

# **A stream bank erosion modelling and prediction in the Great Barrier Reef catchments**

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## **Key Points**

- Stream bank erosion represents a major source of sediment to the Great Barrier Reef (GBR) lagoon.
- The existing Dynamic SedNet model is currently used as a tool to identify sub-catchments at risk of a stream bank erosion however there are issues with applying the model at the reach scale
- Reach scale stream bank modelling is very complex
- An agreed approach for river classification within the Great Barrier Reef catchment would greatly assist modelling and planning

## **Abstract**

Stream bank erosion represents a major source of sediment to the Great Barrier Reef (GBR) lagoon. This paper combines the findings from a number of studies to improve our understanding of stream erosion processes, prediction and modelling. The current Dynamic SedNet model was reviewed along with alternative stream bank models. The paper highlights the difficulties in predicting stream bank erosion across the broad catchments of the GBR. Reach scale stream bank modelling is very complex and to improve our capacity to predict areas of high stream bank erosion risk we need an agreed approach for river classification within the Great Barrier Reef catchments. Significant investments are currently being made in the area of stream bank erosion management. We need to ensure we have the planning processes in place to identify and prioritise areas for riparian restoration.

## **Keywords**

Sediment, bank erosion, modelling, Great Barrier Reef, prioritisation, stream restoration

## **Introduction**

Erosion is a natural and essential process in alluvial systems; however human activities such as land clearing, removal of riparian vegetation or grazing pressure that limits reestablishment of vegetation can result in accelerated rates of stream erosion resulting in damaging channel change. These erosion processes provide a pathway for sediments and nutrients, such as nitrogen and phosphorous, to enter waterways. Land use changes within the GBR catchments have resulted in significant increase in sediment and nutrient loads to the GBR lagoon. As a result, stream bank erosion has been identified as a major sediment and particulate nutrient delivery process impacting on the GBR (Figure 1).

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**Figure 1.** Stream bank erosion along the Fitzroy River (left) and Mary River (right).

The Dynamic SedNet model is currently used within the GBR Source Catchment Modelling framework to assess end of catchment loads and to estimate pollutant load reductions due to adopted improved management practices. The Dynamic SedNet is also used to run scenarios to assess efficacy of other proposed practices. The model, and the data inputs currently utilised, is a reasonable tool for estimating the relative contribution of bank erosion at large whole of catchment scales. However, its applicability at smaller spatial scales (i.e. reach or sub-catchment) to estimate erosion rates and undertake prioritisation is limited due to the coarse datasets used, size of the model links and sub-catchment areas and modelling assumptions. Recent studies have criticised the use of the Dynamic SedNet model for stream bank prediction at anything less than sub-catchment scale, and for use as a reach-scale rehabilitation prioritisation guide (Brooks et. al. 2014).

Significant funding is currently being invested in stream restoration within the GBR catchments. The existing Dynamic SedNet model is currently used as a tool to identify sub-catchments at risk of a stream bank erosion. Given the funding currently being invested in stream restoration, improved approaches are required to identify areas (at the reach or sub-catchment scale) where stream bank management would help reduce sediment and nutrient loads.

This paper explores some of the issues associated with stream bank erosion modelling and prediction in GBR catchments and the importance of understanding the geomorphic form of waterways to inform assessment of stream condition and trajectory.

Specifically, this paper will provide:

1. Background on the need for approaches to help determine channel erosion risk
2. A review of different channel erosion models and an assessment of their applicability to erosion prediction within GBR catchments
3. An assessment of the parameterisation of the Dynamic SedNet model in a range of different river types within the GBR catchment
4. A case study of how stream type assessments can help identify channel erosion risk areas
5. Recommendations for future work to improve stream bank erosion modelling and prediction in GBR catchments

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### **Review of bank erosion models**

In 2020 Alluvium Consulting investigated and assessed options and opportunities for stream bank modelling within the Great Barrier Reef (GBR) catchments (Alluvium, 2020a). The review assessed four different stream bank erosion prediction approaches:

1. The Dynamic SedNet stream bank erosion model (the current approach)
2. Bank Assessment of Non-point Source Consequence of Sediment approach (BANCS)
3. The Bank Stability and Toe Erosion Model (BSTEM)
4. Stream type based approach and multi-temporal analysis

The review highlighted the difficulties in predicting stream bank erosion across the broad catchments of the GBR. Stream bank erosion processes are complex, often non-linear, and involve a range of diverse and interrelated variables. As a result, selecting an appropriate predictive model is very challenging, especially at the scale of the GBR catchments where data availability is limited.

While Dynamic SedNet continues to be used to assess end of catchments loads in GBR catchments the review identified several knowledge gaps within the streambank component which should be addressed. These include assessing the applicability of the model to different river types, improved stream power and erodibility determination and a framework to assist in developing confidence bands based on the river type and data availability. Many of these research needs were identified in Prosser (2018).

The BANCS model offers advantages to the current approach as it is designed to model erosion at the required reach scale based on local remotely sensed and field data. However, opportunities for broader expansion into the GBR catchments may be limited due to the data requirements and uncertainty around its applicability to the hydrologic regimes of GBR catchments and different river types, particularly the entrenched compound channels that are widespread in the coastal rivers of Queensland (Daley,2018) (see Figure 2 below). The model was primarily developed for unconfined laterally meandering rivers in the USA.

BSTEM is generally applicable to the site scale and requires extensive data collection. Furthermore, the model is not applicable to many GBR rivers with a compound channel morphology which have inset geomorphic units with varying erodibility and erosional processes. As a result, there is limited opportunities to use this model in GBR catchments to predict catchment loads.

Finally, an alternative approach was proposed which specifically incorporates a river typology assessment. In this approach, high resolution multi-temporal LiDAR data is used to train coarser datasets for each river type. This proposed approach is yet to be applied but draws on components of other approaches that have been developed and applied in Queensland including the approach proposed by Brooks et. al. (2014). However, of all the approaches assessed this one would require the greatest level of research and development before it can be more broadly applied to a GBR catchment.

### **Review of SedNet parameterisation in GBR streams**

#### **Overview**

The Stream Bank Erosion component of Dynamic SedNet models bank erosion along stream links represented in the node-link (stream) network of Source. The Stream Bank Erosion component models mean annual sediment supply from bank erosion along a link as a function of bankfull stream power in a hypothetical rectangular channel, the extent of riparian vegetation adjacent to the channel, and the level of bedrock confinement. The bank erosion algorithm calculates the erosion rate over the entire length of the link. Key input variables into the model include channel slope, bankfull flow, bank height, bank substrate, and riparian vegetation condition. The fluvial geomorphology of different river types is a key control on many of these variables.

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Based on recommendations in Alluvium (2020a) a study was undertaken to assess the parameterisation of the Dynamic SedNet model in a range of different river types within the GBR (Alluvium, 2020b). The case study areas were selected on the basis of good pre-existing data availability in order to assess the geomorphology and hydro-geomorphic processes. This has resulted in all case study areas being located within the coastal fringes as opposed to inland streams in the upper catchments. The objectives of the study include:

1. Review the fluvial geomorphology and channel change processes within a range of river types within the GBR catchments
2. Assess the parameterisation and outputs of the Dynamic SedNet model in a range of river types within the GBR catchments

The five case study areas are located within the Mary River catchment, Fitzroy River catchment and Mackay-Whitsundays region. A summary of the case study area, river type, processes, channel erosion and Dynamic SedNet parameterisation in the five case study areas is provided in Table 1.

**Table 1 Overview of the case study areas**

Case study area	River type/processes	Channel erosion processes	Dynamic SedNet parameterisation
<i>Mary River</i> - A 40 km section of Mary River which extends from the Yabba Creek confluence to Six Mile Creek, just upstream of Gympie.	Entrenched sand bed channel with a meandering planform. Lateral adjustment of the entrenched channel controlled by bedrock valley margins and fill terraces.  Inset channel flows through more recent inset depositional units (i.e. inset floodplains, benches).	Dominant channel erosion process is fluvial toe scour and subsequent mass failure on the outside of bends within the inset channel.  Erosion is more prevalent in zones where the inset floodplains are more expansive and there is limited woody vegetation coverage.  There are no examples where there has been significant sediment loss from terrace units.  Wet flow failures have historically been prevalent with failure scars clearly visible.	Longitudinal bed profile accurately estimated.  Bank heights assigned to the terraces rather than the active inset channel.  Bankfull flow overestimated (by approximately 275-325%) as inset channel not defined.  Vegetation buffer correctly assigned to inset channel.  Overall good model prediction (84% of actual sediment loss predicted).
<i>Raglan Creek</i> A 73 km section of Raglan Creek reach.	Upper portion consists of partly confined, low sinuosity, gravel bed channel.  Middle portion consists of an entrenched channel confined by terraces with a low sinuosity planform.  Lower portion consists of an unconfined, meandering tidally influenced, channel.	Downstream meander migration and channel widening driven by fluvial toe scour and mass failure is the dominant channel erosion process in the upper portion.  There are limited examples where there has been significant sediment loss from terrace units in the middle portion.  Significant meander migration within the lower tidal reach. This erosion is most likely driven by entrainment of bank sediments (followed by mass failure) due to a combination of fluvial, tidal and wave action.	Longitudinal bed profile overestimated by an order of magnitude.  Bank heights are underestimated by approximately 30 – 60%.  Bankfull flow underestimated by approximately 70 – 90%.  Vegetation buffer does not cover all erodible areas of the channel boundary  Overall good model prediction (86% of actual sediment loss predicted in SC #1766).

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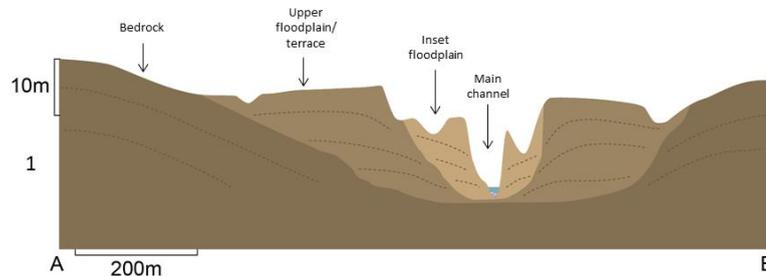
<p><i>Fitzroy River-</i> A 65 km section of the Fitzroy River upstream of the tidal barrage in Rockhampton.</p>	<p>Partly confined sand bed channel with some bedrock controls. Planform is classified as meandering however it contains several higher-angle bends separated by sections that are near straight.</p> <p>The majority of the case study area sits within the weir pool of the tidal barrage.</p>	<p>The majority of sediment loss is derived from meander migration (i.e. fluvial toe scour and subsequent mass failure) processes. A large meander cutoff is driving increased rates of meander development in one location.</p> <p>Significant sediment loss occurred due to scour of in-channel units such as bars and islands.</p> <p>A significant number of wet flow failures were distributed throughout the case study area.</p>	<p>Longitudinal bed profile overestimated by one to three orders of magnitude.</p> <p>Bank heights are overestimated by approximately 45 - 115%.</p> <p>Bankfull flow overestimated by approximately 100-300%.</p> <p>Vegetation buffer does not cover all erodible areas of the channel boundary.</p> <p>Overall average model prediction (192% of actual sediment loss predicted).</p>
<p><i>Murray Creek-</i> A 23 km section of Murray Creek upstream of the Bruce Highway</p>	<p>Upper portion consists of entrenched, low sinuosity, gravel bed channel with discontinuous inset floodplains.</p> <p>Through the mid zone the valley confinement increases, and the channel is significantly confined by bedrock.</p> <p>Lower portion consists of an unconfined, meandering tidally influenced, channel.</p>	<p>Dominant channel erosion process is the result of lateral meander migration processes (i.e. toe scour and subsequent mass failure) across poorly vegetated inset floodplain units.</p> <p>There are no examples where there has been significant sediment loss from terrace units.</p> <p>Increased rates of lateral channel change and meander development due a meander cutoff in the lower estuarine reach.</p>	<p>Large variations in the longitudinal bed profile are not well represented by the modelled average value.</p> <p>Bank heights are generally well defined.</p> <p>Bankfull flow typically underestimated but varies within the case study area (i.e. bankfull flow is generally underestimated by approximately 30 – 60%, however is over estimated by 30% in the lower reaches).</p> <p>Vegetation buffer generally extends across the key geomorphic units.</p> <p>Overall average model prediction (65% of actual sediment loss predicted).</p>
<p><i>O'Connell River-</i> A 17 km section of the O'Connell River which extends from the Andromache River confluence to Bloomsbury.</p>	<p>Upper portion consists of partly confined, low sinuosity, gravel bed channel. Within this section the channel can abut either bedrock, terrace or inset floodplain units.</p> <p>Middle section consists of an entrenched channel confined by terraces with a low sinuosity planform.</p> <p>Lower portion consists of partly confined, low sinuosity, gravel bed channel with expansive inset floodplains within the broader entrenched channel.</p>	<p>Within the upper portion the dominant channel erosion process is fluvial toe scour and subsequent mass failure on the outside of bends within the inset channel.</p> <p>There are no examples where there has been significant sediment loss from terrace units.</p> <p>Major channel erosion as the result of meander development in the lower portion as the river reworked the coarse sediment deposits and created a defined low flow path.</p>	<p>Longitudinal bed profile are generally well represented by the modelled average values.</p> <p>Bank heights are overestimated by 25-125%.</p> <p>Bankfull flow underestimated by approximately 45-80%.</p> <p>Vegetation buffer generally extends across the key geomorphic units.</p> <p>Overall good model prediction (78% of actual sediment loss predicted).</p>

Four of the case studies (i.e. all except the Fitzroy) had sections of channel which had an entrenched morphology (Figure 2). These entrenched channels are relics from past sea level, flow and sediment regimes.

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As a result they do not behave as true self-formed alluvial channels. Within the confines of the alluvial terraces more contemporary alluvial floodplains and benches have formed during the current Holocene period. The case study assessment-identified erosion areas are significantly more prevalent when the channel is bound by inset floodplains and are often concentrated within small areas. This diversity of geomorphic form and erosional processes is not identified when parameterizing at the link scale.



**Figure 2.** Example of entrenched channel morphology within the Mary River, this channel form is common in the coastal rivers of Queensland

### Summary and key findings

Dynamic SedNet is the primary mechanism for predicting stream bank erosion within the GBR catchments. The purpose of these models is to provide estimates of long term pollutant load reductions, however the model outputs are frequently also used as a source of information to assist in prioritisation of stream bank management interventions. This study has shown that using model outputs alone for this prioritisation might not achieve the perceived benefits.

The key findings of this study are:

1. The case study assessment-identified erosion areas are significantly more prevalent when the channel is bound by certain geomorphic units (i.e. inset floodplains) and are often concentrated within small areas. Given the length of modelled links (often 10-15 km) an understanding of the type and prevalence of channel bounding geomorphic units within each link, and their relative erodibility, would greatly enhance stream bank erosion prediction.
2. Overall, the Dynamic SedNet sediment loads are relatively good estimates of sediment loss at the case study scale (i.e. across all links assessed). The overall model performance is similar in case study areas with good parameterisation (i.e. the Mary River and O'Connell River) and case study areas with very poor parameterisation (i.e. Fitzroy River and Raglan Creek). However, at the link scale there is significantly higher variability. How the model is able to predict stream bank erosion results when there are significant errors in the key input parameters is uncertain. The fact that all case studies were located in the coastal fringes where there is generally better data availability for calibration may have assisted the model performance. If the monitoring data and calibration are the key reasons for the good model performance this indicates that the stream bank erosion model has been manipulated as an empirical model for the purposes of predicting the broad distribution of stream bank erosion at sub-catchment scales across large river basins(see point below).
3. This study identified that the process-based components of the model are not performing as intended at the link/sub-catchment scale in the five case studies assessed. Despite the good predictive power of the model at the catchment scale there were very large errors in the variables which drive the process-based component of the model in several case study areas. Given there are such large errors in some of the input parameters it is difficult to assess the process-based components of the model performance in the different river types assessed in this study.
4. No observable correlation between bankfull total cross-sectional stream power (or bankfull mean specific stream power) and channel erosion was identified within the five reach scale case studies assessed. Stream power is still likely a major driver of erosion, however the variability in the character and erodibility of the

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channel boundary sediments overwhelms other controls (i.e. stream power). This aligns with findings of Brooks et.al. (2014).

5. Other erosion processes including wet flow failures (Thompson et.al. (2014), tidal erosion, avulsions and inset floodplain scour are also currently not specifically accounted for within the Dynamic SedNet model (although some of the key variables that drive these processes are within the model i.e. stream power).

### Stream type assessment – Case study of the Mackay Whitsunday assessment

In 2016 Alluvium undertook a stream type assessment of the Mackay Whitsunday region. The first level of the classification was the degree of confinement by either bedrock or resistant terraces. Streams were differentiated based on the degree of lateral confinement and presence of erodible floodplains along a waterway. Four degrees of confinement were outlined. Within the MW region many streams have an entrenched morphology and are significantly confined by terraces (see example in Figure 2). However, the stream type assessments identified several reaches across the region which are either laterally unconfined or slightly confined (see example in Figure 4). In addition to confinement a range of other metrics were incorporated into the assessment including riparian vegetation condition, channel stability and physical form habitat.

In 2017 Alluvium assessed flood related channel change following the Cyclone Debbie rainfall event in March 2017 (Alluvium, 2017). The assessment identified several reaches that experienced significant channel change during the flood event. All of the reaches were in areas assessed as having high erosion risk in the 2016 assessment due to their level of confinement and riparian vegetation condition. The outcomes of the post flood assessment highlighted the benefits of regional stream classification approaches to identify areas prone to channel erosion.

### Conclusions

In recent years there has been a large increase in investment for stream restoration works to reduce sediment loads to the GBR. This requires significant work to identify, prioritise and plan stream restoration work. Within GBR catchments there is no standardised approach to assess river types, erosion processes and channel erosion risk which have been developed in other states (i.e. the River Styles(Brierley G, & Fryirs K, 2005) framework which has been applied extensively in NSW). In many cases the Dynamic SedNet model is currently used as a tool to identify sub-catchments at risk of a stream bank erosion.

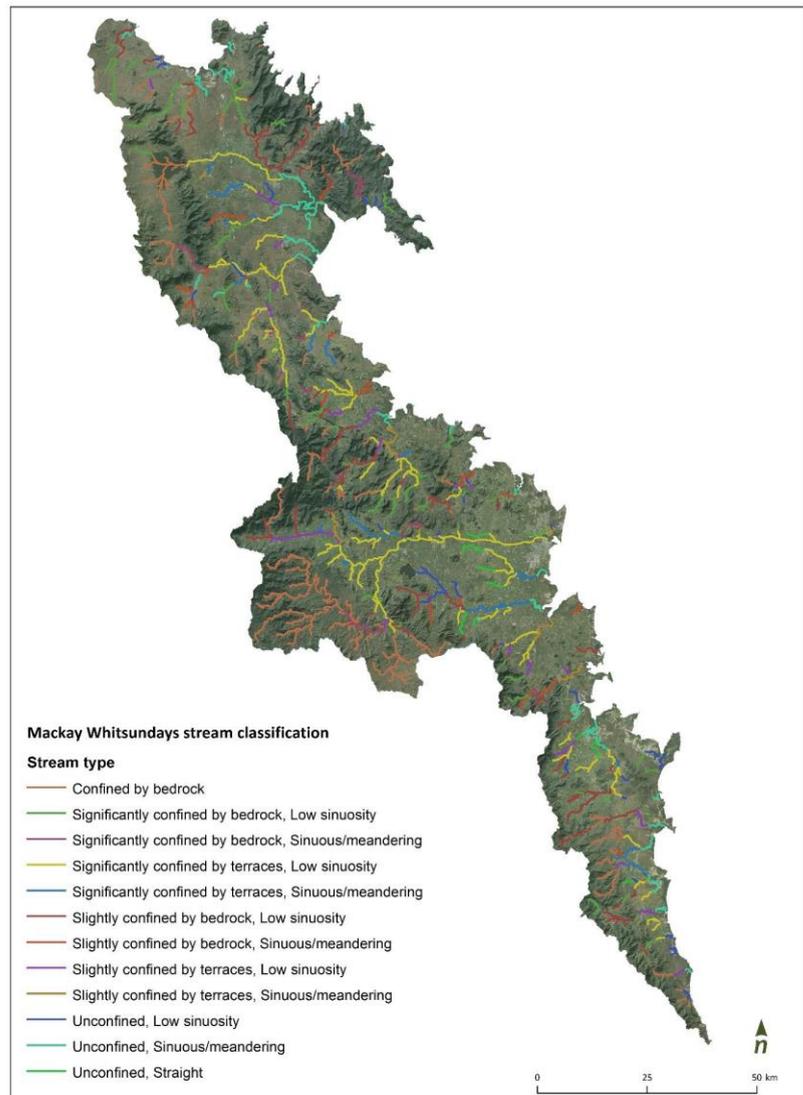
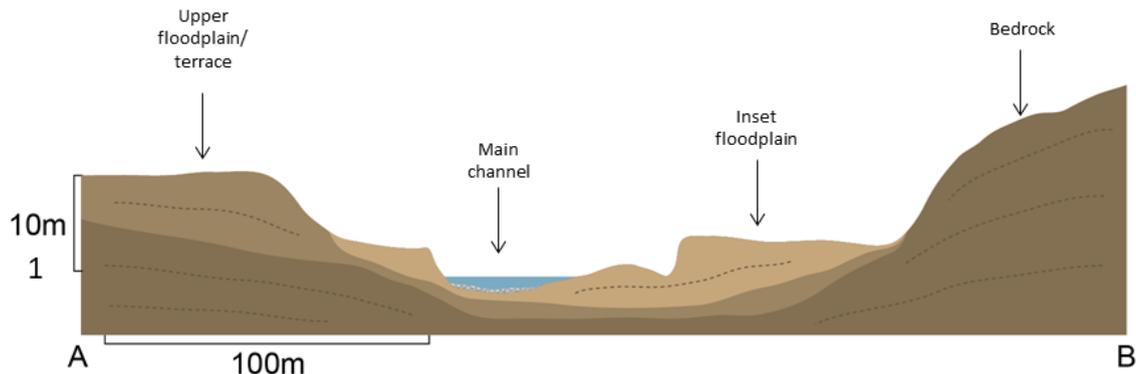


Figure 3. Stream classification within the Mackay Whitsundays (Alluvium, 2016)

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**Figure 4.** Murray Creek within the Mackay Whitsundays region which is only slightly confined by terraces and/or bedrock, this means there is more capacity for lateral adjustment

The purpose of the Dynamic SedNet model is to provide estimates of long term pollutant load reductions, however the model outputs are frequently also used as a source of information to assist in prioritisation of management interventions for stream bank management. However, its applicability at smaller spatial scales (i.e. reach or sub-catchment) to estimate erosion rates and undertake prioritisation is limited due to the coarse datasets used, size of the model links and sub-catchment areas and modelling assumptions.

An attempt to assess the process-based components of the Dynamic SedNet model performance in the different river types was not possible due to the large errors in parameterisation. Despite the errors, there is generally good model performance at the sub-catchment. It is likely monitoring data and calibration are the key reasons for the good model performance which indicates that the stream bank erosion model has been manipulated as an empirical model. This limits its ability as a predictive tool as the processes that drive channel erosion are not accurately modelled.

A review of alternative bank erosion models has highlighted the difficulties in predicting stream bank erosion across the broad catchments of the GBR. Stream bank erosion processes are complex, often non-linear, and involve a range of diverse and interrelated variables. Within the GBR catchments there is a huge diversity of river typologies ranging from classic self-formed meandering systems, anatomising systems, entrenched compound channel systems which are confined by resistant floodplain/terrace material with contemporary (i.e. Holocene) inset deposits, bedrock constrained, semi-alluvial channels and typical incised channels as defined by Schumm et al (1984) (typically in smaller tributary channels). The erosional processes within the channel will differ significantly for each type of river system.

Accurately predicting stream bank erosion will be difficult without an understanding the spatial distribution of each river type and processes that impact erosion in each system. As a result, the development of a framework for undertaking regional river classification within GBR catchments is required to inform stream management planning. Understanding the spatial distribution of each river type and processes that impact erosion in each catchment will greatly assist in prioritising sediment reduction programs. It would also help inform broader river management programs which target river health outcomes.

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### **Acknowledgments**

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