FINAL REPORT:

The Hawkesbury-Nepean River System Estuary Bank Erosion Assessment and Options Report

December 2022

Developed as a part of:

Hawkesbury-Nepean River System (HNRS) Coastal Management Program (CMP) – Stage 2

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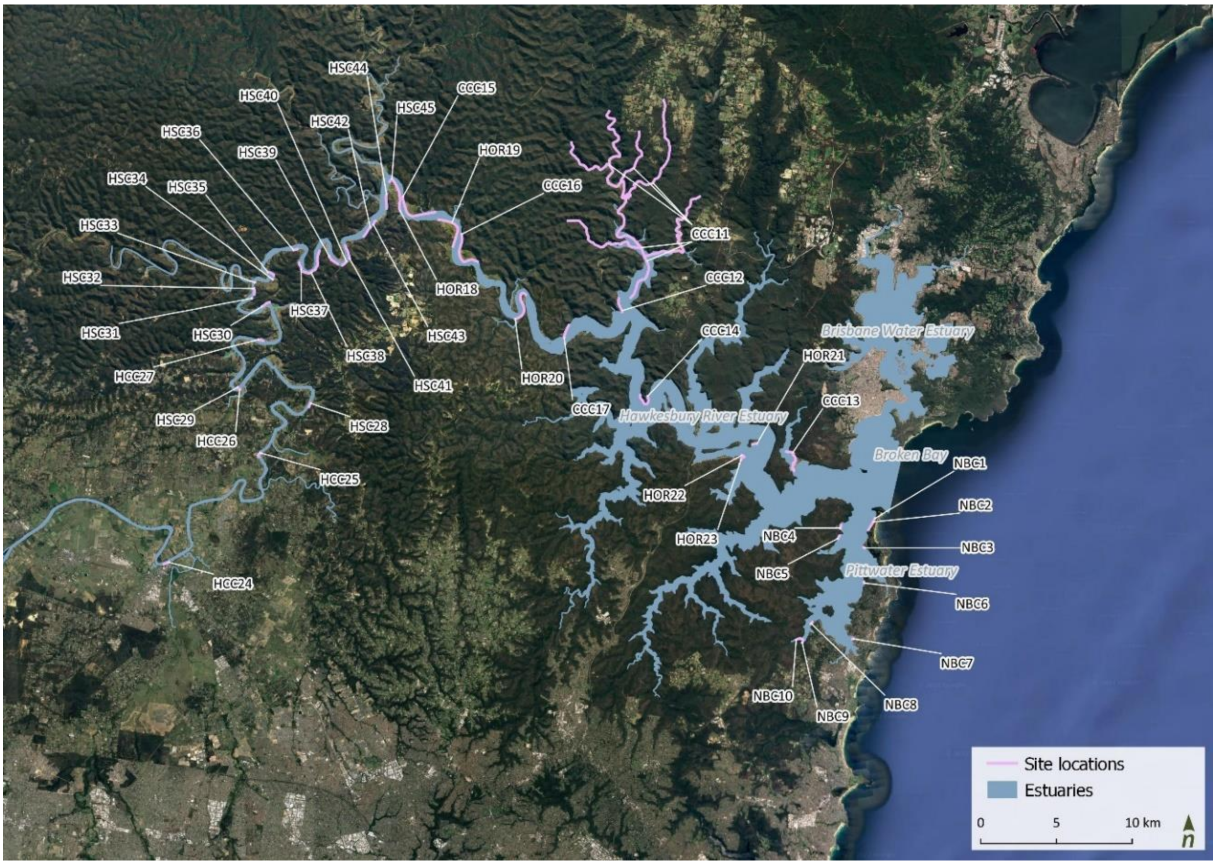
Executive Summary

This report was prepared as part of Stage 2 of the Hawkesbury Nepean River System Coastal Management Program (HNRS CMP) to improve the understanding of risk and exposure to bank erosion at key sites throughout the system. It presents an overview of the processes and existing bank condition at 45 sections of the Hawkesbury River System (including Pittwater and Patonga estuaries) identified by Partner Councils as high priority for further investigation. This report forms the basis for the prioritisation of bank stabilisation works within the study area and is supported by an options assessment that documents a clear rationale for the preferred option for each site and/or group of sites.

The sites assessed are located throughout the HNRS as mapped in the figure below. A larger reproduction of this figure is provided in Section 2.1.



Sites were assessed via a desktop study which investigated the geomorphic form, riparian vegetation extent, and change over time for each site. This was supported by field investigations where data was collected on site including extensive photos and site specific data relating to bank condition, causes and trajectory of erosion, and values associated with the site. This information was collated into detailed site summaries for each location.

The desktop and field assessments were used to quantify the risk level for each site which informed the bank stabilisation options assessment process. Sites were grouped by considering risk, erosive drivers, and mitigation potential. Options for bank stabilisation were proposed and assessed for priority sites considering multiple potential benefits. These options will be further considered in the following stages of HNRS CMP development.

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1 Introduction

Alluvium Consulting Australia Pty Ltd (Alluvium) was engaged by the Partner Councils of the Hawkesbury Nepean River System (Partner Councils - Hawkesbury City Council, The Hills Shire Council, Hornsby Shire Council, Central Coast Council, Ku-ring-gai Council and Northern Beaches Council) to develop 'The Hawkesbury-Nepean River System Estuary Bank Erosion Assessment and Options Report' (hereafter the HNRS Bank Erosion Assessment Report) as part Stage 2 of the Hawkesbury Nepean River System Coastal Management Program (HNRS CMP).

This project builds on previous studies on foreshore and bank erosion in the Hawkesbury Nepean River Estuary system, updating and enhancing the knowledge of risk and exposure. This assessment will inform multiple Councils, operating both collaboratively and individually, in future management decisions and community engagement. The issues explored and recommended options will be carried forward to Stage 3 of the HNRS CMP.

This report presents an overview of the processes and existing bank condition at the 45 sections of the Hawkesbury River system identified by Partner Councils as high priority for further investigation[1]. This report forms the basis for the prioritisation of bank stabilisation works within the study area and documents a clear rationale for the preferred stabilisation option for each site and/or group of sites.

The Hawkesbury River Estuary at the confluence of Mangrove Creek near Spencer. (Photo – Misko Ivezich)

[1] Priority sites were identified by Partner Council after the March 2021 flood event. Several major flood events occurred soon after Alluvium conducted the site assessments described in this report. These floods have changed the condition at some sites, however the information provided in this report is still considered to be relevant. A post-flood assessment of the upper Hawkesbury reach from Windsor to Wisemans Ferry was undertaken. Results are provided as an attachment to this report.

1.1 Study overview and objectives

The Stage 1 scoping study for the HNRS CMP identifies the need to complete an estuary bank erosion update study to fill knowledge gaps. This Stage 2 study addresses this knowledge gap by determining risks, vulnerabilities, and opportunities of known erosion sites in the Hawkesbury River system (including Pittwater and Patonga Creek estuaries). This information will be used to determine appropriate management actions in Stage 3 and 4 of the CMP.

The purpose of this study is to characterise and map foreshore erosion of known priority erosion areas and fill knowledge gaps by assessing nominated sites not previously investigated using a robust and standardised assessment method. The results will be used to inform and prioritise strategies intended to manage and mitigate risks of foreshore erosion. Two assessment methods were applied: a full bank erosion assessment for 44 identified sites, and a first pass bank erosion assessment for 1 site encompassing the foreshores of Mangrove Creek and its main tributaries.

The primary objectives of this project are to:

1. Develop two assessment tools with different resolution output for specific sites identified by Partner Councils to evaluate erosion risks and vulnerabilities;
2. Apply the proposed methodology to selected areas of the HNRS;
3. Map and assess the condition of nominated foreshores and embankments in relation to erosion;
4. Determine vulnerability to erosion;
5. Identify areas of future risk;
6. Identify causes of erosion;
7. Prioritise work for the assessed sites based on risk and condition;
8. Recommend mitigation options to protect and improve the condition of the coastal zone; and

1.2 Report structure

This summary and issues report is presented in several sections including:

Section 1 – Introduction: provides an overview of the study, study area and report structure.

Section 2 – Background: provides a summary of the geomorphic processes, riparian and foreshore condition and key values within the study area, and provides an overview of previous relevant studies.

Section 3 – Method: outlines the methods used for the desktop and field site assessment.

Section 4 – Site summaries: presents an overview of the full erosion assessment results (with individual site summaries in Attachment A), and results from the first pass erosion assessment.

Section 5 – Risk assessment and prioritisation: describes the method used to determine the consequence and likelihood of erosion at each site, informing the risk assessment and prioritisation results.

Section 6 – Bank stabilisation options: priority sites are grouped by similar characteristics, and feasible stabilisation options are described and assessed, producing a recommended option for each priority site.

Section 7 – Conclusion, next steps and additional considerations: Summarises the findings of the report, outlines how the information will be used in following CMP stages, and discusses the implications of the 2022 floods.

Section 8 – References

2 Background

2.1 Study area

The geographical scope of the wider study area spans from the upper tidal reaches of the estuary where fluvial processes are dominant, to the lower estuary where coastal processes play a more substantial role.

Key areas of focus are:

- Windsor, Ebenezer, Sackville and Cumberland Reach (Hawkesbury City and The Hills Shire Council);
- The Hills Shire Council owned foreshore along River Road;
- the reach from Wisemans Ferry to Spencer (Hornsby Shire and Central Coast Council);
- Mangrove Creek (first pass risk assessment);
- Bar Point (Central Coast Council), Brooklyn and Dangar Island (Hornsby Shire Council);
- Lower Patonga Creek (Central Coast Council); and
- Pittwater Estuary (Northern Beaches Council).

The study area encompasses 45 site locations throughout the Hawkesbury River Estuary for either a full or first pass bank erosion assessment (Table 1; Figure 1). These sites consist of publicly and privately owned stretches of foreshore within 5 of the 6 Partner Council LGAs. These sites were identified by the Partner Councils based on significant known erosion issues (as per October 2021), knowledge gaps, and vulnerable areas of potential future erosion impacts.

Table 1. List of sites identified by each Partner Council

Hawkesbury City Council (4 sites)	The Hills Shire Council (18 sites)	Hornsby Shire Council (6 sites)	Central Coast Council (6 sites)	Northern Beaches Council (10 sites)
HCC24 – The Terrace, Windsor (341 m) **HCC25** – Argyle Bailey Reserve (307 m) **HCC26** – Churchills Wharf Reserve (25 m) **HCC27** – Holmes Drive Reserve (335 m)	**HSC28** – NULL (239 m) **HSC29** - NULL (35 m) **HSC30** – NULL (572 m) **HSC31** – NULL (19 m) **HSC32** – NULL (392 m) **HSC33** – NULL (21 m) **HSC34** – NULL (29 m) **HSC35** – NULL (452 m) **HSC36** – NULL (272 m) **HSC37** – NULL (431 m) **HSC39** – NULL (2208 m) **HSC38** – NULL (800 m) **HSC40** – NULL (365 m) **HSC41** – NULL (894 m) **HSC42** – NULL (751 m) **HSC43** – NULL (275 m) **HSC44** – NULL (929 m) **HSC45** – NULL (713 m)	**HOR18** – Just downstream Wisemans Ferry (1727 m) **HOR19** – Laughtondale (2698 m) **HOR20** – Singletons Mills (2393 m) **HOR21** – Dangar Beach (296 m) **HOR22** – Lower McKell (229) **HOR23** – Brooklyn Harbour foreshore (158 m)	**CCC15** – Gunderman North (3036 m) **CCC16** – Gunderman South (2930 m) **CCC17** – Upstream of Spencer (895 m) **CCC12** – Mangrove Creek, Spencer (949 m) **CCC14** – Bar Point (1393 m) **CCC13** – Patonga Creek (1847 m)	**NBC1** – Station Beach 1 (210 m) **NBC2** – Station Beach 2 (605 m) **NBC4** – Great Mackerel beach (221 m) **NBC5** – Currawong Beach (211 m) **NBC3** - Sand Point Beach (78 m) **NBC6** – Paradise Beach (90 m) **NBC8** – McCarrs Ck Foreshore Reserve (146 m) **NBC10** – McCarrs Creek (412 m) **NBC9** – Cicada Glen Creek (172 m) **NBC7** – Crystal Bay (59 m)

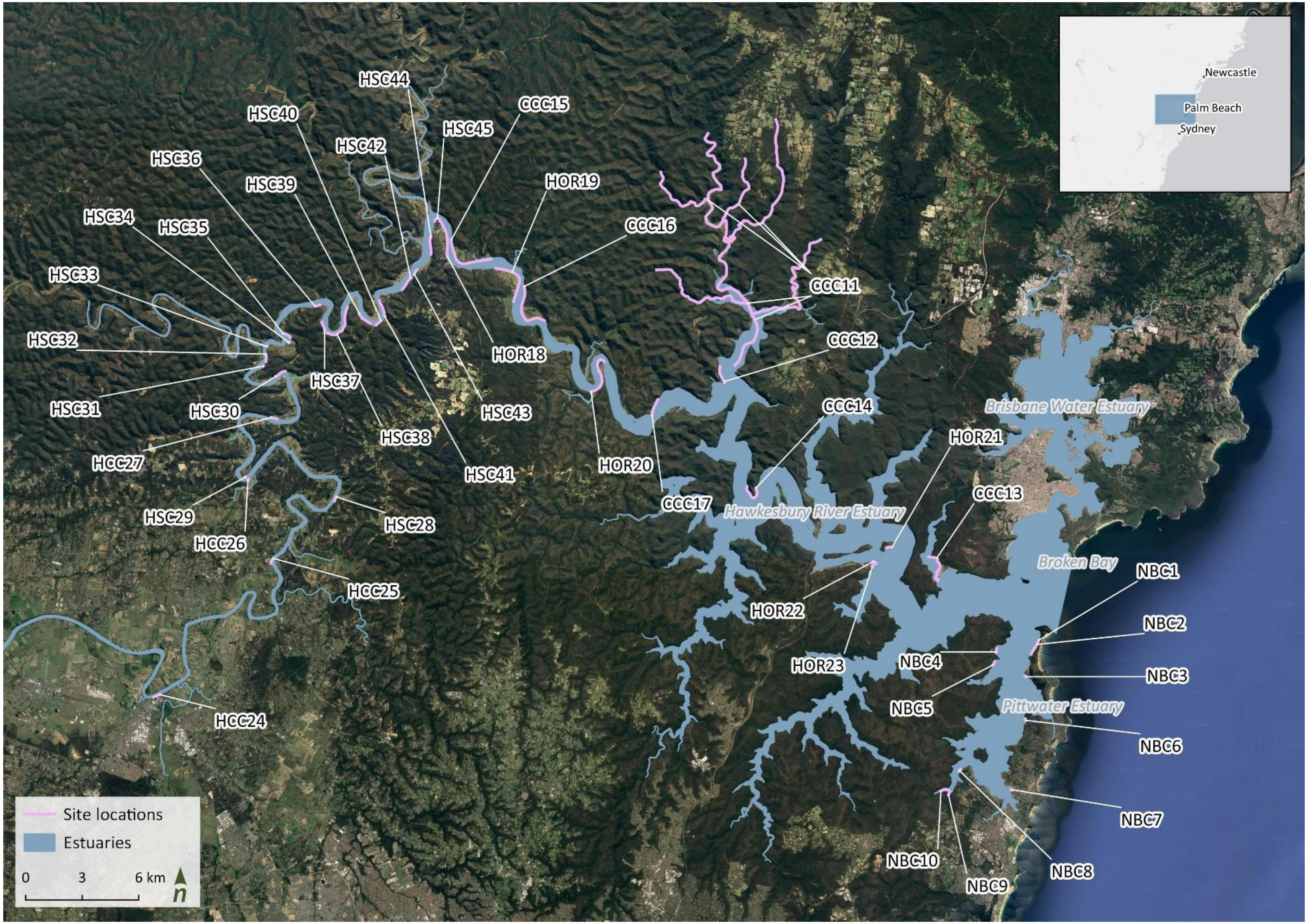


Figure 1. *The Hawkesbury River bank erosion assessment study area. Partner Councils identified 45 sites within the study area*

2.2 Values

The Hawkesbury-Nepean River System (HNRS) is one of the most environmentally and socially important estuaries on the NSW coast. Local people have strong historical and cultural ties to the river through historical artifacts of early colonial Australia and the ongoing relationship of the Traditional Owners.

The estuarine section of the Hawkesbury River is one of the busiest waterways in New South Wales and is a valued recreational asset for the community and residents of two growing metropolitan regions of Sydney and the Central Coast. The river and estuary are used for a variety of recreational pursuits, including fishing, boating, swimming and canoeing/kayaking. There are also a number of commercial activities occurring within the estuary including boat hire and charters, short term holiday rental properties, oyster farming, and commercial fishing.

The estuary and its tributaries support a diverse ecosystem including riparian vegetation, mangroves, saltmarshes and seagrasses. Submerged rocky reefs, tidal mudflats and sandbars, and dunes also provide habitat to a diverse array of flora and fauna. It is also highly valued for its natural scenic amenity, cultural and historical significance.

The Hawkesbury River estuary is regarded for its cultural, recreational and ecological values. Left –Koveda Holiday Park looking upstream. Right – near Courangra Point (Photos – Misko Ivezich)

2.3 Geomorphic processes and condition

The catchment of the Hawkesbury Nepean river system (HNRS) covers approximately 21,400 km^2 and its riverine components include over 470 km of waterway. The river system itself commences near Goulburn in the south and discharges into the Pacific Ocean at Broken Bay, north of Sydney. The tidal component of the HNRS begins near Yarramundi in north-western Sydney.

The Hawkesbury River exhibits many different geomorphic features over its significant catchments. This includes incised valleys and hard rock drowned river valleys (Roy et al. 2001), and soft sandy coasts that produce barrier estuaries, lakes, and deltas (Kench 1999).

The lower Hawkesbury River is deeply incised (Hughes 1998) and presents as a drowned river gorge carved into Triassic Hawkesbury sandstone (Roy et al. 1980). It has steep bedrock valley walls, and laterally restricted swamps with fringing mangrove stands (Hughes 1998). It is a tectonically stable region (Roy and Thom 1981; Roy 1984). The river can be divided into three broad sedimentary zones, as per (Nichol et al. 1997).

1. The first zone represents the majority of the river-dominated channels, levees and floodplains and is mostly fluvial and shaped by infrequent floods (Hubble and Harris 1994). The channel width is about 150 m and about 2 m deep at the tidal limit at Yarramundi. This zone stretches approximately from Yarramundi to Wiseman's Ferry.

2. The second zone contains a mix of finer grained sediments from the river catchment and sub-tidal and intertidal muds and muddy sands. The depth of the river is about 10 m at 100 km inland (Hughes et al. 1998). This zone stretches approximately from Wiseman's Ferry to Bar Point.

3. The third zone is marine-dominated and extends about 6 km upstream from the mouth of the estuary at Broken Bay to Bar Point. The estuary is about 3,500 m wide at the entrance and about 15–20 metres deep (Hughes et al. 1998). The area contains a large, subtidal sandy, flood-tidal delta, which dissipates wave energy and causes tidal levels to be the predominant marine mechanism operating upstream.

As a result of the HNRS's proximity to Sydney large portions of the estuarine catchment and its shoreline have been developed for agricultural and urban purposes and are subject to pressures arising from this peri-urban setting. Extensive floodplain modifications have been undertaken including drainage and levelling works to support agriculture and urban development, construction of roads and levees and clearing of vegetation. The lower Hawkesbury River estuary has natural rock armouring along its foreshore (WRL 2014), but the Broken Bay and northern Pittwater beaches are exposed to storm erosion and swells.

The Pittwater Estuary is tide dominated, however refracted ocean swell contributes to geomorphological processes, especially at the pocket beaches on the north west shoreline. The fluvial catchments are small, and the estuary has an extensive and deep mud basin (Lawson & Treloar 2003). A flood tide delta extends 2 km into the estuary southward from the mouth to a drop-over approximately located around Observation Point. Fine sediments accumulate within the deep mud basin, while coarser fluvial sediments accumulate within fluvial deltas closer to the tributary sources (Lawson & Treloar 2003).

Patonga Creek is a small estuary located behind Patonga Beach, a curving south to southeast-facing beach backed by a low 200-400m wide sandy barrier. In the late 1960s the outlet to Patonga Creek meandered to the north eroding into the caravan park. Council constructed a training wall on the northern side of the entrance in 1969/70 to direct flows further to the south, while another wall was constructed in 1971 immediately upstream of the training wall to prevent erosion in this area (Worley Parsons 2014).

Rural residential land use on the Hawkesbury River floodplain near Laughtondale (Photo – Misko Ivezich)

2.4 Factors contributing to erosion

Riverbank and foreshore erosion within the study area are a result of several interconnected mechanisms that are influenced by a number of factors, both natural and human made. A brief summary of the primary factors contributing to erosion assessed in this study are outlined below:

- Altered flow patterns associated with clearing of the catchment along with rural and urban development.
- Flood conditions result in discharge of water at high velocities particularly on the outside of meanders. As a result, shear stress on the outside of meanders is often sufficient to erode the bank material.
- Saturated bank soils immediately following a flood event can subsequently dislodge bank material through seepage processes where there is poor root reinforcement.

- Waves generated by boat wash is a significant issue within the study area.
- Tidal processes can contribute to erosion both through sediment transport via tidal currents and by changing water levels causing wave related forces to approach the shore at varying heights. Sea level rise will exacerbate this process in the future.
- Wind waves are largely dependent on fetch. Although the wind climate has not likely changed, the removal of riparian vegetation may have impacted on the local wind conditions and exposed banks to increased wind generated waves.
- Ocean waves, especially from the E and NE direction, are refracted into Broken Bay and Pittwater.

The factors described above result in various mechanisms of erosion or bank failure, including:

- Surface scour of bank material by both fluvial processes and wave action resulting in bank retreat and over-steepening of the bank profile
- Excessive pore water pressure
- Mass failure of over-steepened bank profiles

Several other factors contribute to bank erosion in the study area including:

- Degraded riparian vegetation dues to grazing, clearing and exotic species
- Increase amplitude of repetitive wake generating activities e.g. wake boarding and wake surfing
- Adjacent land uses including rural residential and recreational leading to public and private water and foreshore access
- Inappropriate or poorly maintained foreshore protection structures or structures not designed to cater for sea level rise
- End effects caused by foreshore protection structures or other assets
- Dredging
- Illegal vehicle access
- Climate change including increased storm activity and sea level rise

2.5 Riparian and foreshore vegetation condition

Following over 200 years of European settlement, the riparian and foreshore vegetation of the Hawkesbury River estuary has been significantly altered. Vegetation condition varies throughout the HNRS, with riparian vegetation in relatively poor condition in the Upper Hawkesbury (BMT 2013), relatively good condition in the middle estuary (WRL 2014), and healthy, although under significant pressure from foreshore development in the Lower Hawkesbury and Pittwater Estuary (Rhelm 2018).

Riparian vegetation in the catchment is dominated by stands of river oak (*Casuarina cunninghamiana*), with water gum (*Tristania laurina*) also present along the more protected freshwater zones of the river and creek banks (DPI 2006). Other important plant species include Swamp Oak (*Casuarina glauca*), Swamp Mahogany (*Eucalyptus robusta)*, Forest Red Gum (*Eucalyptus tereticornis)*, Narrow-leaved Paperbark (*Melaleuca linariifolia*), common reed (*Phragmites australis*) and Broad leafed paperbark (*Melaleuca quinquenervia*). The transition from freshwater to more saline tolerant estuarine vegetation communities occurs near Wiseman's Ferry, with isolated mangroves recorded slightly upstream near Carinya Ski Ranch (field observations). Fringing mangroves are present in the lower estuary along many of the undisturbed banks with saltmarsh communities also present where suitable low-lying terrain and lack of development coincide. Both grey (*Avicennia marina)* and river mangrove *(Aegiceras corniculatum)* are found along the stretch from Wisemans Ferry to Spencer. The largest estuarine wetlands are found at the confluence of Mangrove Creek and the Hawkesbury River, near the town of Spencer.

The riparian and fringing terrestrial vegetation of the Pittwater estuary consists of remnant urban bushland and riparian vegetation on the eastern side of the estuary, and extensive Eucalypt bushland areas along the western shoreline within Ku-ring-gai Chase National Park (Lawson & Treloar 2003).

Seagrass, mangroves and saltmarsh are vital estuarine habitats in the Hawkesbury River estuary system. Patonga Creek (Photo – James Teague)

Fringing riparian vegetation helps to stabilise river banks and foreshore. Looking upstream near Laughtondale (Photo – Misko Ivezich)

2.6 Previous studies

The following studies considered bank erosion in the study area and have provided useful information and context for this current study. Detail summaries of these are provided in Attachment A.

- Estuarine habitat mapping and geomorphic characterisation of the lower Hawkesbury river and Pittwaterestuaries. K. Astles, G. West and R.G Creese, 2010
- Upper Hawkesbury River Bank Erosion, Foreshore Structure and Weed Mapping. BMT WBM, 2013.
- Erosion Assessment of the Lower Hawkesbury Estuary. UNSW Water Research Laboratory, 2014.
- Geotechnical Risk Assessment River Road Stages 2 & 3 Landslide Risk Assessment Report. Coffey, 2016
- Pittwater Coastal Management Program Scoping Study - Issues Paper. Rhelm, 2018
- Report on Geotechnical Assessment of 14 High Risk Sites - The River Road - Sackville North to Wisemans Ferry. Douglas Partners, 2019.
- Hawkesbury-Nepean River March 2021 Flood Review. Infrastructure NSW, 2021

3 Method

3.1 Desktop assessment

A desktop analysis of the site locations within the study area was undertaken utilising GIS. This was a preliminary assessment used to identify areas of riverbank within the identified site locations where erosion may threaten various infrastructure or assets and make a preliminary assessment of the geomorphology and riparian condition.

The key components of the preliminary desktop assessment of the geomorphology and riparian condition are described below.

Geomorphic form

An assessment of terrain, channel form and bank morphology was undertaken using the most recent available LiDAR data (see Figure 2). A terrain assessment provided an understanding to the types of geomorphic units surrounding each site and the degree of valley confinement, which helps inform where channel instabilities/adjustments are more likely to occur. Within the study area the lateral adjustment of the river is typically limited by the bedrock along the valley margins. Within the valley margins floodplains are formed in some location as a result of both lateral and vertical accretion. A typical cross section showing these geomorphic units is shown in Figure 3. Other key geomorphic parameters that were assessed from the LiDAR data included the bank angle and height.

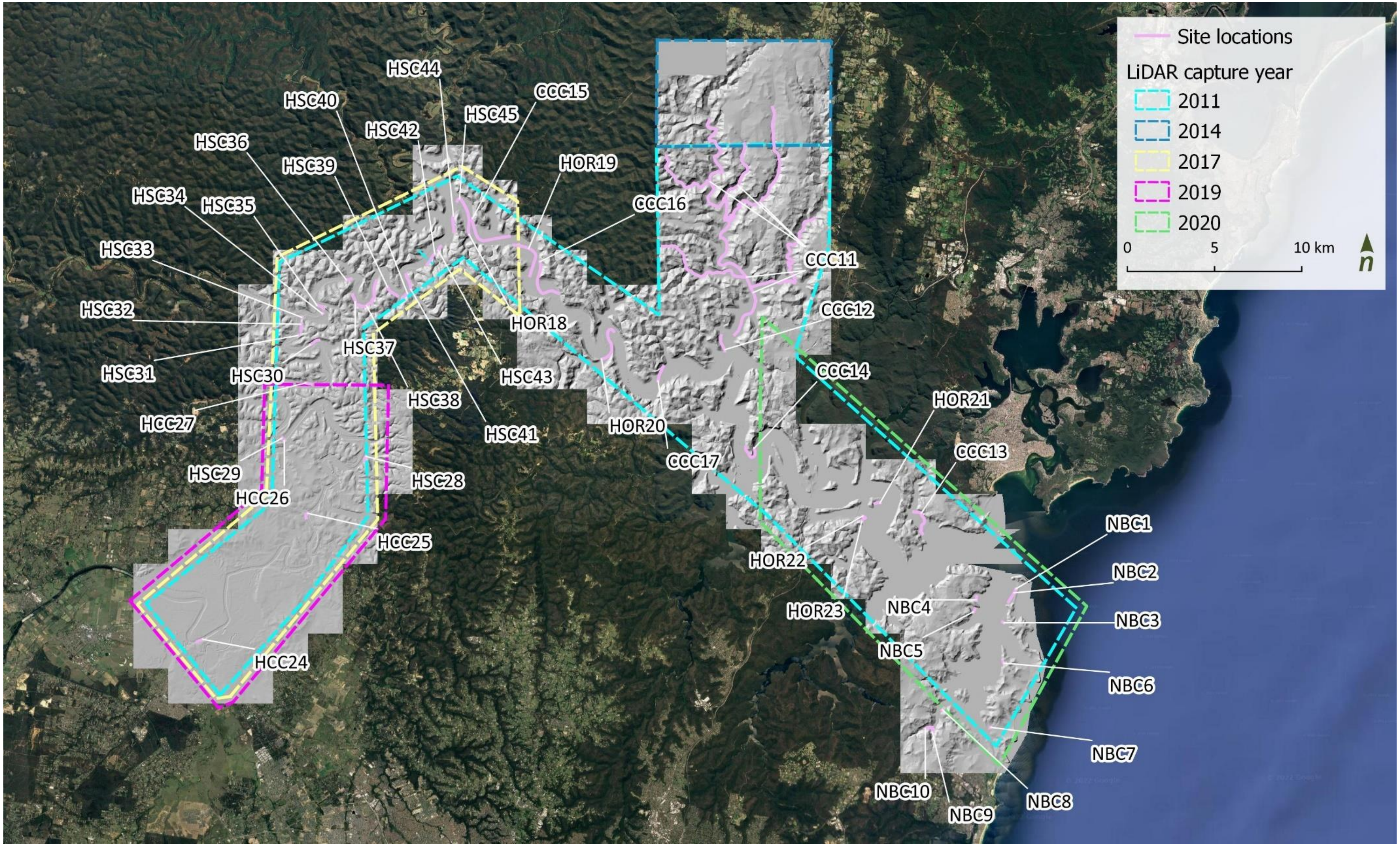


Figure 2. *LiDAR availability across the study area*

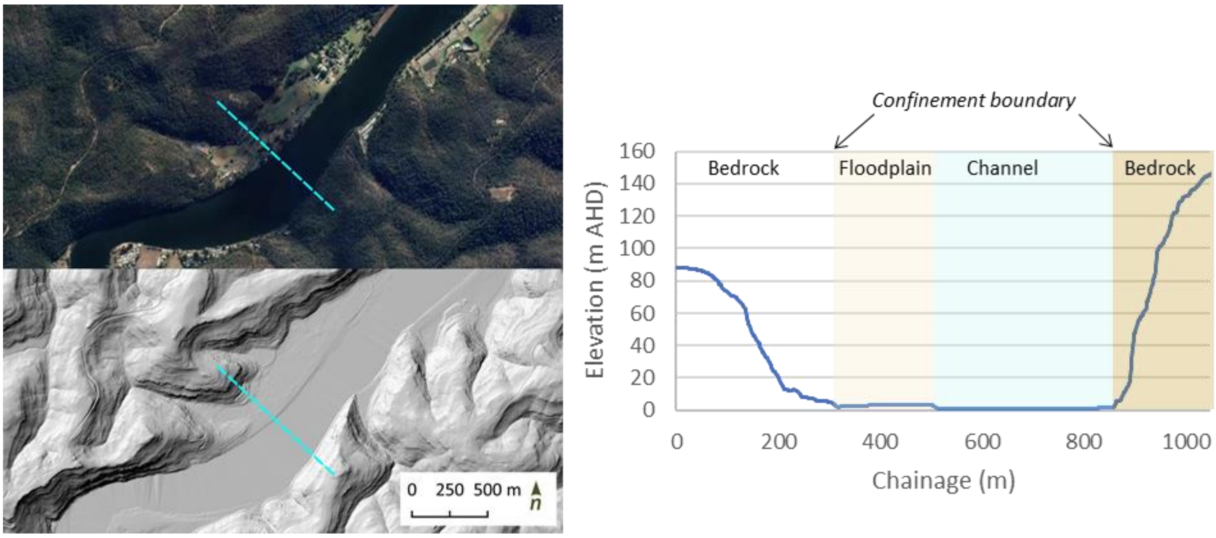


Figure 3. *A typical cross section of the Hawkesbury River (upstream of Wisemans Ferry) showing the channel confined by bedrock on the right bank, and unconfined on the left bank with an alluvial floodplain pocket approximately 200m in width.*

Riparian vegetation extent

A higher-level assessment of riparian vegetation type and extent was undertaken. The most recently available high-resolution imagery was assessed at each site to determine the longitudinal connectivity and width of the woody riparian vegetation. Estuarine habitat mapping sourced from the NSW DPI Fisheries Estuarine Habitat Dashboard ([NSW Estuarine Mapping (shinyapps.io)]) was also mapped to help identify extents of mangrove, saltmarsh and seagrass habitats surrounding the study sites. An example of the habitat mapping is provided in Figure 4. The date of available habitat mapping was 2018 for the Pittwater estuary and 2005 for the Hawkesbury River estuary.

Figure 4. *Example of NSW estuarine habitat mapping at Patonga Creek*

Multi-temporal analysis

Multi-temporal imagery analysis was undertaken to assess planform changes and gain a high level understanding of recent rates of channel change. Understanding historical rates of change assists in the development and understanding of the future trajectory. High resolution aerial imagery was obtained from NearMaps at two capture dates.

Aerial imagery from various years between 1955 and 2020 was available to assess the historical channel change. The analysis of historical aerial photos enabled changes in vegetation condition, channel form and planform to be assessed.

Understanding historical rates of change can assist in predicting the future trajectory of the system. The most recent imagery available across the study sites (at the time of assessment) was from 2021 (either April or October depending on location). This was then compared with the recent historic imagery from the last 12 years. The availability of historic images used for comparison varied across the study sites from between 2009 and 2018. Where a comparison was only available for a short period i.e. between 2021 and 2018, historic imagery from Google Earth was used as an additional comparison. However, the Google Earth imagery is a lower resolution imagery and more difficult to make accurate comparisons. The comparison allowed for an estimate of bank retreat and recent erosion rates (example shown below in Figure 5). It was not always possible to assess the change in bank position due to vegetation cover (example shown below in Figure 6).

Figure 5. *Multi-temporal aerial imagery analysis at Sand Point Beach, Pittwater, showing up to 10 m of bank retreat between 2009 and 2021.*

Figure 6. *Multi-temporal aerial imagery analysis where dense vegetation obscures vision of underlying bank*

LiDAR data is available for the study area across various capture dates (see above in Figure 2). Where multiple years of data overlapped multi-temporal LiDAR analysis was undertaken. Digital Elevation Models (DEMs) were created from the LiDAR data and compared by developing a DEM of Difference (DoD). A DoD identifies changes in ground surface elevation from two LiDAR datasets captured at different temporal scales. From the DoD the dominant erosional process can be assessed (i.e. meander migration, channel widening etc.). However, LiDAR cannot penetrate the water surface, as such where there is water in the channel an accurate estimation of bed level cannot be determined. This also can limit the usefulness of such a comparison in tidal areas with low bank heights (much of the study sites) as variations picked up in the analysis can be a result of different water levels at the time of capture rather than change in ground elevation. The DoD assessment was utilised in conjunction with aerial imagery analysis at sites with bank heights typically greater than 1 m. An example of the DoD analysis at a site on the Hawkesbury River at Holmes Drive Reserve is provided below in Figure 7.

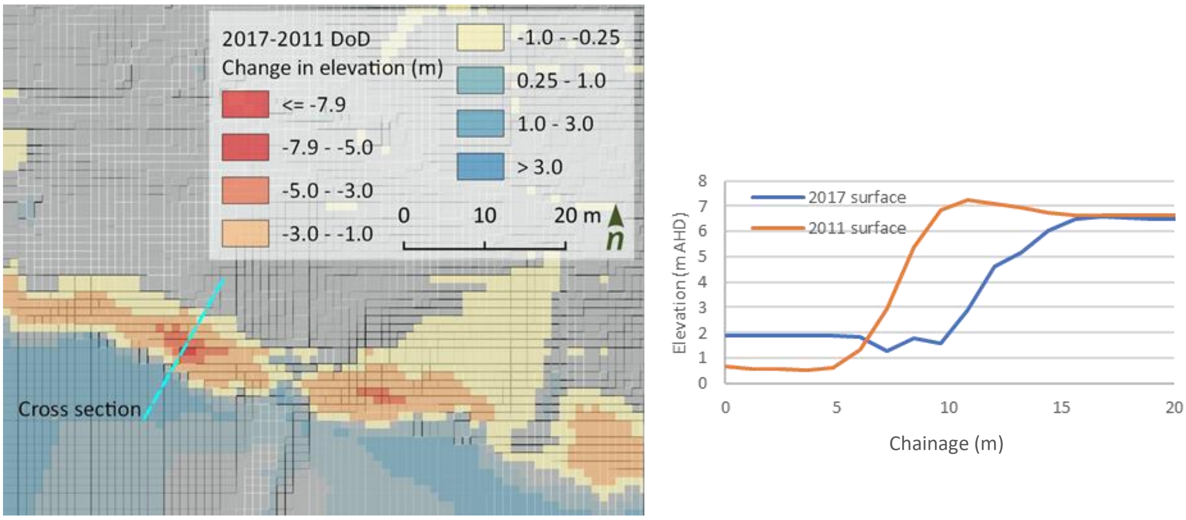


Figure 7. *Example of DoD analysis between 2017 and 2011 on the Hawkesbury River at Holmes Drive Reserve. Cross section comparison of bank morphology shown on right.*

3.2 First pass bank erosion assessment

A first pass bank erosion assessment was undertaken for the foreshores of Mangrove Creek including the area from the confluence with the Hawkesbury River at Spencer to the Mangrove Creek weir, including five tributaries, namely: Dinner Creek; Popran Creek; Ironbark Creek; Sugee Bag Creek; and Bedlam Creek.

The assessment involved delineating each of the streambanks into sections based on five key criteria, each of which are briefly described below:

Erodible width (confinement)

Within the area of interest, the channel can be confined by bedrock hillslopes. The degree to which the channel is confined is directly related to the ability of the channel to laterally adjust within contemporary timeframes. An assessment of the level of confinement or erodible width was undertaken using LiDAR and aerial imagery analysis. The erodible width of each bank was broken down into one of the following categories (example shown in Figure 8):

- **Confined -** Channel boundary is confined by bedrock hillslope
- *1m - 10m*
- *10m - 25m*
- *25m - 50m*
- >50 m

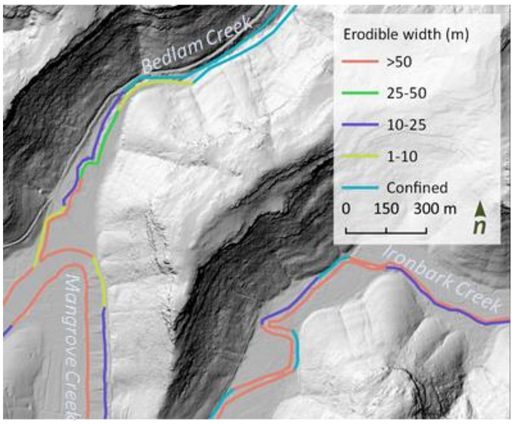


Figure 8. *Example of streambank delineated by erodible width*

Erodible height (bank height)

The erodible height or bank height was attributed to the section of bank not confined by hillslopes based on LiDAR analysis. Used in conjunction with the erodible width, the erodible height gives an indication as to the sediment availability if erosion is to occur. The height also provides context and scale to the stability assessments (discussed below) which rely on aerial imagery analysis. The following erodible height categories were used:

- 0 m – 1 m

- 1 m – 3 m
- 3 m – 5 m
- >5 m

Vegetation extent
A higher-level assessment of riparian vegetation extent was undertaken. For this assessment canopy cover was used as a surrogate for root reinforcement and hydraulic resistance along channel banks. The assessment utilised the most recent and highest resolution aerial imagery available for each creek (between 2015 and 2021 depending on location). A four-tier rating system was adopted and comprised of (see also Figure 9 below):

- **Good** - Riparian zones typically have 90 -100 % woody vegetation canopy longitudinal connectivity and riparian buffer width greater than 10 m
- **Moderate** - Riparian zone typically has greater than 70 % woody vegetation canopy cover however riparian buffer width is typically less than 5-10 m
- **Poor** - Degraded riparian zone with isolated native vegetation cover - typically less than 70 % woody vegetation canopy longitudinal connectivity
- **Very Poor** - Very degraded riparian zone with only isolated native vegetation cover in the riparian zone - typically less than 20 % woody vegetation canopy longitudinal connectivity.

Figure 9. *Examples of riparian vegetation extent used for the first pass assessment*

Stability
Each bank has been assessed based on its recent lateral stability. The lateral stability was assessed using multi-temporal analysis of high-resolution aerial imagery of various years between 2009 and 2021 and classified as:

- **Laterally stable** (No observed lateral adjustment - or existing bank protection i.e. rock revetment present)
- **Minor lateral adjustments** (Longitudinally isolated adjustment of channel boundary of less than 5 m or 10 % of channel width)
- **Moderate lateral adjustments** (longitudinally widespread adjustment of channel boundary of less than 5 m or 10 % of channel width)

- **Major lateral adjustments** (longitudinally widespread adjustment of channel boundary of greater than 5 m or 10 % of channel width)

Examples of each category within the Assessed sites are shown in Figure 10.

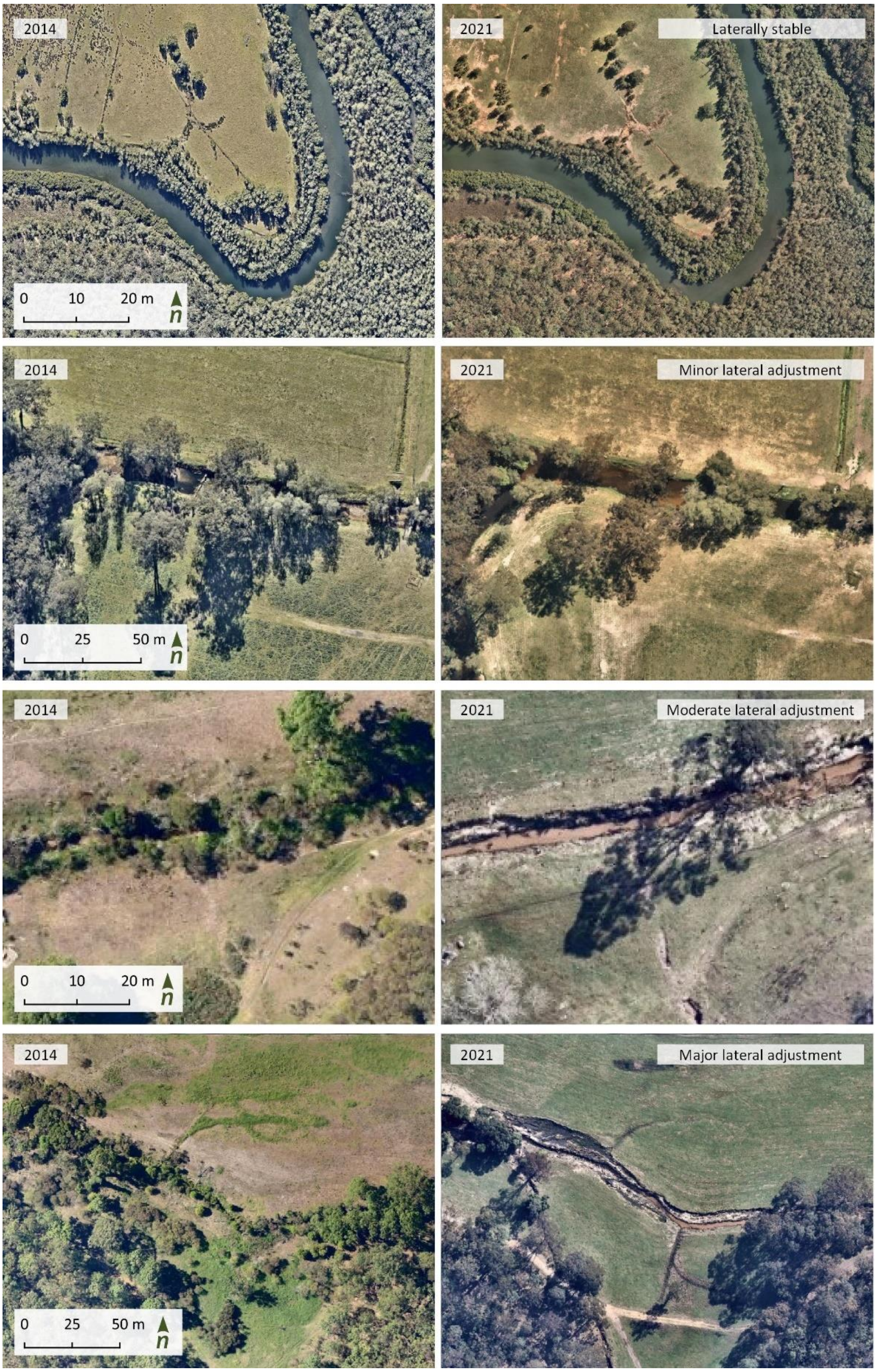


Figure 10. *Examples of multi-temporal analysis for each of the lateral stability categories (Top two comparisons image from Popran Creek, Bottom two comparisons from Ironbark Creek).*

Threats from erosion
If lateral channel instabilities were identified then the threats from erosion were identified as either loss of land, environmental degradation and/or exposed assets.

The results from this first pass assessment are provided in Section 4.

3.3 Full bank erosion assessment

A boat-based field assessment was undertaken by Alluvium staff from the 7th to the 10th of February 2022 to assess the bank and foreshore condition for each of the identified sites. Our field assessment program was designed to maximise field time at or around low tide allowing for the majority of the intertidal zones to be assessed. Some sites were split into sub-sites based on the characteristics of the bank or foreshore.

A field assessment approach was developed to provide a repeatable site condition assessment and was largely based on the *NSW DPI: Fisheries Development and Validation of a Decision Support Tool for Bank Erosion Management in NSW Estuaries, Part A: Desktop and Field Erosion Risk Assessment Methodology*. Additional fields were also created to aid in the management options development, including bank height, bank slope, width of intertidal bench, presence of mangroves as well as notes on surrounding instream habitat features and / or constructability constraints. The field data collected as a part of the site condition assessment is discussed below and outlined in Table 2. Detailed definitions of the field and options are provided in Attachment B.

On-site data collection
Geographical Information System (GIS) spatial data was collected on site during the field assessment. Prior to entering the field, a data collection form was created and linked to a GIS workspace that included spatial files showing the location of each site and other useful information such as roads and estuarine vegetation.

At each site, a new georeferenced feature was created, the data collection form was completed and synced to the GIS workspace (Figure 11). Where there were significant changes in site characteristics such as erosion severity, bank condition/substrate, areas with existing erosion controls etc. sites were broken down into sub-sites.

In addition to the field data, georeferenced photos along the length of each site were taken, capturing images of vegetation, habitat features, bank substrate/condition, existing protection, and erosion hotspots. Photos were captured from the boat or shore if possible as a minimum. Where flying regulations allowed, high resolution Unmanned Aerial Vehicle (UAV) imagery was also captured.

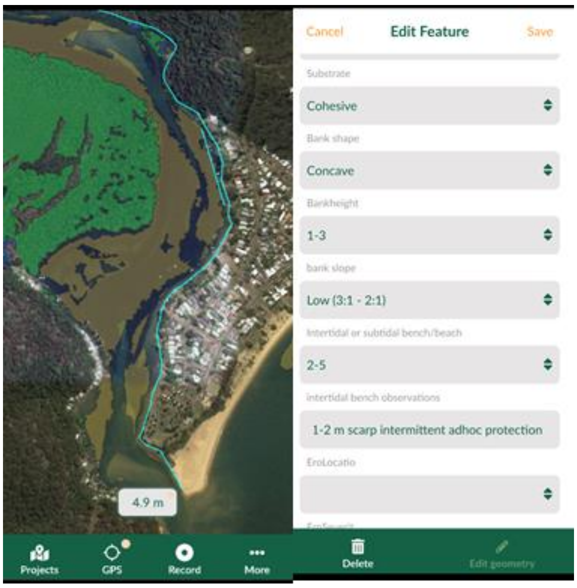


Figure 11. *GIS application used to collect field data*

Table 2. Field data collection form. Field and options definitions provided in Attachment B.

Substrate	Bedrock	Cohesive	Non-cohesive	Bedrock / cohesive	Bedrock / non-cohesive	Cohesive / non-cohesive	All					
Bank shape	Concave	Convex	Planar	Steeped	Wide lower bench	Undercut						
Bank height	<1	1-3	3-6	6-10	>10							
Bank slope	Gentle (<3:1)	Low (3:1 - 2:1)	Moderate (2:1 - 1:1)	Steep (>1:1)	Vertical							
Intertidal / subtidal bench	<2	2-5	>5	none								
Current Erosion severity	Negligible	Low	Moderate	High	Extreme							
Estimated future trajectory	Not occurring, not likely	Not occurring, but likely	Occurring and continuing	Occurring and accelerating	Occurred but ongoing unlikely							
Existing protection present	None	Rock revetment	Geobags	Timber walling	Timber revetment	Large woody debris	Revegetation	Groynes	Cobble beach	Seawall Concrete	Other - acceptable	Other - unacceptable
Condition of existing protection	No existing control	Completely	Partially-condition	Partially-design	Ineffective							
Immediate landward constraint	>10	5-10	3-5	<3	unconstrained							
Mangroves	Present	Nearby	None	Cleared								
Riparian vegetation type	Natural riparian vegetation	Mixed veg fringing altered land use	Low - common land / foreshore	Insignificant - weed infested								
Riparian vegetation value	High - conservation value	Moderate - native veg in good condition	Low - common land / foreshore									
Riparian vegetation continuity	None	Low	Moderate	High								
Riparian vegetation width (m)	<2m	<5m	<10m	<20m	>20m							
Landuse	Road reserve	Grazing	Other agricultural	Commercial	Residential	Urban	Parkland / recreational					
Erodible width	Confined	<3	3-10	>10								
Contributing causes of erosion	Wind waves	Ocean waves	Vessel waves	River / tidal flow	Sediment extraction	Stock access	Public access	Overland flow	Bank saturation			
High value asset at immediate risk	Yes	No										
Environmental impact	Negligible	Low	Moderate	High								
Infrastructure / commercial Impact	Negligible	Low	Moderate	High								
Amenity / safety impact	Negligible	Low	Moderate	High								
Public access required	Yes	No										

As mentioned previously, the field assessment approach was guided by the *NSW DPI: Fisheries Development Decision Support Tool for Bank Erosion Management in NSW Estuaries.* One of the key analyses from this tool is to assess the impact of erosion on the site to various values. The classification of each site for these impacts is important in assessing the overall risk the site poses and helps to prioritise sites for mitigation efforts. For our assessments we adapted these definitions slightly to be a *consequence* if erosion was to occur. The consequence can then be compared with the *likelihood* of erosion occurring to provide an overall *risk*. The risk assessment and site prioritisation has been discussed and further developed with the Partner Councils and is described in section 5. The definition for the environmental, infrastructure, and amenity impact scales from this tool are reproduced in Table 3, Table 4, and Table 5.

Another of the key criteria captured was the erosion severity, which will form part of the *likelihood* component of the risk assessment. The definitions of the erosion severity categories are provided below in Table 6. Further explanatory notes on each of the data collection fields are provided in Attachment B.

Table 3. Environmental impact (definitions adapted from DPI Fisheries Decision Support Tool)

Negligible	No features of biodiversity of conservation value likely to be under threat, no impacts of erosion likely to affect downstream environments. No erosion or the erosion is considered within the natural envelope of change.
Low	No features of biodiversity or conservation under significant threat. Potential for localised impacts such as loss of low value vegetation or localised water quality impacts. Impacts are small scale and threats to biodiversity and conservation values are considered minimal.
Medium	Features of biodiversity or conservation value affected. Scale of impact is significantly greater than natural. Impacts on instream values through siltation or turbidity likely to extend beyond the length of the bank segment.
High	Features of listed biodiversity or conservation value are directly threatened. Significant direct impacts to features of biodiversity or conservation value. Potential for downstream impacts due to turbidity or extensive siltation.

Table 4. Infrastructure / commercial impact (definitions adapted from DPI Fisheries Decision Support Tool)

Negligible	No built or land assets under threat.
Low	Minor assets of low value potentially under threat. May require relocation or minor works typically able to be accommodated without significant labour or cost implications. Loss of land is relatively minor and likely to be of low concern to landholder.
Medium	Assets of intermediate value threatened. Relocation or repairs necessary with costs up to $100,000. Examples include boat ramps, footpaths, park benches, minor access stairs, etc. Loss of land is likely to be of concern to landholder.
High	High value or otherwise important assets under threat. Likely significant follow-on impacts. Examples include loss of public utilities such as power lines, water and sewer infrastructure, houses, other buildings, roads, carparks. Loss of land likely to be of significant concern to landholder with some evidence of protection works evident. Likely costs > $100,000.

Table 5. Amenity / safety impact (definitions adapted from DPI Fisheries Decision Support Tool)

Negligible	No impact on visual amenity, foreshores not used by public, very low risk of injury attributable to erosion.
Low	Some impact on a small number of people, low risk of serious injury.
Medium	Significant visual impact. Public access to foreshore impeded. Potential for increased risk of injury to members of the public due to greater usage and/or hazard.
High	Amenity for large number of users is affected. Foreshore access significantly impeded. Specific public safety risks in popular areas.

Table 6. Erosion severity (definitions from DPI Fisheries Decision Support Tool)

Negligible	Currently aggrading or stable (i.e., no or very insignificant erosion)
Low	Some erosion occurring but considered within the natural parameters, low erosion rate, low scarp height or minor undercutting
Medium	Rate or scale of erosion is considered more than natural, elevated scarp height, considerable undercutting or minor evidence of slumping/mass failure
High	High rate of erosion, scale of erosion is significant, significant scarp height, significant undercutting or evidence to suggest slumping/mass failure

4 Site summaries

4.1 Overview

A site summary has been prepared for each of the identified sites and sub-sites based on the outputs from the desktop and field assessments. There were 44 sites that had the 'full assessment' undertaken and these were further broken down to a total of 76 sub-sites, totalling more than 30 km of stream bank assessments. Full summaries are provided in Attachment C. The following elements are included in each summary:

- Site ID, name (if available), and LGA
- Estuary zone, broken into one of the following categories:
  - Upper estuary: Riverine dominant system, typically no mangroves present
  - Mid estuary: Riverine with increased tidal influence, mangroves present
  - Lower estuary inlets: Lower estuary inlets feeding into the marine dominant lower estuary
  - Lower estuary - sandy shoals and beaches: Largely open marine dominant water, presence of mangroves and seagrasses
- A high-resolution aerial image of the entire site containing:
  - Site extent and sub-section delineations
  - Photo capture points for both drone and boat/land photos
  - Overlay of NSW Estuarine Habitat Mapping (DPI Fisheries)
- A brief description of the site including its geomorphic characteristics, proximity to assets and/or areas of ecological value, and any other notable features
- Sub-section summaries including:
  - Representative photos illustrating the bank condition
  - Approximate length (m)
  - Site condition information for:
    - bank height
    - bank substrate
    - intertidal / subtidal bench width
    - erodible width
    - landward constraint
  - Vegetation condition/extent information for:
    - Mangroves
    - Vegetation type
    - Vegetation value
    - Vegetation continuity
    - Vegetation width
  - Likelihood of erosion including information about existing protection
  - Consequence of erosion considering the impact on environment, infrastructure, and amenity

An overall likelihood and consequence of ongoing significant erosion has also been provided as part of the site summaries. The consequence has been derived from a combination of the three impact categories that have been described above, that is:

- Environmental impact
- Infrastructure/commercial impact
- Amenity/safety impact

The overall likelihood of ongoing significant erosion has been derived based on a semi-qualitative assessment of the of the site conditions including:

- Erosion severity
- Erosion trajectory
- Recent historic rates of erosion
- Existing erosion controls
- Riparian and intertidal vegetation condition/extent
- Causes of erosion

4.2 First pass bank erosion assessment for Mangrove Creek

A first pass bank erosion assessment was undertaken for Site CCC11 which included the foreshores of Mangrove Creek including the area from the confluence with the Hawkesbury River at Spencer to the Mangrove Creek weir, including five tributaries, namely: Dinner Creek; Popran Creek; Ironbark Creek; Sugee Bag Creek; and Bedlam Creek.

A first Pass Condition Rating & Prioritisation will be undertaken using the results of the assessment following discussions with the Partner Councils as a part of the next phase of this project. The results and prioritisation will help inform field assessment planning and future prioritisation for further investigation.

The results for each of the key criteria assessed are summarised below in Table 7, Table 8, Table 9, Table 10, and mapped below in Figure 12, Figure 13, Figure 14 and Figure 15.

Table 7. Summary of erodible width results

Erodible width (m)		**Confined**		**1m - 10m**		**10m - 25m**		**25m - 50m**		**>50m**	
Locality	***length (m)***	***Length (m)***	***%***	***Length (m)***	***%***	***Length (m)***	***%***	***Length (m)***	***%***	***Length (m)***	***%***
Bedlam Creek	***8,372***	6,600	79	589	7	505	6	312	4	366	4
Dinner Creek	***12,844***	5,875	46		-	660	5	1,971	15	4,337	34
Ironbark Creek	***18,728***	11,659	62	185	1	1,144	6	2,532	14	3,207	17
Mangrove Creek	***37,776***	4,571	12	1,089	3	4,641	12	4,714	12	22,761	60
Popran Creek	***16,750***	3,922	23		-	854	5	2,570	15	9,403	56
Sugee Bag Creek	***8,468***	4,865	57	214	3	670	8	1,796	21	922	11
Total (m)	**102,938**	**37,492**	**36**	**2,078**	**2**	**8,475**	**8**	**13,897**	**13**	**40,996**	**40**

Table 8. Summary of erodible height results

Erodible height (m)		Hillslope		0m - 1m		1m - 3m		3m - 5m		>5m	
Locality	*length (m)*	*Length (m)*	*%*	*Length (m)*	*%*	*Length (m)*	*%*	*Length (m)*	*%*	*Length (m)*	*%*
Bedlam Creek	***8,372***	6,600	79		-	1,772	21		-	-	
Dinner Creek	***12,844***	5,687	44	5,626	44	1,530	12		-	-	
Ironbark Creek	***18,728***	11,659	62	3,640	19	3,429	18		-	-	
Mangrove Creek	***37,776***	4,844	13	8,710	23	22,138	59	2,084	6	-	
Popran Creek	***16,750***	4,471	27	5,064	30	5,434	32	1,781	11	-	
Sugee Bag Creek	***8,468***	4,865	57		-	2,658	31	945	11	-	
Total (m)	**102,938**	**38,126**	**37**	**23,041**	**22**	**36,960**	**36**	**4,810**	**5**		

Table 9. Summary of riparian vegetation extent results

Riparian vegetation extent		Good		Moderate		Poor		Very poor	
Locality	*length (m)*	*Length (m)*	*%*	*Length (m)*	*%*	*Length (m)*	*%*	*Length (m)*	*%*
Bedlam Creek	***8,372***	6,600	79	582	7	1,055	13	135	2
Dinner Creek	***12,844***	9,809	76	1,332	10	154	1	1,549	12
Ironbark Creek	***18,728***	14,017	75	2,015	11		-	2,697	14
Mangrove Creek	***37,776***	22,676	60	12,186	32	1,448	4	1,467	4
Popran Creek	***16,750***	9,962	59	3,362	20	2,383	14	1,042	6
Sugee Bag Creek	***8,468***	5,964	70	2,504	30		-		-
Total (m)	**102,938**	**69,027**	**67**	**21,980**	**21**	**5,041**	**5**	**6,890**	**7**

Table 10. Summary of lateral stability results

Lateral stability		Existing protection		Stable		Minor		Moderate		Major	
Locality	*length (m)*	*Length (m)*	*%*	*Length (m)*	*%*	*Length (m)*	*%*	*Length (m)*	*%*	*Length (m)*	*%*
Bedlam Creek	***8,372***		-	7,986	95	386	5		-		-
Dinner Creek	***12,844***		-	12,844	100		-		-		-
Ironbark Creek	***18,728***		-	15,684	84	348	2	390	2	2,307	12
Mangrove Creek	***37,776***	424	1	33,877	90	3,129	8	346	1		-
Popran Creek	***16,750***	305	2	13,735	82	1,668	10	902	5	141	1
Sugee Bag Creek	***8,468***		-	8,468	100		-		-		-
Total (m)	**102,938**	**728**	**1**	**92,594**	**90**	**5,531**	**5**	**1,638**	**2**	**2,448**	**2**

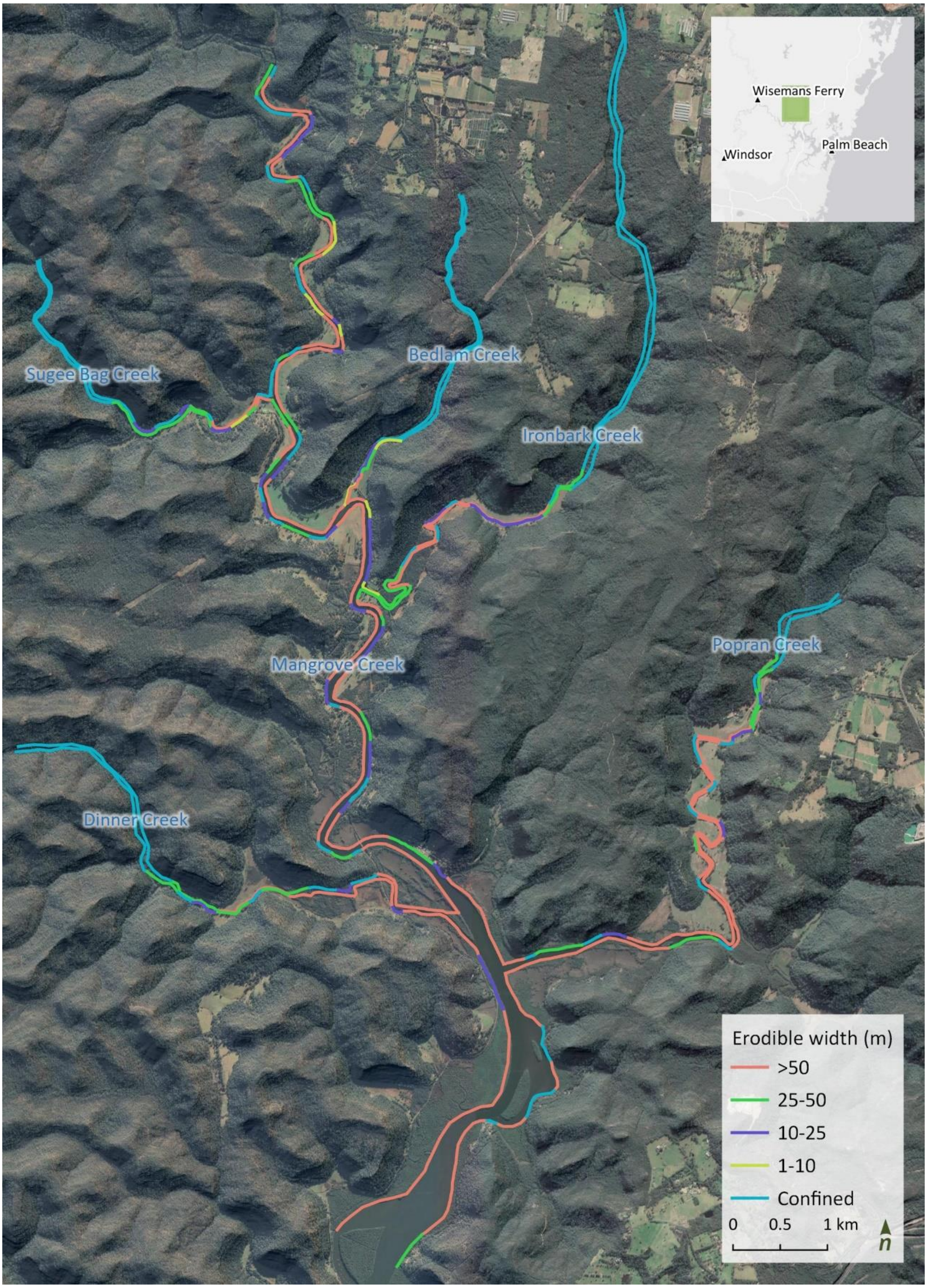


Figure 12. *Erodible width (confinement) across the streambanks within the CCC11 site.*

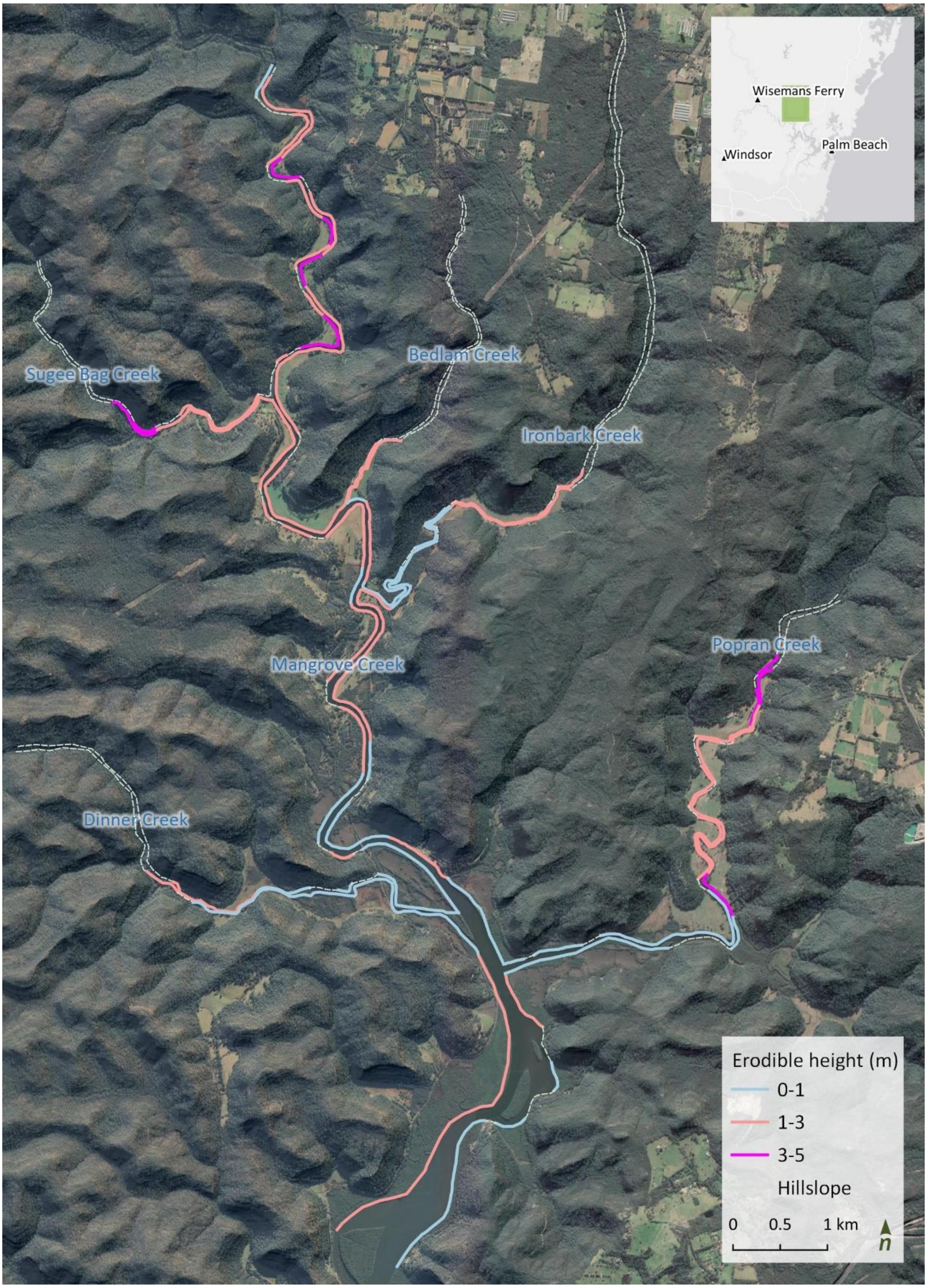


Figure 13. *Erodible height (bank height) across the streambanks within the CCC11 site.*

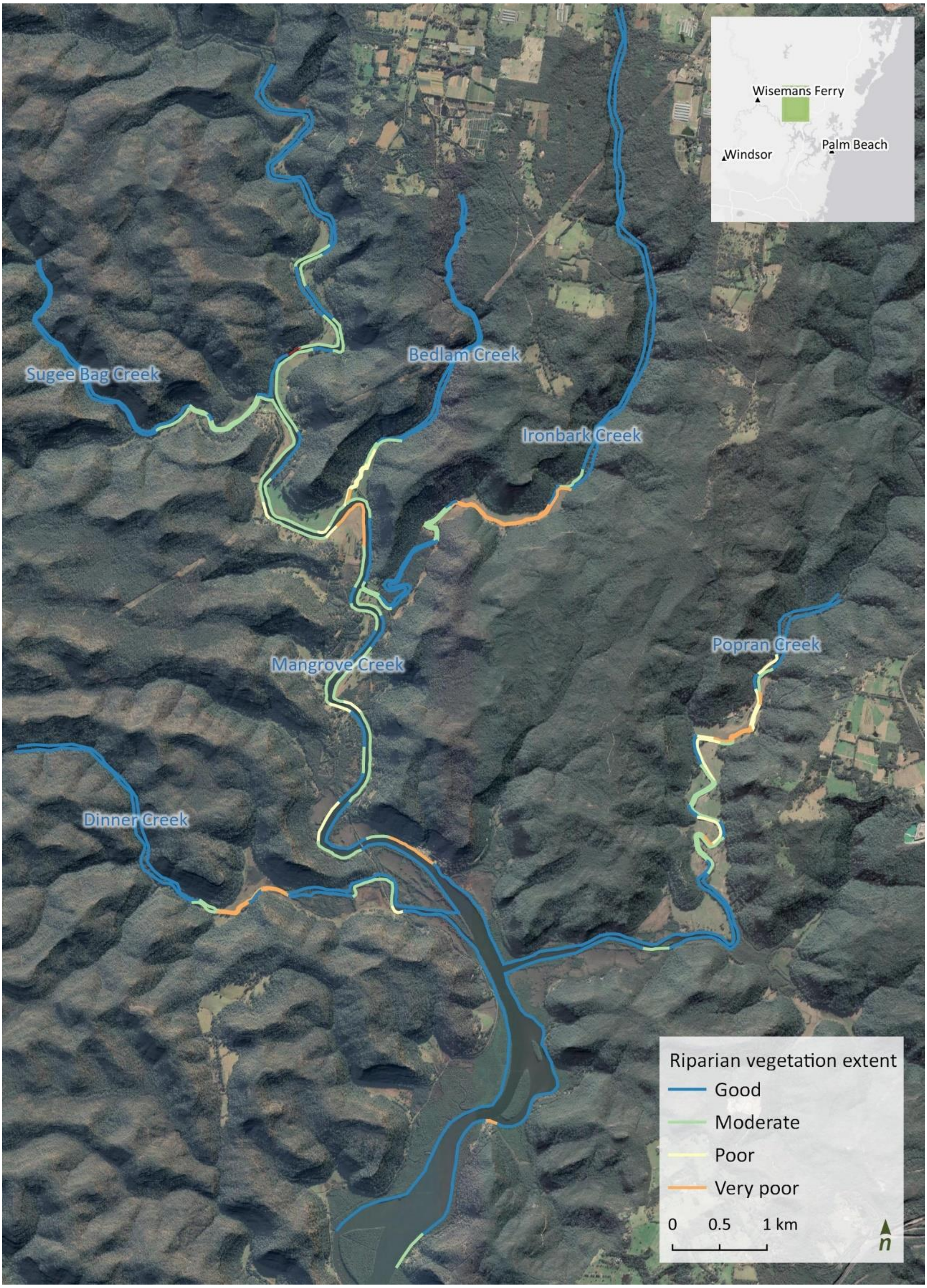


Figure 14. *Riparian vegetation extent across the streambanks within the CCC11 site.*

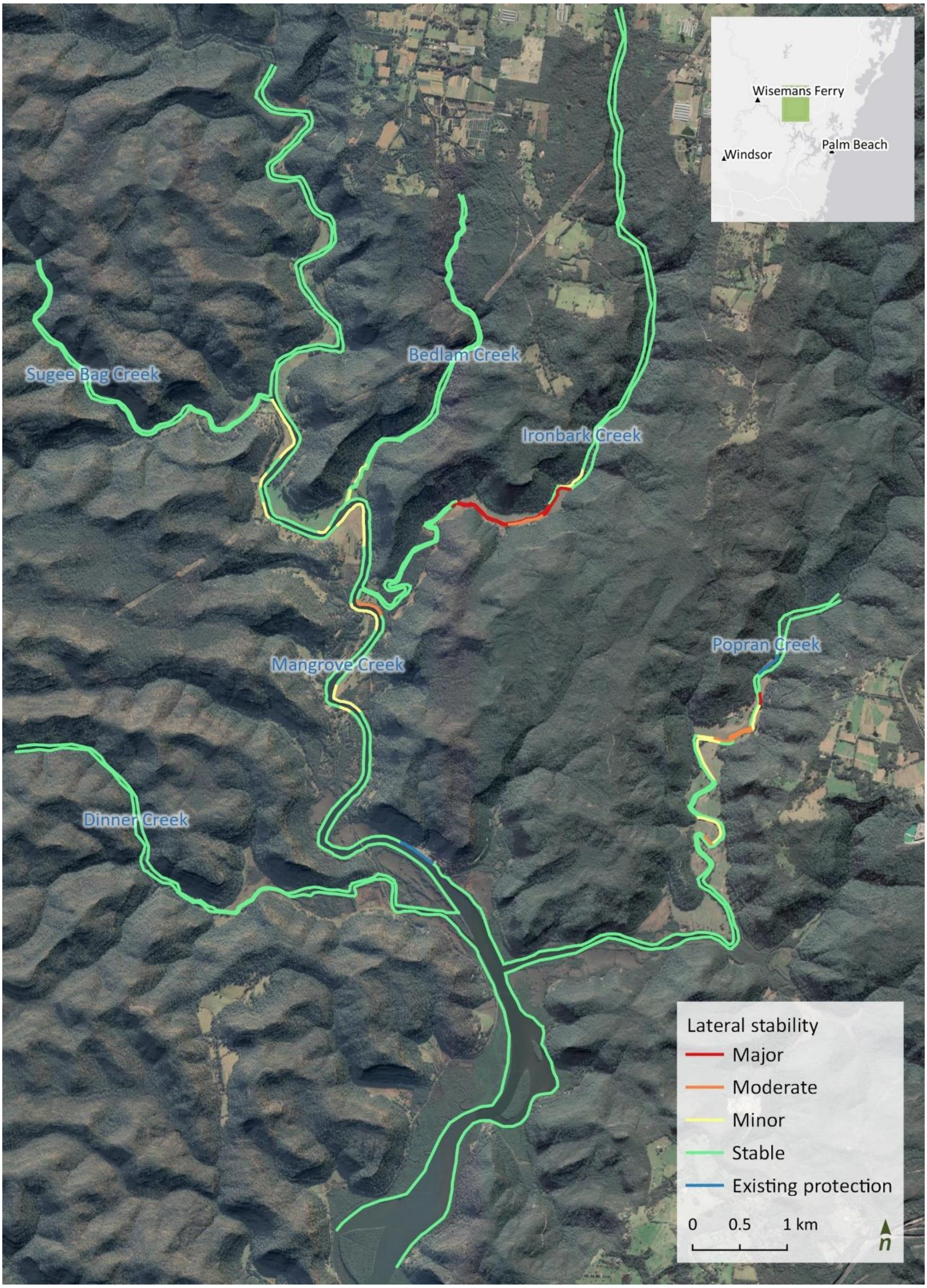


Figure 15. *Lateral stability across the streambanks within the CCC11 site.*

4.3 Full bank erosion assessment

There were 44 sites that had the 'full assessment' undertaken and these were further broken down to a total of 76 sub-sites, totalling more than 30 km of stream bank assessments. It should be noted that these assessments were undertaken prior to multiple significant flood events that impacted the study area in between March and September 2022. The flood events may have resulted in changes to the bank/riparian condition that will not be reflected in the results of the site assessments. Further discussion on the impacts of the post-assessment floods is provided in section 7.2.

Across the 76 sub-sites assessed under the 'full bank erosion assessment' method, there were:

- 5 classified as having a 'High' erosion severity (approximately 675m),
- 16 classified as medium severity (approximately 6,000m),
- 20 classified as low severity (approximately 8,000m) and
- 36 as negligible severity (approximately 16,000m).

The erosion severity at each site is mapped below in Figure 16, Figure 17, Figure 18, Figure 19, and a spatial dataset that includes the full set of assessment results for the metrics outlined above in Section 3.3 has also been provided to Partner Councils. Of the five sites with high erosion severity, three of them were in the upper estuary zone (HCC25b, HCC26 and HCC27) upstream of Wisemans Ferry, one was in the lower estuary inlet of Patonga Creek (CCC13g) and another in the lower estuary - sandy shoals and beaches at Sandy Point Beach (NBC3).

A summary of the some of the key outputs from the erosion assessment for each site are outlined below in Table 11. The likelihood and consequences outlined in Table 11 will be used to in inform the risk assessment and prioritisation in the next phase of the project. Full site summaries are provided in Attachment C.

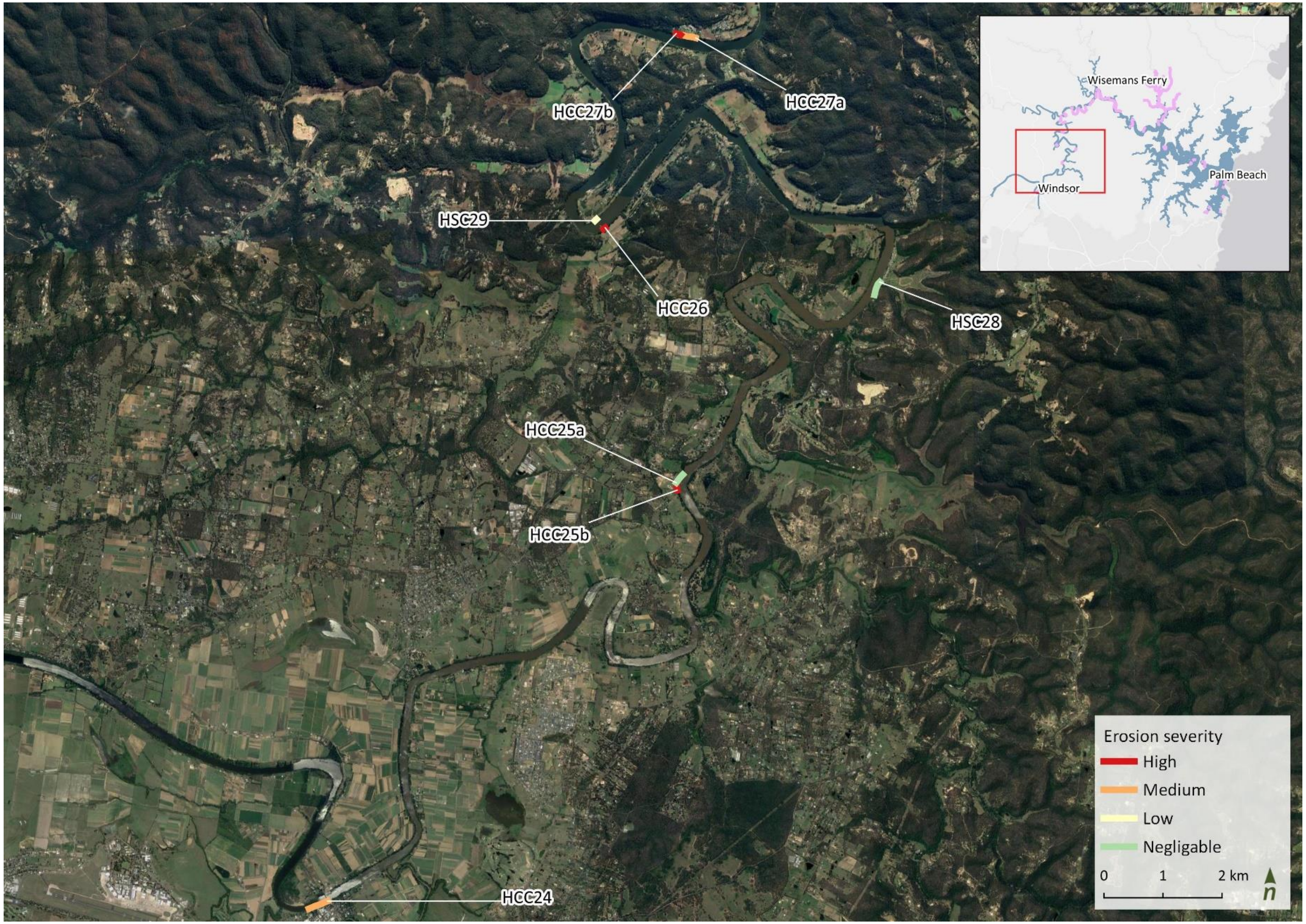


Figure 16. *Erosion severity at the full bank erosion assessment sites between Windsor and Cumberland Reach*

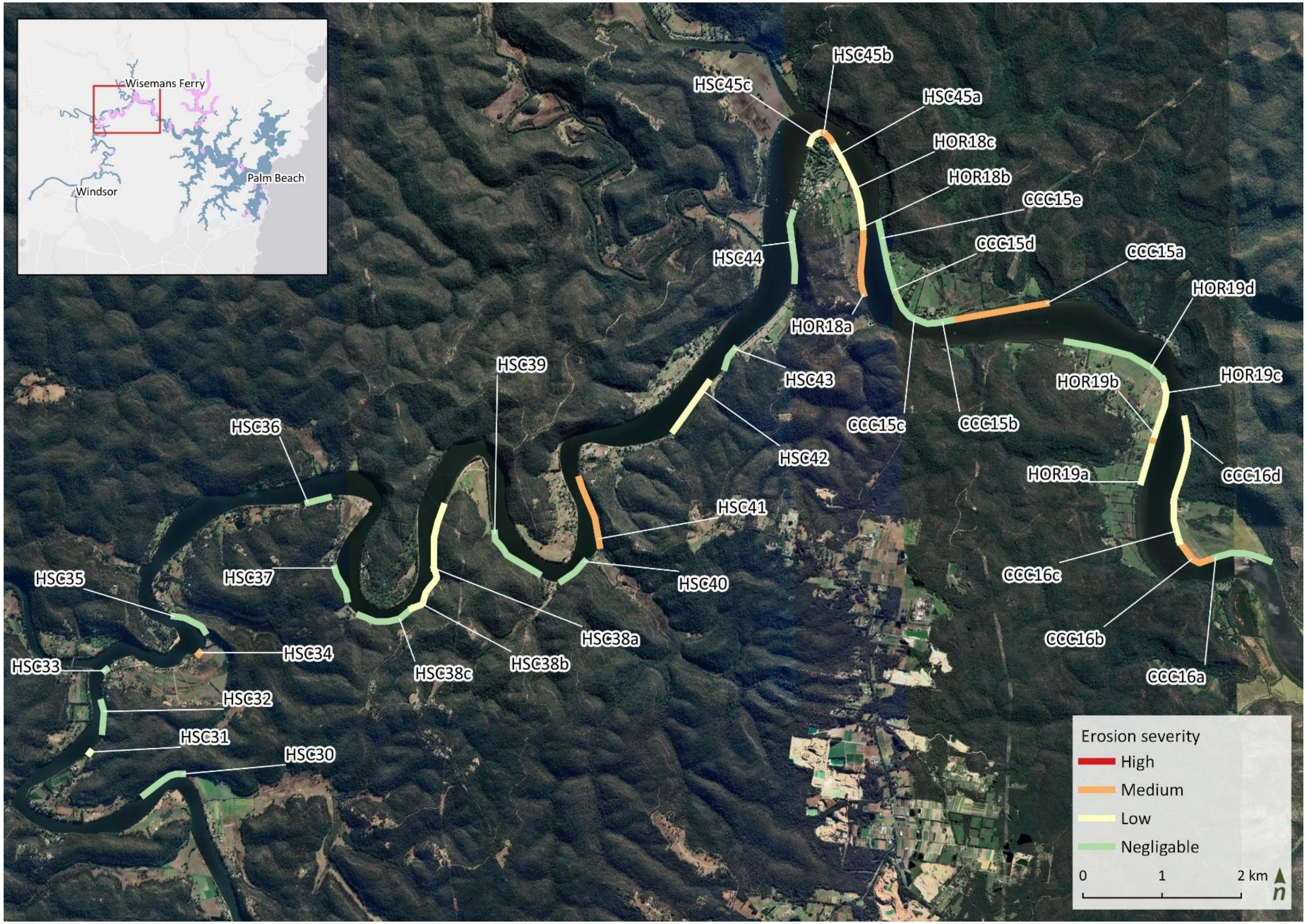


Figure 17. *Erosion severity at the full bank erosion assessment sites between Portland and Laughtondale*

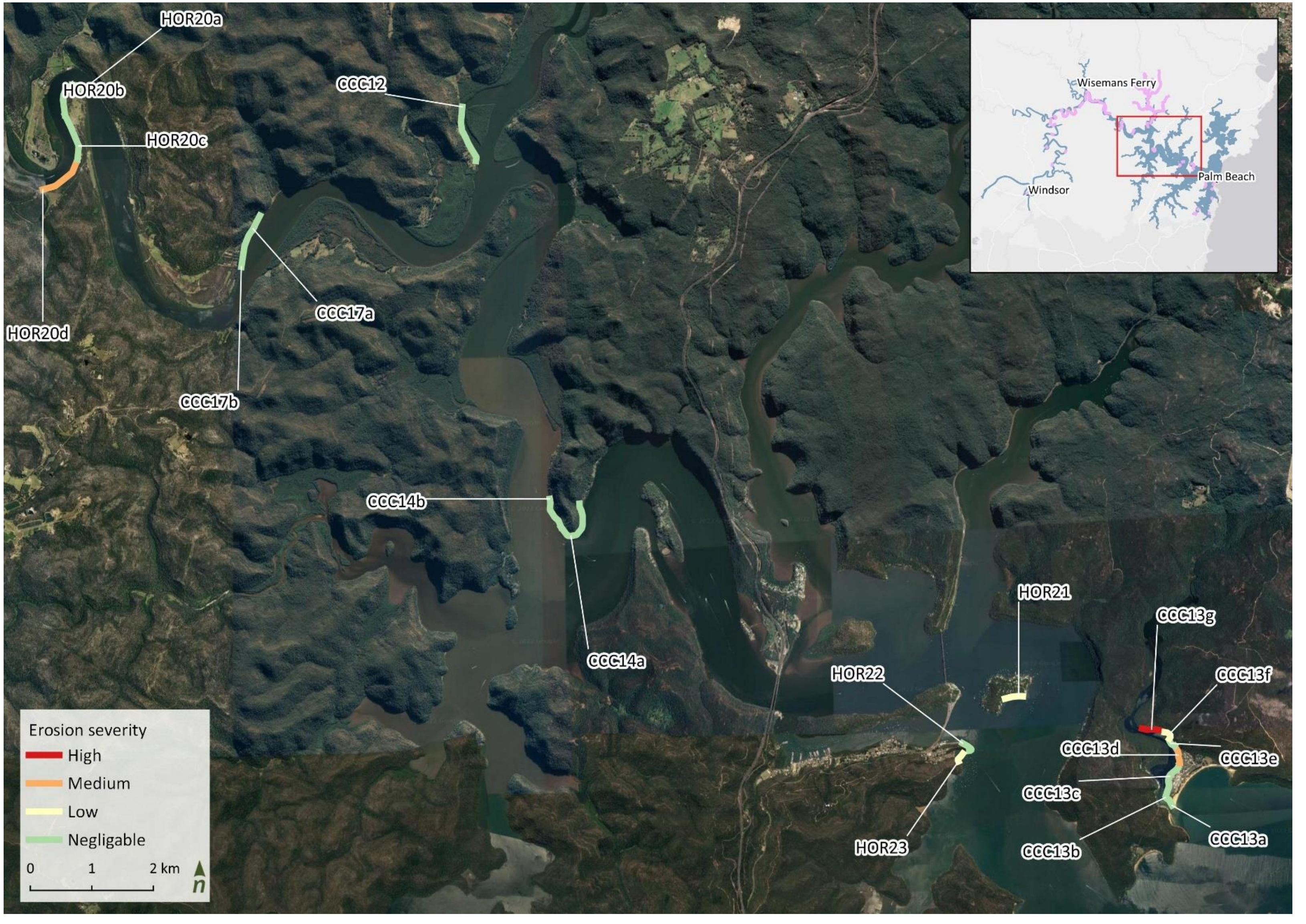


Figure 18. *Erosion severity at the full bank erosion assessment sites between Singletons Mill to Patonga*

Figure 19. *Erosion severity at the full bank erosion assessment sites within Pittwater Estuary*

Table 11. Summary of key metrics relating to consequence and likelihood of erosion from the full bank erosion assessment

LGA	Site number	Site ID	*Consequence*				*Likelihood*			
			Environmental	Infrastructure	Amenity/Safety	Overall	Erosion severity	Erosion trajectory	Recent erosion rate	Overall Likelihood
Central Coast Council	CCC12	CCC12	Low	High	High	Major	Negligible	Not Occurring, not likely	Not evident	Very low
	CCC13	CCC13a	Medium	Low	High	Moderate	Negligible	Not Occurring, but likely	Not evident	Very low
		CCC13b	Medium	Medium	High	Moderate	Negligible	Not Occurring, but likely	Not evident	Very low
		CCC13c	Low	Low	Medium	Minor	Negligible	Not Occurring, not likely	Not evident	Very low
		CCC13d	Low	High	High	Major	Medium	Occurring and continuing	Low	Low
		CCC13e	Medium	Low	Medium	Minor	Negligible	Not Occurring, not likely	Not evident	Very low
		CCC13f	High	Low	Medium	Moderate	Low	Occurred but ongoing unlikely	Not evident	Very low
		CCC13g	High	Negligible	Medium	Moderate	High	Occurring and continuing	High	High
	CCC14	CCC14a	Medium	High	Medium	Moderate	Negligible	Not Occurring, not likely	Very low	Very low
		CCC14b	Medium	Medium	Low	Minor	Negligible	Not Occurring, not likely	Not evident	Very low
	CCC15	CCC15a	Medium	Low	Negligible	Minor	Medium	Occurring and continuing	Not evident	Low
		CCC15b	Negligible	Medium	High	Moderate	Negligible	Occurred but ongoing unlikely	Not evident	Very low
		CCC15c	High	Medium	Medium	Moderate	Negligible	Not Occurring, not likely	Not evident	Very low
		CCC15d	Medium	Low	Medium	Minor	Medium	Occurring and continuing	Medium	Medium

LGA	Site number	Site ID	*Consequence* Environmental	Infrastructure	Amenity/Safety	Overall	*Likelihood* Erosion severity	Erosion trajectory	Recent erosion rate	Overall Likelihood
		CCC15e	High	Medium	Medium	Moderate	Negligible	Not Occurring, not likely	Not evident	Very low
	CCC16	CCC16a	High	Negligible	Negligible	Moderate	Negligible	Not Occurring, not likely	Undiscerned	Very low
		CCC16b	Low	Negligible	Low	Insignificant	Medium	Occurring and continuing	Low	Low
		CCC16c	Medium	Negligible	Low	Minor	Low	Occurring and continuing	Undiscerned	Very low
		CCC16d	Medium	High	High	Major	Low	Occurred but ongoing unlikely	Undiscerned	Low
	CCC17	CCC17a	Low	High	High	Major	Negligible	Not Occurring, not likely	Not evident	Very low
		CCC17b	Medium	Medium	Medium	Moderate	Negligible	Not Occurring, not likely	Not evident	Low
Hawkesbury City Council	HCC24	HCC24	Medium	High	High	Major	High	Occurring and continuing	High	Low
	HCC25	HCC25a	Medium	Medium	High	Moderate	Negligible	Not Occurring, not likely	Not evident	Very low
		HCC25b	Medium	High	High	Major	High	Occurring and continuing	High	High
	HCC26	HCC26	Low	High	High	Major	High	Occurring and continuing	High	High
	HCC27	HCC27a	Medium	Medium	High	Moderate	Medium	Occurring and continuing	High	High
		HCC27b	Medium	Medium	High	Moderate	High	Occurring and continuing	High	High
Hills Shire Council	HSC28	HSC28	Medium	Negligible	Negligible	Minor	Negligible	Not Occurring, not likely	Not evident	Very low
	HSC29	HSC29	Low	High	Medium	Moderate	Low	Occurring and continuing	Low	Low

LGA	Site number	Site ID	Consequence				Likelihood			
			Environmental	Infrastructure	Amenity/Safety	Overall	Erosion severity	Erosion trajectory	Recent erosion rate	Overall Likelihood
	HSC30	HSC30	Medium	High	High	Major	Negligible	Not Occurring, not likely	Not evident	Very low
	HSC31	HSC31	Low	High	Medium	Moderate	Low	Occurring and continuing	Low	Low
	HSC32	HSC32	Medium	High	High	Major	Negligible	Not Occurring, not likely	Very low	Very low
	HSC33	HSC33	Low	High	HIgh	Major	Negligible	Not Occurring, not likely	Very low	Very low
	HSC34	HSC34	Low	High	High	Major	Medium	Occurring and continuing	Very low	Medium
	HSC35	HSC35	Medium	High	High	Major	Negligible	Not Occurring, not likely	Not evident	Very low
	HSC36	HSC36	Medium	High	High	Major	Negligible	Not Occurring, not likely	Not evident	Very low
	HSC37	HSC37	Medium	High	High	Major	Negligible	Not Occurring, not likely	Very low	Very low
	HSC38	HSC38a	Low	High	High	Major	Low	Occurring and continuing	Very low	Low
		HSC38b	Negligible	High	High	Major	Low	Occurred but ongoing unlikely	Very low	Very low
		HSC38c	Low	High	High	Major	Negligible	Occurred but ongoing unlikely	Very low	Very low
	HSC39	HSC39	Low	High	High	Major	Negligible	Not Occurring, not likely	Very low	Very low
	HSC40	HSC40	Low	High	High	Major	Negligible	Not Occurring, not likely	Very low	Very low
	HSC41	HSC41	Low	High	High	Major	Medium	Occurring and continuing	Undiscerned	Medium
	HSC42	HSC42	Low	High	High	Major	Low	Occurring and continuing	Undiscerned	Low

LGA	Site number	Site ID	Consequence: Environmental	Consequence: Infrastructure	Consequence: Amenity/Safety	Consequence: Overall	Likelihood: Erosion severity	Likelihood: Erosion trajectory	Likelihood: Recent erosion rate	Likelihood: Overall Likelihood
	HSC43	HSC43	Low	High	High	Major	Negligible	Not Occurring, not likely	Not evident	Very low
	HSC44	HSC44	Low	High	High	Major	Negligible	Not Occurring, not likely	Not evident	Very low
	HSC45	HSC45a	Medium	Medium	Medium	Moderate	Low	Occurred but ongoing unlikely	Not evident	Very low
		HSC45b	Medium	High	Medium	Moderate	Medium	Occurring and continuing	High	High
		HSC45c	Medium	Medium	Medium	Moderate	Low	Occurred but ongoing unlikely	Not evident	Very low
Hornsby Shire Council	HOR18	HOR18a	Low	Negligible	Negligible	Insignificant	Medium	Occurred but ongoing unlikely	Not evident	Low
		HOR18b	Medium	Negligible	Negligible	Minor	Medium	Occurring and continuing	Undiscerned	Very low
		HOR18c	Low	Negligible	Negligible	Insignificant	Low	Occurring and continuing	Low	Low
	HOR19	HOR19a	Medium	Negligible	Negligible	Minor	Low	Occurred but ongoing unlikely	Low	Low
		HOR19b	Medium	Negligible	Low	Minor	Medium	Occurring and continuing	Medium	Medium
		HOR19c	Medium	Low	Medium	Minor	Low	Occurring and continuing	Not evident	Very low
		HOR19d	Medium	Medium	Medium	Moderate	Negligible	Not Occurring, not likely	Not evident	Very low
	HOR20	HOR20a	High	Negligible	Negligible	Moderate	Negligible	Not Occurring, not likely	Not evident	Very low
		HOR20b	High	Negligible	Negligible	Moderate	Negligible	Not Occurring, not likely	Not evident	Very low

LGA	Site number	Site ID	Consequence				Likelihood			
			Environmental	Infrastructure	Amenity/Safety	Overall	Erosion severity	Erosion trajectory	Recent erosion rate	Overall Likelihood
		HOR20c	Low	Low	Low	Minor	Negligible	Not Occurring, not likely	Not evident	Very low
		HOR20d	High	Low	Negligible	Moderate	Medium	Occurring and continuing	Low	Low
	HOR21	HOR21	Low	High	High	Major	Low	Occurring and continuing	Low	Low
	HOR22	HOR22	Negligible	Medium	High	Moderate	Negligible	Occurring and continuing	Low	Very low
	HOR23	HOR23	Low	High	High	Major	Low	Occurring and continuing	Low	Very low
Northern Beaches Council	NBC1	NBC1	Low	High	Medium	Moderate	Low	Occurring and continuing	Low	Low
	NBC2	NBC2a	Low	High	Medium	Moderate	Negligible	Not Occurring, but likely	Not evident	Very low
		NBC2b	Low	High	Medium	Moderate	Low	Occurring and continuing	Low	Low
		NBC3	Low	High	High	Major	High	Occurring and continuing	High	High
	NBC4	NBC4a	Low	High	High	Major	Medium	Occurring and continuing	High	Medium
		NBC4b	Low	High	High	Major	Negligible	Occurring and continuing	Low	Very low
	NBC5	NBC5	Low	Medium	Medium	Minor	Medium	Occurring and continuing	Medium	Medium
	NBC6	NBC6	Low	High	High	Major	Negligible	Not Occurring, not likely	Not evident	Very low
	NBC7	NBC7	Low	Medium	Low	Minor	Negligible	Occurred but ongoing unlikely	Not evident	Very low
	NBC8	NBC8	Low	High	High	Major	Low	Occurred but ongoing unlikely	Low	Very low

LGA	Site number	Site ID	*Consequence*				*Likelihood*			
			Environmental	**Infrastructure**	**Amenity/Safety**	**Overall**	**Erosion severity**	**Erosion trajectory**	**Recent erosion rate**	**Overall Likelihood**
	NBC9	NBC9	Medium	Low	High	Moderate	Medium	Occurring and continuing	Medium	Medium
	NBC10	NBC10a	High	Low	Medium	Moderate	Negligible	Occurred but ongoing unlikely	Not evident	Very low
		NBC10b	Medium	Low	Medium	Minor	Medium	Occurring and continuing	Medium	Medium

5 Risk assessment and prioritisation

A risk assessment has been undertaken based on the likelihood and consequence of ongoing erosion. Each of the elements of the risk assessment are discussed below.

Likelihood of ongoing erosion based on:

- Recent historic erosion rate
- Erosion severity
- Existing protection
- Erosion trajectory

Each of the sites were given an overall likelihood of ongoing erosion based on each of the categories and metrics (where applicable) outlined in Table 12. It should be noted that recent erosion rate was estimated using the multi temporal analysis outlined in Section 3.1 and as mentioned it was not always possible to assess the change in bank position due to vegetation cover or image quality.

Table 12. Summary of Likelihood categories and metrics

Likelihood	Recent historic erosion rate	Erosion severity	Existing protection	Erosion trajectory
Very low	Not evident or very low	Negligible	No controls or Existing controls - effective	Not occurring, but likely; Not occurring, not likely; Occurring and continuing; Occurred but ongoing unlikely
Low	Low	Negligible - low	No controls or Existing controls - partially effective, ineffective or redundant	Occurring and continuing; Occurred but ongoing unlikely
Medium	Medium	Low-medium	No controls or Existing controls - partially effective, ineffective or redundant	Occurring and continuing
High	High	Medium-high	No controls or Existing controls - partially effective, ineffective or redundant	Occurring and continuing

and, the **Consequence** of ongoing erosion in terms of:

- Environmental impact
- Safety/ amenity impact
- Infrastructure impact

For the purposes of prioritisation it is necessary to be able to compare all of the sites against each other. For this reason, each of the sites were given an overall consequence of erosion based on the combined impacts for the environmental, infrastructure, and amenity impact scales (described in Section 3.3) as per the categories outlined below in Table 13.

Table 13. Summary of overall consequence categories

Consequence	Impacts (environmental, infrastructure, amenity/safety)
Insignificant	Lows and/or negligible
Minor	Medium and lower
Moderate	All mediums or one high
Major	Two or more highs

Following discussions with Partner Councils, it was decided to weight each of the impact categories equally which allows for consistent consideration of overall risk (environmental, infrastructure, amenity/access) across all sites. By nature this means that if a site is less diverse in terms of impacts and is only threatening one of the impact categories for example, then it does result in a lower overall consequence score. The supporting data has been made available to enable different weightings/objectives to be applied in the future.

5.1 Risk

A risk assessment matrix was developed based on the *NSW DPI: Fisheries Development and Validation of a Decision Support Tool for Bank Erosion Management in NSW Estuaries* (see Table 14). The **Risk** = Likelihood x Consequence. For example, a bank segment with an overall likelihood = 'Medium' and a consequence rating of 'Minor' the risk assigned would = 'Low'.

Table 14. Risk matrix

		Likelihood			
		Very low	*Low*	*Medium*	*High*
Consequence	*Insignificant*	Very Low	Very Low	Very Low	Very Low
	Minor	Very Low	Low	Low	Medium
	Moderate	Very Low	Low	Medium	High
	Major	Low	Medium	High	Extreme

The results of the risk assessment are presented below in Table 15.

Table 15. Summary table showing the risk assessment results

LGA	Site number	Site ID	*Consequence*				*Likelihood*				
			Environmental	Infrastructure	Amenity/Safety	Overall	Erosion severity	Erosion trajectory	Recent erosion rate	Overall Likelihood	Overall Risk
Central Coast Council	CCC12	CCC12	Low	High	High	Major	Negligible	Not Occurring, not likely	Not evident	Very low	**Low**
	CCC13	CCC13a	Medium	Low	High	Moderate	Negligible	Not Occurring, but likely	Not evident	Very low	**Very low**
		CCC13b	Medium	Medium	High	Moderate	Negligible	Not Occurring, but likely	Not evident	Very low	**Very low**
		CCC13c	Low	Low	Medium	Minor	Negligible	Not Occurring, not likely	Not evident	Very low	**Very low**
		CCC13d	Low	High	High	Major	Medium	Occurring and continuing	Low	Low	**Medium***
		CCC13e	Medium	Low	Medium	Minor	Negligible	Not Occurring, not likely	Not evident	Very low	**Very low**
		CCC13f	High	Low	Medium	Moderate	Low	Occurred but ongoing unlikely	Not evident	Very low	**Very low**
		CCC13g	High	Negligible	Medium	Moderate	High	Occurring and continuing	High	High	**High**
	CCC14	CCC14a	Medium	High	Medium	Moderate	Negligible	Not Occurring, not likely	Very low	Very low	**Very low**
		CCC14b	Medium	Medium	Low	Minor	Negligible	Not Occurring, not likely	Not evident	Very low	**Very low**
	CCC15	CCC15a	Medium	Low	Negligible	Minor	Medium	Occurring and continuing	Not evident	Low	**Low**
		CCC15b	Negligible	Medium	High	Moderate	Negligible	Occurred but ongoing unlikely	Not evident	Very low	**Very low**
		CCC15c	High	Medium	Medium	Moderate	Negligible	Not Occurring, not likely	Not evident	Very low	**Very low**
		CCC15d	Medium	Low	Medium	Minor	Medium	Occurring and continuing	Medium	Medium	**Low**
		CCC15e	High	Medium	Medium	Moderate	Negligible	Not Occurring, not likely	Not evident	Very low	**Very low**
	CCC16	CCC16a	High	Negligible	Negligible	Moderate	Negligible	Not Occurring, not likely	Undiscerned	Very low	**Very low**
		CCC16b	Low	Negligible	Low	Insignificant	Medium	Occurring and continuing	Low	Low	**Very low**
		CCC16c	Medium	Negligible	Low	Minor	Low	Occurring and continuing	Undiscerned	Very low	**Very low**
		CCC16d	Medium	High	High	Major	Low	Occurred but ongoing unlikely	Undiscerned	Low	**Medium**

LGA	Site number	Site ID	*Consequence* Environmental	Infrastructure	Amenity/Safety	Overall	*Likelihood* Erosion severity	Erosion trajectory	Recent erosion rate	Overall Likelihood	Overall Risk
	CCC17	CCC17a	Low	High	High	Major	Negligible	Not Occurring, not likely	Not evident	Very low	**Low**
		CCC17b	Medium	Medium	Medium	Moderate	Negligible	Not Occurring, not likely	Not evident	Low	**Low**
Hawkesbury City Council	HCC24	HCC24	Medium	High	High	Major	High	Occurring and continuing	High	High	**Extreme**
	HCC25	HCC25a	Medium	Medium	HIgh	Moderate	Negligible	Not Occurring, not likely	Not evident	Very low	**Very low**
		HCC25b	Medium	High	High	Major	High	Occurring and continuing	High	High	**Extreme**
	HCC26	HCC26	Low	High	High	Major	High	Occurring and continuing	High	High	**Extreme**
	HCC27	HCC27a	Medium	Medium	High	Moderate	Medium	Occurring and continuing	High	High	**High**
		HCC27b	Medium	Medium	High	Moderate	High	Occurring and continuing	High	High	**High**
Hills Shire Council	HSC28	HSC28	Medium	Negligible	Negligible	Minor	Negligible	Not Occurring, not likely	Not evident	Very low	**Very low**
	HSC29	HSC29	Low	High	Medium	Moderate	Low	Occurring and continuing	Low	Low	**Low**
	HSC30	HSC30	Medium	High	High	Major	Negligible	Not Occurring, not likely	Not evident	Very low	**Low**
	HSC31	HSC31	Low	High	Medium	Moderate	Low	Occurring and continuing	Low	Low	**Low**
	HSC32	HSC32	Medium	High	High	Major	Negligible	Not Occurring, not likely	Very low	Very low	**Low**
	HSC33	HSC33	Low	High	HIgh	Major	Negligible	Not Occurring, not likely	Very low	Very low	**Low**
	HSC34	HSC34	Low	High	High	Major	Medium	Occurring and continuing	Very low	Medium	**High**
	HSC35	HSC35	Medium	High	High	Major	Negligible	Not Occurring, not likely	Not evident	Very low	**Low**
	HSC36	HSC36	Medium	High	High	Major	Negligible	Not Occurring, not likely	Not evident	Very low	**Low**
	HSC37	HSC37	Medium	High	High	Major	Negligible	Not Occurring, not likely	Very low	Very low	**Low**
	HSC38	HSC38a	Low	High	High	Major	Low	Occurring and continuing	Very low	Low	**Medium**
		HSC38b	Negligible	High	High	Major	Low	Occurred but ongoing unlikely	Very low	Very low	**Low**

LGA	Site number	Site ID	Consequence: Environmental	Consequence: Infrastructure	Consequence: Amenity/Safety	Consequence: Overall	Likelihood: Erosion severity	Likelihood: Erosion trajectory	Likelihood: Recent erosion rate	Likelihood: Overall Likelihood	Overall Risk
		HSC38c	Low	High	High	Major	Negligible	Occurred but ongoing unlikely	Very low	Very low	**Low**
	HSC39	HSC39	Low	High	High	Major	Negligible	Not Occurring, not likely	Very low	Very low	**Low**
	HSC40	HSC40	Low	High	High	Major	Negligible	Not Occurring, not likely	Very low	Very low	**Low**
	HSC41	HSC41	Low	High	High	Major	Medium	Occurring and continuing	Undiscerned	Medium	**High**
	HSC42	HSC42	Low	High	High	Major	Low	Occurring and continuing	Undiscerned	Low	**Medium**
	HSC43	HSC43	Low	High	High	Major	Negligible	Not Occurring, not likely	Not evident	Very low	**Low**
	HSC44	HSC44	Low	High	High	Major	Negligible	Not Occurring, not likely	Not evident	Very low	**Low**
	HSC45	HSC45a	Medium	Medium	Medium	Moderate	Low	Occurred but ongoing unlikely	Not evident	Very low	**Very low**
		HSC45b	Medium	High	Medium	Moderate	Medium	Occurring and continuing	High	High	**High**
		HSC45c	Medium	Medium	Medium	Moderate	Low	Occurred but ongoing unlikely	Not evident	Very low	**Very low**
Hornsby Shire Council	HOR18	HOR18a	Low	Negligible	Negligible	Insignificant	Medium	Occurred but ongoing unlikely	Not evident	Low	**Very low**
		HOR18b	Medium	Negligible	Negligible	Minor	Medium	Occurring and continuing	Undiscerned	Low	**Very low**
		HOR18c	Low	Negligible	Negligible	Insignificant	Low	Occurring and continuing	Low	Low	**Very low**
	HOR19	HOR19a	Medium	Negligible	Negligible	Minor	Low	Occurred but ongoing unlikely	Low	Low	**Low**
		HOR19b	Medium	Negligible	Low	Minor	Medium	Occurring and continuing	Medium	Medium	**Low**
		HOR19c	Medium	Low	Medium	Minor	Low	Occurring and continuing	Not evident	Very low	**Very low**
		HOR19d	Medium	Medium	Medium	Moderate	Negligible	Not Occurring, not likely	Not evident	Very low	**Very low**
	HOR20	HOR20a	High	Negligible	Negligible	Moderate	Negligible	Not Occurring, not likely	Not evident	Very low	**Very low**
		HOR20b	High	Negligible	Negligible	Moderate	Negligible	Not Occurring, not likely	Not evident	Very low	**Very low**
		HOR20c	Low	Low	Low	Minor	Negligible	Not Occurring, not likely	Not evident	Very low	**Very low**

LGA	Site number	Site ID	*Consequence* Environmental	Infrastructure	Amenity/Safety	Overall	*Likelihood* Erosion severity	Erosion trajectory	Recent erosion rate	Overall Likelihood	Overall Risk
		HOR20d	High	Low	Negligible	Moderate	Medium	Occurring and continuing	Low	Low	**Low**
	HOR21	HOR21	Low	High	High	Major	Low	Occurring and continuing	Low	Low	**Medium**
	HOR22	HOR22	Negligible	Medium	High	Moderate	Negligible	Occurring and continuing	Low	Low	**Low**
	HOR23	HOR23	Low	High	High	Major	Low	Occurring and continuing	Low	Low	**Medium**
Northern Beaches Council	NBC1	NBC1	Low	High	Medium	Moderate	Low	Occurring and continuing	Low	Low	**Low**
	NBC2	NBC2a	Low	High	Medium	Moderate	Negligible	Not Occurring, but likely	Not evident	Very low	**Very low**
		NBC2b	Low	High	Medium	Moderate	Low	Occurring and continuing	Low	Low	**Low**
	NBC3	NBC3	Low	High	High	Major	High	Occurring and continuing	High	High	**Extreme**
	NBC4	NBC4a	Low	High	High	Major	Medium	Occurring and continuing	High	High	**Extreme**
		NBC4b	Low	High	High	Major	Negligible	Occurring and continuing	Low	Low	**Medium**
	NBC5	NBC5	Low	Medium	Medium	Minor	Medium	Occurring and continuing	Medium	Medium	**Low**
	NBC6	NBC6	Low	High	High	Major	Negligible	Not Occurring, not likely	Not evident	Very low	**Low**
	NBC7	NBC7	Low	Medium	Low	Minor	Negligible	Occurred but ongoing unlikely	Not evident	Very low	**Very low**
	NBC8	NBC8	Low	High	High	Major	Low	Occurred but ongoing unlikely	Low	Very low	**Low**
	NBC9	NBC9	Medium	Low	High	Moderate	Medium	Occurring and continuing	Medium	Medium	**Medium**
	NBC10	NBC10a	High	Low	Medium	Moderate	Negligible	Occurred but ongoing unlikely	Not evident	Very low	**Very low**
		NBC10b	Medium	Low	Medium	Minor	Medium	Occurring and continuing	Medium	Medium	**Low**

**For site CCC13d, additional information arose after the site prioritisation and options assessment had been completed which increased the risk rating from "Low" to "Medium". Site CCC13d has been included in group 2 (Table 18) and the management options provided for that group are feasible for that site, subject to further site specific options assessment.*

5.2 Prioritisation

The risk assessment identified a total of 18 sites with a medium risk or higher. A prioritisation approach was developed to determine priority sites for management intervention within the study area. Using key information gathered as a part of the full bank erosion a simple Multi-Criteria Analysis (MCA) was developed and used. As well as the likelihood and consequence of erosion, the prioritisation criteria for the MCA were selected to consider the broader benefits of the works at each site in terms of:

- Enhancement of instream habitat values and fishing opportunities
- Aesthetic values of the river
- Riparian values within the river including enhancing connectivity

A scoring system for each of the criteria was then developed, and the total sum of the scores used to prioritise the sites. The prioritisation criteria and scores used are presented in Table 16, and a summary of the results presented in Table 17 and Figure 20.

Table 16. Proposed detailed prioritisation metrics and scores

Overall risk	**Score**
Extreme	300
High	200
Medium	100
Erosion severity	
High	3
Medium	2
Low	1
Negligible	0
High value asset at risk	
Yes	1
No	0
Public access to site	
yes	1
no	0
Vegetation value (at and surrounding the site)	
High - conservation value	2
Moderate - native veg in good condition	1
Low - common land/foreshore	0
Insignificant - weed infested	0
Vegetation type (at and surrounding the site)	
Natural riparian vegetation	2

Mixed veg fringing altered land use	1
Cleared veg	0.5
Absent	0
Vegetation continuity (at and surrounding the site)	
High	3
Moderate	2
Low	1
None	0
Vegetation width (at and surrounding the site)	
>20m	4
<20m	3
<10m	2
<5m	1
<2m	0
Mangroves	
Present	2
Nearby	1
None	0
Existing habitat features (eg. large woody debris)	
Present	3
Nearby	2
None	1

Table 17. Results from site prioritisation of medium or higher risk sites

LGA	Location	Site ID	Risk	Risk score	Erosion severity	High value asset at risk	Public access	Habitat features	Vegetation type	Upstream vegetation value	Downstream vegetation value	Downstream vegetation continuity	TOTAL priority score	RANK
NBC	Great Mackerel beach	NBC4a	Extreme	300	2	1	1	0	1	2	0	1	318	1
HCC	Argyle Bailey Reserve	HCC25b	Extreme	300	3	1	0	0	1	0	1	3	317	2
HCC	Churchills Wharf Reserve	HCC26	Extreme	300	3	1	1	0	1	0	1	3	316	3
HCC	The Terrace, Windsor	HCC24	Extreme	300	3	1	1	0	1	0	0	1	315	4
NBC	Sand Point Beach	NBC3	Extreme	300	3	1	1	0	1	0	0	0	306	5
CCC	Patonga Creek	CCC13g	High	200	3	0	0	1	2	2	2	3	233	6
Hills SC		HSC45b	High	200	2	1	1	1	2	1	1	2	223	7
HCC	Holmes Drive Reserve	HCC27b	High	200	3	0	1	0	1	0	0	1	212	8
Hills SC		HSC34	High	200	2	1	1	1	1	0	0	2	212	9
HCC	Holmes Drive Reserve	HCC27a	High	200	2	1	1	0	1	0	0	1	210	10
Hills SC		HSC41	High	200	2	1	1	0	1	0	0	2	210	11
NBC	Cicada Glen Creek	NBC9	Medium	100	2	0	1	2	2	1	0	1	123	12
CCC	Gunderman S	CCC16d	Medium	100	1	1	0	2	2	1	0	1	119	13
Hills SC		HSC38a	Medium	100	1	1	1	0	2	1	0	2	116	14
Hornsby SC	Dangar Beach	HOR21	Medium	100	1	1	1	0	1	1	0	1	113	15
NBC	McCarrs Creek	NBC10b	Medium	100	1	0	1	1	0.5	0	0	1	110.5	16
Hills SC		HSC42	Medium	100	1	1	1	1	1	0	0	1	109	17
Hornsby SC	Parsley Bay breakwall	HOR23	Medium	100	1	1	1	0	0	0	0	0	103	18

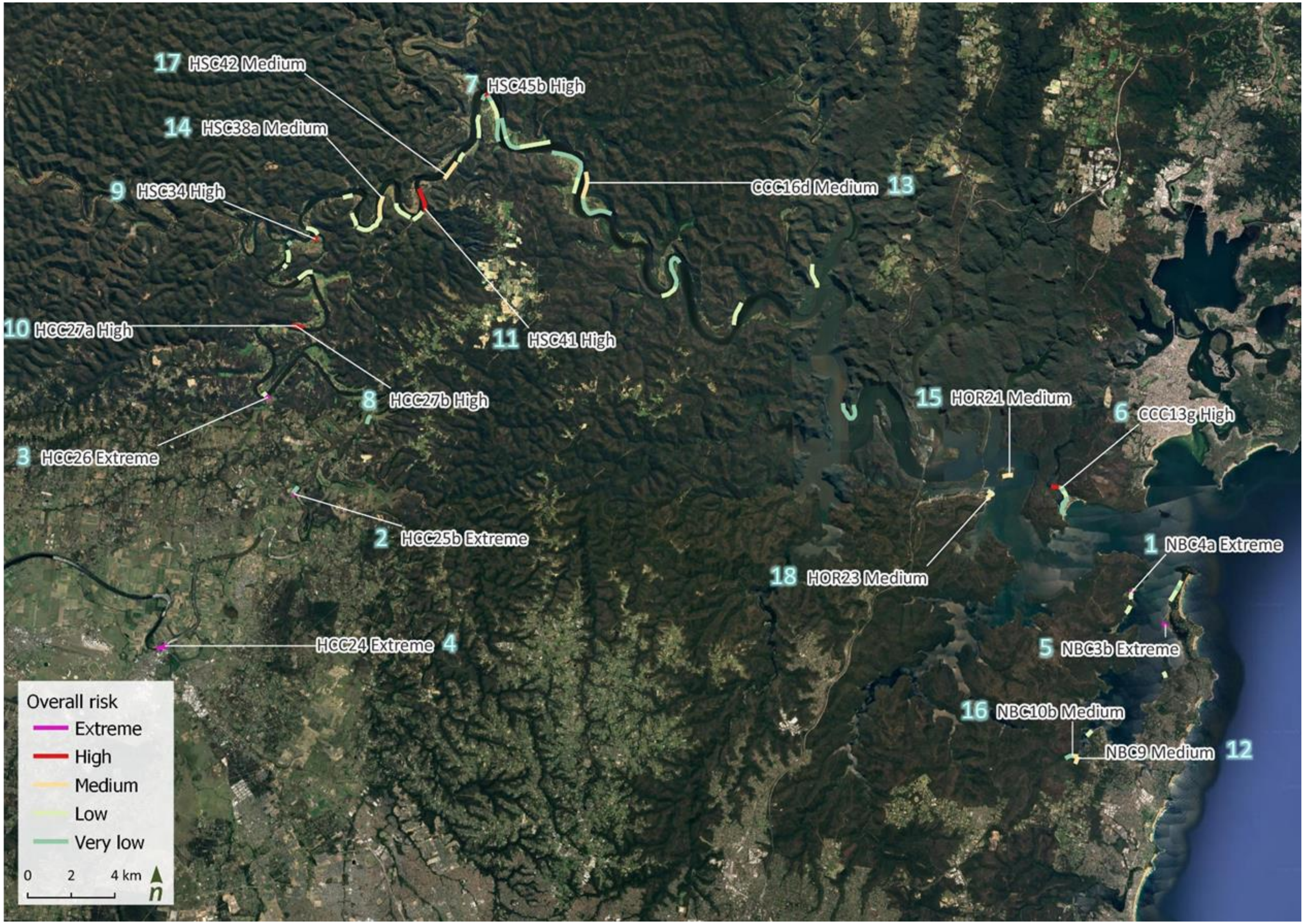


Figure 20. *Priority ranking (blue text) of full bank erosion assessment sites with the sites at medium or higher risk labelled*

6 Banks stabilisation options

Bank stabilisation options have been developed for the 18 priority sites (Medium risk and above) outlined in Section 5. Where possible, sites with similar characteristics have been grouped together and stabilisation options developed for each group of sites. The site groupings are outlined in more detail in the following section (Section 6.1).

For the Very low and Low risk sites, a monitoring program that aligns type and frequency of monitoring with the risk/vulnerability of the sites has been recommended and is detailed further in Section 6.3.

6.1 Site groupings

Sites have been grouped into seven categories based on characteristics relating to:

- Location in the estuary
- Asset type at risk and immediately adjacent land use
- Distance to property and infrastructure and feasible set-back extent
- Presence/condition of existing protection
- The existing bank slope
- The presence or absence of an intertidal beach
- The existing subtidal and intertidal habitat values
- The existing riparian vegetation condition and extent

The site grouping categories are presented below in Table 18 along with the key characteristics of each of the groups. Where possible, the remaining study sites (low and very low risk) have been categorised into these groupings also.

Table 18. Site grouping categories

Site category	Key characteristics	Example	Priority sites	*Low/Very low risk sites with similar attribute*
1. Estuarine inlets - Natural	• Natural estuarine inlet • Native vegetation in good condition • Land use primarily conservation/recreation • Steep upper erosion scarp with intertidal beach		• CCC13g – 'Patonga Creek' *(example photo)*	• CCC13f
2. Estuarine inlets - Artificial	• Artificially created estuarine inlet • Land use – public recreation • Public access and safety/amenity impacts • Moderate to wide intertidal bench with mangroves present or nearby • Low bank height with some setback available		• NBC9 – 'Cicada Glen Creek' *(example photo)* • NBC10b – 'McCarrs Creek'	• NBC10a • CCC13d*

3. Lower estuary/marine sandy beaches and shoals	• Sandy beach/shoal • Limited/no available set back • Private assets in close proximity and at risk • Public access and amenity impacts		• NBC3- 'Sand Point Beach' • NBC4a – 'Great Mackerel Beach' *(example photo)* • HOR21- 'Dangar Beach'	• NBC1 • NBC2a • NBC2b • NBC4a • NBC4b • NBC5
4. Lower estuary/marine sandy beaches and shoals -Existing protection	• Existing breakwall • Public access and safety/amenity impacts		• HOR23- 'Parsley Bay breakwall' *(example photo)*	• HOR22 • NBC6
5. Mid/upper estuary - High banks, limited setback	• Mid-upper estuary • Impacted by estuarine and riverine processes • Steep and high banks (>3m in height) • Limited/no setback available • Narrow or no intertidal bench • Public access and safety/amenity impacts		• HCC24 – 'The Terrace, Windsor' • HCC25b- 'Argyle Bailey Reserve' *(example photo)* • HCC26- 'Çhurchills Wharf' • HSC34	

6. Mid/upper estuary - Low-moderate banks, setback available	• Mid-upper estuary • Impacted by estuarine and riverine processes • Low to moderate bank height (<3m) • Some setback available • Public access and safety/amenity impacts • Intertidal bench		• HCC27 a– 'Holmes Drive Reserve' • HCC27b- 'Holmes Drive Reserve' *(example photo)*	
7. Mid/upper estuary - Existing protection	• Mid-upper estuary • Impacted by estuarine and riverine processes • Limited/no setback available • Road/asset immediately adjacent • Existing protection there in varying types and conditions		• CCC16d- 'Gunderman S' • HSC38a • HSC41- *(example photo)* • HSC42	• HSC30 • HSC35 • HSC37 • HSC38b • HSC38c • HSC43 • HSC44
8. Mid estuary – Low bank height setback available, mangroves nearby	• Mid estuary • Mangroves present • Low bank height • Some setback available • Public access and safety/amenity impacts • Intertidal bench		• HSC45b	• CCC16b • HOR18c

**For site CCC13d, additional information arose after the site prioritisation and options assessment had been completed which increased the risk rating from "Low" to "Medium". Site CCC13d has been included in group 2, and the management options provided for that group are feasible for that site, subject to further site specific options assessment.*

6.2 Stabilisation options

A range of options are available to protect road infrastructure, enhance riparian vegetation communities and fish habitat values within the study area. The suitability of the various options at different sites within the study area will vary depending on the adjacent land use, distance to key infrastructure, existing riparian and marine vegetation and channel morphology. This section provides:

1. An overview of the types of bank stabilisation tools that are available within the study area and the suitable site conditions for each option.
2. An overview of the fish habitat features that could be incorporated into bank stabilisation works and their suitable sites conditions.

This assessment has informed the option development for bank stabilisation and inclusion of fish habitat features for the priority groups. In some cases the fish habitat feature is contributing to, or is the key component of, the bank stabilisation option.

Bank stabilisation tools

Bank erosion in each of the priority areas, and within the study area more broadly, is driven by a range of processes. These include:

- Surface scour of bank material by both fluvial processes and wave action resulting in bank retreat and over-steepening of the bank profile
- Excessive pore water pressure
- Mass failure of over-steepened bank profiles

A range of bank stabilisation tools are available to reduce these drivers of bank erosion. These are summarised in Table 19. Each of these stabilisation tools require different conditions and setback requirements to be effective.

Where feasible a bank stabilisation approach that allows native riparian vegetation establishment is preferred. The vegetation can provide long term bank stability and provides a range of ecological values. To provide an environment suitable for planting and maintenance the site may require bank reprofiling and setback of the top of bank. Depending on the height of the bank and available setback (i.e. distance to key assets/values), more detailed information may be required to determine feasible stabilisation options, including but not limited to geotechnical analysis, and topographic and bathymetric survey.

Table 19. Bank stabilisation tools

Bank stabilisation tools	Example	Process
Native vegetation establishment		**Root reinforcement** – The root networks of trees and shrubs provide root reinforcement to the bank substrate and provide tensile strength which reduces gravitational mass failure of the bank substrate. **Scour protection** – The foliage of grasses and groundcovers armour the underlying sediments and protect them from fluvial and wave action. **Hydraulic roughness** – The foliage of trees, shrubs and groundcovers provide frictional resistance which dissipates flow energy and reduces the near bank velocity and shear stress.
Reduce fluvial energy		**Hydraulic roughness –** Structural works provide frictional resistance which dissipates flow energy and reduces the near bank velocity and shear stress. Timber structures have a reduced design life and may not be appropriate for providing long term protection to high value-built assets.
Reduce wave action		**Scour protection** – Structural works dissipate the wave energy and protect the bank from wave action.

Armour bank		**Scour protection** – Structural bank protection (i.e. rock) armour the underlying sediments and protect them from fluvial and wave action. **Geotechnical stability -** Structural bank toe protection (i.e. rock) can increase the geotechnical slope stability.
Reprofile bank		**Geotechnical stability –** Reducing the bank slope can increase the geotechnical slope stability. **Vegetation establishment** - Reducing the bank slope can provide more favourable conditions for vegetation establishment.
Beach nourishment		**Geotechnical stability -** Reduction in bank slope can increase the geotechnical slope stability. **Wave protection -** Beach nourishment mimics the natural beach recovery processes but increases the recovery rate compared with natural processes. Adding sediment into system can provide a buffer to long term recession. In combination with revegetation can be used for dune building.

Fish habitat features

A range of fish habitat features have been considered within the study area. Each of these features and their applicability to both the broader study area and priority sites is discussed below. Many of these fish habitat features will also help to reduce bank erosion though a range of processes including increased bank strength, providing hydraulic roughness, and armouring and/or dissipating wave and fluvial action.

Riparian vegetation

Overview

Riparian vegetation is vegetation above the high tide level. Within the Hawkesbury River estuary native riparian vegetation would consist of groundcovers, shrubs and small trees and larger trees (Figure 21). The vegetation provides a range of benefits including channel stability, ecological corridors and terrestrial habitat.

Figure 21. *Example of a self-sustaining riparian vegetation community on the Hawkesbury River*

Fish habitat values

Healthy riparian vegetation can provide a range of fish habitat outcomes including shading and cooling, food sources including insect and debris, and supply of large wood to the river system.

Considerations

Requires a gentle slope for safe planting and maintenance works. Typically requires a minimum width of 10 m to create a self-sustaining riparian community. The opportunity for riparian vegetation establishment within the priority sites is often limited due to proximity of infrastructure such as roads, public access and buildings.

Estuarine vegetation (i.e. mangroves)

Overview

Mangroves are marine plants which grow in the upper tidal range (Figure 22). There are two main types of mangroves found in the study area including Grey and River mangrove species (*Avicennia marina, Aegiceras corniculatum*).

Figure 22. *Example of mature mangrove community along intertidal bench on the Hawkesbury River*

Fish habitat values

Mangroves provide a range of instream benefits for fish including shading and cooling and food sources including insect and debris. The roots and trunks provide complex physical habitat. The wood surface can provide surface for algae. Mangroves also provide water quality benefits by interception runoff and stabilizing bed and bank sediments.

Considerations

The high boat usage and public access is currently limited mangrove re-establishment due to wave action which is eroding sediments. Mangroves typically have a very narrow tidal range where establishment can occur. Where there are steep bank slopes with limited tidal bench there is limited opportunities for mangrove establishment. Some of the priority sites with appropriate intertidal beach area are currently utilised by the public as recreation areas - consideration would need to be given to reducing this usable area to establish mangroves.

Concrete habitat reefs

Overview

Habitat reefs can be created from standalone fibre reinforced concrete modules (Figure 23). The modules can be arranged to suit site characteristics. Concrete habitat reefs provide hardened, roughened surfaces to facilitate settlement of marine organisms. They also provide physical habitat.

Figure 23. *A concrete pyramid habitat reef unit (photo Catchment Solutions)*

Fish habitat values

The groves and pits improve settlement of sessile marine organisms (e.g. oysters, sponges). Increased consolidated surface area provides substrate for algal growth which is a food source for herbivorous fish. Overhangs and ledges provide ambush spots for predatory fish. Small caves provide refuge for prey and small and juvenile fish. Caves, overhangs and ledges also provide low light areas for nocturnal species. The structures can also break currents to provide resting areas (i.e. eddies) for fish.

Considerations

Within unconsolidated alluvial sediments the foundation design needs to consider subsidence. The reefs should be placed in the subtidal area to maximise fish utilisation. However, this may create hazards for boats. Appropriate markers should be installed to manage safety risk. The design should cater for various life stages and trophic levels (e.g. internal compartments which separate large predators from small juveniles).

Bench construction and protection

Overview

Intertidal benches provide areas within the river with differing depth and velocity environments which can provide favourable surfaces for marine plant establishment. Benches may already be existing or can be constructed through either cut or fill earthworks.

Figure 24. *Example of timber fillet bench protection in the Coomera River (photo: City of Gold Coast)*

Fish habitat values

Intertidal areas are critical habitat for estuarine plants, instream fauna (fish, crabs etc.) and microorganisms. They are dynamic environments with a diversity of physical and hydraulic habitat which is distinctly different to the sub-tidal area. Wider intertidal benches allow the establishment of estuarine plants (i.e. mangroves) and refuge for prey species and juveniles. Healthy intertidal zones within estuaries is critical for overall ecosystem health.

Considerations

Within the study area intertidal benches are common and in some cases recent bank erosion has recreated intertidal surfaces. However, rehabilitation of these intertidal areas is restricted by boat wash and public access that mobilises sediments and plant seeds prior to establishment.

Figure 25. *Example of rock fillet bench protection in the Kalang River*

Estuarine plants generally establish within a very narrow band of the tidal range (typically in the upper quarter of the tidal range). Expanding this zone through bench construction can increase the likelihood of successful vegetation establishment. This could occur through earthworks which cut into the bank or alternatively filling with sand behind an appropriate retaining structure.

Within the study area structural works are likely required to dissipate wave action and provide more favourable conditions for vegetation establishment on the bench. A range of options are available to dissipate wave energy including:

- Timber fillets/walls (Figure 24)
- Rock fillets/walls (Figure 25)
- Geotextile bag fillets/walls
- Floating boom arrangements (Figure 26)

Figure 26. *A floating boom arrangement within the Maribyrnong River*

Instream timber

Overview

Prior to European settlement the study area is likely to have a very high loading of instream timber due to the dense coverage of trees, shrubs and groundcovers along the riverbanks. Instream timber can create eddy zones, scour holes and depositional areas which creates additional bed habitat diversity.

Fish habitat values

Instream timber provides a diversity of complex structural habitat for various life stages and trophic levels. Complex arrangements (e.g. jams/modules) provide good refuge for prey species and juveniles. Open arrangements or larger voids in complex arrangements provide ambush spots for predatory fish. The consolidated surface area of the wood provides substrate for algal growth which is a food source for herbivorous fish.

Figure 27. *Instream timber toe protection*

Considerations

Instream timber structures can be implemented in a range of forms including toe protection (Figure 27), groynes, wood fillets for wave dissipation and modular units within the channel (Figure 28). Larger logs have longer services life however smaller wood structures (twigs and branches) provide greater complexity. Root balls generally provide the best compromise from a single piece of wood. Wood is likely to decay due to marine borer attack over time. Instream wood should be placed partially within the subtidal area to maximise fish utilisation.

Figure 28. *Modular complex timber structures (photo Catchment Solutions)*

A summary of the fish habitat features and their applicability to the priority areas and the study area more broadly are provided below in Table 20.

Table 20. Fish habitat features

Fish habitat element	Fish habitat value	Applicability to priority areas	Applicability to broader study area
Terrestrial vegetation 	**Very high** - provide bank stability, shade and cooling of intertidal areas and ongoing supply of instream wood.	**Moderate** – There is often limited area available for vegetation establishment due to proximity of infrastructure such as roads/paths, and or private property.	**Moderate/high** –The establishment of self-sustaining riparian vegetation communities can occur where appropriate buffer areas are available.
Marine vegetation (i.e. mangroves) 	**Very high** – provides bank stability, shade and cooling of intertidal areas and physical habitat.	**Low/moderate** – Public access and beach usage, as well as wave action may limit mangrove establishment at many of the priority sites. However, if reducing open beach sections was feasible there are sites where mangroves could establish.	**Moderate/high** – Suitable where there is intertidal areas at the appropriate level however may require wave dissipation works to allow for establishment.
Concrete habitat reefs 	**High** – Provide complex structure and food sources.	**High** – The units can be set out from the proposed works or incorporated into the lower area of bank stabilisation works within the sub-tidal area, however run the risk of being buried with sediment.	**High** – The units can be used within bank stabilisation and wave dissipation structures.

Fish habitat element	Fish habitat value	Applicability to priority areas	Applicability to broader study area
Bench construction and protection - Fillets (rock, timber or geobag) 	**Very high** - provide areas within the river with differing depth and velocity environments which can provide favourable surfaces for marine plant establishment.	**Moderate –** fillets can protect existing benches at some sites.	**High –** Required to protect existing and constructed intertidal bench areas from wave action.
Bench construction and protection – floating boom 	**Very high** - provide areas within the river with differing depth and velocity environments which can provide favourable surfaces for marine plant establishment.	**Low –** Booms can be used to protect existing benches in one location.	**High –** Required to protect existing and constructed intertidal bench areas from wave action.
Instream timber 	**Very high -** Provide complex structure and food sources.	**High –** Large wood can be incorporated into toe and bench protection within the intertidal and subtidal area.	**High** – Large wood can be incorporated into rock toe protection within the subtidal area. Can also be used for wave dissipation and modular units within the channel.

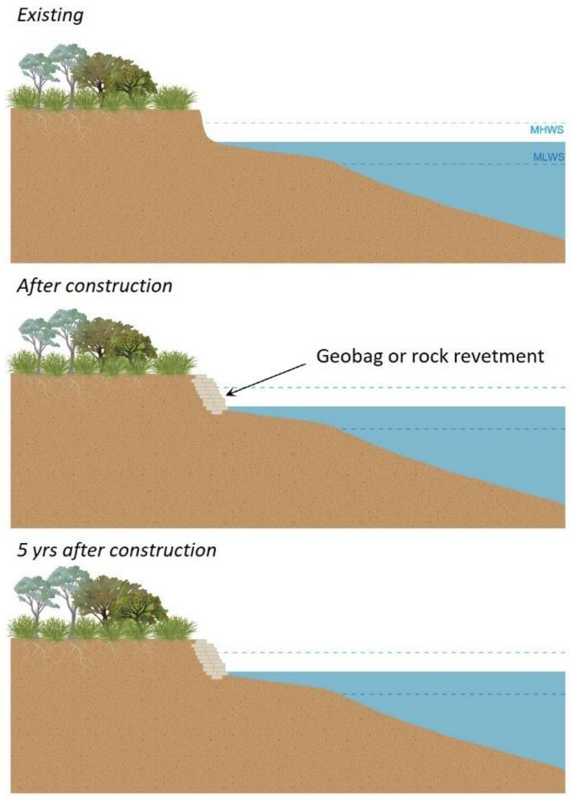
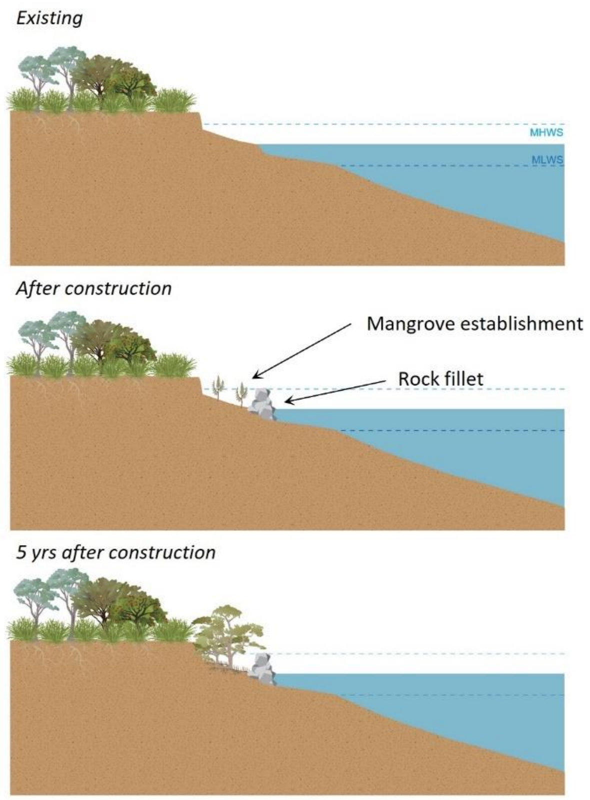
6.3 Bank management options

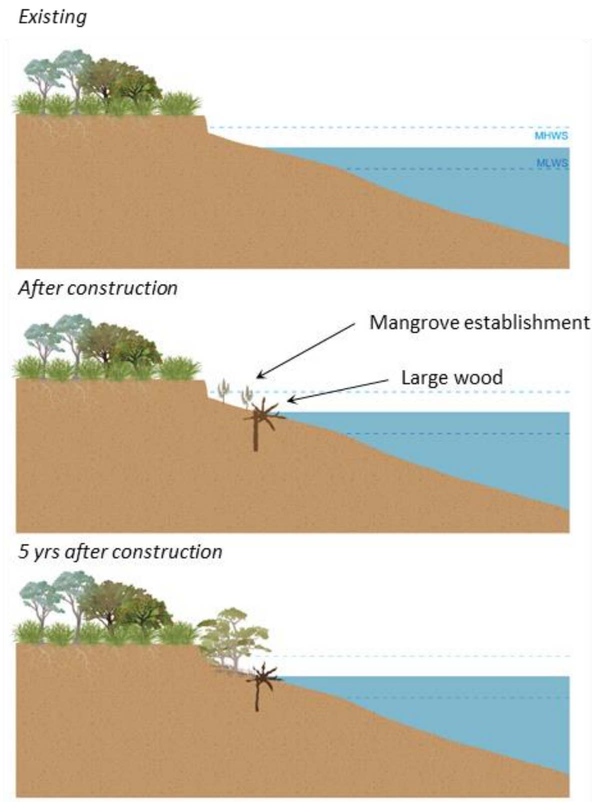
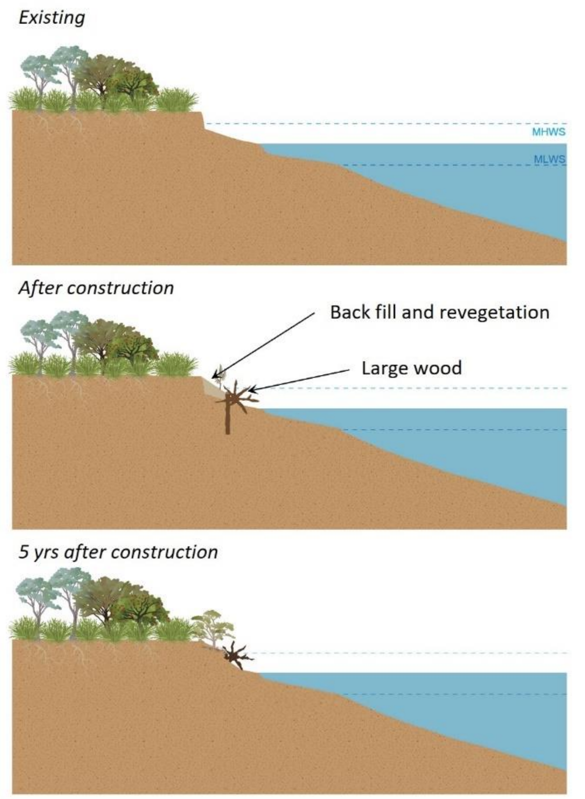
Several bank management options for each of the site groupings have been developed based on the applicability of the available stabilisation options and fish habitat considerations outlined above. In addition to this the priority site data was processed through the *NSW DPI: Fisheries Decision Support Tool (DST) for Bank Erosion Management in NSW Estuaries.* This provided a first pass assessment of the potential types of options available. While this tool provides a range of recommendations based on the input data, suggested options were further evaluated based site visits and professional opinion to determine applicability/appropriateness for inclusion in the options assessment.

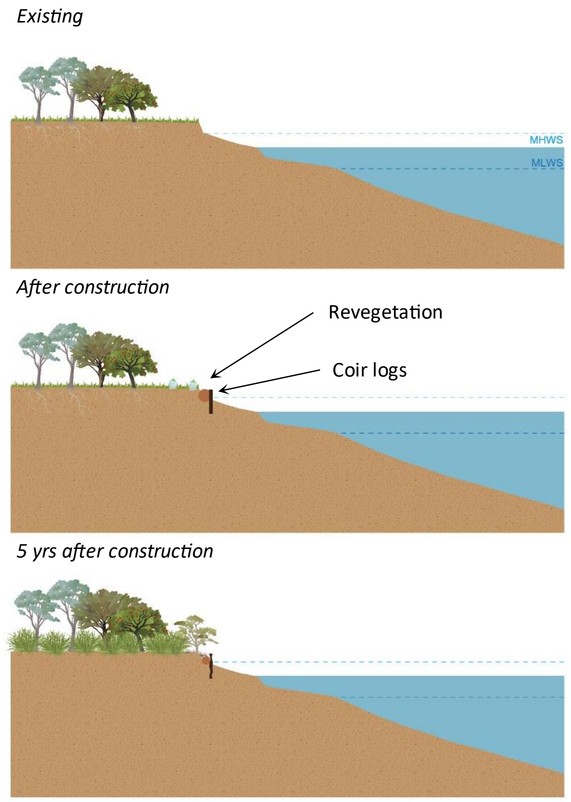
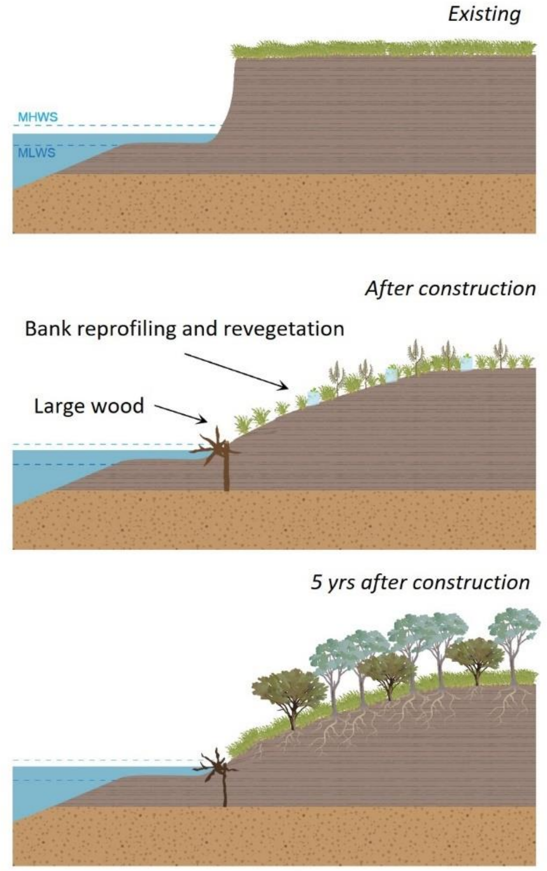
A summary of the bank management options considered across the priority sites, along with the advantages/disadvantages and relative costs is provided in Table 21. A summary table of the proposed options for each site grouping is provided in Table 22.

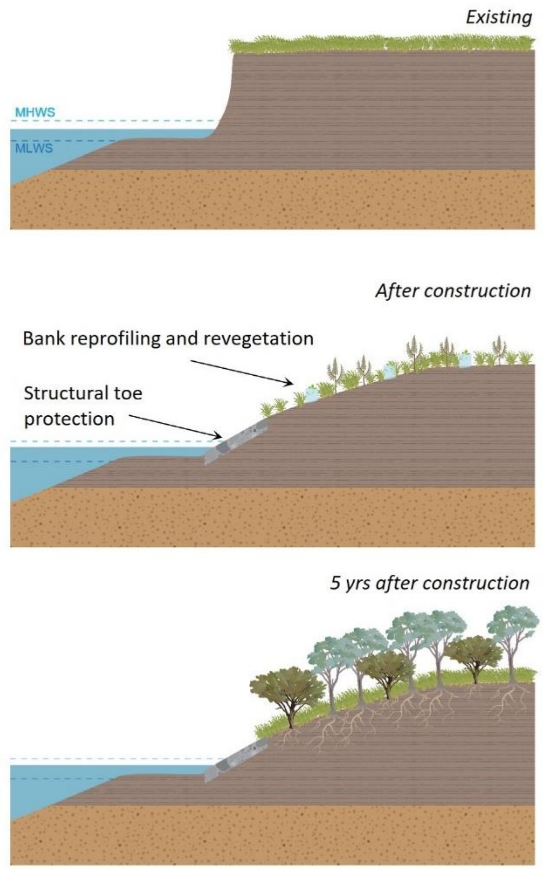
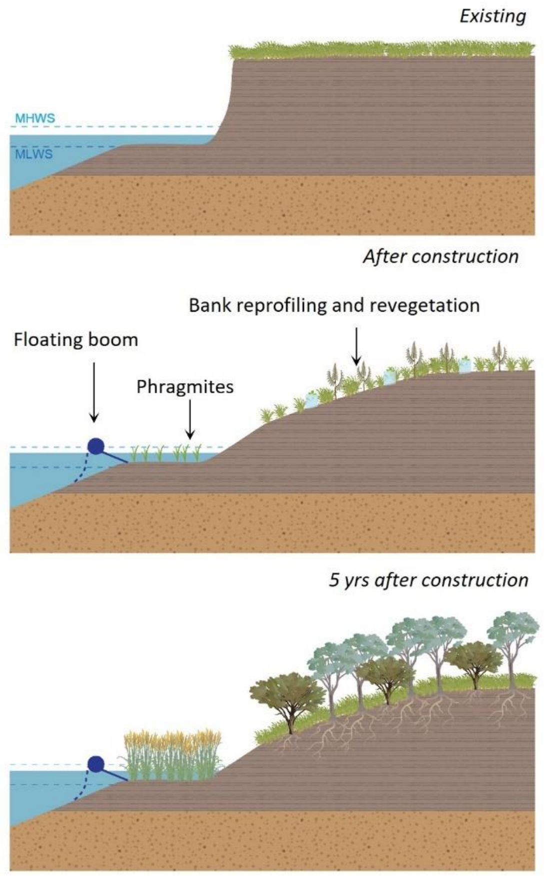
It should be noted that the options development has been based on site assessments that were undertaken prior to multiple significant flood events that impacted the study area in between March and September 2022. The flood events may have resulted in changes to the bank/riparian condition that will not be reflected in the results of the site assessments and ultimately the options development process.

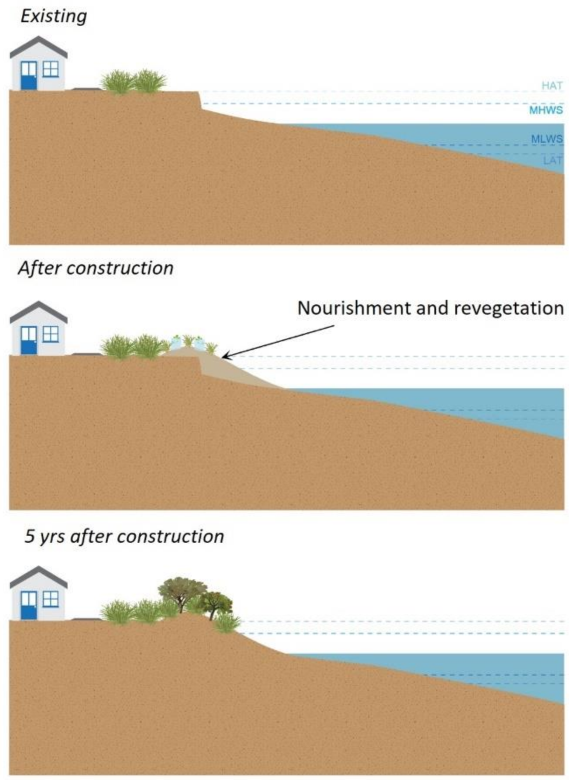
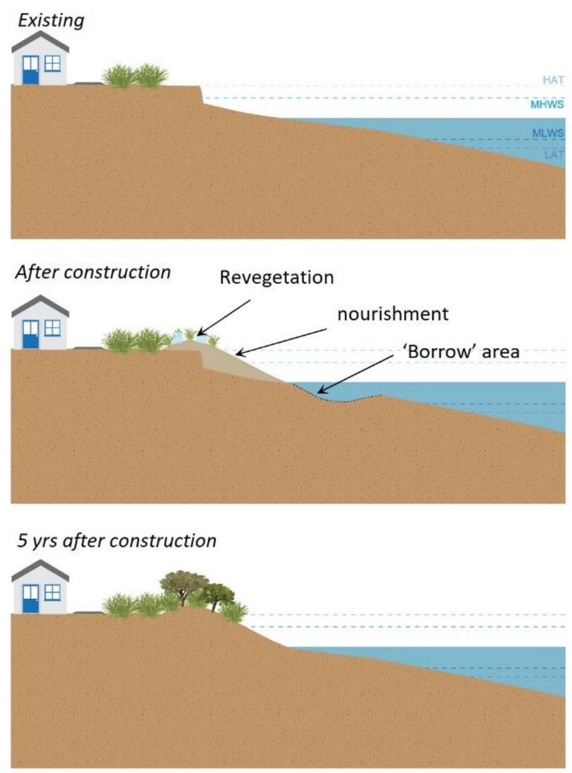
Table 21. A summary of the bank management options considered across the priority sites

Option	Examples	Process	Strengths	Weaknesses	Relative cost	Example profile showing present day conditions, conditions after construction and conditions 5 years after construction
Armour bank with: • Logs • Piled rock or rock rubble • Geotextile sandbags	 	**Wave and scour protection** – Structural bank protection (i.e., rock) armour the underlying sediments and protect them from fluvial and wave action. **Geotechnical stability** - Structural bank toe protection (i.e., rock) can increase the geotechnical slope stability.	• Can incorporate materials that enhance aquatic habitat (i.e. large wood, concrete reef habitats, lunkers) • Suitable for high energy environments • Provides immediate stabilisation solution • Provides long-term stabilisation solution • Relatively low maintenance • Vegetation can be established in overbank zone	• Require the import of large quantities of material • Requires access by machinery • Modifies the aquatic/riparian ecosystem • Can result in erosion outside of armored area i.e. endwall effects • Can result in beach loss • Reduced aesthetic values • Potential public safety issues • Reduction in potential emergent vegetation	High	
Bench and lower bank protection to reduce wave action with rock fillets		**Wave and scour protection** - Structural works dissipate the wave energy and protect the bank from wave action.	• Can provide additional estuarine habitat • Provide some immediate protection from wind/wave erosion • Does not impact riparian ecology • Provides protection to allow establishment of vegetation on intertidal bench which can then provide long term bank stabilisation	• Require the import of material • Requires access by machinery • Can only be used where bench or suitable bed grade present • Impacts access to shoreline from water	Moderate-high	

Large wood installation – bench protection		**Hydraulic roughness –** Structural works provide frictional resistance which dissipates flow energy and reduces the near bank velocity and shear stress. Timber structures have a reduced design life and may not be appropriate for providing long-term protection to high-value built assets. **Wave and scour protection** - Structural works dissipate the wave energy and protect the bank from wave action.	• Can provide additional estuarine habitat • Provide food source for invertebrates • Provides some immediate protection from wave impacts • Provides structural protection with a more natural appearance than other solutions such as rock • Do not impact riparian ecology • Provides protection to allow establishment of vegetation on intertidal bench which can then provide long term bank stabilisation	• Requires access by machinery • Can only be used where bench or suitable bed grade present • Impacts access to shoreline from water • Can impede navigation	Moderate-high	
Large wood installation -toe protection and backfill material		**Hydraulic roughness –** Structural works provide frictional resistance which dissipates flow energy and reduces the near bank velocity and shear stress. Timber structures have a reduced design life and may not be appropriate for providing long-term protection to high-value built assets. **Wave and scour protection** - Structural works dissipate the wave energy and protect the bank from wave action.	• Can provide additional estuarine habitat • Does not impact riparian ecology • Vegetation can be established on bank • Provides protection to allow establishment of vegetation on bank which can then provide long term bank stabilization • Can be used to stabilise infill material to allow for reprofiling of upper bank to a more gentle grade	• May require the import of material • Requires access by machinery	Moderate-high	

Coir log protection		**Wave and scour protection** – Structural bank protection (i.e., rock) armour the underlying sediments and protect them from fluvial and wave action.	• Provide immediate temporary stabilisation while vegetation establishes • Install does not require machinery • Can be replaced as necessary • Provides a natural aesthetic	• Provides limited long term stability on its own • Stability of logs could be compromised in high traffic areas such as boat landing zones and lifespan may be reduced • Limited to low bank heights and relatively low rates of erosion	Low	
Bank reprofiling and large wood installation		**Hydraulic roughness –** Structural works provide frictional resistance which dissipates flow energy and reduces the near bank velocity and shear stress. Timber structures have a reduced design life and may not be appropriate for providing long-term protection to high-value built assets. **Wave and scour protection** - Structural works dissipate the wave energy and protect the bank from wave action. **Geotechnical stability** - Structural bank toe protection (i.e. timber) and reduction in bank slope can increase the geotechnical slope stability.	• Provides structural protection with a more natural appearance than other solutions such as rock • Bank reprofiling improves geotechnical stability • Reprofiling creates more suitable grade for vegetation establishment and maintenance • Provides safer bank grade for access • Enhances riparian habitat and connectivity	• Requires export of material offsite • Requires import of material onsite	Moderate-high	

Bank reprofiling and structural toe protection (geobag or rock)		**Hydraulic roughness –** Structural works provide frictional resistance which dissipates flow energy and reduces the near bank velocity and shear stress. Timber structures have a reduced design life and may not be appropriate for providing long-term protection to high-value built assets. **Wave and scour protection** - Structural works dissipate the wave energy and protect the bank from wave action. **Geotechnical stability** - Structural bank toe protection (i.e. rock) and reduction in bank slope can increase the geotechnical slope stability.	• Can be incorporate materials that enhance aquatic habitat (i.e. large wood, concrete reef habitats) • Reprofiling creates more suitable grade for vegetation establishment and maintenance • Suitable for high energy environments • Provides immediate stabilisation solution • Provides long-term stabilization solution • Relatively low maintenance • Vegetation can be established in upper bank and overbank zone	• Require the import of large quantities of material • Requires access by machinery • Modifies the aquatic/riparian ecosystem • Can result in erosion outside of armored area i.e endwall effects • Can result in beach loss • Reduced aesthetic values • Potential public safety issues • Reduction in potential emergent vegetation on lower bank	High	
Bench protection - Floating boom	  	**Wave and scour protection** – A floating boom can dissipate the wave energy and protect the bench and lower bank from wave action. **Geotechnical stability** - Reduction in bank slope can increase the geotechnical slope stability.	• Can accommodate changing water levels • The boom and skirt will help to mitigate impact on the bank from waves from boat wake • Once established the bank vegetation is a permanent solution that is a good aesthetic outcome • The floating booms can be removed once vegetation is successfully established. They may then be deployed elsewhere. • The floating booms can be launched from the bank and maneuvered into position with a vessel on the River	• Requires access by machinery • Impacts access to shoreline from water • May impede navigation	Moderate-high	

Beach nourishment		**Geotechnical stability** - Reduction in bank slope can increase the geotechnical slope stability. **Wave protection** - Beach nourishment mimics the natural beach recovery processes, but increases the recovery rate compared with natural processes. In combination with revegetation can be used for dune building.	• Mimics the natural beach recovery process • Improves amenity • Importing more sand into system can provide buffer to ongoing recession and provide good level of protection • In combination with revegetation can be used for dune building • Can be used in conjunction with structural protection to reduce/buffer the impact of beach loss due to refraction	• Requires access by machinery • Require the import of large quantities of material • Ongoing nourishment likely to account for long term recession	Moderate-high	
Beach scraping		**Geotechnical stability** - Reduction in bank slope can increase the geotechnical slope stability. **Wave protection** - Beach scraping mimics the natural beach recovery processes, but increases the recovery rate compared with natural processes. In combination with revegetation can be used for dune building.	• Mimics the natural beach recovery process • In combination with revegetation can be used for dune building • Can be used in conjunction with structural protection • Can be used as short-term solution until a longer term can be implemented	• Sand borrow area limited to intertidal zone (may limit the available sand volume) • Can only scrape outside of protected areas such as seagrass zones (may limit the available sand volume) • Requires access by machinery • May require multiple scraping episodes • Ongoing scraping likely to account for long term recession rates • Not importing any material so can result in net loss to system if area under long term recession regime • If not done properly can result in increased erosion through changes in beach slopes etc. – requires monitoring • Unlikely to be permanent solution	Low	

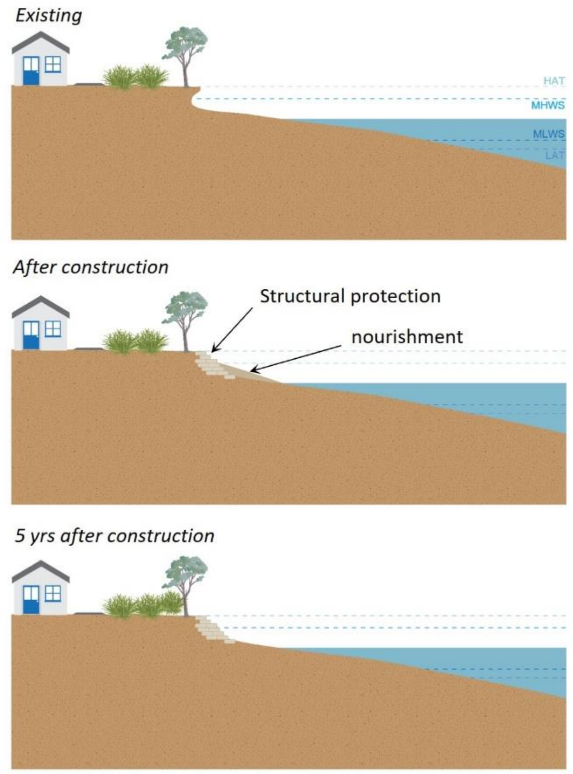
Structural protection and beach nourishment		**Wave and scour protection** – Structural works can dissipate the wave energy and protect the dune and lower bank from wave action. **Geotechnical stability** - Reduction in bank slope can increase the geotechnical slope stability.	• Helps buffer short-medium term beach losses through refraction off structure • Provides immediate protection • Importing more sand into system helps provide buffer	• Ongoing nourishment likely required to prevent beach loss due to refraction and long-term recession • Requires access by machinery • Require the import of large quantities of material • Reduced aesthetic values • Potential public safety issues	High	

Table 22. A summary table of the proposed options for each priority site grouping

Site group	Sites	Option 1	Option 2	Option 3	Option 4	Option 5
1. Estuarine inlets - Natural	CCC13g – 'Patonga Creek'	The Patonga Creek system is a dynamic system with a range of processes influencing channel dynamics and behavior. Developing a detailed understanding of these processes is required before being able to inform appropriate bank stabilisation options. It is recommended that a sediment dynamics and hydrogeomorphic study be undertaken across the creek to build the necessary understanding before implementing any management intervention works. If the site is not found to be contributing significant amounts of sediment to the system and the erosion rate is likely to be plateauing, then it may be appropriate to limit any management intervention.				
2. Estuarine inlets – Artificial	NBC9 – 'Cicada Glen Creek' *(example photo)* NBC10b – 'McCarrs Creek'	Armour banks – Install logs, geobags or rock in front of near vertical escarpment, maintain existing beach. Formalise access. *Concrete reef habitats can be incorporated*	Bench protection with rock fillets infill to height for mangrove establishment if required (incorporate a BESE-Elements grid (biodegradable 3-D grid structure) to encourage deposition of sediments and seeds and provide some protection to saplings). *Concrete reef habitats can be incorporated*	Large wood installation -toe protection and backfill material. Large log (or geobag) installations just above high tide level and then back fill to gentle slope install coir matting and revegetate. Formalise access. *Concrete reef habitats can be incorporated*	Coir logs and revegetation of overbank. Formalise access *Concrete reef habitats can be incorporated*	Do nothing/monitor
3. Lower estuary/marine sandy beaches and shoals	NBC3- 'Sand Point beach' NBC4a – 'Great Mackerel Beach' *(example photo)* HOR21- 'Dangar Beach'	Structural protection (geobag or rock) and beach nourishment/scraping. **Recommendation for Sand Point Beach (WRL,2019; Horton, 2017))*	Beach scraping	Beach nourishment	Beach scraping and nourishment (dune building) – required at Great Mackrel Beach where scraping volumes are insufficient **Recommendation for Great Mackerel Beach (WRL,2020)*	Coir logs and revegetation
4. Lower estuary/marine sandy beaches and shoals -Existing protection	HOR23- 'Parsley Bay breakwall'	Infill upper section of breakwall with appropriate rock				
5. Mid/upper estuary - High banks, limited setback	HCC24 – 'The Terrace, Windsor' HCC25b- 'Argyle Bailey Reserve' *(example photo)* HCC26- 'Çhurchills Wharf' HSC34	There is currently insufficient information to inform a bank stabilisation option development. More detailed data including ground survey, bathymetry, hydraulic parameters and geotechnical investigations will be required to properly inform the development and assessment of management options and then develop an appropriate design. This information will enable the assesses of what types of works are actually feasible at each site and the relative likelihoods of success, costs etc. Given the height and steepness of the banks, limited or no set back available at the top of bank, and lack of intertidal bench the management options will likely largely be limited to a 'hard' engineering approach utilizing rock fill and retaining walls or similar. More detailed investigations are required to develop and assess appropriate management options.				
6. Upper estuary - Low-moderate banks, setback available	HCC27 a– 'Holmes Drive Reserve' HCC27b- 'Holmes Drive Reserve' *(example photo)*	Bank reprofiling, large wood installation and revegetation. *Concrete reef habitats can be incorporated*	Bank reprofiling, structural toe protection (rock or geobag) and revegetation. *Concrete reef habitats can be incorporated*	Bank reprofiling and revegetation with bench/toe protection from floating boom		

7.	Mid/upper estuary - Existing protection	CCC16d- 'Gunderman S' HSC38a HSC41 HSC42	These sites contain a variable types, extents and conditions of existing protection. For example, there are sections of newly constructed rock or gabion basket protection that will require no additional work, Sections of old rock revetment in variable condition that may require structural assessment and redesigns or infill/top up of existing material. There is insufficient information to develop and assess discrete options that account for the variability in conditions across the sites. It is recommended more detailed investigations are undertaken including geotechnical design/condition assessment, and survey including bathymetry to develop and assess appropriate management options at each site. However, given the proximity to road infrastructure options are likely going to be limited to hard engineering approaches such as rock revetment.				
8.	Mid estuary - Low-moderate banks, setback available, mangroves nearby	HSC45b	Armour banks – Install logs, geobags or rock in front of near vertical escarpment, maintain existing beach. Formalize access. *Concrete reef habitats can be incorporated*	Bench protection with rock fillets infill to height for mangrove establishment if required (incorporate a BESE-Elements grid (biodegradable 3-D grid structure) to encourage deposition of sediments and seeds and provide some protection to saplings). *Concrete reef habitats can be incorporated*	Large wood installation -toe protection and backfill material. Large log (or geobag) installations just above high tide level and then back fill to gentle slope install coir matting and revegetate. Formailise access. *Concrete reef habitats can be incorporated*	Coir logs and revegetation of overbank. Formalise access. *Concrete reef habitats can be incorporated*	Do nothing/monitor (natural replenishment) **Note imagery analysis suggests there may have been significant natural replenishment observed since the 2022 flood events. The site sits on inside bend and would typically be an area of deposition rather than erosion. An ongoing monitoring and a 'do nothing' approach could also be warranted.*

Very low to low risk sites

A list of options was not proposed for sites that are classified as very low or low priority. These sites were included in the detailed risk assessment because there was visual evidence of erosion. However, due to low consequence, low likelihood of ongoing erosion, or a combination of those two factors, at this stage they do not require proactive bank management.

For these sites, the most appropriate action is to implement a fit-for-purpose monitoring program. The monitoring program could utilise available aerial imagery to periodically update the multi-temporal analysis to detect any acceleration of erosion rates. For 'Low' risk sites that are classified as a low risk of ongoing erosion but there is a medium or high consequence of erosion, more frequent field monitoring is recommended as conditions that impact erosion can change, which could increase the risk as the site. A site such as this may require ongoing monitoring at a higher frequency than a site that has a 'Very low' risk, where the likelihood and consequence of erosion are both low.

6.4 Options assessment

There is a range of management options that can be considered to help manage and enhance estuarine and foreshore areas for each site, in line with the desired outcomes. A multi-criteria analysis (MCA) approach has been adopted to assess all the potential management options across the priority sites. The MCA evaluates the management options by assessing each option against a defined set of decision criteria that represent the range of values and interests at each site. The degree to which the option achieves the above criteria is scored out of 5 according to Table 23, and each criterion is weighted based on priorities for individual sites. An MCA for each individual site has been undertaken to help determine the preferred option. As each site may have different priorities for management, a weightings approach has been developed and is discussed further below.

Table 23. MCA assessment criteria scoring

Criteria	1	2	3	4	5
Accessibility					
Ability to increase usage and access the foreshore or surrounding areas	Significant reduction of usage and access to foreshore.	May restrict foreshore usage and access – more difficult to walk along foreshore.	No change to foreshore usage and access.	Moderate increase in usage and access to foreshore.	Increase usage and access to foreshore. Fully DDA compliant.
Adaptability					
Longevity of the solution, in relation to potential future sea level rise.	No ability to be adapted for future needs.	Very difficult to be adapted for future needs.	Limited adaptability to future needs.	Can be adaptable to future needs, with some challenges.	Readily adaptable to future needs.
Protection					
Short-term stability	Limited to no increase in short-term stability	Minimal increase in short-term stability	Moderate increase in short-term stability	Significant increase in short-term stability	Effective in providing short-term stability
Long-term stability	Limited to no increase in long-term stability	Minimal increase in long-term stability	Moderate increase in long-term stability	Significant increase in long-term stability	Effective in providing long-term stability
Environmental					
Impact on riparian condition and values	Significant adverse impact on natural processes and riparian condition and values	Notable adverse impact on natural processes riparian condition and values.	No adverse impact on natural processes and riparian condition and values	Minimal adverse impact on natural processes, enhance riparian condition and values	No impact on natural processes, enhance riparian condition and values
Impact on instream condition and values	Significant adverse impact on natural processes and instream condition and values	Notable adverse impact on natural processes instream condition and values.	No adverse impact on natural processes and instream condition and values	Minimal adverse impact on natural processes, enhance instream condition and values	No impact on natural processes, enhance instream condition and values
Safety *Risks to public safety*	Potentially intolerable risks (high to extreme risks).	Moderate, but tolerable risks (injury/first aid).	No impact on safety.	Moderate positive impact on safety.	Significant positive impact on safety.
Value (cost)					
Relative cost, including capital costs and ongoing maintenance requirements.	High	Moderate - high	Moderate	Moderate - low	Low
Visual amenity					
Impacts on visual and recreational amenity	Significant reduction to visual amenity and recreational use of the foreshore .	Moderate reduction to visual amenity and recreational use of the foreshore.	No impact on visual amenity and recreational use of the foreshore.	Moderate improvement to visual amenity and use of the foreshore.	Significantly improve to visual amenity and use of the foreshore.

Weightings

A pairwise matrix approach has been used to determine weightings for each of the criteria (Table 24). The pairwise approach involves comparing and prioritising each of the selected criteria against each other sequentially. The pairwise ranking provides decision-makers with oversight into the relative degree of importance of each criterion with respect to each other within the scope of decision context. As each of the priority sites have different uses, values etc. the scoring can be adapted for each individual site before applying to the MCA, to help determine recommended management options. Representatives from Partner Councils were provided the opportunity to complete the pairwise comparison matrix for each of the priority sites within their LGA. The key steps involve:

1. Enter criteria on the vertical and horizontal axis
2. Compare criteria on the horizontal axis (HA) against criteria on the vertical axis (VA) as per:

   0 = Number is less important than letter

   1 = Number is equally as important as letter

   2 = Number is more important than letter
3. Calculate weightings and rank criteria.

Table 24. Example pairwise matrix weightings

Criteria		Accessibility	Adaptability	Protection - short term	Protection - long term	Environmental - riparian	Environmental - instream	Safety	Value (cost)	Visual and recreational amenity	Total	Weighting (%)	Rank
		a	b	d	e	f	g	h	i	j			
Accessibility	1	1	2	0	0	2	2	0	1	1	9	10.8%	6
Adaptability	2	0	1	0	0	0	0	0	0	0	1	1.2%	9
Protection - short term	3	2	2	1	1	1	1	1	2	2	13	15.7%	2
Protection - long term	4	2	2	2	1	1	1	1	2	2	14	16.9%	1
Environmental - riparian	5	1	2	1	1	1	1	1	2	1	11	13.3%	4
Environmental - instream	6	1	2	1	1	1	1	1	2	1	11	13.3%	4
Safety	7	1	2	1	1	1	1	1	2	2	12	14.5%	3
Value (Cost)	8	1	2	0	0	0	0	0	1	1	5	6.0%	8
Visual and recreational amenity	9	1	2	0	0	1	1	0	1	1	7	8.4%	7

6.5 Recommended options

These site specific weightings, as determined by Partner Council representatives, were applied to the MCA to determine a recommended management option at each site. While a single option for each site has been highlighted via this method, this does not prevent additional consideration from decision makers in determining which option is actually included in the CMP for implementation. Additional considerations may include the economic viability, costs and benefits analysis, and the acceptability of the options which must be assessed with community and stakeholder input in Stage 3 of CMP development.

Full weighting and MCA results are provided in Attachment D. Recommended options for each site have been described including details on the indicative extent of works, proposed works overview and specifications, and high level cost estimates. Summaries for the recommended option are provided in Attachment E.

7 Conclusion, next steps, and additional considerations

As a part of this study over 30 km of stream bank and foreshore have been assessed in order to characterise and map foreshore erosion of known priority erosion areas. The results are used to inform a consistent and reproducible method for assessing risk, prioritising and comparing feasible stabilisation options for identified sites located throughout the Hawkesbury Nepean River Estuary system. Additionally, a first pass bank erosion assessment was undertaken in Mangrove Creek.

The study sites sit across a range of geomorphic settings, have varied degrees of erosion severity and likely causes of the erosion. For the upper estuary sites the common erosional mechanism of failure was bank slumping and mass failure. This was likely driven by a combination of bank saturation and slumping following flood water recession and scour of the toe of bank driven by river/tidal flows and vessel waves. The erosional mechanism at the lower estuary inlet site appeared to be scour and undercutting of the toe of bank (caused by river/tidal flow and vessel waves) followed by mass failure of relatively non-cohesive materials. Erosion at the sandy beach sites in the lower estuary is likely driven by open water wave action caused by refracted ocean swell, wind waves and vessel waves causing erosion of a poorly vegetated foredune. Additional factors contributing to erosion include public and private water and foreshore access, inappropriate or poorly maintained foreshore protection structures, and end effects caused by foreshore protection structures or other assets.

The consequences of erosion are also varied and largely depend on the riparian and intertidal condition and habitat values, and adjacent land use as well as type and proximity of assets/infrastructure. Vegetation profiles are dependent on the location of a site within the estuary system with freshwater riparian ecosystems in the upper estuary transitioning to estuarine mangroves and saltmarsh ecosystems in the middle estuary and sandy dune vegetation in the lower estuary sites. The condition of vegetation along the banks and foreshore either provides an erosion buffer if it is healthy or exacerbates erosion if it is degraded.

The results of the first pass bank erosion assessment of the Mangrove Creek catchment show that the most actively eroding river banks and those in the poorest condition are in the mid reaches of Ironbark Creek and an isolated section of the mid reaches of Popran Creek. The riparian vegetation extent through these reaches is very poor and likely impacted by grazing. The lateral stability through Mangrove Creek is largely stable in the upper and lower reaches and some isolated areas of minor or moderate instabilities in the mid reaches with the most active section immediately downstream of the Ironbark Creek confluence. The upper and lower reaches of Mangrove Creek have good riparian vegetation extent, with native bushland on the hillslopes fringing the discontinuous floodplain pockets in the upper reaches and significant stands of mangrove and saltmarsh habitat bordering the lower reaches. The mid reaches contain intermittent sections of poor, moderate and very poor vegetation extents where the adjacent land use is more agricultural or rural residential.

Sites were assessed via a desktop study which investigated the geomorphic form, riparian vegetation extent, and change over time for each site. This was supported by field investigations where data was collected on site including extensive photos and site specific data relating to bank condition, causes and trajectory of erosion, and values associated with the site. This information was collated into detailed site summaries for each location. The desktop and field assessments were used to quantify the risk level for each site which informed the site prioritisation and bank stabilisation options analysis process. Sites were grouped by considering risk, erosive drivers, and mitigation potential.

Options for bank stabilisation were proposed and assessed for each group of sites considering multiple potential benefits. A multi criteria analysis supported by site specific criteria weighting was undertaken for each site to score proposed options and generate a recommended option. For some sites, their extent and complexity precluded useful analysis using the MCA. For these sites an overview is provided of the steps needed to obtain the necessary information to develop a feasible stabilisation option. The outputs of this study were developed to allow the Partner Councils to be armed with the information needed to proceed to Stage 3 of CMP development.

7.1 Next steps

The bank stabilisation options produced as an output of this study will be further considered in the following Stage 3 of HNRS CMP development where Partner Councils will evaluate management options and identify which should be included in the CMP for implementation. The process for evaluating options in Stage 3 includes determining:

- feasibility of coastal management actions: determined by effectiveness, practicality and reliability of the measure or technology
- viability of implementation: determined by anticipated cost, availability of resources, time and commitment and anticipated benefits
- the acceptability of the risks to the Council, key stakeholders such as public authorities, and the community, including willingness to contribute to the upfront and ongoing maintenance costs.

The MCA and results from this study provide a list of feasible management actions for each site. The information to determine the viability of implementation is also provided, allowing Partner Councils to evaluate the anticipated costs in the context of their availability of resources. During the options evaluation component of Stage 3, Councils will need to consider additional factors of viability including:

- roles and responsibilities of particular stakeholders
- approval processes and legislative requirements
- time required to plan, design and implement a coastal management action
- staging and sequencing of coastal management actions
- cost of different coastal management actions, including long-term maintenance
- benefits and beneficiaries of implementing the coastal management action
- disadvantages of implementing the coastal management action and how they are distributed across stakeholders, communities, and environment
- level of uncertainty associated with the outcome.

The final step in the evaluation process is to determine which of the feasible and viable coastal management actions are recommended to be included in the CMP. This involves consulting with the community and stakeholders to determine the acceptability of the actions. Proposed coastal management actions may be assessed in terms of:

- consistency with the objectives of the CM Act and council's long-term strategic direction
- public interest and wider public benefit
- effectiveness in reducing risks and threats
- whether the action is proportional to the level of risk
- sustainability
- potential impacts and their distribution
- value for money and efficient use of resources
- timeliness
- fairness and equity
- community cohesion and resilience.

7.2 Additional considerations regarding post-study flood events

During the development of this study, and following the on-site data collection, the Hawkesbury Nepean River experienced two major floods (March 2022, July 2022) and a prolonged period of wet conditions in the catchment which dramatically impacted on local communities and considerably altered the extent, distribution, and severity of erosion along the Hawkesbury River. A hydrograph of the water levels at the WaterNSW Windsor gauge (ID 212903) for the calendar year 2022 is provided in Figure 29.

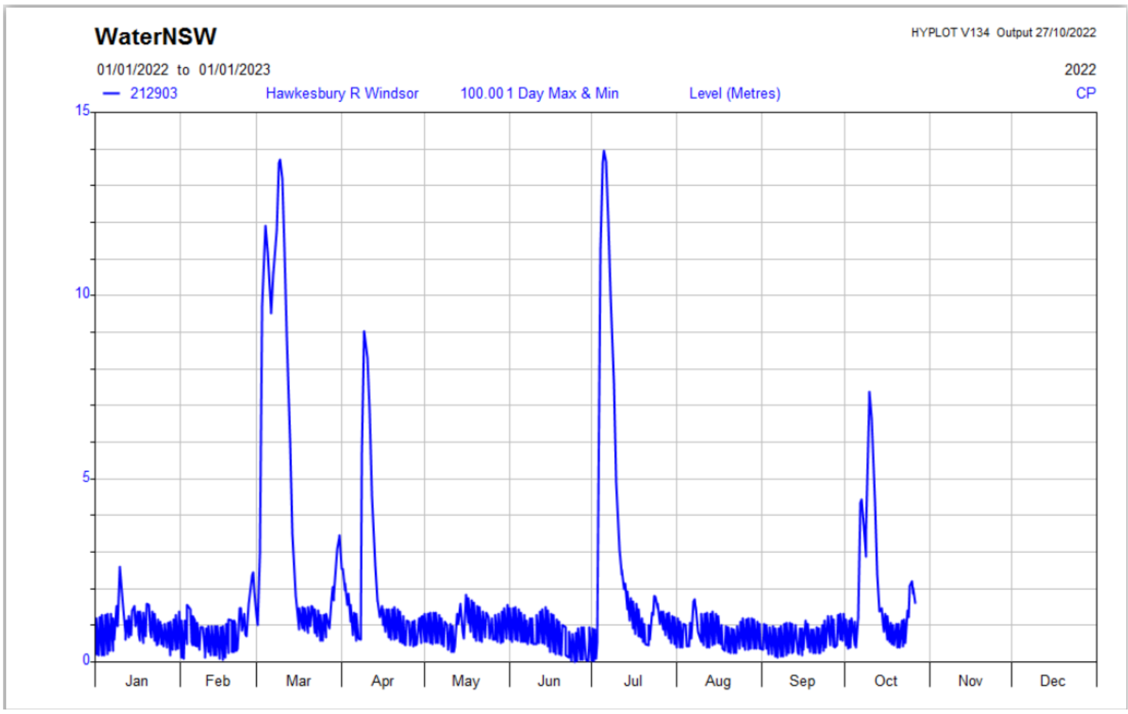


Figure 29. Hydrograph of the water levels at the WaterNSW Windsor gauge (ID 212903) for the calendar year 2022.

In response, on 8 September 2022, Alluvium undertook post-flood assessments of the identified priority sites in the Upper Hawkesbury LGAs (Hawkesbury City Council and The Hills Shire Council) totalling ten sites altogether. It was determined by the other Partner Councils that the priority sites in their LGAs did not warrant a full re-assessment due to the lessened impact of flood waters on erosion at these sites. The objective of the re-assessment was to determine the impact of the major floods on the sites and to determine if the assessments completed in this study were still appropriate. For these priority sites, the option summary in Attachment E describes the impact of the floods on the site and provides an updated assessment of recommended or required works. A flood impact summary has been developed and is provided in Attachment F. For some of these sites, an accelerated timeline of works is justified by the severity of the erosion and the immediate threat to assets and public safety, thus requiring council to seek alternative pathways for securing funding outside of the CMP framework. The information provided in the options summaries for these sites can support council's application and scoping of these works.

The re-assessment of priority sites was supplemented with an assessment of both banks of the Upper Hawkesbury River, from Windsor to Wiseman’s Ferry, identifying post-flood erosion. In total, 63 sites were identified, and georeferenced photos were taken from the boat and via drone of areas with evidence of significant active erosion. Information was gathered about the erosion severity, assets and values exposed, and their distance to the erosion scarp. Associated spatial data and a summary table of the collected data has been provided to Hawkesbury City Council and The Hills Shire Council. Such significant change in the landscape of the study area since the scoping and initiation of this study has implications for the utility of its results.

The risk assessment, prioritisation and options assessment remain valid and useful for the purpose of determining appropriate bank stabilisation actions, monitoring programs, and further studies for the 45 sites identified for this study. However, it is also recommended that erosion areas that have either been worsened or initiated by the recent floods also be assessed and prioritised.

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