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Status: Final
02/08/2021

Dear Daniel,

Reference # 13610.101.L1.Rev0

RE: CUTTAGEE LAKE BRIDGE REPLACEMENT - COASTAL HAZARDS ASSESSMENT

This letter provides a coastal hazard assessment for Cuttagee Lake entrance, particularly focussed on the proposed replacement of Cuttagee Bridge. The existing bridge crosses Cuttagee Lake entrance area at the northern end of Cuttagee Beach and is a crucial linkage between Barragga and Bermagui providing access to the Sapphire Coast. Cuttagee Lake is a shallow saline coastal lagoon with an intermittently closed entrance. The existing bridge spans across the lake close to the intermittent entrance to the Tasman Sea, in an area that can be considered the active lake entrance region. It is noted that a section of the existing bridge was washed away during coastal storm events in the 1970s, with the northern spans having to be rebuilt. However, more recently significant structural concerns have prompted the proposal of a new bridge, which will be constructed along the same alignment as the existing bridge.

This coastal hazard assessment has reviewed and utilised numerous relevant studies to provide a summary of coastal hazards and associated exposure for both the existing and proposed bridges. This has been performed for both present day and at the 2050 planning level.

Coastal Hazards

The existing and proposed Cuttagee Lake bridges are exposed to several coastal hazards, that can occur individually or together to impact upon the bridge. This section outlines the coastal hazards through the entrance area of Cuttagee Lake, and predominantly leverages off the Bega Valley Shire Coastal Processes and Hazards Definition Study (WBM, 2015) that defines coastal hazards along Cuttagee Beach. WBM (2015) defines a series of likelihood scenarios for use in coastal hazard classifications, based on a standard risk assessment framework (ISO 31000). This assessment utilises the 'Immediate Unlikely' and '2050 Unlikely' planning scenarios. The Unlikely scenario is defined as having "*a low possibility that the event (or chain of events) will occur, however, there may be a history of infrequent or isolated occurrences at some locations.*" and could be considered analogous to the 100-years Average Return Interval (ARI) condition. In fact, the adopted storm demand values for the unlikely scenario are equivalent to the commonly referenced 100-years ARI storm demand values on the NSW coast (e.g. from Gordon, 1987). The 100-years ARI storm condition is considered a suitable probability for consideration of coastal hazard exposure at Cuttagee Bridge, noting that design criteria for critical infrastructure would typically adopt a probability level of 500-years or higher. The Tathra-Bermagui Road may be considered critical infrastructure for its use as part of evacuation routes during natural disasters.

Extreme Still Water Levels

Elevated still water levels (SWL) offshore of Cuttagee Lake occur during storm events. Elevated water levels during a storm event may be a result of:

- Barometric pressure set up.
- Wind setup.
- Astronomical tide.

The extreme SWL for the Cuttagee Lake region (Bermagui) has been calculated by MHL (2013), excluding wave setup and wave run up. The 1 in 100-year ARI SWL is 1.32 mAHD.

Sea Level Rise

The Bega Valley Shire Council has adopted a sea level rise (SLR) policy of an increase in mean sea level of 0.91m by 2100 above 1990 levels (WBM, 2015). However, to adequately account for the uncertain amount of SLR in the future, a range of SLR scenarios was adopted in WBM (2015) for the Almost Certain, Unlikely and Rare scenarios, as 0.12 m, 0.34 m and 0.5 m respectively by 2050, calculated as metres above present-day levels. This coastal hazard assessment has adopted a SLR of 0.34 m for the 2050 calculation (in keeping with the ‘Unlikely’ scenario).

Offshore Waves

The coastline off Cuttagee Lake is periodically exposed to large waves originating from a range of weather systems. The ARI of significant wave height (H_s) has been calculated from historical measured records at the Eden offshore buoy (Shand et al. 2011), using the one-hour exceedance value. The 1-year ARI H_s is 5.4m, increasing up to 8.5 m at the 100-year ARI. The storm peak wave period (T_p) ranges between 10 – 14 seconds, with the largest waves originating from a South-Easterly direction. The wave direction is an important consideration for Cuttagee Lake, as the entrance is afforded protection from offshore wave directions north of east due to the presence of Cuttagee Point. For example, the June 2016 east coast low event that cause widespread erosion in the Shoalhaven region did not significantly affect the existing Cuttagee Bridge, as the peak wave conditions arrived from the East-Northeast direction. The entrance is relatively more exposed to the predominant South-Easterly direction offshore wave direction.

Coastal Inundation Level

The inundation of the lower Cuttagee Lake area can be influenced by elevated ocean levels propagating through the open entrance channel. WBM (2015) calculated the coastal inundation for the Immediate ‘Unlikely’ scenario to be 2.59 mAHD, and the 2050 ‘Unlikely’ scenario as 2.93 mAHD, with the latter incorporating a SLR of 0.34m. The inundation levels take account of wave setup (the super elevation of the water surface due to the release of energy from the breaking waves) at the shoreline, which can be more than 1m in magnitude for extreme conditions.

Lake Flood Behaviour

Cuttagee Lake is a shallow Intermittent Closed and Open Lake/Lagoon (ICOLL) which is periodically open to the ocean. However, the entrance is predominantly closed, as the influences of oceanic processes (primarily waves) are dominant compared with catchment inputs. The catchments of these systems are relatively small and therefore catchment flows are insufficient to keep the entrances permanently open (WBM, 2015). The entrance naturally opens during periods of increased catchment inflows. Typically, the lake water level reaches greater than 2.1 mAHD before this entrance opens naturally (BVSC, 2016). However, at 1.8 mAHD the inundation of roads starts to occur and to avoid this, the artificial opening the lake has been enacted and is formalised through the Cuttagee Lake Entrance Opening Policy (BVSC, 2016). The policy sets out that the entrance channel is opened when water level in the lake is greater than 1.8 mAHD, with the artificial entrance created east of the bridge, towards the northern end of the beach. Despite choosing the initial opening location when artificially managing the lake, the natural variability of the channel could mean that a wide area of the entrance will scour, where it is not limited by bedrock. The area of potential entrance scour has not previously been defined.

The joint occurrence of catchment flows and offshore storm conditions has not been explicitly assessed, as it has been assumed that a natural or artificial breakout of the lake entrance would occur ahead of the peak of the coastal storm event.

Erosion and Recession Hazard

The erosion and recession hazard at Cuttagee Bridge is associated with several coastal processes, including short-term storm related erosion, long-term recession due to sea level rise and lake entrance processes. The following provides a summary of the erosion hazard at the site.

- **Erosion Hazard Extents**
    - WBM (2015) determined erosion and recession hazard extent lines based on wave climate, wave exposure, beach storm bite extent and capacity, extreme still water level, natural short to medium term shoreline variability and long-term recession, and SLR projections. A 100-year ARI storm demand of approximately 200 m^3/m at Cuttagee Beach was adopted (WBM, 2015).
    - The immediate erosion hazard line incorporates the storm bite to the crest of the erosion scarp above 0 mAHD, and short- to medium-term variations in shoreline position due to wave climate.
    - The 2050 and 2100 erosion hazard lines were determined by projecting the ‘immediate’ erosion extents and by incorporating shoreline recession trends and shoreline recession due to future SLR.
    - The 2050 Planning Horizon hazard extents show that in the Unlikely scenario, the bridge and southern access road may be exposed to erosion/recession (WBM, 2015). The 2100 Planning Horizon for the Unlikely scenario is to the west of the existing bridge, and therefore the bridge may be exposed to long-term erosion and recession hazard if no protection works are undertaken.
- **Erosion depth**
    - The impact of erosion on the bridge location is also bounded by the erosion depth through the entrance areas.
    - The northern extent of the existing bridge is founded on Palaeozoic age Adaminaby group bedrock, with Cainozoic age Quarternary coastal marine deposits. The proposed bridge at the northern abutment will be founded with concrete spread footings on the bedrock, and therefore will limit erosion to bedrock depth (Marshmen O’Neill Engineers, 2021).
    - At the southern end, the base bedrock is covered by a deep layer of coastal sand, that is greater than 10.45 m (below the current surface). The existing bridge pylons are supported through the dune system with driven fiction steel and timber piles. It is recommended by Marshmen O’Neill Engineers (2021) that the proposed southern abutment and intermediate piers be founded through the deep (>10.45 m) sand into the base bedrock.
    - A lagoon entrance scour depth of -0.5 mAHD was adopted for the immediate case, taken as the maximum scour depth that is likely to occur during a channel opening event, based on experience of flooding behaviour at other small ICOLLs in NSW. For the 2050 case, the erosion hazard line would encroach up to the bridge alignment and hence the channel scouring from flooding would have less of an influence than wave-dominated erosion. Therefore, the 2050 case has a scour depth of -1 mAHD (based on Neilson et al, 1992).
- **Historical Entrance Behaviour**
    - Baird performed an analysis of historical satellite images to determine the typical entrance channel location and behaviour, enabling a greater understanding and assessment of the likely entrance

position during an extreme event. This analysis applied the InletTracker Python toolkit to satellite images from 1987 - 2021, using a novel least cost pathfinding method to determine the channel position, and a machine learning algorithm to ascertain if the lake was open or closed (Heimhuber et al, 2021). This analysis revealed that the sand shoals are dynamic and constantly shifting; however, the channel typically runs closer to the northern abutment of the bridge, as seen in Figure 1. The imagery also revealed that the dune at the southern extent of the bridge is consistently vegetated, in addition to the vegetated island to the west of the bridge. This suggests that these locations are rarely inundated or affected by scour and have been adopted as the southern limit of entrance erosion in this assessment.

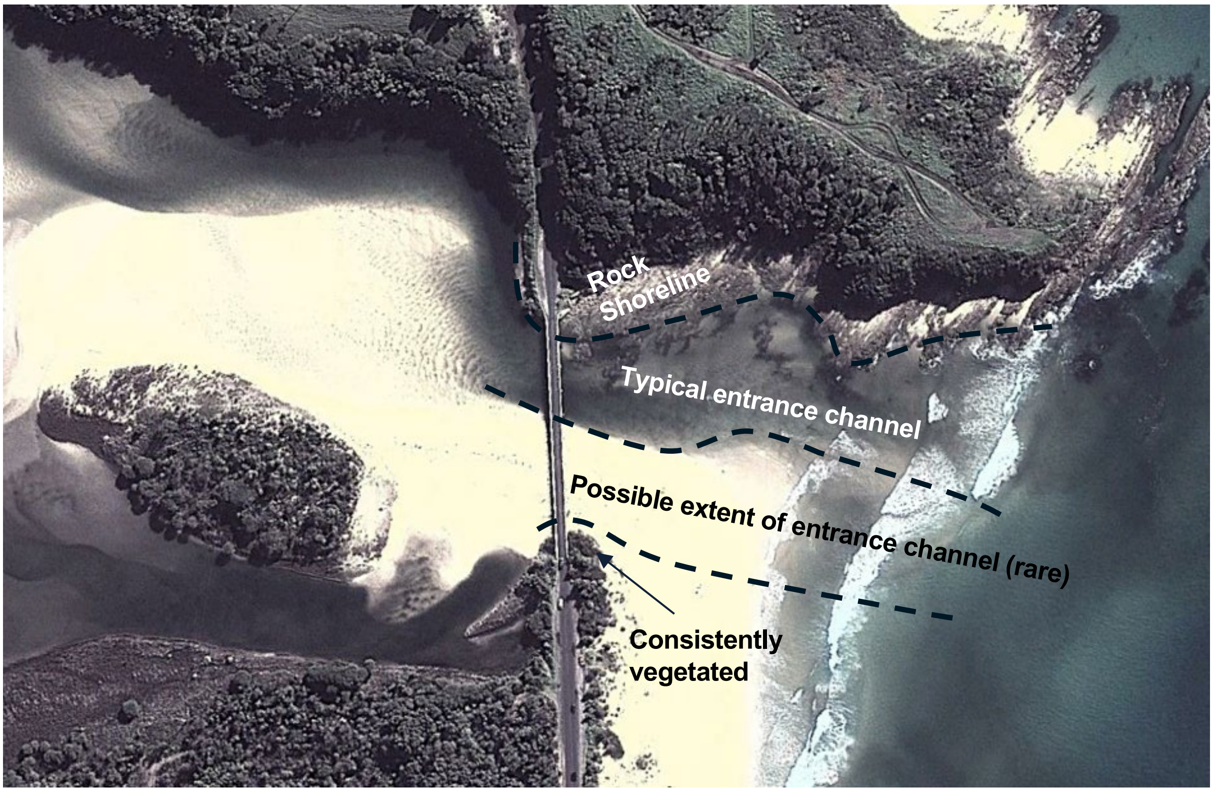

Figure 1: Summary of Cuttagee Lake Entrance Conditions

Through a detailed review of the WBM (2015) erosion/recession hazard lines, satellite imagery and analysis and assessment of the entrance channel behaviour, we have revised the Immediate ‘Unlikely’ hazard lines to extend through the entrance area. The 2050 ‘Unlikely’ hazard line on the open coast has remained the same. Figure 2 depicts the revised erosion/recession hazard lines using the ‘Unlikely’ scenario.

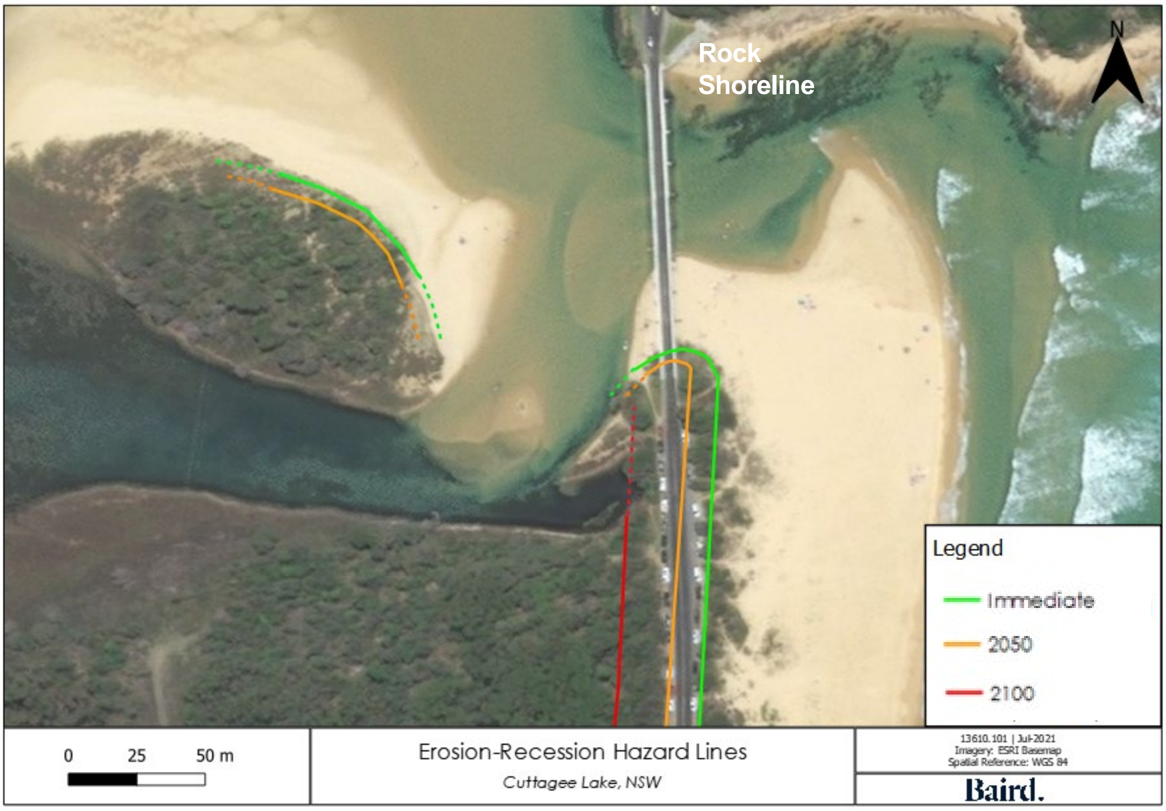

Figure 2: Extended Erosion/Recession Hazard Lines at Cuttagee Lake Entrance

Wave Runup and Propagation

The wave runup level for Cuttagee Beach was estimated as +5.5 mAHD (WBM, 2015). This wave runup level will not be achieved through an open entrance, however, wave penetration through an open entrance under an elevated SWL is possible. Therefore, Baird has calculated the maximum wave conditions that could impact the existing and proposed bridges. The nearshore significant wave height for the overtopping calculation was determined by applying the breaking wave equation of Goda (2010) to the offshore significant wave height of 8.5 m (WBM, 2015), with a period of 14 s (the 100-year ARI condition). This resulted in a nearshore depth limited significant wave height of 2.6 m in a water depth of 3.1 m for the immediate planning period, and a nearshore significant wave height of 3.0 m in a water depth of 3.9 m for the 2050 planning period. From this, the maximum wave crest elevations (wave crest height + coastal inundation level) were calculated to be +5.8 mAHD and +6.6 mAHD for the Immediate and 2050 planning periods, respectively.

Wave Overtopping

The overtopping rates for the existing and proposed bridge were evaluated for both the immediate and the 2050 planning periods, using the empirical EurOtop method for wave overtopping of plain vertical walls (EurOtop, 2018). Wave overtopping was calculated to estimate whether the rate of overtopping of the bridge surface remained within tolerable limits and hence considered safe for both cars and pedestrians. EurOtop (2018) provides guidance for acceptable mean overtopping rates based on the incident wave height. For the wave conditions described above, the following thresholds are interpreted (from EurOtop, 2018, Table 3.3):

- < 0.8 litres/sec per m for pedestrians
- < 7 litres/sec per m for vehicles

Determination of the overtopping rate requires the definition of the bridge design crest elevation as well as hydraulic input parameters including the water elevation, the significant wave height (H_s) and the mean wave period (for the calculation of wavelength, to define the occurrence of impulsive wave conditions). Wave overtopping equations for a vertical wall under impulsive wave conditions were applied (Equation 7.9 from EurOtop, 2018) which is considered a conservative estimate for the bridge structure. In reality, the open spans of the bridge would likely reduce the overtopping rate of the bridge deck compared to an impermeable vertical wall, however no readily applicable relationship exists for such structures.

The crest freeboard of the bridge was calculated as the bridge crest elevation minus the still water level. The existing and proposed bridge crest level is +4 mAHD, and the water level taken as the coastal inundation level, using the WBM (2015) ‘Unlikely’ values for the Immediate and 2050 cases, as outlined above.

For the existing and proposed bridge crest elevation of +4 mAHD, the following mean overtopping rates are estimated:

- Immediate ‘Unlikely’ scenario = 7.6 litres/sec per m
- 2050 ‘Unlikely’ scenario = 8.1 litres/sec per m

Under both planning period scenarios, a bridge crest elevation of +4 mAHD is marginally above the acceptable overtopping rates for vehicles and significantly exceeds acceptable criteria for pedestrian access. Table 1 provides a summary of the bridge crest levels that would achieve the allowable overtopping thresholds.

Table 1: Bridge Crest Levels for Acceptable Overtopping Rates

Planning Period	Acceptable for Cars	Acceptable for Pedestrians
Immediate	+4.3 mAHD	+ 6.8 mAHD
2050	+4.5 mAHD	+ 7.6 mAHD

Note that the overtopping calculations apply an empirical relationship for solid vertical walls, and as such represent an upper estimate of mean overtopping rates of an open bridge span. To this end, a bridge crest level of +4 mAHD is considered to meet the allowable overtopping rate threshold for slow moving vehicles (defined as vehicles travelling <10km/hr). However, based on the wave crest elevation estimates there will be periods of time during an extreme event where overtopping depths are greater than 0.5m. At these depths cars and vans are unstable (HR Wallingford, 2006) hence it is recommended that for bridge crest levels lower than +5.5mAHD the bridge is closed to normal traffic during extreme coastal storm conditions.

To achieve safe access for pedestrians during extreme events, the bridge crest level would need to be raised. The required crest levels summarised in Table 2 have adopted a bridge crest level that elevates the bridge deck soffit to the maximum wave crest elevation for each planning period. This assumes a bridge deck thickness (soffit depth) of 1m based on the preliminary bridge design (Marshman O’Neill Engineers, 2020). This would minimise the amount of wave overtopping during extreme wave events thereby improving pedestrian access under such conditions, if required.

Summary

Baird have completed a coastal hazard assessment for Cuttagee Lake entrance in relation to the existing and proposed bridges that span the active lake entrance region. The coastal hazard assessment has considered available studies and data to define the offshore extreme wave and water level conditions, wave runup, and erosion and recession hazards. An assessment of channel entrance conditions, wave penetration and wave overtopping at the bridge location has then been made to determine the exposure of the bridge located to coastal hazards.

The assessment identifies that the existing and proposed bridge alignments are not at direct risk of erosion/recession hazards at the present day. However, the access road to the south of the bridge (Tathra-Bermagui Road) may be impacted by erosion during extreme event under the 2050 'Unlikely' scenario (nominally a 100yrARI coastal storm event that occurs in 2050) as shown in Figure 2.

An assessment of wave penetration and overtopping rates indicates that both the existing and proposed bridge crest elevations (+4 mAHD) would allow safe access for slow moving vehicles at both the Immediate and 2050 planning periods, assuming a structurally sound bridge structure. It is noted that for vehicles driven at moderate to high speed (>40km/hr), almost any wave overtopping would be deemed hazardous (EurOtop, 2018). Further, the calculated wave overtopping rates are very close to the acceptable thresholds for slow moving vehicles and wave overtopping depths would regularly exceed 0.5m during an extreme coastal event (a flood depth threshold for light vehicle stability; HR Wallingford, 2006). To this end, for a bridge crest level of +4 mAHD it would be recommended that access to the bridge be restricted to essential vehicles only during extreme coastal storm events, with road closed signage established. It is noted the wave overtopping rates significantly exceed acceptable criteria for pedestrian access for both the immediate and 2050 planning periods.

Raising the bridge to a level that minimises wave overtopping (thereby ensuring safe access for pedestrians and fast-moving vehicles) would require the bridge deck to be elevated above +7 mAHD which is not considered a practical or desirable solution. This is also the case for the Tathra-Bermagui access road to the south, that has pavement level at +4mAHD, and it is noted that safe access across the bridge would be governed as much by conditions on the access road as the bridge deck elevation.

It is understood that a dedicated pedestrian walkway is to be included in the bridge design. It would be recommended that the pedestrian walkway be located on the western side of the bridge alignment, to minimise wave overtopping exposure of the walkway during moderate to severe coastal events. Council may also consider the use of appropriate signage on the walkway waning of the potential dangers to pedestrians during extreme coastal storms.

It is noted that no assessment of the structural integrity (including potential wave loads and local scour around bridge piles) has been made for either the existing or proposed bridge structures.

With thanks,

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Document Approval and Revision History

Revision	Status	Comments	Prepared	Reviewed	Approved
A	Draft	Issued for Client Review	CS/SG	JC	SG
0	Final	Issued to Client	SG	JC	SG

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