Quantifying estuarine erosion using field-based and remotely sensed data in NSW estuaries

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Key points

- Integration of field-based assessments with repeat LiDAR analyses improved the interpretation of estuarine erosion processes and sediment source dynamics.
- Localised reaches of active bank erosion can contribute substantive estuarine sediment inputs despite the broader system generally exhibiting low overall erosion severity.
- Constraining DEM differencing to verified erosion areas reduced the influence of DEM noise, interpolation artefacts and false change detection.
- The integrated methodology provides a more robust framework for quantifying estuarine sediment yields and prioritising erosion management responses.

Abstract

The sediment contribution from estuarine bank erosion is often considered a comparatively minimal component of catchment sediment yields. Yet bank erosion has been a long-term issue in many of our estuaries for over a century, requiring targeted management for estuarine stability. Bank erosion destabilises estuarine habitats, alters channel morphology, degrades water quality and threatens infrastructure. Often, these threats have been assessed through discrete field inspections and community concerns, but systematic, data-driven analyses remain limited.

Recent field-based datasets of whole-of-system bank conditions, coupled with repeat lidar volumetric erosion analyses and bank retreat rates, have been developed throughout New South Wales (NSW) estuaries as part of the NSW Estuary Asset Protection (NEAP) Program. Field surveys were conducted to systematically assess the severity and spatial variability of estuarine bank erosion, dominant processes and contributing factors, as well as other key attributes of riparian vegetation and bank protection works.

Repeat lidar data has also been used to quantify sediment yields over the past decade in key estuarine systems. Together these data provide critical insights into erosion dynamics across different systems. Comparisons between field-based assessments and volumetric analyses reveal a coherent alignment, demonstrating substantial localised sediment contributions within our estuaries. Yet key discrepancies in these data highlight the complexity of estuarine hydrodynamics. The assessment also reveals critical limitations and differences in quantifying erosion in estuaries compared to freshwater environments.

By integrating these analytical approaches, a more comprehensive understanding of estuarine erosion processes can be achieved, supporting informed management and targeted intervention strategies.

Keywords

Bank erosion, estuaries, sediment yields, systematic surveys, empirical datasets, lidar, geomorphic assessment

Introduction

While the sediment contribution from estuarine bank erosion is often considered a comparatively minimal component of catchment sediment yields, recent evidence suggests estuarine bank erosion contributes large volumes of localised sediment to the estuary (Owens, 2020; Rangel-Buitrago et al., 2023). In the Richmond River, recent analyses indicate that approximately one quarter (23%) of total channel erosion within the catchment over the past decade occurred within the estuary (Brooks et al., 2026). The geomorphic setting of estuarine environments also means that banks are commonly comprised of fine-grained sediments, which can have disproportionately high impacts on estuarine water quality when mobilised.

The relatively recent development of lidar technology has provided a powerful tool for analysing geomorphic change across entire catchments. Repeat lidar has transformed the identification of sediment sources by enabling high-resolution, spatially continuous quantification of landscape and channel change through time (Okyay et al., 2019; Wheaton et al., 2010). This has allowed erosion and deposition processes to be measured volumetrically rather than inferred from discrete field observations alone.

However, the growing capability and accessibility of this remotely-sensed technology can also foster overconfidence in automated outputs and an uninformed optimism regarding their precision and applicability (Daley et al., 2024). Without appropriate geomorphic understanding, field validation and recognition of dataset limitations, such analyses can misrepresent dominant processes, misidentify sediment sources and produce misleading volumetric estimates. Datasets remain constrained by the density and distribution of the underlying point cloud data, particularly in complex estuarine environments where water surfaces, dense vegetation and steep banks can reduce ground returns and obscure terrain representation. These limitations can introduce uncertainty into DEM generation and change detection analyses, particularly along submerged or densely vegetated bank margins.

This study evaluates the integration of field-based erosion assessments and repeat lidar analyses for identifying estuarine sediment sources. It highlights that methods commonly applied in larger freshwater systems may not directly translate into complex estuarine and small-channel environments, where limitations in terrain representation and process interpretation can influence the quantification of erosion sources. It aims to provide a reliable and process-based framework for identifying priority erosion sources and improving estuarine management outcomes.

Methods

This study presents findings from River Estuary Bank and Riparian Condition Assessments undertaken by Fruition Environmental Pty Ltd between July 2024 and May 2026, developed through the NEAP program managed by NSW Department of Primary Industries and Regional Development (DPIRD) - Fisheries. The data and analyses from this assessment are to be used to inform future management actions to improve flood resilience, estuary asset protection, and estuary health including water quality, bank stability and riparian vegetation condition. A detailed methodology is described by Fruition Environmental (2025) and the dataset is available at the New South Wales Estuary Asset Protection Program – Bank and Riparian Condition Public Portal.

Field surveys

Over 2500 km of riverbank was field surveyed across 16 estuaries in NSW (Figure 1). Observational data was collected and mapped directly into ArcGIS Field Maps using an online mapping tool developed by Fruition Environmental to support standardised collection methods.

Over 100 attributes were collected for each mapped bank segment which ranged from 20 – 250 m long. Attributes related to themes of geomorphic setting, bank condition, erosion processes, riparian vegetation condition and existing protection works. Based on current location in the field, survey segments (reaches) were snapped to a line feature of the bank digitised at a scale of 1:2000. Segments were defined based on a change in either erosion severity, riparian vegetation condition, or existing controls. Erosion severity was considered the primary categorical metric and was divided into five classes from Negligible to Extreme based on consistent observable criteria.

Repeat lidar analyses

In addition to comprehensive field mapping, 81 individual severe (either High or Extreme severity) erosion sites were analysed to determine volumetric erosion rates and sediment yields within five estuary systems. The sites typically included one to several adjacent bank segments. Lidar-derived Digital Elevation Models (DEMs), from available 1 m baseline (NSW Government, 2009 – 2012) and 2024 NSW DPIRD 0.5 m captures, were carefully isolated to the erosion site and assessed for quality. Standardised approaches to Geomorphic Change Detection (GCD) and uncertainty analyses using to repeat lidar datasets were adopted (Brasington et al., 2003; Wheaton et al., 2010).

To ensure the reliability of the repeat lidar analysis, DEMs were assessed for horizontal and vertical alignment prior to volumetric change detection. Visual comparison of stable fine-scale features confirmed that no horizontal (x- or y-axis) adjustments were required between the baseline (2009 – 2012) and 2024 DEMs, while vertical offsets were quantified using stable, residual landscape features such as roads. Vertical corrections of 0.12–0.17 m were applied to selected baseline DEMs where offsets exceeded the associated standard deviation. Volumetric change was calculated by subtracting the earlier DEM from the later DEM, with positive values representing deposition and negative values representing erosion in the derived DEM of Difference (DoD). To minimise the influence of analytical uncertainty and DEM noise, a conservative Limit of Detection (LoD) threshold of ±0.25 m was applied based on probabilistic error propagation and validation against a minimum of 12 NSW survey marks in each system (Fuller et al., 2003; Brasington et al., 2003; Wheaton et al., 2010). Elevation changes within this threshold were excluded from the sediment budget analyses.

Each site assessment has been isolated to a limited length of riverbank identified as actively eroding during field surveys (Figure 2). By isolating the assessment, the analysis is constrained to areas where measurable geomorphic change is known or expected to occur. This reduces the influence of stable or non-eroding banks on volumetric calculations and limits the potential influence of DEM noise or interpolation artefacts misclassified as geomorphic change across large areas of otherwise stable terrain. A mask was also applied to remove artificial elevation changes associated with interpolation and DEM generation across water surfaces, further constraining the analysis to only reliable areas of detectable topographic change. Together, these approaches improve the interpretability of erosion rates and sediment yield estimates by focusing the analysis on verified areas of active bank adjustment and sediment release.

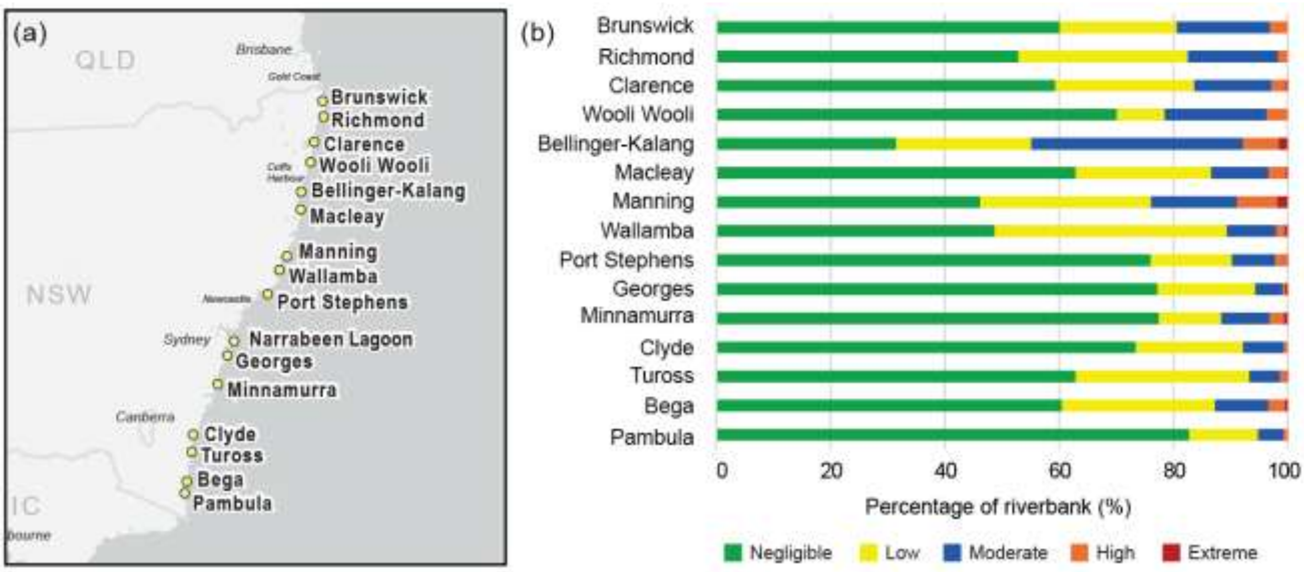

Figure 1 (a) Estuary locations for the NEAP River Estuary Bank and Riparian Condition Assessments; (b) distribution of erosion severity occurring within each estuary at the time of survey

Quantifying sub-tidal erosion

Typical aerial lidar has limited capability to accurately assess volumetric change below the water surface because the wavelengths commonly used are strongly absorbed by water. Point clouds over water bodies are commonly sparse, noisy or entirely absent. This often results in voids within the point cloud or artificially smooth, flattened water surfaces generated during DEM interpolation, with little or no representation of submerged terrain beneath the water surface. GCD analyses generally only quantify changes above the water surface and may underestimate total volumetric change along bank toes and submerged channel margins.

An estimate of the subtidal volume of streambank erosion (erosion beneath the water surface associated with bank retreat) has be approximated using of the field survey attribute Average Water Depth. The primary purpose of this attribute in the dataset is to guide potential remediation options rather than a specific bathymetry. Nonetheless, it provides opportunity to quantify subtidal eroded volumes. Average Water Depth was recorded as Shallow (0 – 0.8 m), Moderate (0.8 – 1.5) or Deep (>1.5 m). Some sites were significantly deeper than the maximum attributed depth of 1.5 m (Figure 2). At each site, the minimum value for water depth, as a conservative estimate, was applied to the areal extent of erosion in the DoD rasters. Areas where slumping of upper banks occurred and did not result in channel widening (mostly confined to the fluvial-dominated reaches of the estuary) were not attributed any sub-tidal erosion.

Extrapolating estuarine sediment yield

While the above analyses were designed to validate field-based assessments, the data provides opportunity to estimate sediment yields throughout the estuary catchment. Using observations from the above analyses, erosion volumes and sediment loads have been extrapolated to other areas of severe erosion, offering indicative estimates (rather than comprehensive assessment) of minimum sediment input from estuarine erosion in catchment sediment budgeting. The estuary-wide extrapolation cannot fully capture the complexities of erosion dynamics or sediment variability within the system. It assumes average or normalised erosion rates based on landscape unit and bend position, as erosion rates have been multiplied by the length of erosion in each segment.

The analysis assumes relative consistency in erosion rates throughout the estuary. An attempt has been made to correlate the process and scale of erosion with comparative analysed sites, and very high yielding sites have been excluded from the analysis (as they relate to localised and specific processes). As such, it is expected that the overall averaging of high and low rates from the volumetric assessment should be relatively balanced at the catchment scale. Additionally, it does not account for Low or Moderate levels of erosion as rates from such sites are likely highly variable across the catchment and estimates would be purely speculative.

Summary of survey data

Figure 1b summarises the proportions of estuary bank which were mapped against each category of erosion severity. On average, more than 60% of surveyed banks were classified as having Negligible erosion severity, with a further 23% classified as Low severity. Isolated occurrences of High to Extreme erosion severity were identified in all systems, typically associated with localised pressures or historical disturbances.

Most estuaries displayed elevated distributions of Low to Moderate erosion relative to the predominantly depositional character expected of mature estuarine environments. While some natural erosion is expected, the results suggest a legacy of long-term degradation and altered estuarine processes in many systems. However, the predominance of Negligible and Low severity classes indicates that severe bank erosion is not currently a widespread systemic issue across most study areas.

Summary of estuarine sediment yields

An example of the site-scale analysis undertaken for each of the severe erosion sites is shown in Figure 2, highlighting the process of analysis and isolation of the eroding area. The selected analysed sites made up to 70% of the derived yield in each catchment, highlighting opportunities for targeted prioritisation of local sediment sources. While both erosion and deposition were investigated during the assessment, most sites did not exhibit any deposition. Apparent in the underlying aerial imagery is the channel thalweg abutting the bank, causing substantive unquantified sub-tidal erosion. Channel depth was observed in the field as approximately 3-4 m deep, adding more than double to the estimated erosion from lidar. At this location, incorporating the sub-tidal volume increased the erosion by an additional 125% over the 15-year period.

Sub-aerial erosion in each estuary system was between 50,000 – 150,000 m^3 of sediment loss over the analysed periods, or an average of 3,000 – 11,000 m^3 per year (Figure 3). The rates are akin to an average of 230 m^3 per km of actively eroding riverbank each year.

In all systems incorporating the sub-tidal component leads to a significantly larger volume of estuarine sediment yield, ranging from a 30 – 55% increase. When the sub-tidal component is incorporated into the analysis, erosion rates double to 6,000 – 18,000 m^3 per year. The results translate to an annual increase in suspended sediment to the estuary from localised sources of between 2,585 t/yr in the Bellinger and 12,595 t/yr in the Clarence. The results provide a first-order approximation of baseline estuary sediment losses and demonstrate major ongoing erosion in the five assessed estuaries. These figures likely represent a conservative, lower limit of average sediment input, as no account has been made for Low and Moderate erosion sources, which make up most erosion sites (Figure 1), while episodic, flood-related erosion is typically not integrated into the assessment.

Figure 2 Geomorphic change along Pelican Island on the Macleay River estuary. Note that the erosion is mostly occurring as lateral scour, resulting in channel expansion. The GCD analysis cannot assess sub-tidal erosion volumes as no return points provide elevation or bathymetry data at the location

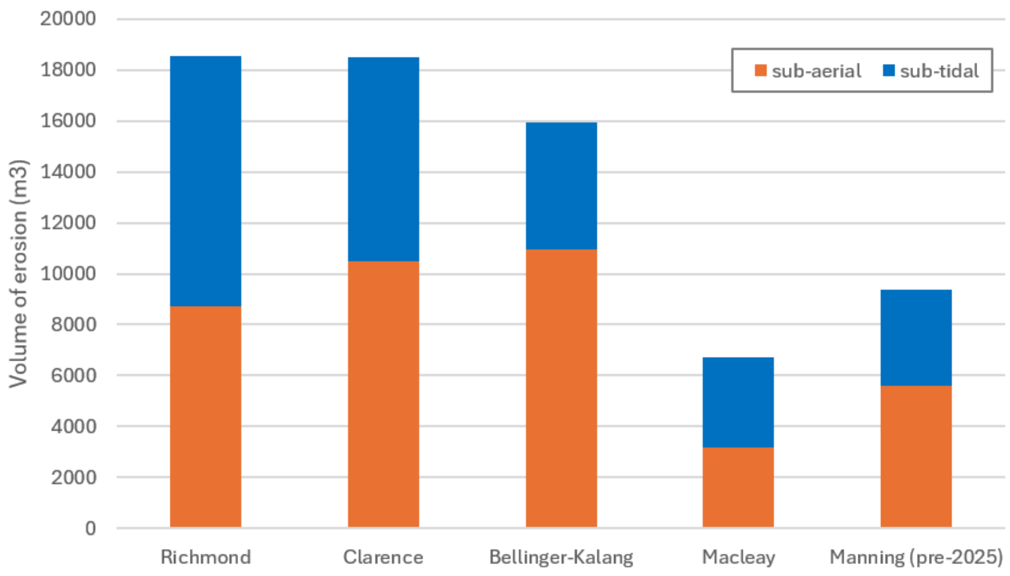

Figure 3 Average annual estuarine erosion estimates within each system, indicative of baseline contemporary erosion under typical conditions (excluding major flood impacts)

Comparison with other catchment estimates

In the Richmond River, estuary bank erosion volumes have also recently been assessed as part of a Coastal Management Program Stage 2 study (Brooks et al., 2025). The approach used a comparable GCD analysis but was undertaken at a broader spatial scale, segmenting the channel network into 500 m reaches. Both assessments cover substantial overlapping portions of the estuary and draw on the same underlying lidar datasets. This overlap provides an opportunity to compare the consistency of volumetric estimates while evaluating the strengths and challenges of each approach.

Comparison of 15 detailed sites common to both assessments demonstrates good agreement in the quantification of major erosion sources despite differences in spatial definition and methodology (Figure 4a). Further, limiting the CMP dataset to only severe erosion segments yields an estimated 98,722 m^3, differing by only 2.2% from the 100,932 m^3 derived in this study. This close agreement provides confidence that constrained GCD analyses can robustly quantify erosion volumes where active bank failure is well defined.

At the broader scale, however, the CMP estimate of 237,846 m^3 is more than double the sub-aerial erosion volume derived in this study (Figure 4b). This difference primarily reflects the different temporal context captured by each assessment rather than inconsistency between methods. The CMP quantifies cumulative geomorphic change resulting from five major floods between 2010 and 2023, whereas this study evaluates the current extent and severity of active erosion. While repeat lidar is highly effective for quantifying cumulative landscape change, the interpretation of contemporary sediment sources benefits from complementary field assessment, particularly where flood-related bank failures have subsequently stabilised through vegetation recovery and are no longer significant sediment sources. Field surveys indicate that many of the high-volume erosion reaches identified in the CMP now exhibit only negligible to moderate erosion. This distinction is particularly relevant when estimating contemporary sediment yields or strategically prioritising erosion management, as reaches that have experienced large historical failures may not necessarily represent the highest ongoing sediment sources. The field-based assessment provides critical geomorphic context for contemporary process interpretation.

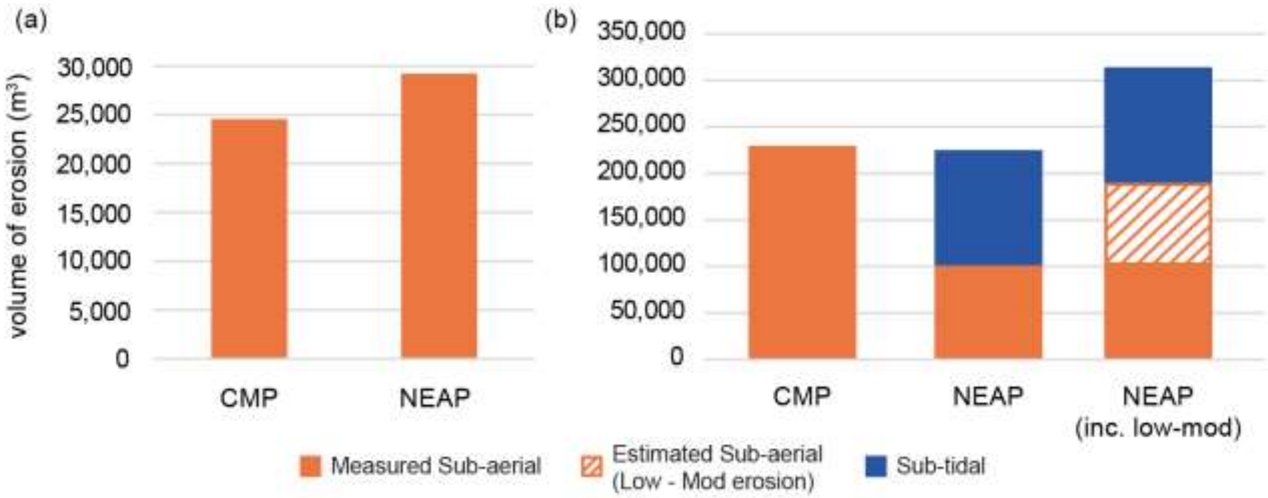

Figure 4 Comparison of Richmond River sediment yields for (a) individual detailed assessment sites; and (b) total estuarine catchment yields

Repeat lidar analyses may also underestimate contemporary sediment loss by failing to capture some erosion processes that are difficult to resolve from terrain models. The inclusion of subtidal erosion approximately doubles the NEAP estimated sediment yield for the Richmond River (Figure 4b), demonstrating the importance of accounting for this component. The apparent similarity between this estimate and the CMP sub-aerial result is simply coincidental and should not be interpreted as the two approaches producing equivalent estimates.

Low rates of bank retreat may also fall below the spatial resolution and LoD thresholds of currently available lidar-derived datasets, or occur in areas obscured by riparian vegetation. For example, wave wash commonly produces toe erosion that, although occurring at relatively low rates, is widespread throughout estuaries and may not be resolved by GCD. While individually such erosion sites contribute relatively small sediment volumes, collectively they may represent a substantial component of estuarine sediment production. Similar limitations may also occur in densely vegetated low-order stream channels, where riparian canopy can obscure channel morphology and reduce the ability to detect subtle terrain change.

Assuming conservative first-order erosion rates of 0.01 m^3 and 0.1 m^3 per metre for Low and Moderate severity banks, respectively, derived from the NEAP field mapping suggests a potential additional 87,967 m^3 of sediment within the Richmond River estuary over the analysed period (Figure 4b). Combined, these two previously unaccounted sources total approximately 200,780 m^3, approaching the entire CMP sub-aerial estimate and demonstrating that processes not typically represented by conventional GCD may collectively contribute substantial sediment volumes. While these estimates should be interpreted with appropriate caution, they illustrate the inherent challenges of estimating catchment-scale sediment yields, where multiple erosion processes operate across different spatial and temporal scales and no single assessment method is likely to capture all sediment sources.

Rather than representing alternative approaches, repeat lidar and systematic geomorphic field mapping provide complementary datasets for catchment-scale erosion assessment. Repeat lidar efficiently quantifies landscape-scale geomorphic change, while systematic field mapping provides process understanding, identifies active sediment sources, and characterises erosion sources not fully represented from GCD alone. Integrating these complementary datasets provides a reliable basis for estimating contemporary estuarine sediment yields and strategically prioritising erosion management than either approach independently.

Conclusions

This study demonstrates the value of integrating systematic catchment-scale field mapping with repeat lidar analyses to improve the quantification of estuarine bank erosion. By combining these two methods, an integrated approach provides provide a robust basis for estimating contemporary estuarine sediment yields and strategically prioritising erosion management across catchments.

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Scan the QR code using your device camera to be directed to the NEAP Bank and Riparian Condition Assessment public web portal

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