine remedial measures (where economically justifiable) with appropriate land use planning. The study indicated that the study findings should be used in determining set back distances for all developments near riverbanks (including levees) in the interim period pending the development of a management strategy.
Umwelt (2006) *Shoalhaven River Estuary Management Plan*	In their review of previous studies conducted on the channel morphology and stability of the lower Shoalhaven River estuary (downstream of Nowra), Umwelt concluded there was evidence of long term (i.e. beyond historical records) major channel realignment of Shoalhaven River downstream of Nowra, which is supported by geomorphic and stratigraphic evidence from previous studies. In their findings, Umwelt advocate that migration of the Shoalhaven River channel appears to have been occurring within the system even prior to the excavation of Berry's Canal (in proximity to the Shoalhaven River mouth) in the 1820s. Umwelt also conclude that morphological evidence of long-term and continuing adjustments to the alignment of the Shoalhaven River estuary channel are also occurring in the area around Pig Island. Umwelt signify that Pig Island (and other islands located downstream in the lower estuary) represents large in-channel alluvial deposits (or sediment stores), and that channel adjustments around these islands contributes to bank erosion within the system. Umwelt indicate that this is supported by the north movement of the Shoalhaven River channel (meander bend) to the north of Pig Island and the next section (meander bend) downstream, which is shifting to the south.

Study	Documented Bank Erosion and Instability
Webb, McKeown & Associates Pty Ltd (2008) *Lower Shoalhaven River Flood Risk Management Study*	The Lower Shoalhaven River Flood Risk Management Study of 2008 prepared by Webb McKeown & Associates (WMA) identified that the channel morphology of Shoalhaven River, downstream of Nowra Bridge, had experienced major changes in the period post-European settlement. The study did indicate, however, that little was known about the morphology of the lower Shoalhaven River channel at the time of European settlement. Morphological change to Shoalhaven River identified by WMA, with particular reference to the area surrounding Pig Island, included: • From 1822 to the early 1900's the river was dredged to maintain navigability. It was estimated that in excess of 1.1 million tonnes of sediment was removed from the river channel in the period of 1893 to 1911. • As was previously highlighted in the MA River Stability Report, sediment deposition downstream of Nowra Bridge has resulted in the growth of Pig Island. Sediment accretion upon the margins of Pig Island has seen island width increase by 31% (from 650 m to 850 m) and island length increase by 43% (from 1,680 m to 2,400 m). It is noted that lateral valley confinement of Shoalhaven River ceases downstream of Nowra Bridge. • Major retreat of the northern riverbank downstream of Nowra Bridge (except near the downstream end of Pig Island), with maximum erosion present near Broughton Creek (downstream of Pig Island). • The southern channel around Pig Island has migrated to the south-east causing retreat of the Terara foreshore by up to 400 m. • A 1822 survey plan indicated that the southern bank at Riverview Road (upstream of Pig Island near Nowra Bridge) has since moved northwards by up to 150 m. In their study, WMA also provided brief comment on the dredging operations conducted by "*Terara Sand and Gravel*" upstream of Terara village. WMA noted that dredging activities have operated at the location since 1992, with approximately 35,000 m^3 (or 50,000 tonnes) of material extracted from the river, per annum. WMA also indicated that the dredging activities occur over a limited area of the river bed, and provide minimal hydraulic benefit to Shoalhaven River, as the dredging works create localised holes in the channel bed, rather than reducing the bed level by a uniform amount over a large distance.
Terara Village Floodplain Management Study 2002 Prepared by Webb, McKeown & Associates Pty Ltd	The 2002 Terara Village Floodplain Management Study prepared by WMA reported that that flood events in 1860 and 1870 resulted in over 50 ha of land being lost near Terara village, and the bank of Shoalhaven River receding by 50 to 100 m. In the historical period following these events, only minor bank retreat has been reported. In their study, WMA documented the bank to be extremely steep and potentially unstable, with some areas of bank remaining heavily vegetated, whilst riparian vegetation had been cleared in other bank locations. WMA also reported that a small, partial rock revetment wall was in place at the time along the bank at Terara, which provided light to moderate bank protection from erosion. WMA noted that inspections of the river bank at Terara in 1993 and 1998 revealed: • Evidence of recent slumping outside No. 1 Nobblers Lane, with the bank within 15 m of the house. • In some places the stone revetment wall, inferred to be of probable 50 year age, was disarticulated, and approximately 10 m away from the existing river bank. • The bank had been "protected" by local residents at various locations using building rubble and vehicle tyres. • Along some bank sections, large trees on the bank had fallen into the river (or pulled out as a result of being used as anchor points) causing localised areas of erosion.

Study	Documented Bank Erosion and Instability
	• Along some bank sections, large trees were perched precariously atop near vertical bank faces. It was considered that trees fall would result in tree root systems removing considerable section of bank. • In many places the bank was being undercut producing a near vertical bank which would ultimately slump. It was inferred this resulted from ongoing tidal and wind wave action, not as a result of recent flooding. • Near the end of Southern Road, a fairly recent slump has removed part of the levee bank

In summary, the main points to draw from the above studies are noted as:

- Bank erosion and instability within the lower Shoalhaven River is partially associated with long term major channel realignment of Shoalhaven River downstream of Nowra and with meander bend development downstream of Nowra Bridge.

- Active sediment deposition occurs downstream of Nowra Bridge, where Shoalhaven River leaves lateral bedrock confinement, which has resulted in sediment accretion and growth of Pig Island (and other islands downstream). Channel adjustments around these islands and sediment stores likely contribute to bank erosion within the system.

- Mechanisms associated with bank erosion, include:

  - Wind-generated and boat-wake generated wave action upon banks.

  - Tidal oscillation, groundwater seepage, and rapid water drawdown.

  - Bank scour associated with flood events and tidal flow.

- Bank erosion and instability in some parts has been compounded by the removal of riparian vegetation.

3.2 Summary of Terara Levee Restoration and Upgrade Project

The Terara Village Floodplain Management Study prepared by Web McKeown & Associates identified the need to carry out a Levee Audit in the vicinity of Terara Village to document riverbank stability and erosion, and this was completed by SKM for Council in March 2002. SKM's investigation study area consisted of a section of levee and riverbank extending approximately 2 km from Ferry Lane (western extent) to Bryant Street (eastern extent). The purpose of the investigation was to characterise the sub-surface conditions and identify the soil types within the study area, and provide recommendations on appropriate soil design parameters for use in later slope stability analysis.

The study reported that bank and levee conditions in the study area consisted generally of stable, relict slides with material deposited in front of the existing levee in the western study area, transitioning downstream to overly-steep embankments undergoing active toe erosion and progressive failure in the east of study area. The Levee Audit study, coupled with additional geotechnical investigation completed by SKM in 2003, indicated that the Shoalhaven River bank in the study area comprised of alluvial floodplain deposits. Bank materials were described as consisting of soft and loose silts, clays and sands, with field descriptions and laboratory testing indicating that all cohesive soils were of low plasticity. Standing groundwater levels were also reported close to mean river level. The studies also indicated that the levee embankment structure comprised a mixture of controlled and uncontrolled fill material, and rapid drawdown conditions associated with falling river levels may also affect slope stability.

Of particular note from both studies, erosion in the Central Section of the study area (defined by chainage section Ch650 m to Ch1250 m) was considered to be generally moderate, with localised undercutting and areas of severe erosion identified in the eastern part of the Central Section. MA note that this eastern part of the Central Section is situated in proximity to the area of bank instability identified by Council in the aforementioned RFI, which is discussed in Section 3.3. Pertinent observations of bank erosion described by SKM from along the Central Section of the study area, include:

- In many places, the toe of the bank slope had been eroded and truncated by river action to a near vertical profile, which was locally undercut.
- Isolated examples of slope instability were identified and comprised mostly of shallow, slumping type failures, associated with under cutting at the toe. A few examples of deeper seated failures were also observed.
- Soils exposed at the ground surface near the crest of the riverbank were observed to be mainly sands and silts, while soils observed immediately above the shoreline were generally more cohesive.
- Toe protection works have been constructed by landowners between Ch1110 m and Ch1250m. Protection works comprised a low stacked rock retaining wall on the beach in front of the slope, backfilled with rubble and blocky fill.
- Steeper slopes were observed at some locations, where the reinforcing effect of mature tree roots binds the soil together.

Recommendations provided for the three Sections, with broadly similar geotechnical and erosion characteristics, include:

- Western Section (and east of Southern Road): 'Do nothing' and/or install localised toe protection works to limit shoreline erosion.
- Central Section: Re-grade slopes or construct toe stabilisation to prevent failures during rapid drawdown or provide localised toe protection works to limit shoreline erosion and accept failures during rapid drawdown.
- Eastern Section: Re-grade slopes and/or construct toe stabilisation to prevent failures during rapid drawdown.

3.3 MA Bank Inspection and Observations

MA undertook a further bank inspection on 25 August 2022. The inspection was undertaken in the vicinity of the existing Terara flood levee where slumping and bank instability was identified by Council in the RFI (being immediately adjacent to existing dredge operation extents), followed by inspection of the southern bank of Shoalhaven River, up and downstream of the Terara Sands depot site.

The inspection was conducted during low-tide conditions, for a period approximate 1 hour prior and 1 hour following low-tide (low-tide height 0.43 m - 2:27 pm). Mean 3 pm wind speed recorded at Nowra RAN Air Station AWS (BOM station No. 068072) at the time of the inspection was light (6 km/hr from the west). No discernible wave action was observed on the Shoalhaven River at the time of the inspection.

The following was observed at the location of slumping / bank instability:

- Estimated bank height was 4 m to 5 m above low-tide level.
- Bank was over steepened and had some toe protection in the form of stacked stones approximately 0.5 m in height.
- A low-grade, inter-tidal and sub-tidal bench was observed downslope of the stone toe protection. This bench extended into the Shoalhaven River for a distance of between 20 to 30 m from the bank. Riparian bank vegetation consisted predominantly of grasses and short ground cover, with localised larger established trees, including *Casuarina sp*.
- Bank failure appeared to involve shallow rotational slump failure of the bank. A noticeable failure scarp was evident at the top of bank, which extended approximately 25 m along the length of the observable failure (see Figure 1).
- The accumulation zone of the slump appeared to have been retained behind the stone toe protection at the base of the bank slope. The failure mechanism at this location may relate to rapid drawdown / tidal oscillation combined with a steep bank. Bank material strength may also have been a factor in the bank failure.
- The presence of dredging works in the vicinity of the failure could not be observed.
- Localised flood scour was observed from recent flood during inspection of the southern bank of Shoalhaven River.

Evidence of prior bank instability was also observed to the east of the bank failure, where a noticeable bulge projecting from the bank was present. Inspection established that the feature was related to a previous tree fall event, with the evident bulge constituting the lower trunk and root ball/soil mass of the fallen tree. This bulge is observable in the far left of the Figure 1 image.

Figure 1: Photograph of slumped bank and levee section documented in Council's RFI, located approximately 50 m downstream of the Terara Sand depot site.

Bank inspection of the southern bank of Shoalhaven River on 25 August 2022 by MA, both up and downstream of the Terara Levee, identified features of bank instability that were generally consistent with observations documented in the MA River Stability Report. These are also congruent with descriptions provided by SKM (2003) for the area of the Terara Levee Study, as discussed in Section 3.2.

Bank positions around the former dredging locations appeared to be largely stable with respect to historical conditions. Dredging operations did not appear to have had any material 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.

A selection of images, relating to observations of bank scour and tree fall associated with wind generated wave action, from the recent inspection of the southern bank of Shoalhaven River, are presented from Figure 2 to Figure 6.

Figure 2: Representative photograph of bank scour along a bank section (identified by red arrows). Blue arrows identify a length of disarticulated bank protection stonework. Note the tidal bench accretion on the lee (downstream) side of the stonework. Flow is right to left. Bank height is about 1.5 m. Location is 1,060 m downstream of Terara Sands depot site.

Figure 3: Representative photograph of episodic tree fall, likely associated with wind-generated wave action impacting the bank during the tidal cycle. Note the toe protection stone present along the bank in the left of the image and recruitment of mangroves upon the tidal bench. Location is 75 m upstream of Terara Sands depot site. Flow is right to left.

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Figure 4: Representative photograph of bank scour along a bank section with an existing tidal bench. Note the partially detach root mat of the tree centre of picture and adjacent bank scour (identified by red arrows). Location is 550 m upstream of Terara Sands depot site. Flow is right to left.

Figure 5: Representative photograph of episodic bank instability induced tree fall, as denoted by both older and more recent tree fall events. Location is 670 m upstream of Terara Sands depot site. Flow is right to left.

Figure 6: Representative photograph of bank scour along a bank section with an existing tidal bench. Note the partially detach tree and root mat in centre of picture and adjacent bank scour (identified by red arrows). Location is 990 m upstream of the Terara Sands depot site. Flow is right to left.

3.4 Summary and Conclusions

We make the following summary statements in relation to general bank instability in the lower Shoalhaven River:

- Previous studies indicate that bank erosion and instability of the lower Shoalhaven River is likely associated with long term major channel realignment downstream of Nowra associated with meander bend development.
- Active sediment deposition downstream of Nowra Bridge, where lateral confinement of Shoalhaven River ceases, has resulting in sediment accretion and growth of Pig Island (and other islands downstream), and channel adjustments around these depositional features is likely contributing to bank erosion within the system.
- Identified mechanisms associated with bank erosion, include:
  - Wind-generated and boat-wake generated wave action upon banks.
  - Tidal oscillation, groundwater seepage, and rapid water drawdown.
  - Bank scour associated with flood events and tidal flow.
- Bank erosion and instability in some parts has been compounded by the removal of riparian vegetation.
- Bank inspection of the southern bank of Shoalhaven River, up and downstream of Terara Levee identified features of bank instability, generally consistent with observations

previous documented in the MA River Stability Report and by SKM (2003) in the Terara Levee study area.

We make the following conclusions in relation to the impact of dredge operations on bank instability:

- Bank positions in the location of the former and current dredge operations appear largely stable and dredging operations do not appear to have had any effect on bank stability.

- Dredging works operate beyond the extent of tidal and sub-tidal benches that extend from the southern bank. This shall continue for further future operations, given the MA River Stability Report recommends dredging stay > 15 m from foreshore mangroves and > 25m from seagrass areas.

- No significant detrimental impacts are anticipated from proposed dredging extraction works on the river banks or the bank protection works, based on the historically stable bank position and the ongoing utility of existing bank protection works.

4 Response to RFI Comment 9(b)

4.1 Review of MA Flood Study Modelling and Evaluation of Potential Bank Erosion

In response to RFI Comment 9(b), modelling outputs from the 10% annual exceedance probability (AEP) flood event scenario, completed by MA (2022), have been utilised for evaluating the effects of the proposed dredge footprint on flow paths within Shoalhaven River and the possibility of exacerbated bank erosion. The 10% AEP flood event and associated modelling outputs are considered appropriate for evaluating possible exacerbated bank erosion, on the basis of the following information:

- The most significant discharge influencing channels and their floodplains was first identified by Wolman and Miller (1960), who emphasised that, given near steady-state conditions over moderate timescales, was the discharge that conducted the most work for its given frequency of occurrence. Discharges of moderate magnitude, often referred to as *effective discharge*, generally consist of discharges at or near bankfull stage, which are of sufficient size, and frequency, that they perform the most geomorphic work. Wolman and Miller (1960) indicated that these discharges (Q) occur at recurrence internals ranging from 2 to 5 years (Q_2 to Q_5).

- *Effective discharge* has been identified widely in the literature across various parts of the globe (e.g., Andrews (1980); Carling (1988); Copeland et al. (2005); Coulthard et al. (2001); Emmett and Wolman (2001); Erskine and Melville (1983)). The literature indicates that average recurrence internals (ARI) of *effective discharge* generally range between Q_1 to Q_3 ARI, but can vary from Q_4 to Q_{10} ARI in variable climatic zones, and are responsible for shaping channel and floodplain morphology (e.g., Costa and O'Conner(1995); Kemp (2004); Jansen and Nanson (2010)) and sediment transport within river systems (e.g., Nash (1994); Pickup and Warner (1976); Rose *et al*, (2020)), more so than rarer, high magnitude events.

- *Effective discharge* is adopted as a key design principle for channel design and development of river restoration guidance in Australia and USA (e.g., Copeland *et al*. (2001); Doyle et al. (2007); Rutherford et al. (2000); Soar and Thorne, 2001; Wyzga *et al*. (2020)).

- In light of the literature discussed above, the 10% AEP flood event (which approximates the 10 year ARI or Q_{10} ARI) is a flood event, although of a slightly larger greater magnitude than typical recurrence intervals of *effective discharge* discussed in the literature, considered to be an acceptable surrogate of *effective discharge* for the purposes of this appraisal.

Potential for erosion during effective discharge (the 10% AEP flood event) has been conducted by reviewing water velocity afflux measurements along respective bank sections of Shoalhaven River and Pig Island within the study area calculated by the modelling. The findings of the review identified the following:

- Negligible water velocity afflux (< +/- 0.1 m/s) along the southern bank of Shoalhaven River.

- Negligible water velocity afflux (< +/- 0.1 m/s) along the southern bank of Pig Island.

- Generally negligible velocity afflux (< +/- 0.1 m/s) along the northern bank of Shoalhaven River, with the maximum potential afflux of 0.1 - 0.25 m/s along a short bank section near the downstream end of Pig Island at some distance from the levee.

- Modelling indicated water velocity afflux on the northern bank of Pig Island in the following areas:

  - Along the central-northern bank with water velocity afflux generally between 0.1 – 0.25 m/s and 0.25 – 0.5 m/s.

  - Along a localised bank section near the downstream end of Pig Island bank with water velocity afflux generally between 0.1 – 0.25 m/s.

  - Water velocity afflux was generally negligible (< +/- 0.1 m/s) along remaining bank areas.

The review indicates that the proposed development footprint will generally result in negligible water velocity afflux during an effective discharge event along most bank sections of Pig Island and Shoalhaven River, with the study area. Consequently, the effects of the proposed dredging footprint on bank erosion in these areas is negligible. Notably, no velocity afflux is expected along the southern Shoalhaven River bank in the vicinity of the levee.

4.2 Summary and Conclusions

We make the following summary statements relating to the effects of the proposed dredge footprint on flow paths within Shoalhaven River and the possibility of exacerbated bank erosion:

- The modelled 10% AEP flood event was adopted as a surrogate for the *effective discharge* to evaluate the effects of the proposed dredge footprint on flow paths within Shoalhaven River and the possibility of exacerbated bank erosion. The *effective discharge* was selected for this evaluation, as the flood event is of moderate magnitude, and of sufficient size and frequency, that it typically performs the most geomorphic work within a river system.

- Review of water velocity afflux measurements derived from condition 10% AEP flood event modelling indicated:

  - No bank flow velocity induced bank erosion is anticipated to be caused by the proposal along the southern or northern Shoalhaven River banks.

  - No flow velocity induced bank erosion is anticipated to be caused by the proposal along the southern bank of Pig Island.

  - The northern half of the northern side of Pig Island may experience flow velocity increases of up to 0.25-0.50 m/s in a 10 year ARI event. These increases are likely to be lower in more frequent events closer to the *effective discharge* range of Q_2-Q_5. Whilst these increases are not considered to be significant in terms of inducing increased bank instability, we recommend that during the operational period that a bank stability monitoring program be implemented for the northern bank of Pig Island. Where increased rates of erosion are observed and can be attributed to the extraction operations, bank remedial remedial and revegetation works should be implemented.

Please contact our offices if you have any further queries regarding this matter.

For and on behalf of

MARTENS & ASSOCIATES PTY LTD

N. Foster

NATHAN FOSTER

Senior Environmental Consultant

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