STABILITY ASSESSSMENT:

O'Connell River

May 2014

Document history

Revision:

Revision no.	02
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Checked	Ross Hardie Dom Blackham
Approved	Steve Skull

Distribution:

Revision no.	01
Issue date	April 2014
Issued to	Will Higham, Adam Folkers (Reef Catchments)
Description:	Draft for comment
Revision no.	02
Issue date	May 2014
Issued to	Will Higham, Adam Folkers (Reef Catchments)
Description:	Final report

Citation:

Alluvium (2014). O'Connell River Stability Assessment. Report P414005_R01 by Alluvium Consulting Australia for Reef Catchments

Ref: V:\Projects\Brisbane_Projects_2014\005_Reef Catchments_O'Connell River stability assessment\1_Deliverables\P414005_OConnell River_V1c.docx

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1 Introduction

Alluvium Consulting Australia Pty Ltd (Alluvium) has been commissioned by Reef Catchments to undertake a stream stability assessment of the O'Connell River. Previous investigations have identified the O'Connell River as one of the largest sources of sediment to the Great Barrier Reef (Brodie et al., 2003). A significant proportion of the sediment supply is understood to be derived from channel erosion (Simon et .al. 2012). Channel erosion also threatens agricultural land and public infrastructure. This study seeks to understand the cause, location, extent and prognosis (trajectory) for channel erosion through the main stem of the O'Connell River. The outputs from this study will inform the development of management strategies to reduce the impact of channel erosion.

1.1 Study overview and objectives

Reef Catchments seek to reduce sediment and nutrient export from the O'Connell River, and to reduce flood related impacts of channel change on public and private assets. Reef Catchments seek to implement programs of sediment reduction in the O'Connell River as efficiently and effectively as possible. Reef Catchments has engaged Alluvium to assist identify areas of potential future stream bank erosion and where programs of stream bank erosion control would be most effective. Alluvium has been commissioned to:

1. Identify recent channel change processes since 2010
2. Estimate hydro–geomorphic parameters within the system (channel bed grade, stream power) that influence channel stability
3. Identify features within the alluvial system that will resist lateral and vertical adjustments (i.e. vegetation, bedrock outcrops, valley margins, terraces etc)
4. Predict the likelihood and location of future channel change
5. Provide recommendations for management.

The investigation is not a waterway management plan, but could form the basis for the development of a waterway management plan for the O'Connell River.

Channel erosion is caused by fluvial geomorphic processes. Understanding these geomorphic processes and their likely future trajectory is important in delivering a cost efficient stream management program. Developing a process understanding can identify the reaches that supply sediment to stream systems and the scale of intervention required to provide effective erosion control. Such investigations can ensure resources are appropriately allocated to erosion control works to address the risks of ongoing erosion and sediment supply.

A 'whole of catchment' approach is required to effectively manage geomorphic processes. Such an approach involves land and water policy and practice incorporating improved land use and land management practices, as well as effective waterway management activities. The focus of this study is the fluvial processes within the main stem of the O'Connell River—i.e. the process that occur in or adjacent to the river channel. Consideration of the processes in tributaries and the broader land management activities are beyond the scope of this study, but may need to be considered by Reef Catchments.

1.2 Study area

The O'Connell River rises in the Clarke Conner Range and flows north for approximately 50 km before discharging into the Great Barrier Reef lagoon (Figure 1). The O'Connell River has a total catchment area of 830 km². The major tributary to the O'Connell River is the Andromache River, which joins from the north approximately 10 km upstream of O'Connell River's mouth.

The O'Connell River flows through a partly confined valley for most of its length which means the valley margins limit lateral migration of the channel. Within the valley, floodplains and terraces (floodplains formed during past flow regimes) are used for both grazing and sugar cane production. Consequently the fluvial deposits of the O'Connell River are an important economic resource to the local community.

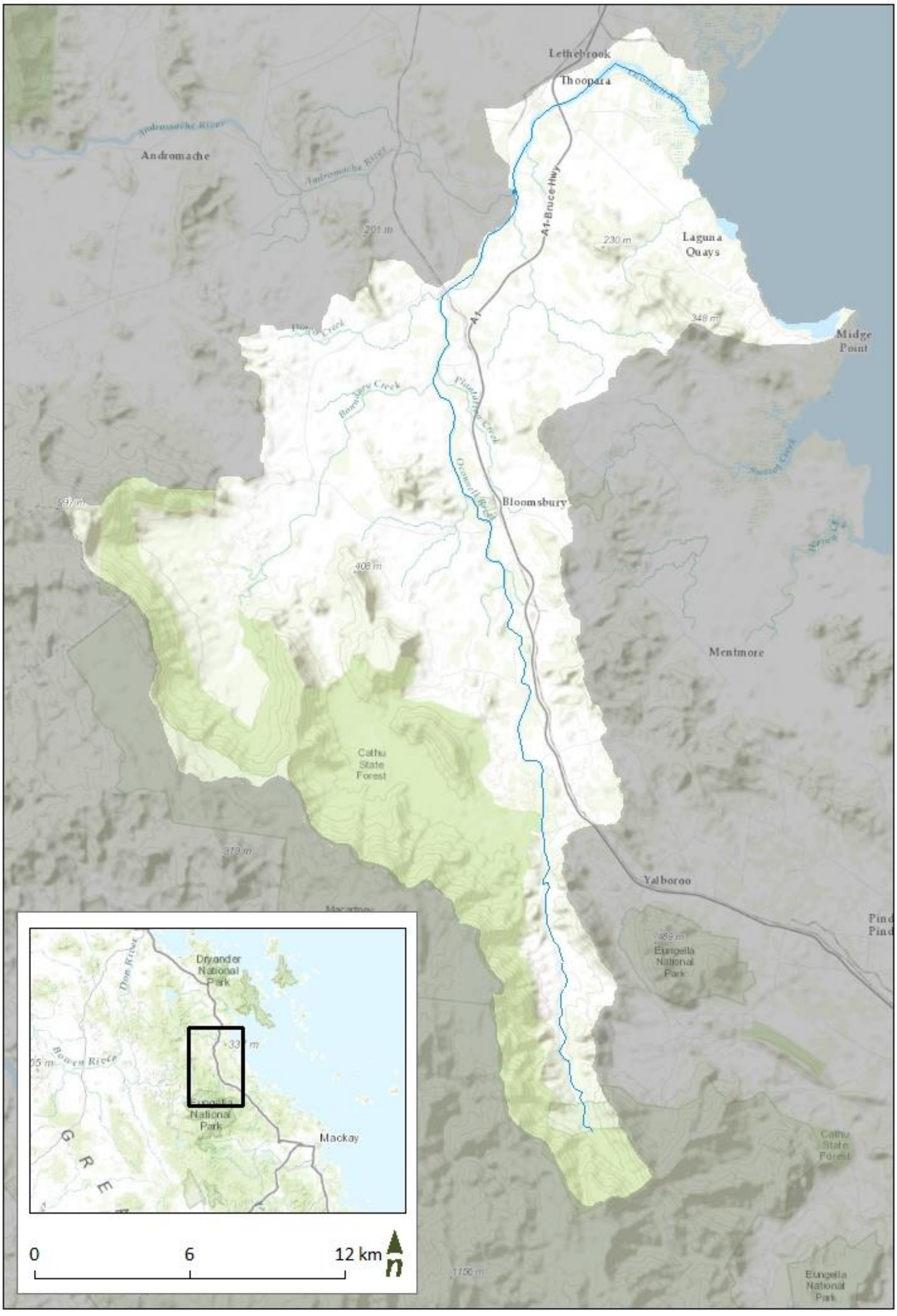


Figure 1. *The O'Connell River study area*

2 Factors affecting erosion

2.1 Erosion processes in alluvial rivers

Rivers that flow through unconsolidated sediments are known as alluvial rivers. These rivers are shaped by their flow regime, base level, sediment inputs and boundary strength. The boundary strength refers to the resistance of the bed and banks of the stream to scour, and is controlled by the characteristics (size) of the bed and bank sediments and the riparian vegetation condition.

The erosion, transport and deposition of sediment in alluvial river systems has been the subject of much scientific research. The study of the interactions between the physical forms and sediment transport processes is known as fluvial geomorphology (geomorphology for convenience in this study).

The sediment processes are of particular interest to Reef Catchments, as described in Section 1. In particular, Reef Catchments are interested in reducing the sediment yield—the total amount of sediment and associated nutrients that are discharged from their catchment to the Great Barrier Reef.

Sediment yield

The amount of sediment delivered to the outlet (or any other location in a catchment) is controlled by the rate of erosion and by the rate of transport to the location. A catchment can be considered in three broad zones: sediment supply, sediment transport and sediment storage (Figure 2).

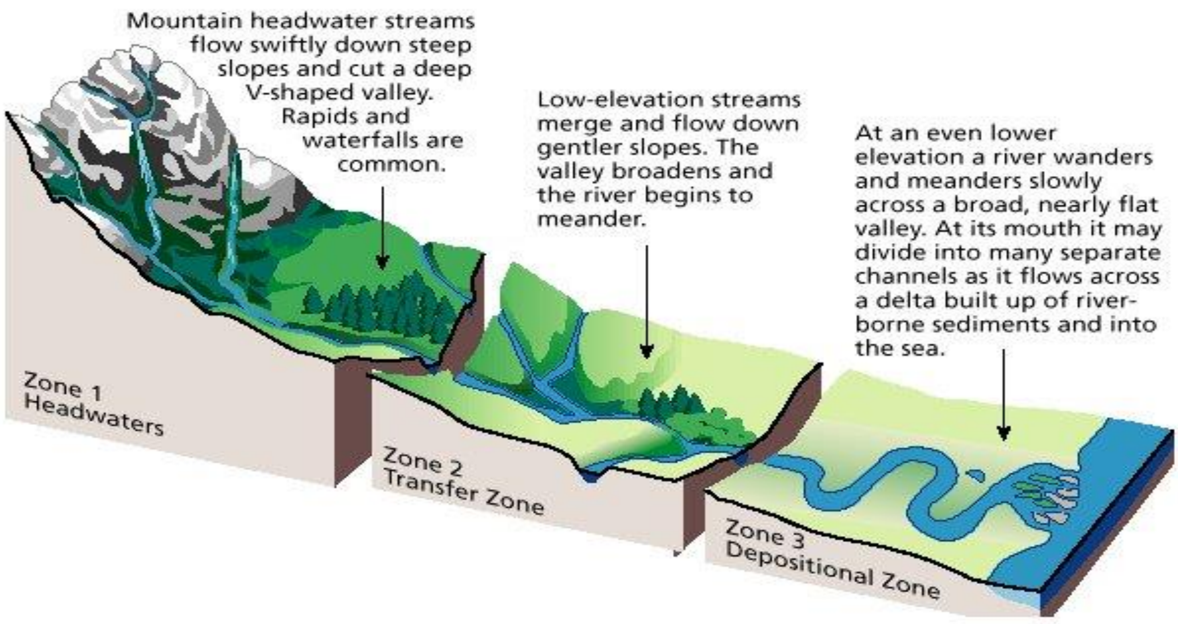


Figure 2. *Sediment zones in a typical catchment. Image reproduced from the Federal Stream Corridor Restoration Handbook (FISRWG, 1998)*

The sediment yield to a location in a catchment is a function of the rate of erosion from source area and transport to the location of interest. Sediment is generated by erosion of hillslopes and headwaters in the upper catchment, and transferred downstream through the channel network.

The form of a channel is largely a function of the water and sediment supplied to it. Adjustments to channel form occur as a result of process feedbacks that exist between channel form, flow and sediment transport. At the reach-scale, the type of adjustment that can take place is constrained by the valley setting, the nature of bed and bank materials, and bank vegetation. This gives rise to a wide diversity of different channel forms.

Channel bed and bank erosion throughout the catchment contributes to the sediment entering a river system. The rate of channel erosion is controlled by factors including the flow regime (channel erosion can increase dramatically during floods), the supply of sediment to a reach, the size, shape and slope of the channel, and the strength of the bed and banks. Riparian vegetation influences a number of these factors. Tree root systems increase the strength of bank material, and above ground vegetative structures slow the flow of water and shield bank sediment from erosion. The valley width also constrains channel erosion by limiting the lateral extent of erosion.

The driving variables and boundary conditions that influence channel form and geomorphic processes are illustrated schematically (Figure 3).

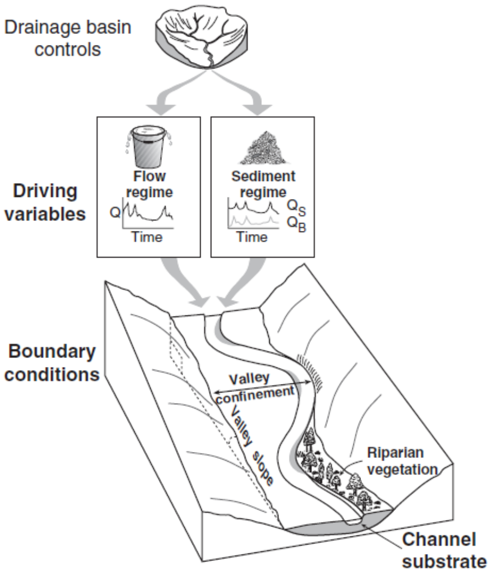


Figure 3. *Schematic representation of the factors influencing channel form and geomorphic process in alluvial rivers (reproduced from Charlton 2008)*

The rate at which sediment is transported through a river system is controlled by:

- The flow regime (more sediment is transported if there are a sequence of large flows than during a long drought)
- The energy (or stream power) in the system (a steep, powerful river will transport more sediment faster than a flat, slow flowing system, everything else being equal)
- The size of the sediment (fine sediment in suspension is transported more quickly than gravels or cobbles).

Only a small proportion of the sediment eroded typically leaves a catchment, because a significant volume of the sediment is stored in transient sediment sinks as it is deposited throughout the catchment. These sediment sinks include floodplain depressions, in-channel islands, bars and benches or floodplains (vegetation can help lock sediment into these sinks). Sediment can be released from storage when it is reworked at a later stage. An individual particle of sediment can be stored and remobilised many times as it is transported through a river system. Changes to land management practices (e.g. clearing of riparian and catchment vegetation) can significantly increase the proportion of sediment that leaves a catchment.

The geomorphic processes that drive sediment transport operate across different spatial scales, from drainage basin or catchment to individual particles of sediment. The relationship between different spatial scales can be considered schematically (Figure 4).

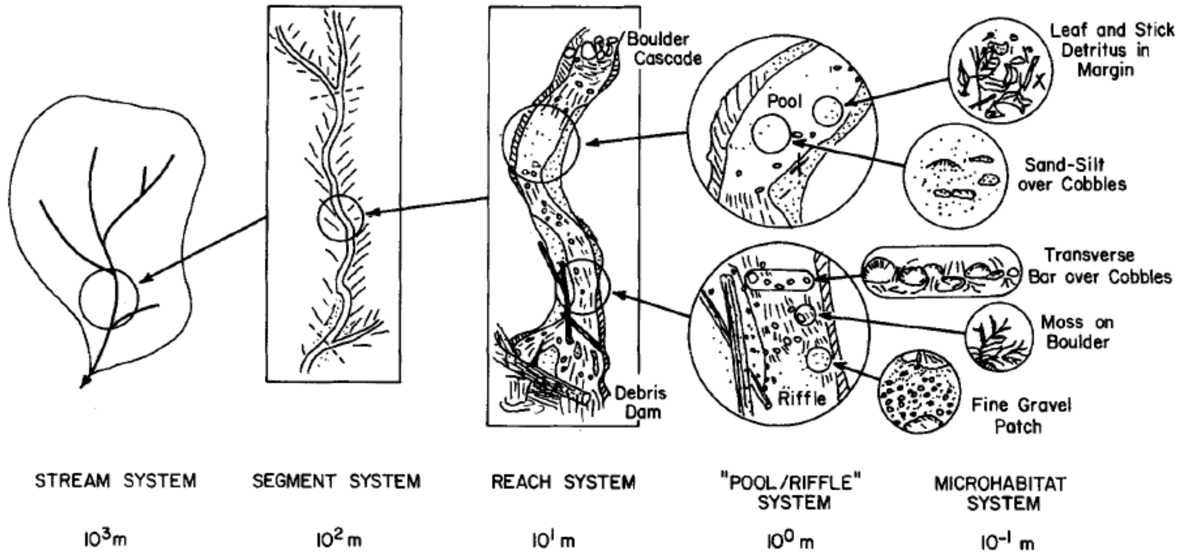


Figure 4. *Hierarchical organization of a spatial scales in a stream system (from Frissell et al 1986).*

Understanding sediment erosion and transport processes is critical to developing a management plan that will reduce sediment yield to a receiving environment. The spatial scales most relevant to managing sediment yield are catchment to reach-scale. A range of fluvial geomorphic processes operate across these scales (see boxes below). Understanding the location of these processes in a catchment, what's driving them, and their likely future magnitude is central to effectively reducing sediment yield.

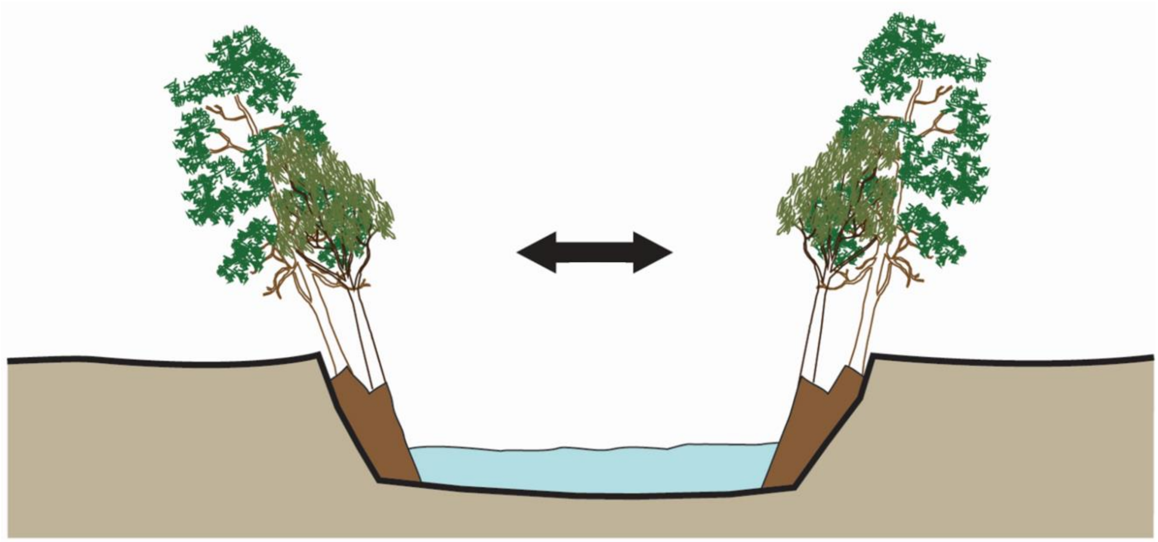
Bank erosion is a ubiquitous geomorphic process in alluvial channels. Bank erosion is important in the development of different channel forms, while the migration of channels across their floodplains involves a combination of bank erosion on one side and deposition on the other (which is often expressed through meander migration. Bank erosion can also create management problems when bridges, buildings, agricultural lands and roads are undermined or destroyed. Large volumes of sediment can be generated and made available for transport to downstream reaches.

Bank erosion is often caused by a number of different geomorphic processes that can operate separately or in combination, and can be considered in three groups:

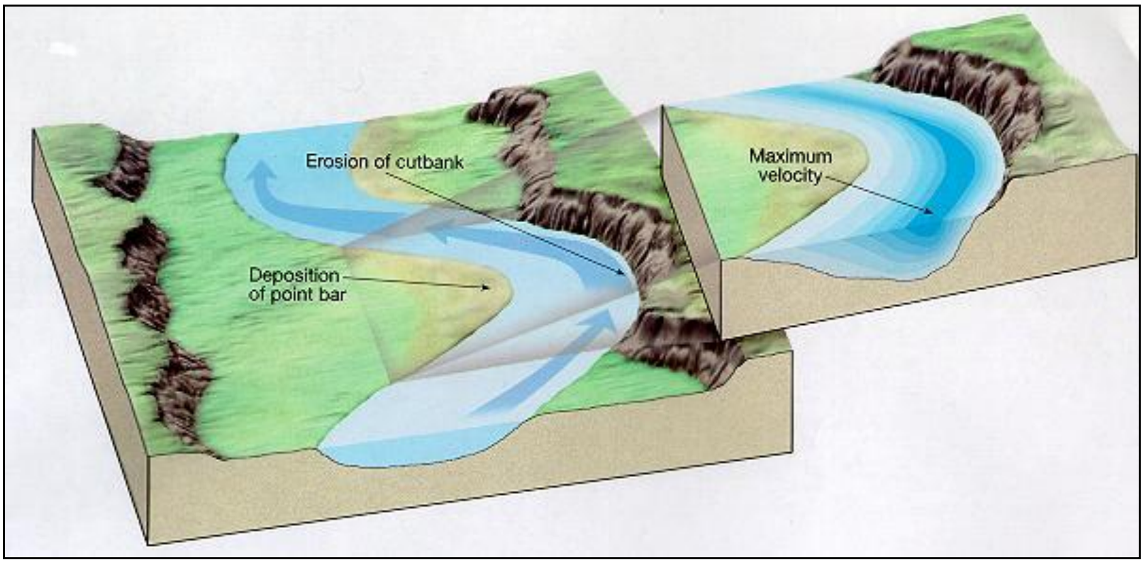
1. Pre-weakening processes such as repeated cycles of wetting and drying or cattle trampling of the substrate, which 'prepare' the bank for erosion.
2. Fluvial processes, where individual particles of sediment are directly entrained (mobilised) by flowing water.
3. Processes of mass failure, which include the collapse, slumping or sliding of bank material into the channel.

Bank erosion is an important contributor to geomorphic related management issues due to the amount of sediment it can release, and its direct impact on floodplain assets and property.

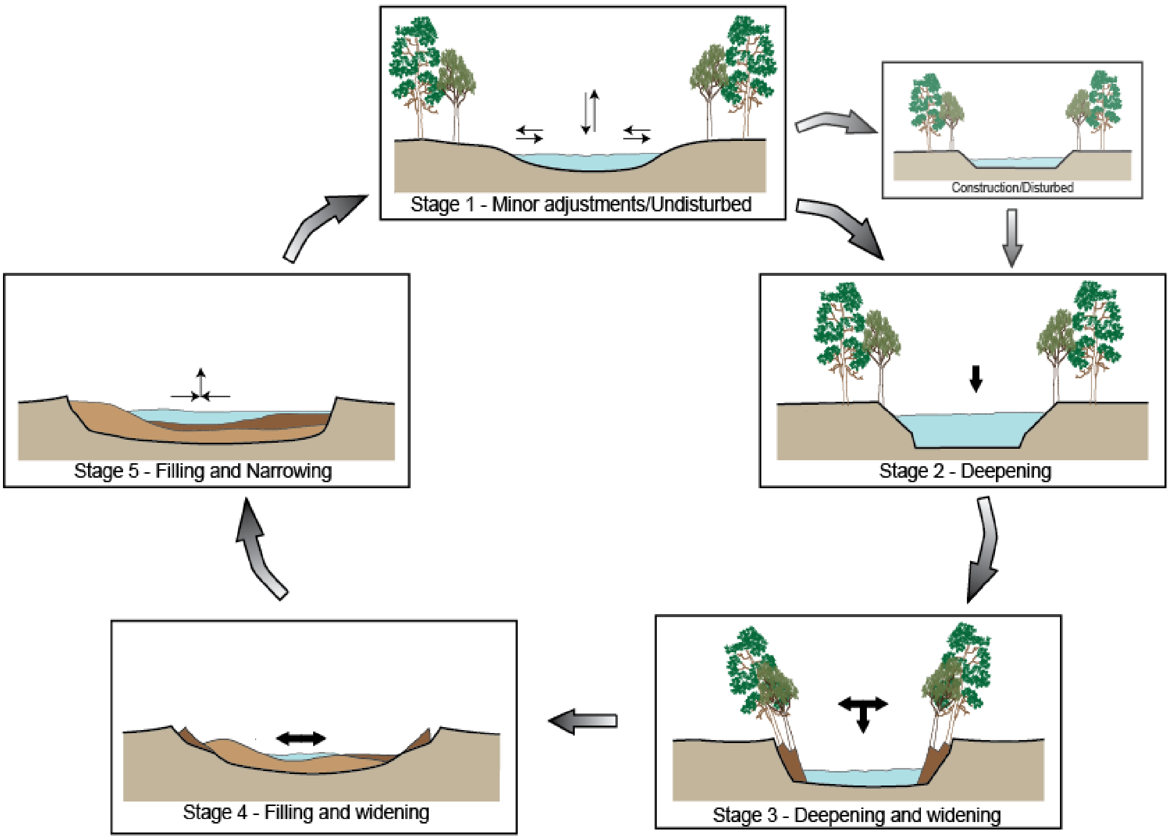
Channel widening occurs when river banks erode on both sides of a channel. Channel widening is often a symptom of a wider scale process, such as an increase in in-channel flow, arising from river regulation, channelisation, deforestation urbanisation or channel incision.



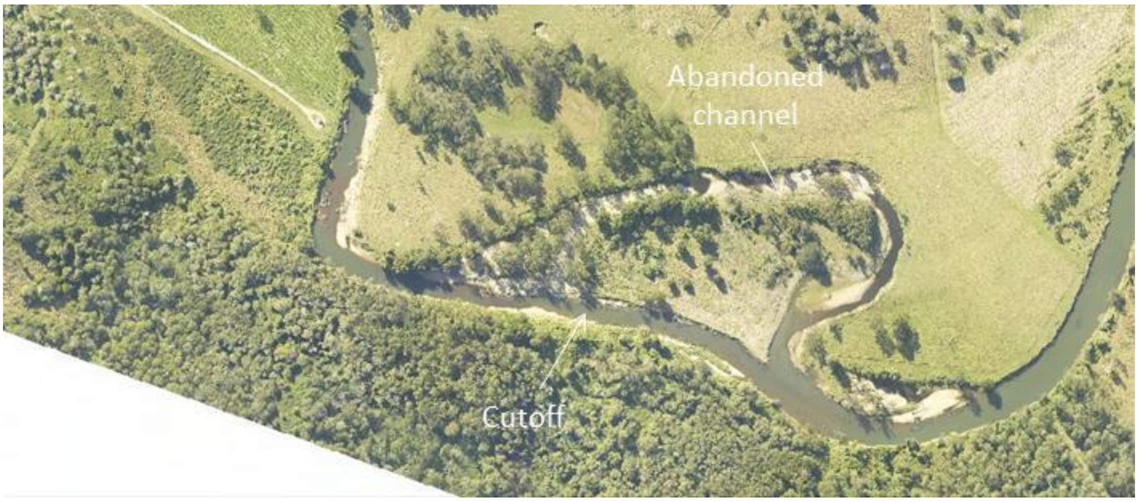
Channel migration is often associated with **meander migration**, and is caused by erosion on one bank and deposition on the other (FISRWG, 1998).



Channel incision occurs when the bed of the channel cuts down and causes reach-scale deepening of the channel. The deepening is then normally followed by widening.



Avulsions and meander cutoffs are both floodplain processes where a new, often shorter, channel is scoured leaving the previous course abandoned.



2.2 Analysis of erosion processes

Large floods can drive a range of fluvial geomorphic processes including bank erosion, channel widening, channel narrowing, incision (i.e. deepening), avulsion, in-channel deposition, floodplain erosion, floodplain accretion, meander cut-offs and bar reorganisation (Kochel, 1988).

There are many factors which govern the nature and magnitude of these geomorphic processes. A simple model that explains why certain systems experience channel change, and the nature of that channel change, is the critical power relationship (Bull, 1979). The critical power threshold is the ratio of the factors that if increased, favour erosion (stream power) to all the factors that if increased would favour deposition (defined as resisting power).

A key driver of erosional channel change is the stream power. As water flows downstream it loses energy, and the rate at which this energy is lost is known as stream power. Much of the energy lost is used to overcome the internal forces (i.e. viscous shear and turbulence) of the flowing water and the frictional resistance of the channel (channel roughness). The remainder is used to transport available sediment. If there is still excess energy, the channel boundary may begin to erode, and channel change is observed.

Specific stream power, or the energy available to do work on the channel boundary, is directly proportional to the discharge and the energy gradient (which can be approximated as the channel gradient) and is inversely proportional to the channel width. Specific stream power increases in a flood event as a result of increased stream flow. This increased stream power may be resisted by the vegetation and bed and bank material. Alternatively the channel can widen thereby reducing stream power to a level equivalent to the resisting power of any remaining vegetation and bed and bank material. The following text box provides a description of stream power.

Stream power terminology
Stream power is the rate of energy dissipation against the bed and banks of a river or stream. It is given by the equation:

$\Omega = \rho gQS$

where Ω is the stream power, ρ is the density of water (1000 kg/m3), g is acceleration due to gravity (9.8 m/s2), Q is hydraulic discharge (m3/s), and S is the channel slope.

Rhodes (1987) proposed that the term mean specific stream power (ω) refer to the stream power per unit wetted area of a defined channel given by the equation

$$\omega = \frac{\rho g Q S}{w}$$

where w = wetted perimeter of the channel and can be approximated to the channel width

This is the equation used within and the standard result output that can be produced by the HEC-RAS hydraulic modelling package used for this project.

For the purpose of this report we have adopted the term ‘specific stream power’ as it has been commonly applied, estimated using the above equation, and produced by the HEC-RAS hydraulic modelling software. The term ‘stream power’ used in this report is an abbreviated form of the term ‘specific stream power’.

The SI units for unit stream power as adopted for this report are W/m^2. These units are equivalent to N/ms, the standard form of output from HEC-RAS.

For the purpose of this report we have used the term (specific) stream power for the primary stream channel, excluding inundated floodplain areas unless stated otherwise.

This concept of specific stream power can be explored longitudinally down through a stream system. While a lowland stream reach will have higher peak flood flow rates than an upland reach on the same system, the extent to which the lowland reach will be subject to flood induced channel change will be a function of the extent to which the lowland reach is flatter and wider than the upstream reach. If the increase in flood flow is offset by a larger combination of reduced bed grade and increased channel width, we would expect to see a reduction in peak flood event specific stream power. Conversely if the combination of the decrease in bed grade and increase in channel width is less than the increase in stream flow we would find an increase in stream power in the downstream reach and the potential for an increase in flood related channel change. Typically we see a reduction in peak flood event specific stream power in a downstream direction once streams leave the confines of the bedrock gorges and upland regions. This is not universal and is dependent on the catchment geology, topography and climate.

However it is not just the magnitude of the stream power that can influence channel change. The duration of flood events also has the capacity to influence channel change. Flood events of long duration have capacity to do more work on a channel than events of similar magnitude but shorter duration. In effect the total stream power or work done on a stream channel in a flood event is the combination of the magnitude and duration of the stream power. Generally peak stream power is higher in the upper catchment; however flood events are normally shorter. Peak stream power in the lower catchment can be comparatively low however the duration of events is longer and considerable work can still be done on the channel boundary.

As outlined above the extent to which flood related stream power results in major erosion, is in part a function of the bed and bank material. Very high flood event stream power may occur regularly in steep mountain streams. However the presence of resistant bed and bank material such as bedrock may confine the system and limit the extent of gross channel change. For alluvial stream systems with limited valley confinement (bedrock controls) the resisting power is provided by bank material cohesion, bed material size, sediment supply and, importantly, vegetation.

As outlined above there are channel characteristics that can increase the predisposition of a stream to channel change. Kochel (1988) observed that streams which experience major geomorphic responses to floods typically have channel factors characterised by high channel gradients, abundant coarse substrate, relatively low bank cohesion and low width/depth ratios . This observation has been supported by many, including Fuller (2008), who noted that geomorphic impacts are typically greater in steep, narrow channels compared to broad, low-gradient valleys. However as also outlined below the extent of channel change is also influenced by vegetation.

2.3 The influence of vegetation on erosion

Erosion is a natural and essential process in alluvial systems; however human activities such as land clearing and stripping of riparian vegetation can result in accelerated rates of erosion resulting in damaging channel change. As discussed earlier there is a range of erosional processes that can occur independently or in unison resulting in channel change.

Riparian vegetation plays an important role in minimising the rates of erosion in each of these three erosional categories. However for each category different types of vegetation impact on the processes differently. Furthermore as highlighted by Abernethy and Rutherfurd (1998), the means by which different types of vegetation impact on erosional channel change is also dependant on the location within the catchment. A summary of how different vegetation types limit each of the three erosion categories is given in Table 1.

Table 1.Vegetation and its influence on each of the three erosional processes (adapted from Abernethy and Rutherfurd, 1998)

Erosion process	Vegetation interaction
Mass failure	Root reinforcement – Riparian trees strengthen bank substrate and tend to resist mass failure. The extent of reinforcement is dependent on root strength and the density of the root structure. The effect of the roots is to increase the effective cohesion of the sediments. The longer and more extensive the root network the greater the degree of reinforcement. As a result, smaller shrubs and grasses are less effective at limiting mass failure. (Abernethy and Rutherfurd 2000) Bank moisture – Saturated banks are less stable than unsaturated banks as water increases the weight of the bank, encouraging mass failure. All vegetation types decrease the level of bank saturation by intercepting precipitation and by transpiration (Abernethy and Rutherfurd 2000)
Fluvial scour	Resistance of bank material – Vegetation on the bank increases cohesion and bank strength through the root networks. Smaller shrubs and grasses, which have limited impact on mass failure processes, are more effective at limiting the ability of bank sediments to be entrained due to their more extensive coverage of the bank surface area (Blackham 2006). Near bank velocities – Vegetation increases hydraulic roughness, which reduces near bank velocities. The shear force exerted against the bank is thus reduced. The impact of vegetation on hydraulic roughness is complex and varies with type of vegetation and discharge. At low flow, grasses and shrubs that stand rigid have a high wetted surface area and provide hydraulic resistance (Blackham 2006). As discharge increases, the herbaceous vegetation often cannot withstand the force and is flattened against the bank. Hydraulic resistance is reduced but the vegetation protects the bank substrate from erosion (Abernethy and Rutherfurd 1999). Large trees provide minimal resistance during low flow but as discharge increases their large trunks and branches provide the majority of the resistance once the herbaceous vegetation has been flattened.
Sub-aerial preparation	Piping – Seepage of water can lead to leeching and softening of the bank material making the bank more susceptible to mass failure. Vegetation can reduce the onset of saturated flow through evapotranspiration. However, cavities from decomposed roots can encourage subsurface flow. The risk of this can be reduced with an appropriate suite of riparian vegetation. Desiccation – Dry and cracking banks are more susceptible to mass failure. Vegetation can reduce desiccation by binding the substrate together. (Wynn and Mostaghimi 2006).

Importantly, and as outlined in Table 1, for these different forms of erosion, vegetation plays two critical roles in limiting channel change:

1. Hydraulic (frictional) resistance: According to Anderson and Rutherfurd (2003) riparian vegetation adds additional resistance elements in the main channel and on the floodplain of waterways such that flow velocity and conveyance are reduced. As a result:
    - In-channel stream power is lower in vegetated reaches compared to systems with bare banks, and
    - near bank stream velocity is lower in vegetated reaches compared to systems with bare banks .
    - Flood wave speed is also reduced through vegetated channel networks.
2. Structural protection to the stream bank: The vegetation provides structural reinforcement to the bank material increasing the cohesive properties of the soil.

Single vegetation species such as large trees or ground cover grasses will not provide for these diverse roles provided by vegetation and as a consequence are not the most effective controls to limit erosion and downstream flood wave speed. Large trees may provide some structural reinforcement to the stream bank, but do not reduce the near bank stream velocity. Grasses can provide a physical barrier between water and the soil, but do not provide deep structural support, nor lower overall stream velocity. A suite of vegetation types is required to provide for both the hydraulic resistance and structural protection to the streambank. Such a suite of vegetation includes instream vegetation, stream bank ground covers, shrub species and trees. This suite of vegetation is typical of the O'Connell River remnant native riparian vegetation community.

2.4 Relevance to this study

This study will help Reef Catchments identify where along the O'Connell River erosion and sediment export in future flood events is most likely. An understanding of both the distribution of stream power along the river and the ability of the system to resist erosion is required. An overview of the analyses and tools used in this assessment are:

- **Assessment of factors that drive erosion**
    - Hydraulic modelling to assess the in-channel stream power for a range of flood events
    - Analysis of aerial imagery and historic and contemporary LiDAR datasets to assess past and potential future floodplain flow paths that may result in floodplain erosion
- **Assessment of factors that resist erosion**
    - Analysis of aerial imagery, historic and contemporary LiDAR datasets and targeted field inspections to assess the bed and bank strength including riparian vegetation condition.
    - The degree of valley confinement to determine the capacity for lateral adjustment. The distribution, spatial extent and erodibility of terraces were assessed through analyses of LiDAR data and field inspections.
    - A visual assessment of the quality and extent of vegetation at targeted sites through the system

The following section provides a brief overview of the method used in this study.

3 Method

A range of tools were available to assess the stability of the O'Connell River. A brief summary of these tools and methods used in this assessment is presented below.

Aerial imagery analysis
High resolution aerial imagery was captured in early 2014 of the main stem of the O'Connell River. From the imagery riparian and floodplain vegetation condition, channel width and planform was estimated.

Terrain modelling
LiDAR data was commissioned by Reef Catchments in early 2014. From this data a Digital Elevation Model (DEM) was created with a one metre grid size. The 2014 DEM could then be compared to a 2010 LiDAR data derived DEM supplied by the Queensland state government. From the 2010 and 2014 DEMs a DEM of Difference (DoD) was developed (Figure 5). A DoD identifies changes in ground surface elevation from two LiDAR datasets captured at different points in time. From the DoD the volume of sediment eroded from the bed or banks at a specific location or the distance of bank migration can be estimated.

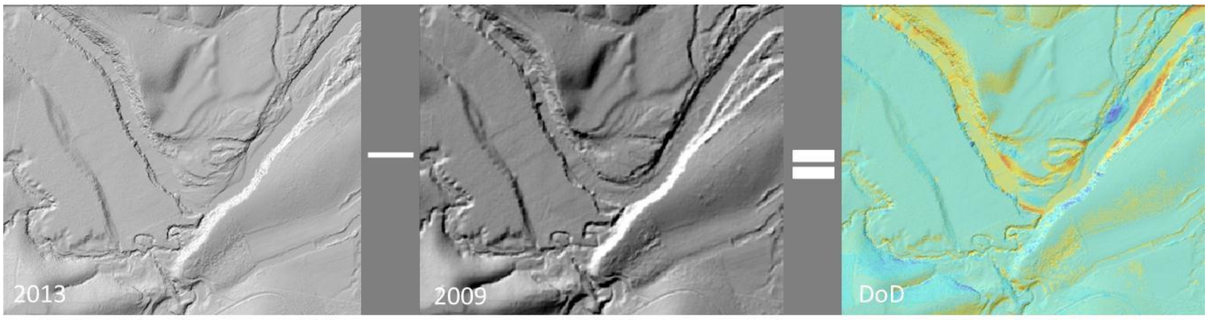


Figure 5. *Example of how DEM of Difference (DoD) is created from two LiDAR datasets. In the DoD at the far right yellow and orange displays a drop in elevation indicating erosion has occurred. Blue displays an increase in elevation indicating deposition.*

Other key parameters that were estimated from the DEM were the longitudinal streambed profile and bank angle and height. Oversteepened sections of streambed or sudden changes in bed profile (i.e. knick points) can help identify zones of instabilities while high, oversteepened banks are less resistant as the gravitational forces that drive mass failure are greater.

One-dimensional hydraulic modelling
A one-dimensional HEC-RAS hydraulic model of the O'Connell River was developed using the 2014 DEM to describe the channel morphology. The hydraulic model generates a relationship between flow and stream power throughout the system. Peak flow rates for various design events were estimated from gauged data and the Rational Method (Appendix A) and used as upstream boundary conditions for the hydraulic model. The hydraulic model estimates stream power throughout the study area, which can be used in conjunction with an assessment of bed and bank resistance to identify zones that may be at risk to future erosion or channel aggradation. The hydraulic modelling utilised in this assessment provided a higher level assessment of stream power at the reach scale and not of the level of detail required to assess the stream power at a particular site (i.e. an outside meander).

Field inspections
To supplement and confirm findings from the desktop analysis targeted field inspections were also undertaken by Ross Hardie and Misko Ivezich (Alluvium). The purpose of the field inspections was to assess the dominant geomorphic processes and likely future trajectory of the river. Observations relating to geomorphic forms and processes, and riparian and instream vegetation condition and structure were made to supplement our findings from the desktop assessments.

4 System scale assessment outcomes

This section provides a brief overview of some of the system-wide outcomes from the assessments undertaken for this investigation. The overview covers reach delineation, bed grade assessment and stream power assessment. More detailed reach scale outcomes and interpretations are provided in Section 5.

4.1 Overview of geomorphic form

For the majority its length the O'Connell River flows through a partly confined valley setting. Within a partly confined setting the lateral adjustment of the river is 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. In many locations terraces are perched above the active floodplains. These terraces are former floodplains abandoned due to changes in base level (decrease in sea level or tectonic uplift) or shifts in sediment and flow regimes which resulted in downcutting.

Within the O'Connell River the channel (streambed) abuts either

- An alluvial floodplain
- A terrace
- The bedrock valley margin

Each different unit can have a different composition and as a result a different erodibility. A conceptual diagram of a typical valley cross-section with each different major geomorphic unit is shown in Figure 6.

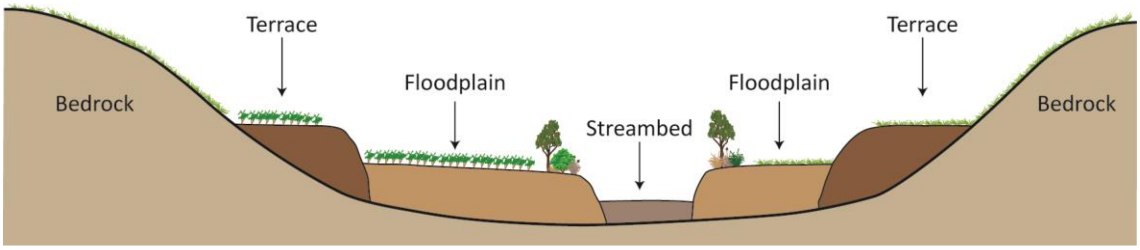


Figure 6. *Conceptual diagram of a typical valley cross-section within the O'Connell River showing bedrock valley margins, terraces, floodplain and stream bed*

While there were differences between the reaches we typically found:

- The **bedrock** to be highly resistant to erosion and form an effective boundary that confines the bed and bank of the river.
- The **terraces** to be comprised of a red sandy clay that was relatively resistant to erosion and limited the lateral migration of the river
- The **floodplain** material to be composed of fines, sands, gravels and cobbles and in the absence of stabilising vegetation to have low resistance to erosion and provide limited control on the movement of the river system
- The **streambed** to be armoured with large gravels and cobbles, providing a control on the vertical movement (incision) of the stream system. The streambed also contained bedrock bars in locations where the streambed abutted the valley margins (bedrock).

Based on the valley setting and the floodplain/terrace configuration we have divided the O'Connell River into five reaches:

- **Reach 1**- Extends from Dingo Creek confluence to the sea. Channel abuts both active floodplain and terraces.
- **Reach 2** - -Extends from a point two hundred metres downstream of the Boundary Creek confluence to the Dingo Creek confluence. The channel abuts the valley margins and a terrace – there are no areas of active floodplain.
- **Reach 3** –Extends from Horse Creek confluence to two hundred metres downstream of the Boundary Creek confluence. Floodplain of varying width abuts the channel through most of the reach, in some location one side of the channel occasionally abuts the valley margins or a terrace.
- **Reach 4** –Extends from Cathu-O'Connell River Road to Horse Creek confluence. Floodplain of varying width abuts the channel through most of the reach however the apex of meanders often abuts the valley margins or a terrace.
- **Reach 5** –Extends from the headwaters to Cath-O'Connell River Road. Channel migration is confined by the valley margins however there are still large areas of floodplain.

The five reaches delineated for this study are presented in Figure 7.

4.2 Longitudinal streambed grade assessment

Longitudinal bed grade assessments can help identify over steepened reaches and sections of stream susceptible to instabilities. They can also help determine the bed grade in stable reaches which can then be used as a template for restoration. The longitudinal bed grade within the O'Connell River ranges from 0.0003 m/m upstream of the estuary to 0.011 m/m towards the headwaters (Figure 8).

There is a general trend of a decreasing bed grade moving down the catchment. There are two out of character short steep changes in gradient at chainage 16,000 m and 10,000 m. The first of these (Ch 16,000m) is a bedrock control which extends across the channel as the systems transitions from Reach 3 to Reach 2 which is confined by the valley margin and a terrace. The second (Ch 10,000m) occurs approximate 3 km downstream of Reach 2 as the system enters the less confined lower catchment (Reach 1). As the system transitions from Reach 2 to Reach 1 there is a large reduction in sediment transport capacity which results in significant channel aggradation. The abrupt change in gradient at Ch10,000 m is at the downstream extent of the coarse sediment deposits, associated with this aggradation. We did not find any evidence that the abrupt change in gradient at Ch10,000 was associated with a bedrock outcrop.

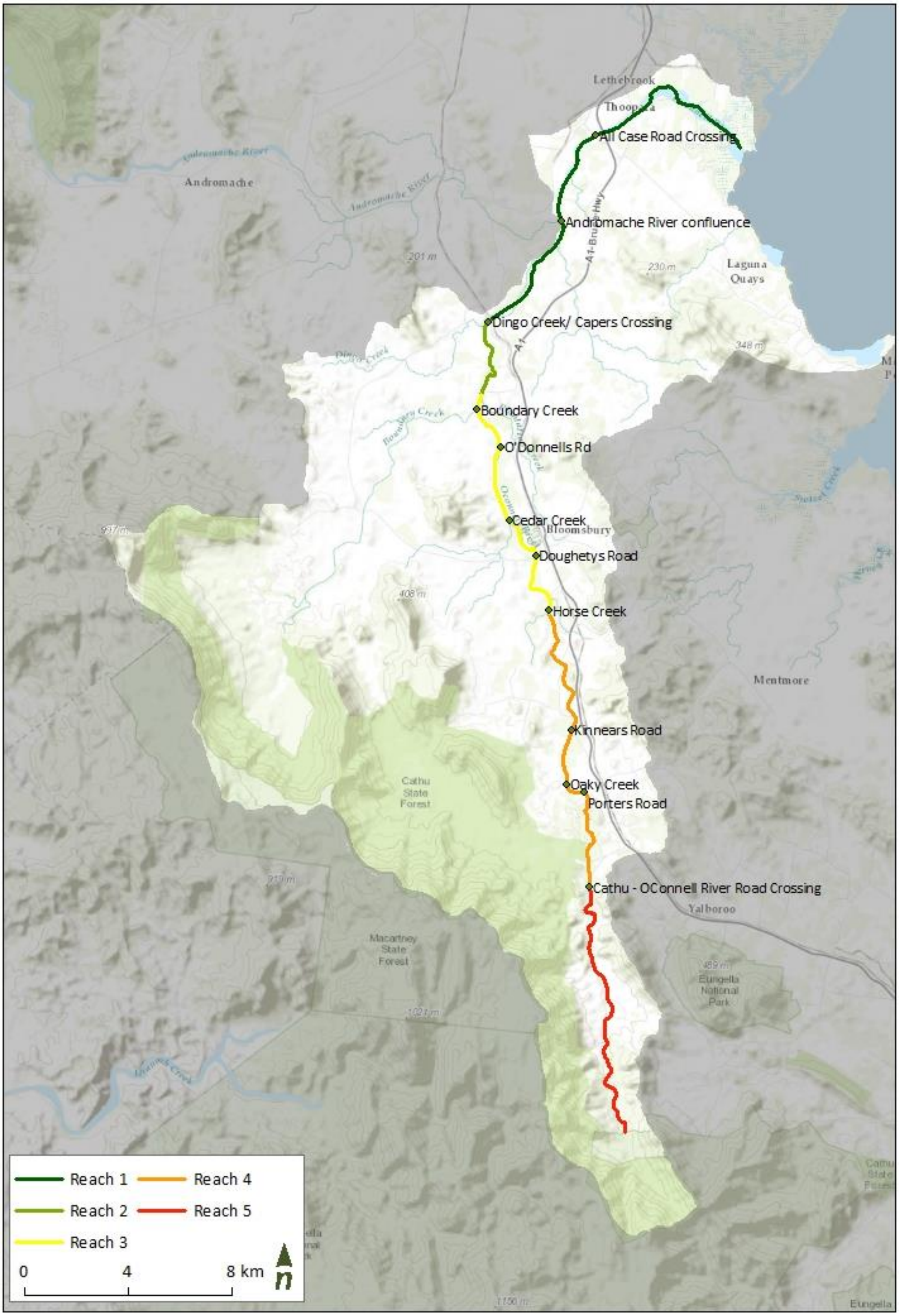


Figure 7. *The five reaches delinated along the O'Connell River*

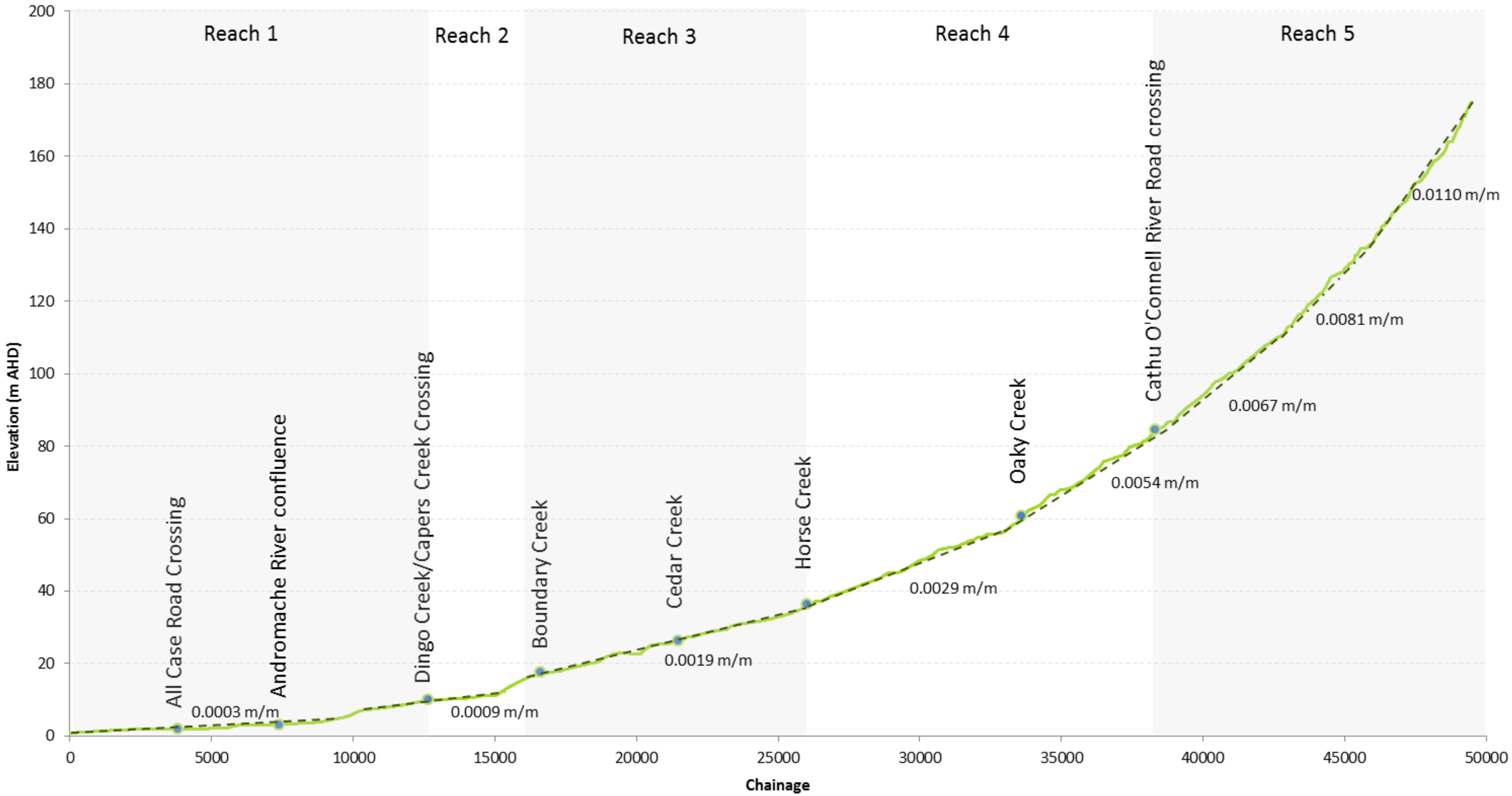


Figure 8. *Longitudinal bed grade along the O'Connell River*.

4.3 Stream power assessment

Streams with steep and narrow channels have a greater predisposition to channel change than broad and low-gradient systems (Fuller, 2008). Unfortunately these factors cannot be easily compared between river systems as they are a function of the flow regime, which is related to the catchment's rainfall, size, shape and morphology.

Previous investigations have identified a relationship between the two and fifty year ARI specific stream power within a system and the potential or predisposition for channel change within that system (Alluvium, 2011, Hardie 2005, Bledsoe 2002). The two and fifty year ARI specific stream power provides a standardised, comparable metric that helps identify reaches of stream that may be predisposed to channel change (i.e. they are steeper and narrower).

Alluvium has compiled a database of alluvial stream systems which assessed the extent of channel change following flood events, riparian vegetation condition and the stream power in the two and fifty year ARI events. We have identified stream power reference values for the two and fifty year ARI events of 60 W/m² and 150 W/m² respectively. When the two and fifty year ARI event stream power is above these reference values we have found increased incidence of instabilities associated with flood events if there is limited ability to resist the excess energy. These reference values are a guide only and will vary for different systems. Crucially these values will be highly dependent on the riparian vegetation condition. For instance we have found in streams with a two year ARI stream power of between 60 and 100 W/m² the presence of remnant standard riparian vegetation can provide the critical resistance to channel change during flood events (Alluvium, 2011). However we have also found that the establishment of native vegetation is very difficult with instream stream power in excess of 60 W/m².

The results for the two and fifty year stream power assessment are presented in Figure 9 and Figure 10. Average stream power in each reach is presented in Table 2. The stream power results give reveal where excess energy is likely to be dissipated against the channel boundary. The erodibility of the channel substrate will govern the scale of any channel change. From these results the stream power in Reach 1 and Reach 3 is in the range where the establishment of remnant standard riparian vegetation would have a high likelihood of success and could significantly reduce stream bank erosion.

The stream power results also give an indication of the sediment transport capacity of the system. Where there is a sudden change in stream power there is likely to be a sediment transport imbalance which can result in instabilities. The stream power results are interpreted for each reach in Section 5.

Table 2. Reach average peak stream power for the two and fifty year ARI event stream power

	Reach average 2 year ARI stream power (W/m²)	Reach average 50 year ARI stream power (W/m²)
Reach 1	62	147
Reach 2	253	506
Reach 3	77	124
Reach 4	139	234
Reach 5	471	873

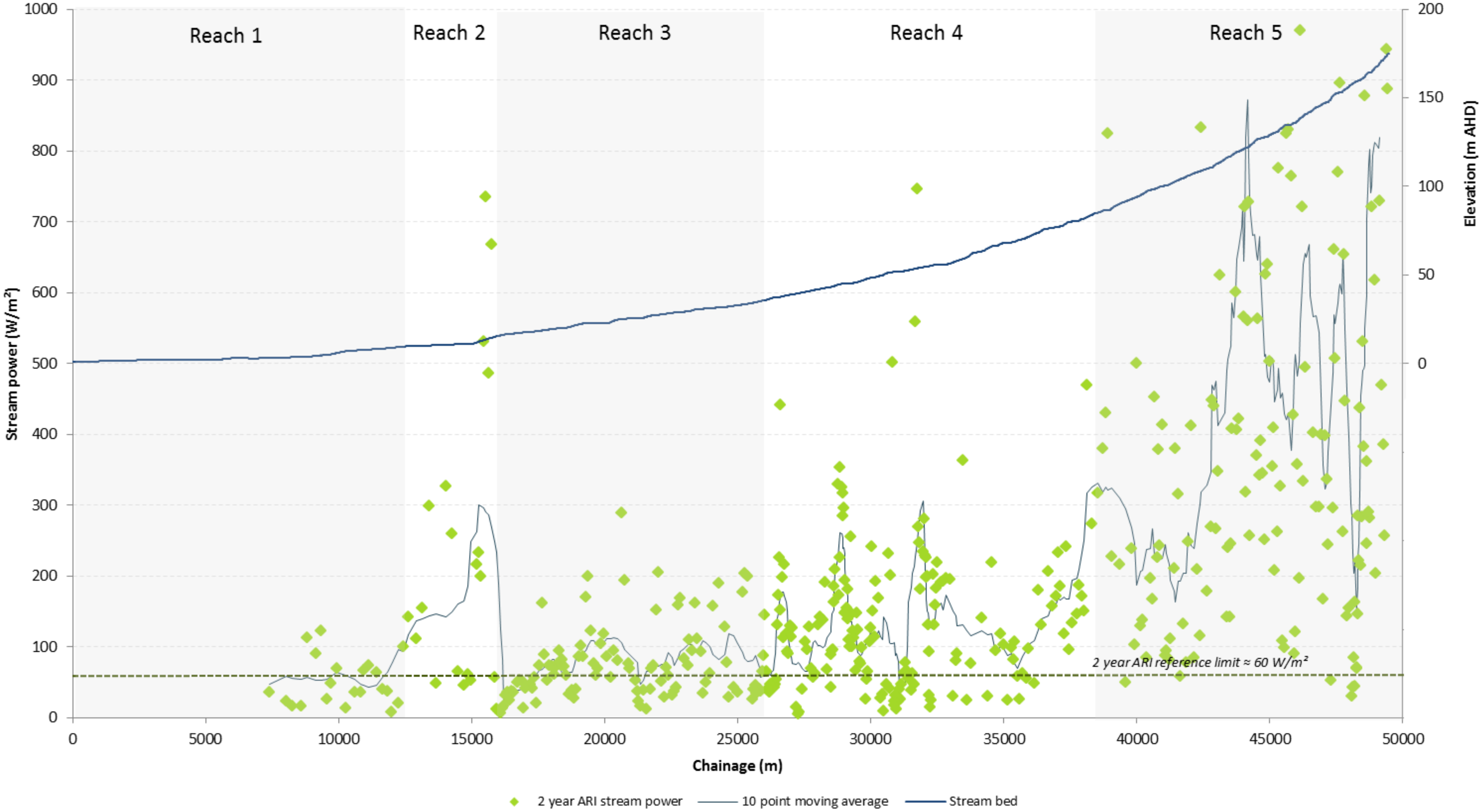


Figure 9. *Results from the two year ARI stream power assessment along the O'Connell River along with the reference value – hydraulic model only extend upstream of the Andromache confluence*

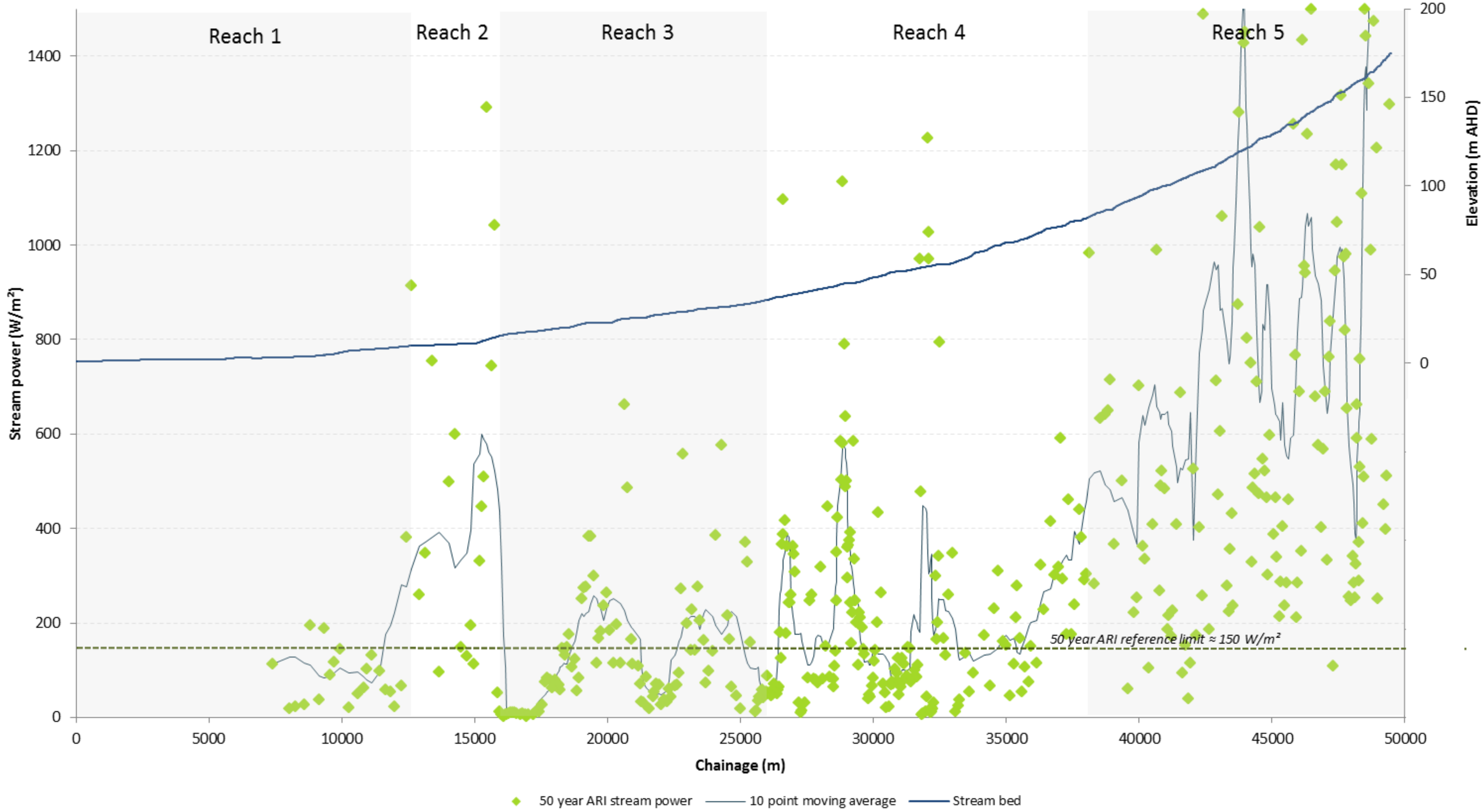


Figure 10 . *Results from the fifty year ARI stream power assessment along the O'Connell River along with the reference value - hydraulic model only extend upstream of the Andromache confluence*

5 Reach-scale findings

5.1 Reach 1

Reach 1 extends from the Capers Crossing to the mouth of the O'Connell River at Laguna Quays (Figure 11). The channel abuts active floodplain, terraces and the bedrock valley margins throughout this reach (Figure 12). The terraces and floodplains are predominately used for sugarcane cultivation. The system is a gravel bed stream at the upstream end of the reach and transition to predominantly sandy bed system closer to its mouth. Floodplain deposits consist of a mix of sand, silts and clays. Key findings from the stability assessment include:

- The peak event stream power through Reach 1 is on average just below the reference values, however there are some areas where the reference values are exceeded.
- The reach is at the downstream end of the catchment and as a result the duration of flood events is likely to be longer than reaches upstream; as result there is still likely to be significant work done on the channel boundary during flood events.
- There is a major reduction in stream power between Reach 2 and Reach 1 resulting in a reduction in sediment transport capacity and a zone of channel aggradation at the upstream extent of the reach.
- The downstream extent of the zone of aggradation is identifiable in the longitudinal profile where there is a transition from a gradient of 0.009 m/m to 0.003 m/m.
- Significant channel change has recently occurred through this zone resulting in over 100,000 m^3 of sediment loss through bank erosion processes (Figure 13).
- The channel change is the result of meander development as the river reworks the coarse sediment deposits and creates a defined low flow path. During this process, bank erosion along the active floodplain has resulted in significant sediment loss. The large volume of sediment loss is partly due to the height of bank which is 6- 8 m (Figure 14 and Figure 15).
- There was minimal sediment loss where the channel abuts the terraces.
- The major erosion sites in this reach released approximately 170,000 m^3 from floodplain deposits. The total sediment released from floodplain deposits is likely to have been considerably higher than this figure due to the additional minor stream bank erosion throughout the reach.
- The reach has been cleared for agriculture and has limited extent and quality of native riparian vegetation
- Ongoing bank erosion of the floodplain material is likely in this zone due to the over steepened banks and limited extent and quality of riparian vegetation. This erosion is likely to result in significant ongoing sediment release and threaten land used for sugarcane cultivation.
- The reach is in close proximity to the estuary and coast and as a consequence would have a high delivery of fine material (sediment and attached nutrients) to the coast.

Figure 11. *Aerial imagery captured in 2014 of Reach 1*

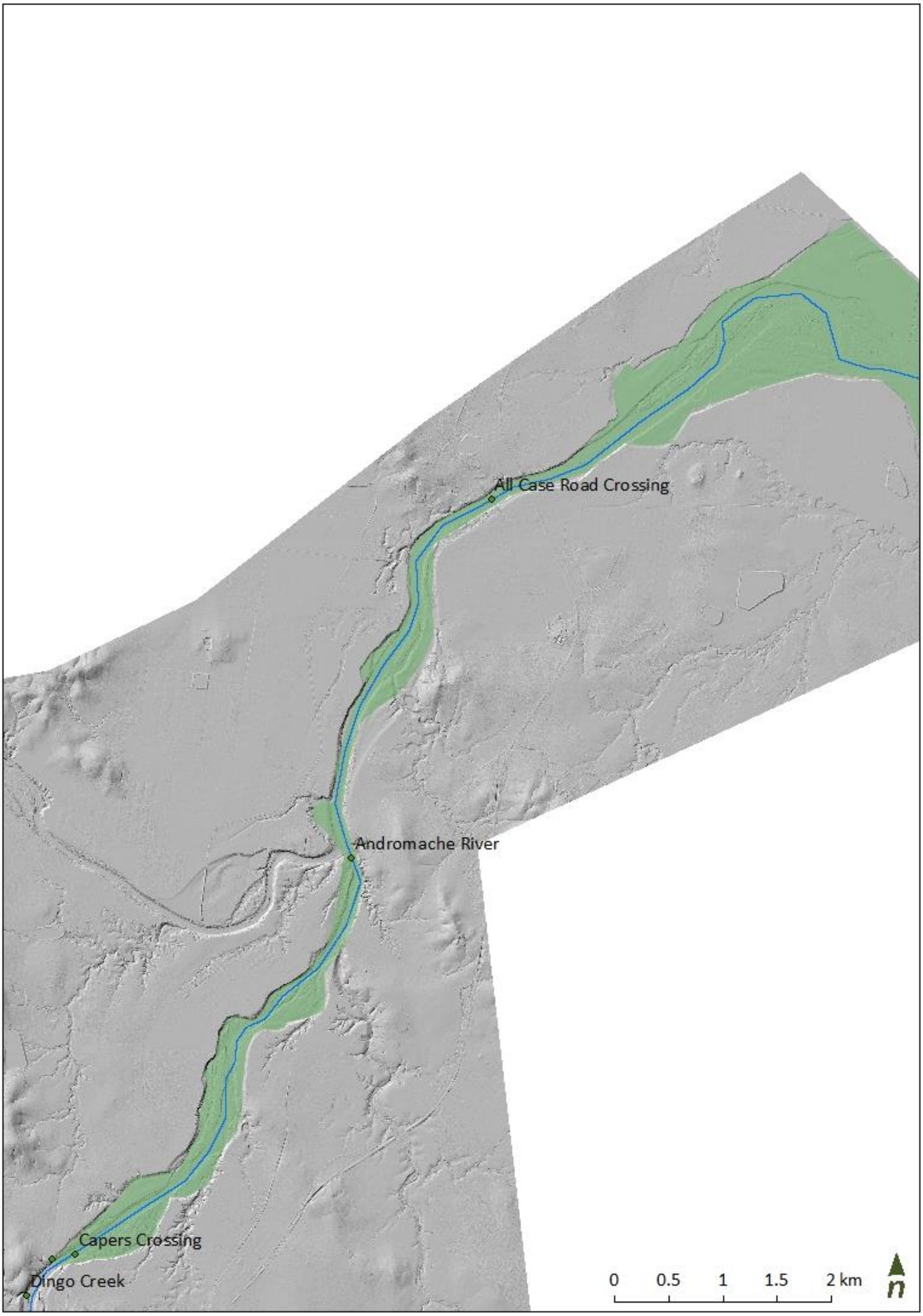


Figure 12. *Area of active floodplain (green) within Reach 1(note: valley confinement comprising both terrace and bedrock material shown in grey)*

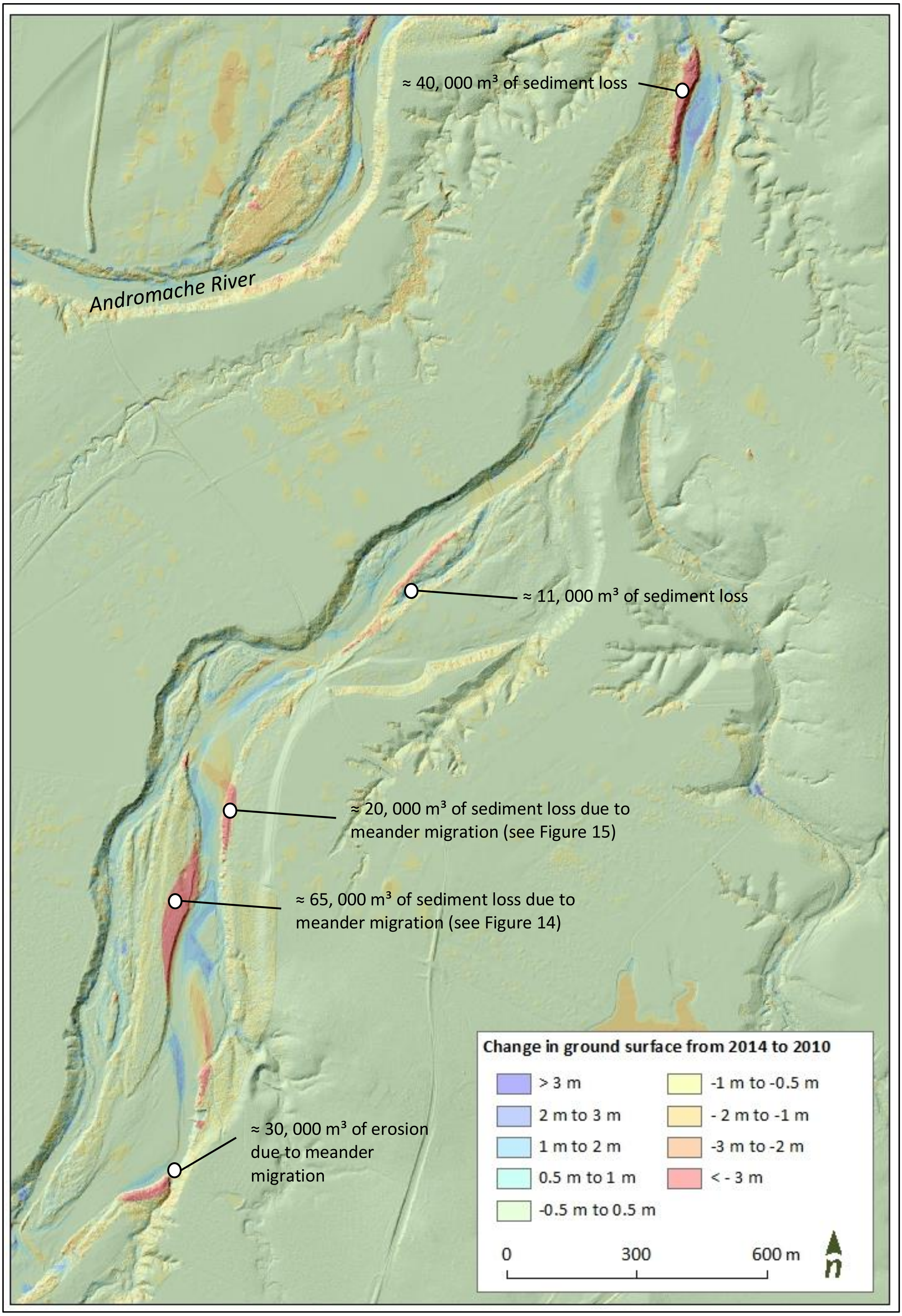


Figure 13. *Changes in elevation between 2014 and 2010 included estimates of sediment loss in the area upstream of the Andromache River confluence*.

Figure 14. *Looking across river toward left bank which has undergone meander migration. Approximately 65,000 m³ of sediment was eroded from this bank between 2010 and 2014. The bank substrate was sandy with some fines.*

Figure 15. *Looking downstream along the eroded right bank. Approximately 20,000 m³ of sediment was eroded from the bank between 2010 and 2014. The bank substrate had a higher clay content then the opposite bank.*

5.2 Reach 2

Reach 2 extends from a point two hundred metres downstream of the Boundary Creek confluence to the Dingo Creek confluence (Figure 16). The channel abuts the valley margins and a terrace – there are no areas of active floodplain (Figure 17). No site inspections were undertaken during this assessment however the key findings from the desktop assessment revealed:

- The peak event stream power through this reach is very high indicating a high sediment transport capacity.
- A large bedrock outcrop at the upstream end of the reach creates a steepening of the bed grade and limits any vertical adjustment.
- Significant volumes of sediment are stored in large point bars within the channel. Sediment in these deposits is likely to be mobilised, transported and subsequently deposited further downstream during flood events.
- There was minimal sediment loss from banks within this reach with only one major erosion site identified which generated 7,000 m^3 of sediment (Figure 17).
- The terraces within this reach appear to have a high resistance to erosion.
- Reach 2 is unlikely to be a source of large volumes of fine grained sediment from bank erosion processes in future flood events. However large volumes of sediment are likely to be transported through Reach 2 to Reach 1 via bedload and suspended load transport processes.

Figure 16. *Aerial imagery captured in 2014 of Reach 2*

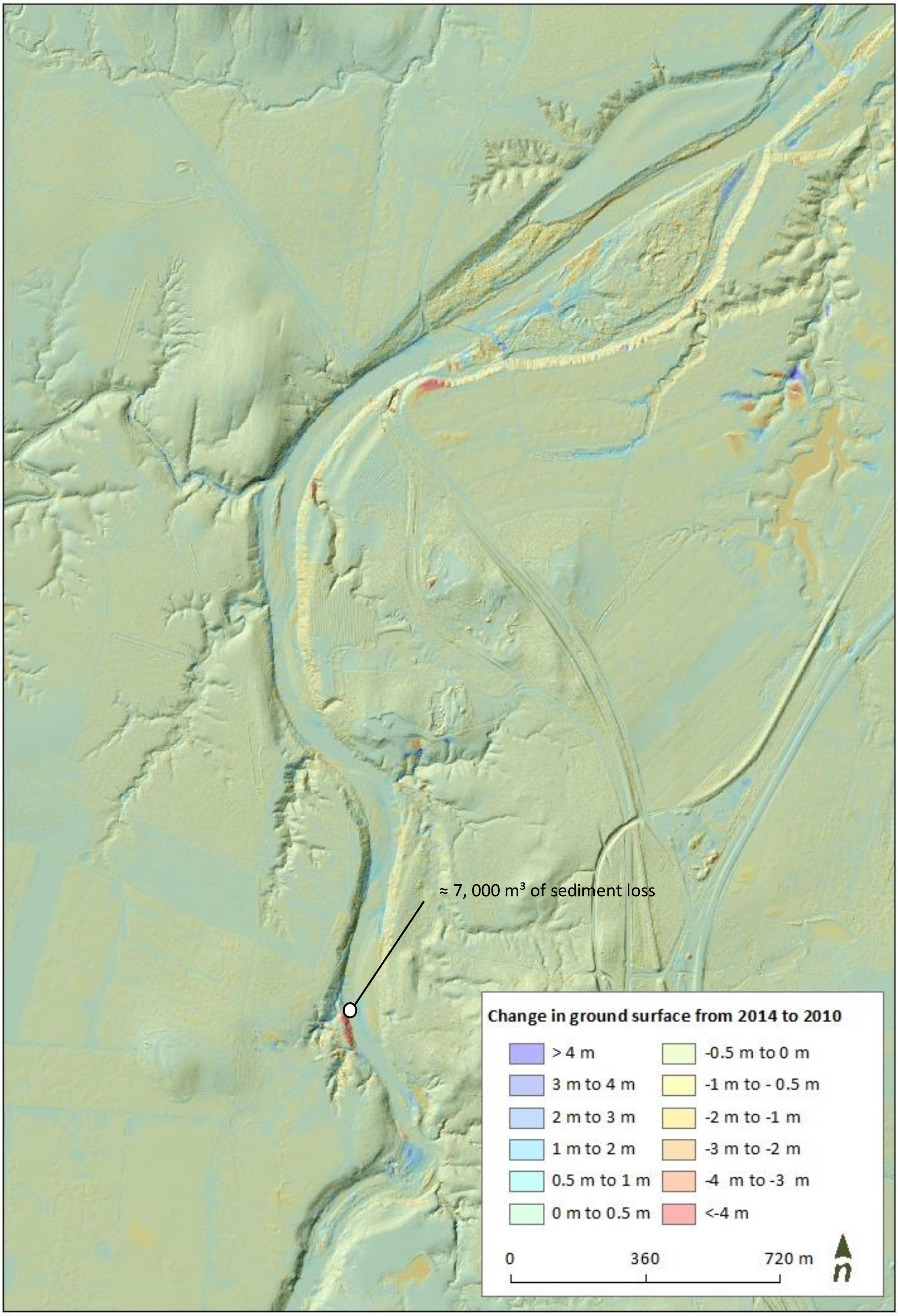


Figure 17. *Changes in elevation between 2014 and 2010 included estimates of sediment loss at the only site which had major erosion*

5.3 Reach 3

Reach 3 extends from Horse Creek to two hundred metres downstream of the Boundary Creek confluence (Figure 18). The floodplain is typically several hundred metres wide with a low sinuosity cobble bed channel. There are some localised areas where the floodplain width is limited and the channel is confined by terraces or the valley margin (Figure 19). The floodplain and terraces are predominately used for sugarcane cultivation however there are also some small areas used for grazing. Key findings from the stability assessment include:

- The reach average peak stream power for the two year ARI event is slightly above reference values for much of the reach. For the fifty year event there are two distinct zones where the stream power exceeds reference values.
- Within this reach there were multiple locations of major bank erosion which resulted in significant soil loss (see Figure 20, Figure 21 and Figure 22).
- The bank erosion predominately occurred where the channel abuts sections of floodplain which has a high fraction of fine grained sediment which is likely to be transported to the marine environment.
- The major stream bank erosion sites in this reach released approximately 50,000 m^3 from floodplain deposits. The total sediment released from floodplain deposits is likely to have been higher than this volume due to minor stream bank erosion throughout the reach.
- The sites which contributed the greatest soil loss were on the outside of bends (see Figure 20). The erosion at these sites was due to meander migration – the downstream progression of meanders over time.
- Bedrock controls within this reach limit the ability for any vertical adjustment.
- Ongoing meander migration is likely at a number of locations – particularly in the area upstream of Boundary Creek.
- Active floodplain areas without remnant standard riparian vegetation are likely to be significant sources of sediment in future flood events.
- Reef Catchments have recently undertaken revegetation programs along section of floodplain within this reach (Figure 26). Once the vegetation is established these works are likely to increase resistance to erosion in these areas.
- Agricultural land on floodplain areas without remnant standard riparian vegetation are under threat from erosion in future flood events.

Figure 18. *Aerial imagery captured in 2014 of Reach 3*

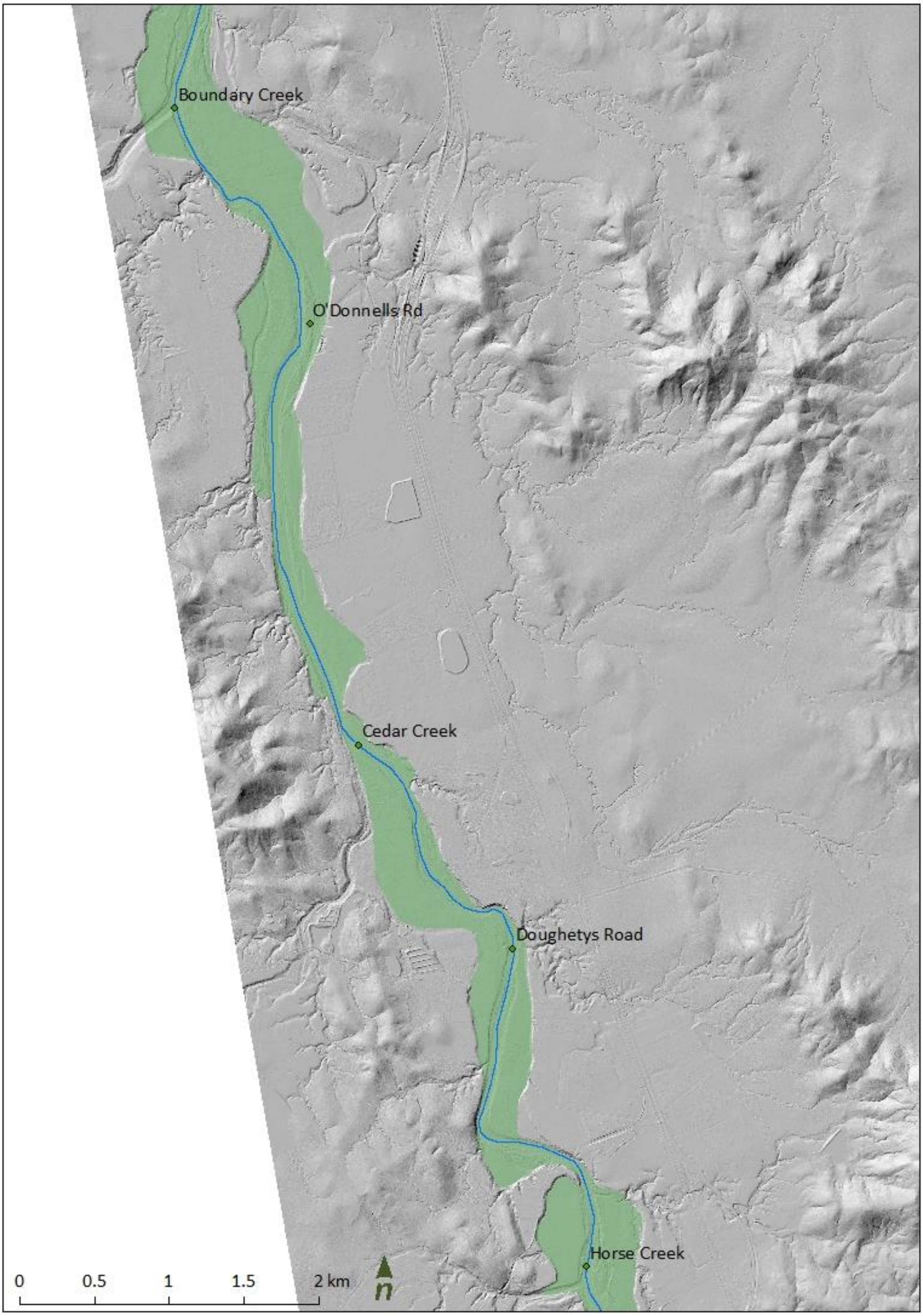


Figure 19. *Area of active floodplain shown by green shading within Reach 3*

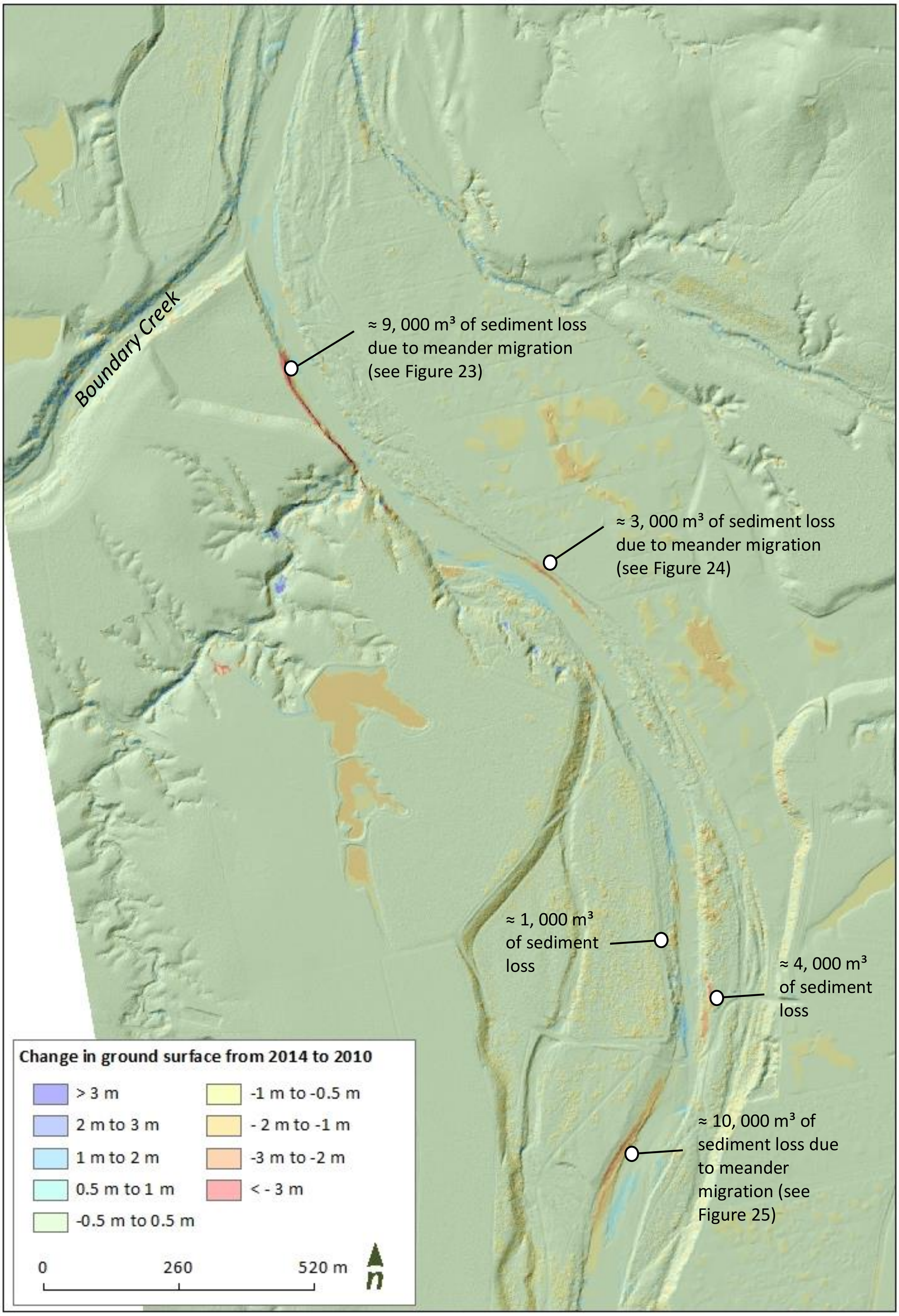


Figure 20. *Changes in elevation between 2014 and 2010 included estimates of sediment loss at major erosion sites in the lower area of reach 3 near the Boundary Creek confluence*

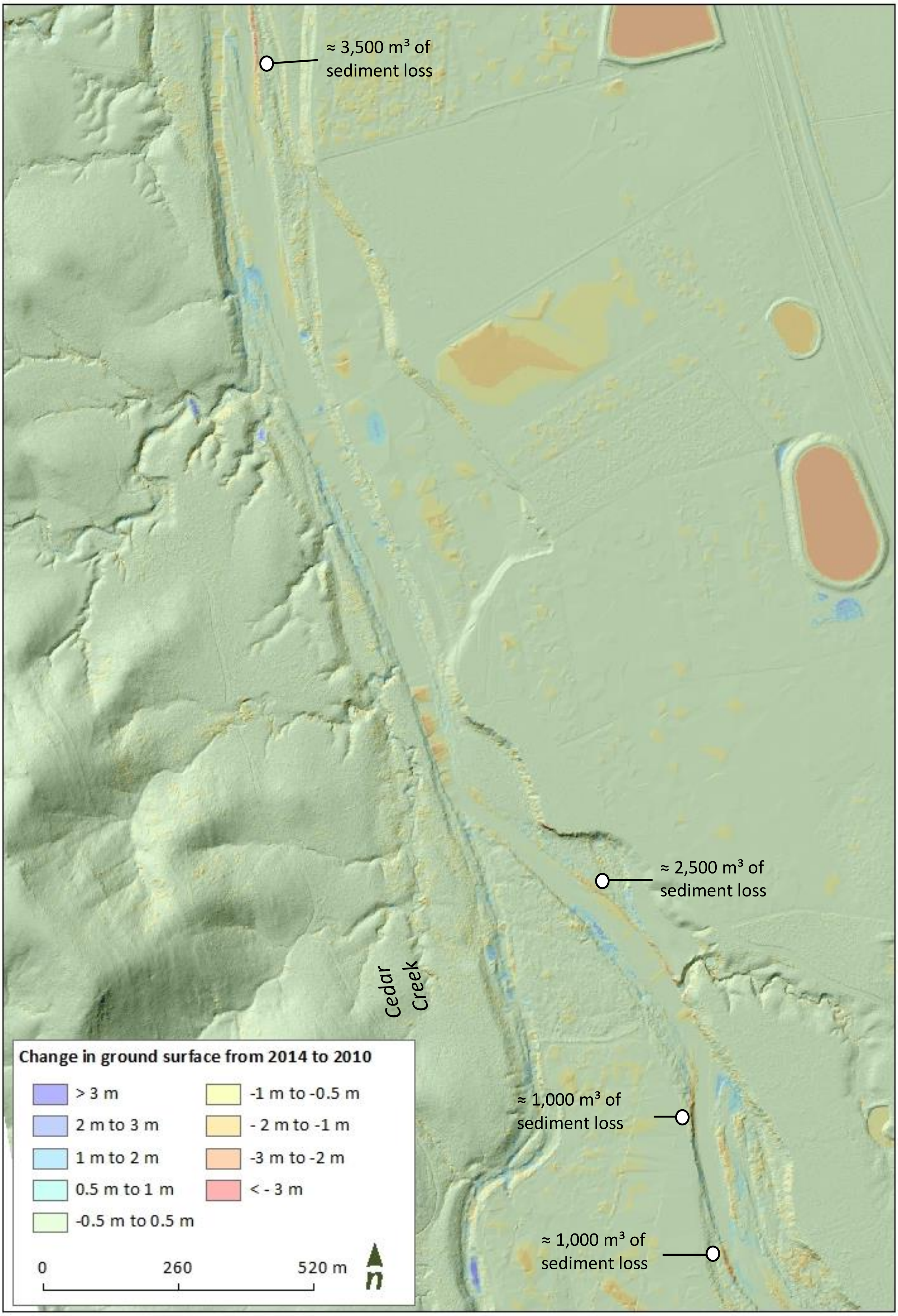


Figure 21. *Changes in elevation between 2014 and 2010 included estimates of sediment loss at major erosion sites in the mid area of Reach 3 near the Cedar Creek confluence*

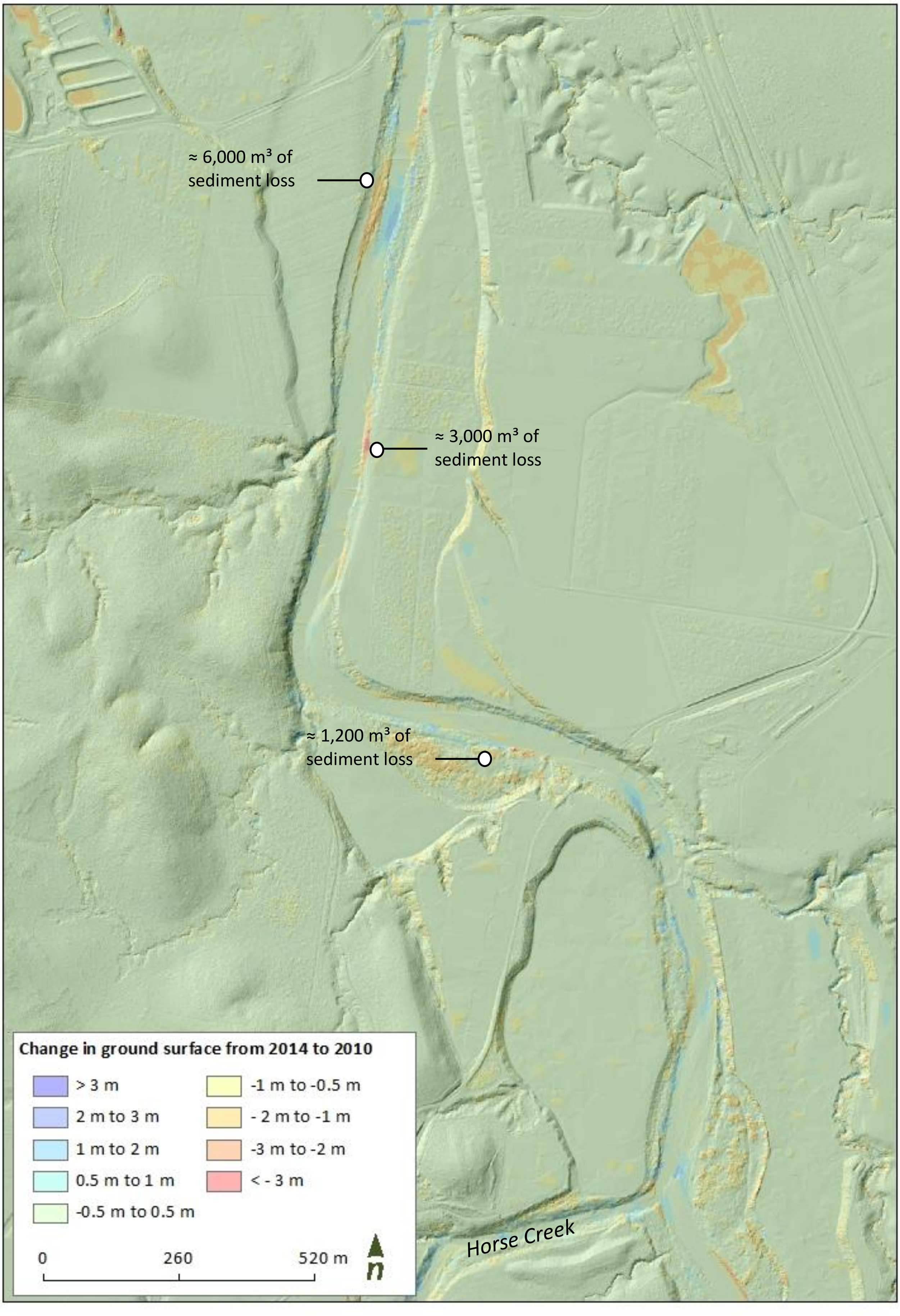


Figure 22. *Changes in elevation between 2014 and 2010 included estimates of sediment loss at major erosion sites in upper Reach 3 near the Horse Creek confluence*

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Figure 23. *Looking across at the left bank immediately upstream of the Boundary Creek confluence – terrace to the left of the image and active floodplain to the right. This site has contributed 9, 000 m ³ of sediment loss between 2010 and 2014.*

Figure 24. *Looking downstream along the right bank located 1.5 km upstream of the Boundary Creek confluence. Site is subject to meander migration. This site has contributed 3,000 m ³ of sediment loss between 2010 and 2014.*

Figure 25. *Looking across at the right bank near O'Donnells Road. Site is subject to meander migration. This site has contributed 3,000 m ³ of sediment loss between 2010 and 2014.*

Figure 26. *Section of floodplain which has recently been revegetated by Reef Catchments in Reach 3*

5.4 Reach 4

Reach 4 extends from Cathu – O'Connell River Road crossing to the Horse Creek confluence (Figure 27). The floodplain within this reach is variable but can be up to 800 m wide (Figure 28). The channel also abuts terraces or the valley margins in a number of locations. The channel has a low sinuosity and a cobble bed. The floodplain and terraces are predominately used for sugarcane cultivation at the downstream end of the reach, while grazing is more prevalent at the upstream end. This change in land use is likely a reflection of the greater proportion of fine grained sediments in the downstream floodplains. Key findings from the stability assessment include:

- The reach average peak stream power for the two and fifty year ARI event is significantly above the reference values.
- In the streams current alignment there is limited capacity for meander migration as the apex of the meanders generally abuts the valley margins or a terrace (Figure 28).
- Terraces were predominately fine grained material which had a higher resistance to erosion compared to the floodplain substrate. However, in some locations erosion of terrace material has contributed significant sediment loads in recent years (Figure 30).
- The majority of sediment loss occurred where the channel abuts the floodplain (see Figure 29, Figure 30, Figure 31 and Figure 32)
- A floodplain flow path which could develop into a meander cutoff was identified near the Porters Road Crossing (see Figure 31). The floodplain currently has relatively good vegetation coverage and no scour was observed in the recent years.
- There is a large reduction in stream power between Reach 4 and Reach 5 resulting in a reduction in sediment transport capacity and a zone of channel and floodplain aggradation at the upstream end of the reach immediately downstream of the Cathu- O'Connell River Road crossing (Figure 32).
- The major erosion sites in this reach released approximately 45,000 m^3 from floodplain and terrace deposits. The total sediment released from floodplain deposits is likely to have been considerably higher than this volume due to minor stream bank erosion throughout the reach.
- The stream banks in this zone of aggradation are particularly vulnerable as the river reworks the coarse sediment deposits to create a defined low flow channel.
- Active floodplain areas without significant remnant riparian vegetation are likely to be significant sources of sediment in future flood events.
- Engineered log jams recently constructed by Reef Catchments near the upstream extent of the reach have reduced the rate of bank erosion, promoted some deposition and created scour holes for fish habitat (Figure 36).

Figure 27. *Aerial imagery captured in 2014 of Reach 4*

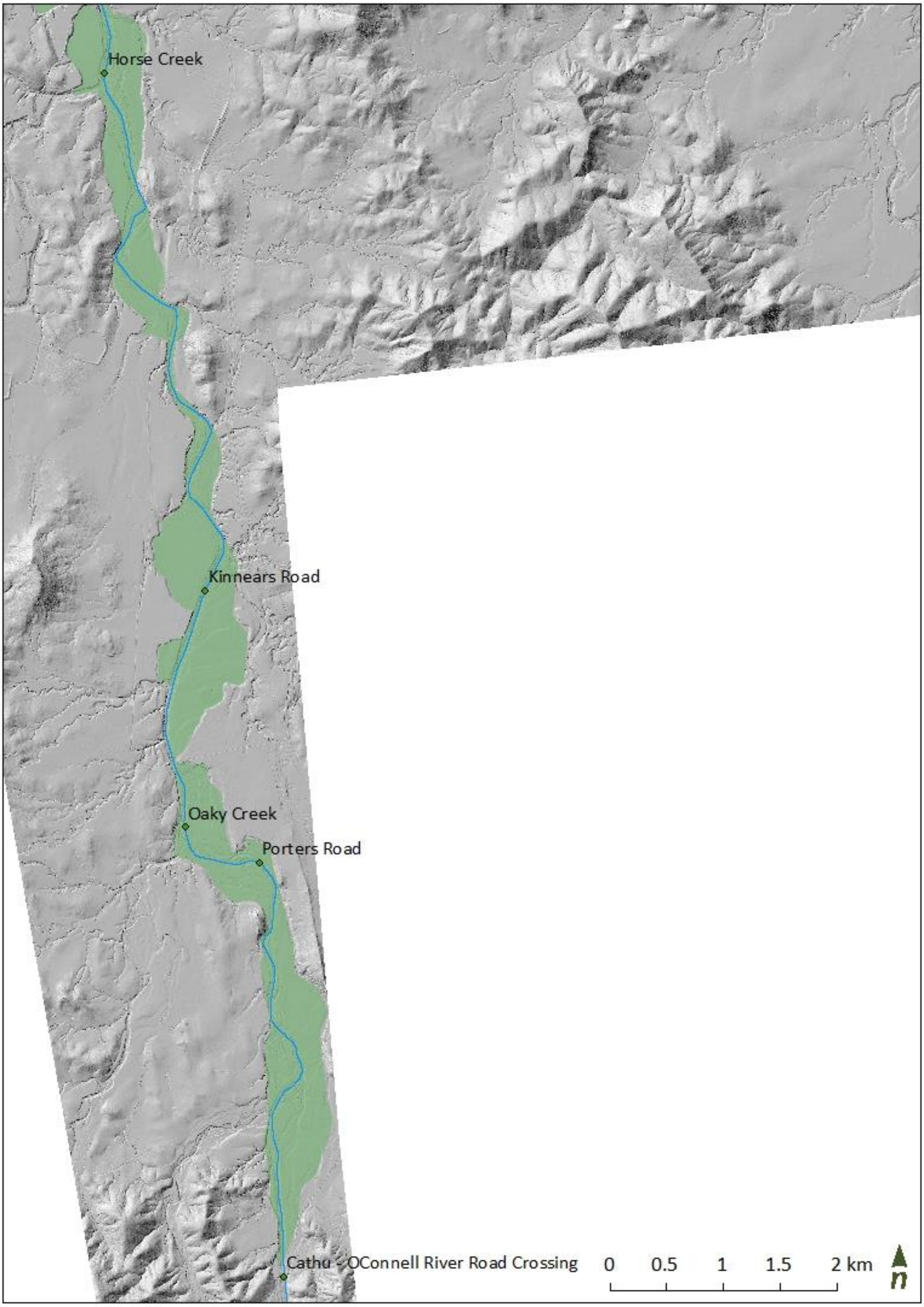

Figure 28. *Area of active floodplain shown by green shading within Reach 4*

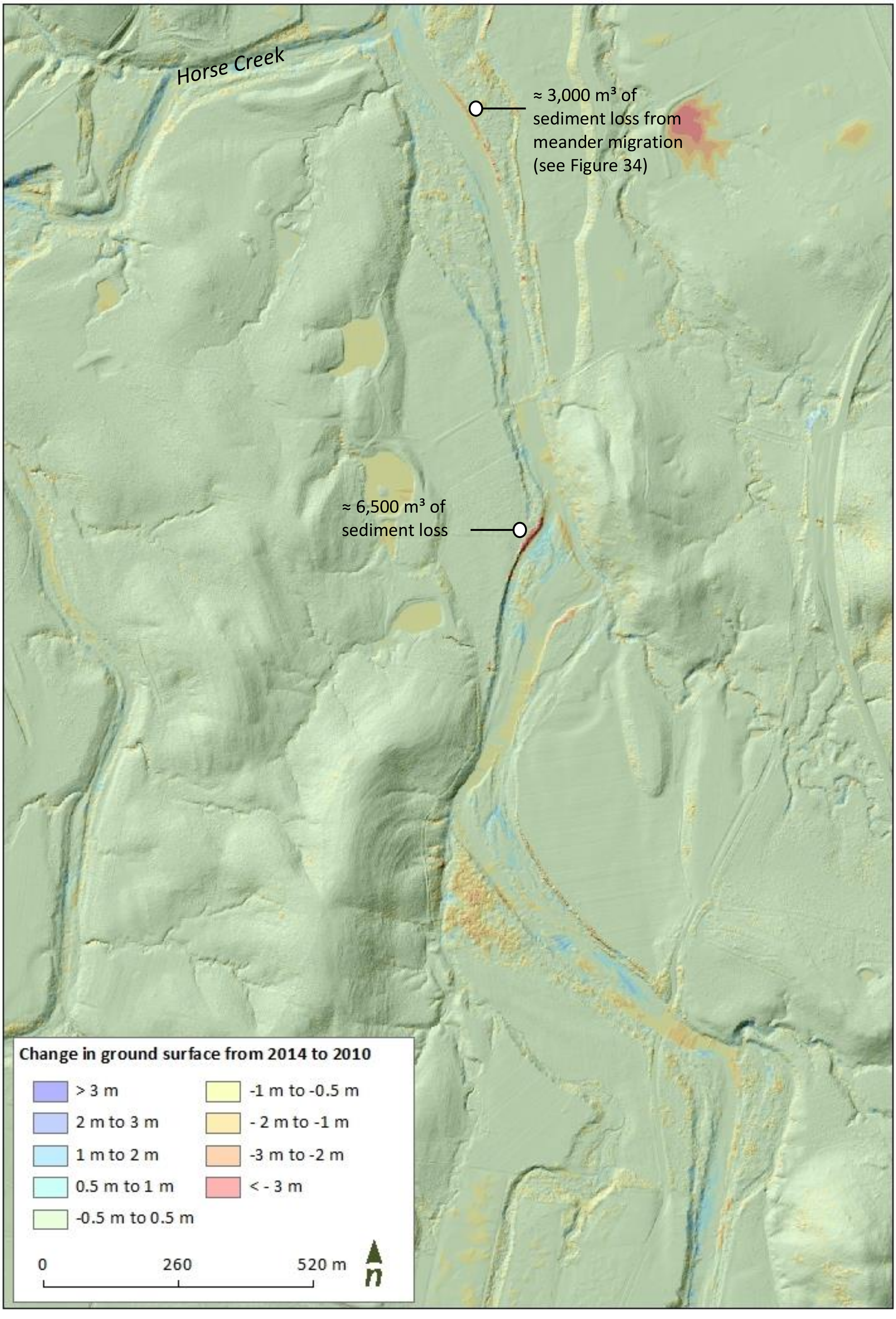

Figure 29. *Changes in elevation between 2014 and 2010 included estimates of sediment loss at the major erosion sites at the downstream end of Reach 4 near the Horse Creek confluence*

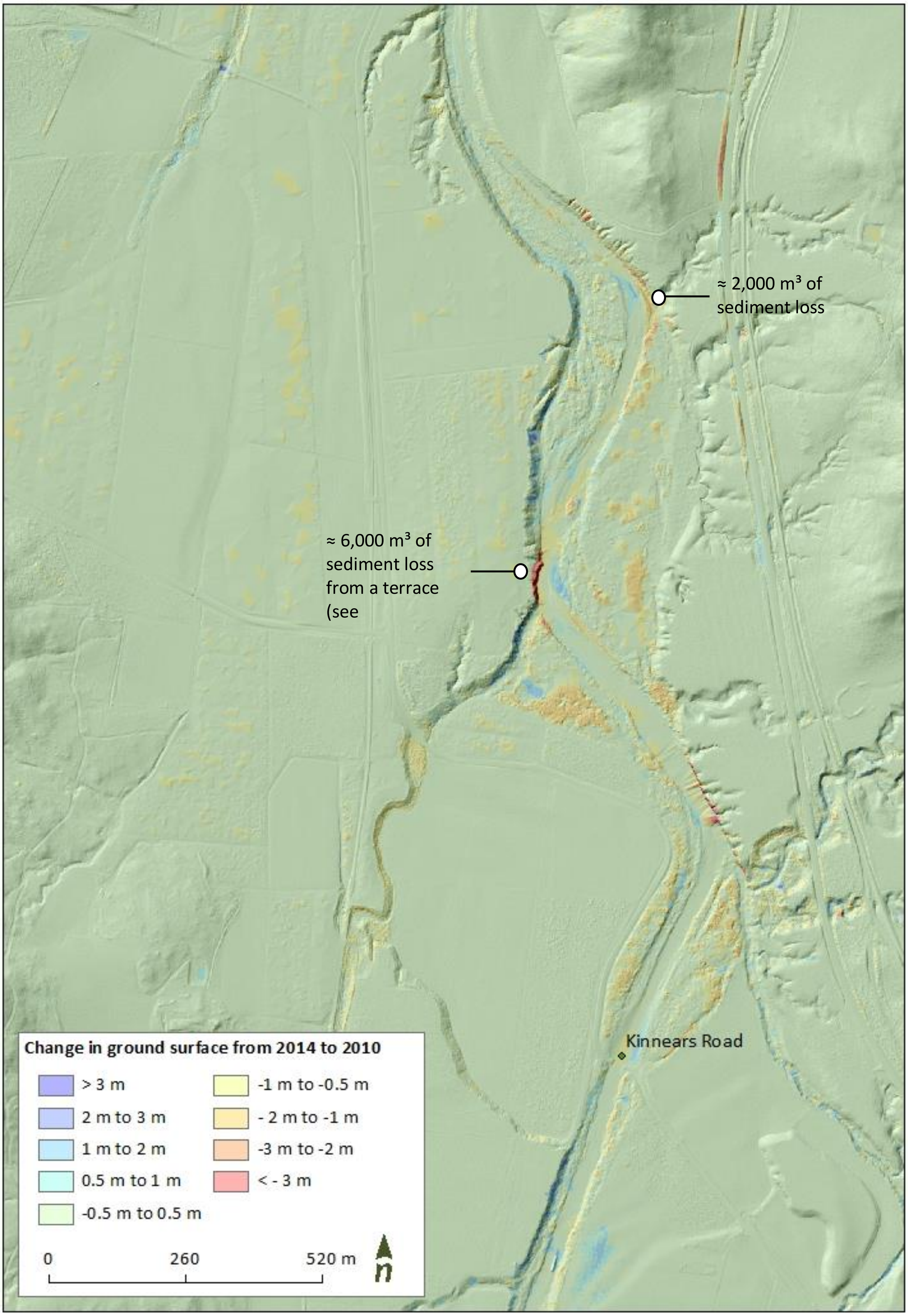

Figure 30. *Changes in elevation between 2014 and 2010 included estimates of sediment loss at the major erosion sites in Reach 4 near Kinnears Road crossing*

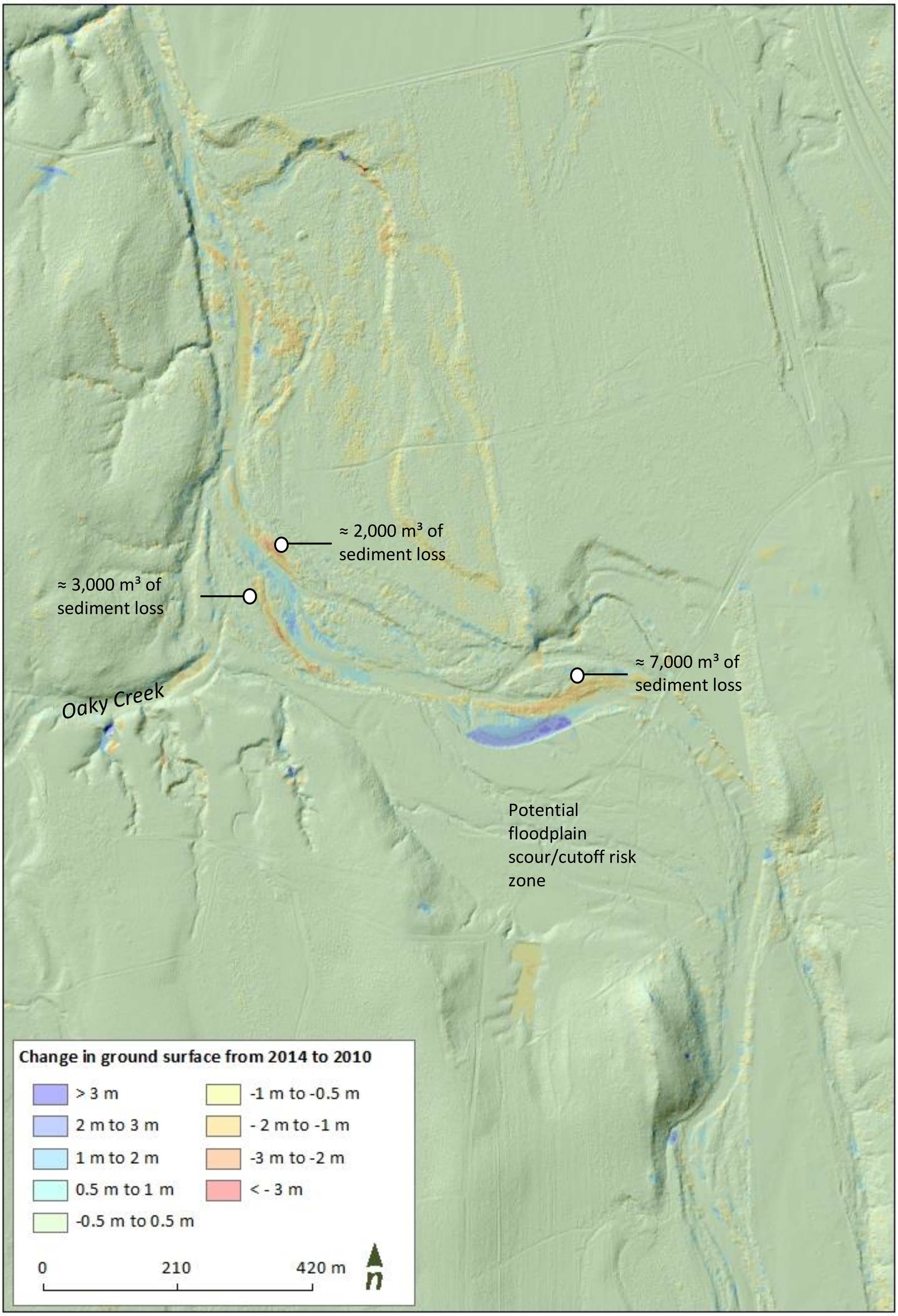

Figure 31. *Changes in elevation between 2014 and 2010 included estimates of sediment loss at the major erosion sites in Reach 4 near the Oaky Creek confluence*

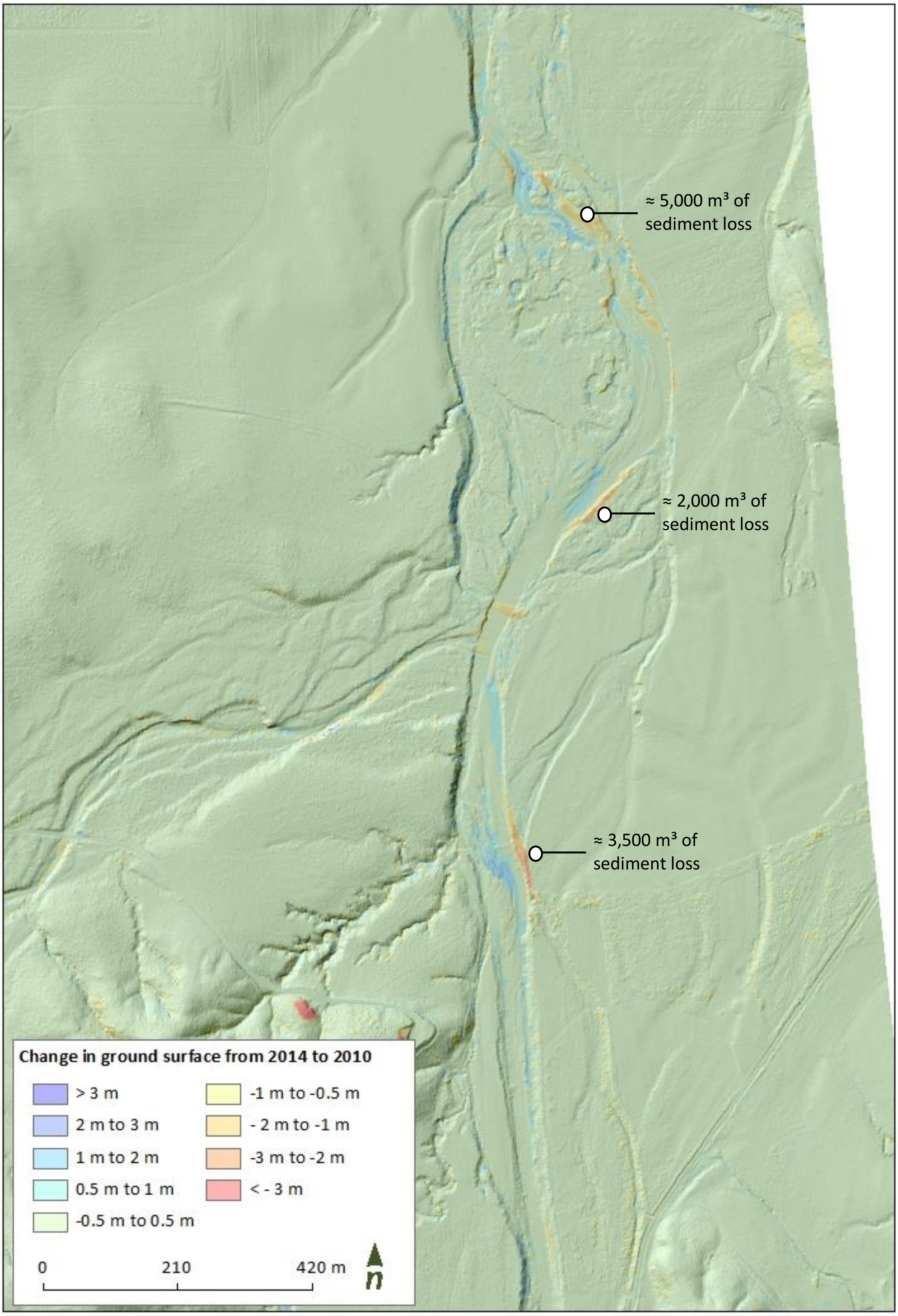

Figure 32. *Changes in elevation between 2014 and 2010 included estimates of sediment loss at the major erosion sites downstream of Cathu – OConnell River Road at the upstream end of Reach 4*

Figure 33. *Near vertical terrace along the outside of a meander downstream of Kinnears Road. This site contributed 6,000 m³ of sediment between 2010 and 2014.*

Figure 34. *Looking across at the right bank opposite the Horse Creek confluence – meander migration of this bank has resulted in 3000 m ³ of sediment loss between 2010 -2014. Grass has grown over the eroding river bank since the recent erosion.*

Figure 35. *Eroding floodplain section downstream of Cathu –O'Connell River Road. This site has contributed 3,500 m ³ of sediment loss between 2010 and 2014.*

Figure 36. *Engineered Log Jams near the upstream extent of Reach 4*

5.5 Reach 5

Reach 5 extends from the headwaters to Cathu-O'Connell River Road (Figure 37). The system is partly confined however still has a floodplain several hundred metres wide in most locations (Figure 38). The system is a cobble bed stream with a high degree of bedrock control. Floodplain deposits have a high fraction of coarse sediment. Many of the floodplains in this area are used for grazing. Key findings from the stability assessment include:

- The reach average peak stream power for the two and fifty year ARI event is significantly above the reference values.
- The system has a very high sediment transport capacity and large volumes of coarse sediment are likely to be mobilised, transported and subsequently deposited further downstream during flood events.
- A cutoff has formed near the junction of Cathu-O'Connell River Road and law Road (Figure 39).
- The cutoff has a similar length to the original course and is unlikely to result in ongoing instabilities.
- In the streams current alignment there is limited ability for lateral adjustment due to the apex of meanders abutting the valley margins – these areas typically have a high degree of bedrock intrusion within the channel (Figure 40)
- Riparian vegetation coverage is generally poor. Weeds and groundcover pastures are providing some limited protection to floodplain and instream material.

Figure 37. *Aerial imagery captured in 2014 of Reach 5*

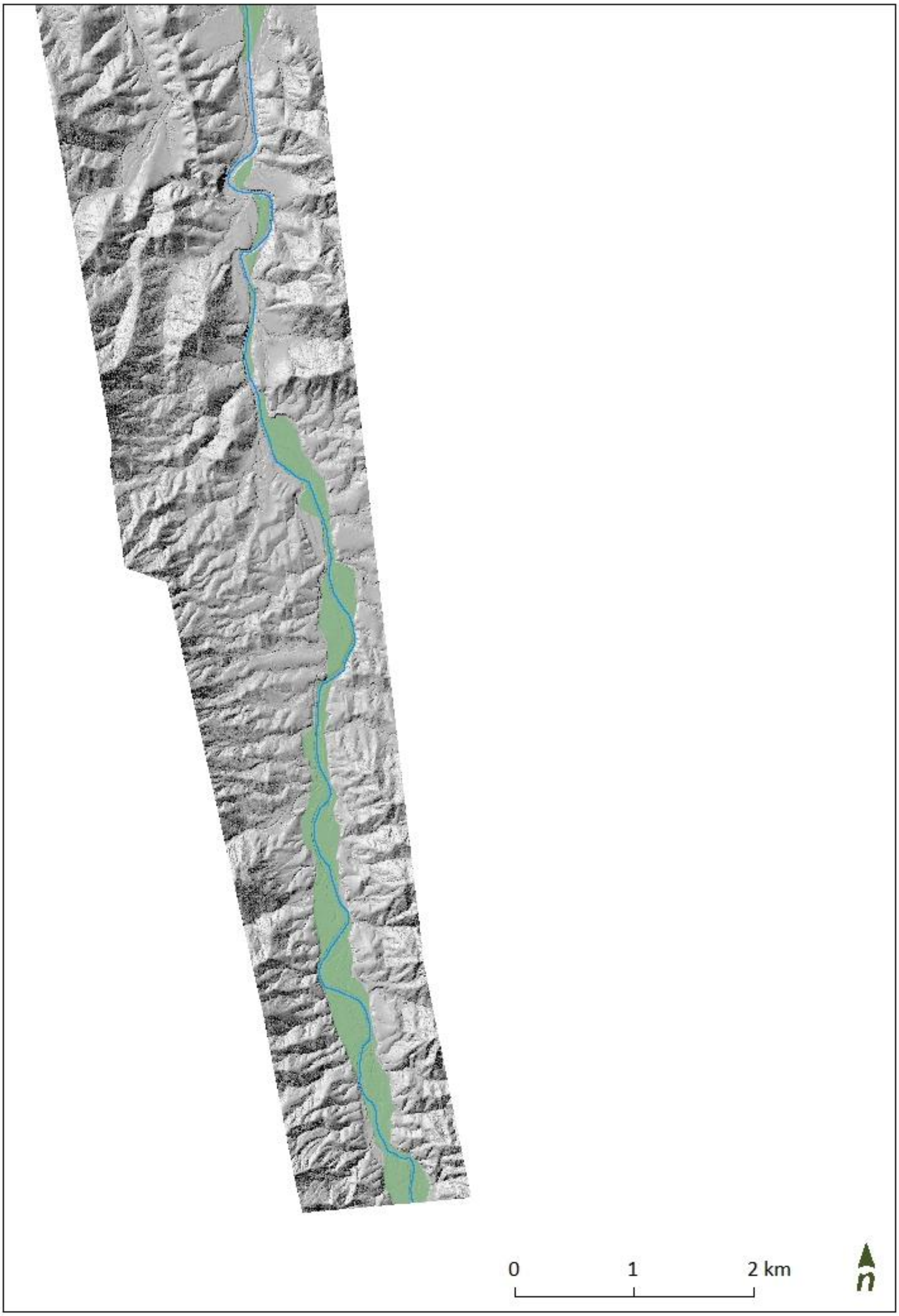

Figure 38. *Area of active floodplain shown by green shading within Reach 5*

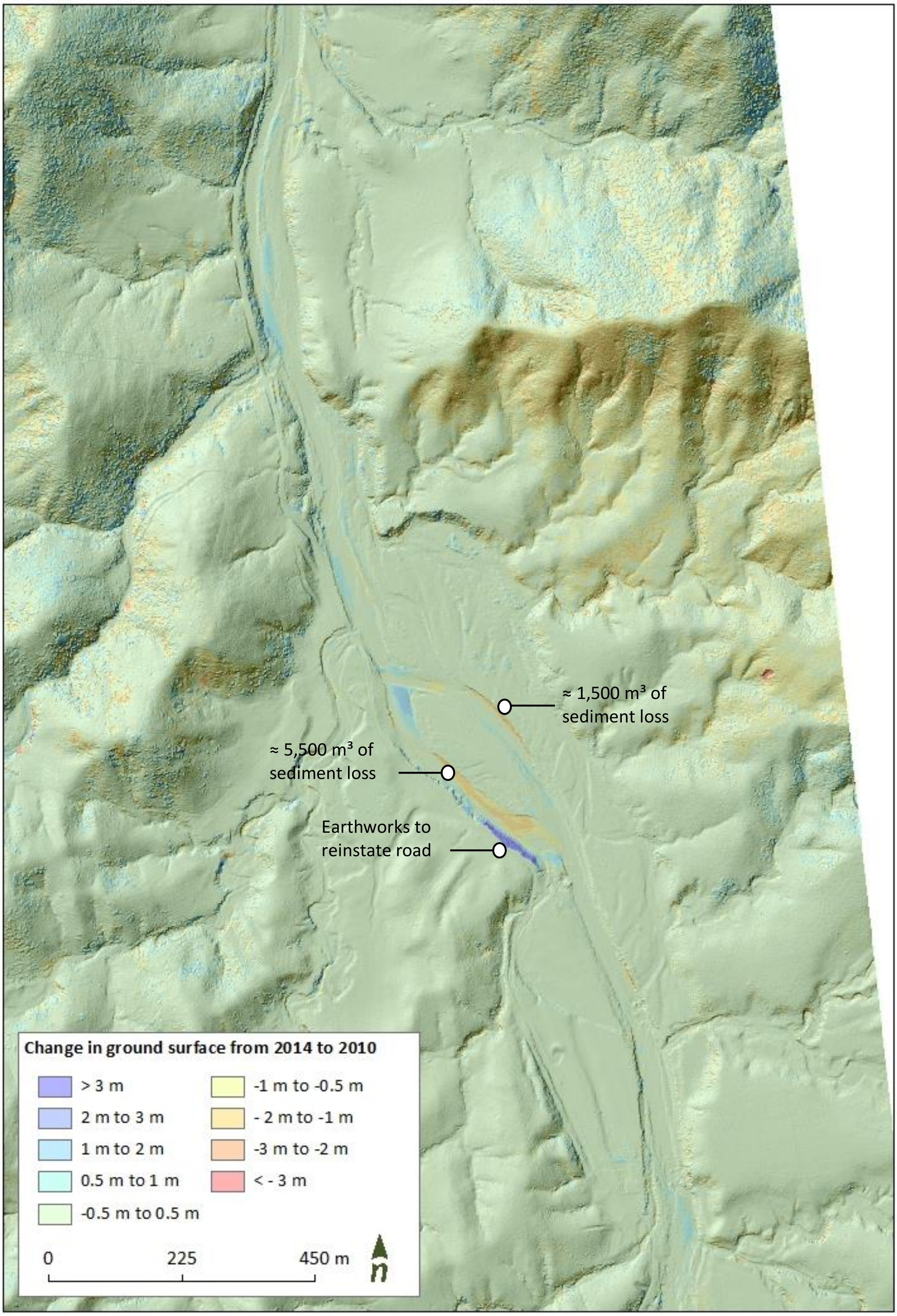

Figure 39. *Changes in elevation between 2014 and 2010 included estimates of sediment loss at the major erosion site near the junction of Cathu -O'Connell River Road and Law Road*

Figure 40. *Bedrock controls within the channel in Reach 5*

Figure 41. *Looking downstream along the cutoff path near the junction of of Cathu -O'Connell River Road and Law Road*

6 Summary and recommendations

Stream bank erosion in the O'Connell River has been a significant source of sediment between 2010 and 2014. The O'Connell River is a gravel bed stream with a high degree of bedrock control and as a result vertical adjustment(incision) of the main stem has not been identified as a major issue. The dominant erosion process is lateral meander migration. The majority of the erosion has occurred where the channel abuts areas of active floodplain. These areas are typically used for sugarcane cultivation – which is extremely important to the local economy. Floodplains are sediment sinks which capture sediment during major events. The floodplain within the O'Connell River provides a buffer against sediment transfer to the Great Barrier Reef. Stream bank erosion releases fine grained material into the water column in flood events and increases the transport of this material and attached nutrients to the coast.

Temporal analysis of LiDAR data between 2010 and 2014 has allowed accurate assessment of sediment release from *major* erosion sites – there is a high degree of confidence that when there is large variation in elevation near stream banks the majority of this is due to stream bank erosion. Estimating the cumulative sediment release from all minor stream bank erosion (i.e. less than 0. 5m of difference) can be misleading due the differences in water surface and the position of pools on the day of survey, differing accuracy of datasets and differing ability to penetrate vegetation foliage. As a result only sediment release from major erosion sites has been estimated in this study. Total sediment release from stream bank erosion is likely to be significantly higher than these estimates. However the volume of sediment released from major erosion sites provides a good indication of the major sources of sediment along the O'Connell River. The estimates of sediment loss from sites of major channel change for each reach are provided in Table 3.

Table 3. Estimates of sediment release at major erosion sites in each reach

	Estimates sediment release from major erosion sites (m^3)
Reach 1	170,000
Reach 2	5,000
Reach 3	50,000
Reach 4	45,000
Reach 5	12,000

We found Reach 1 to have released significantly more sediment from major stream bank erosion than other reaches. This large volume of sediment was derived from only four sites. The banks in Reach 1are high (6-8 m) and when mass failure occurs (as a result of toe scour and/or pre-weakening) large volumes of sediment are released. The sediment only has a short distance to travel before it is discharged into the marine environment. The peak event stream power in Reach 1 is within the reference values and as a consequence we have confidence that a revegetation program with only limited structural interventions can be implemented with a high likelihood of success. Given the scale of the erosion and the importance of reducing sediment release in this reach the structural intervention will need to be designed to an appropriate standard to support the vegetation during the establishment phase.

Reach 3 has large areas of floodplain at risk due to stream bank erosion -in particular on the outside of bends due to meander migration processes. Stream power in Reach 3 is close to the target range required for successful revegetation programs however some structural intervention is likely to be required to protect the vegetation during the establishment phase.

Terraces appear to have a greater resistance to erosion compared to the active floodplain zones. Some large volumes of sediment were still released from terraces however the vast majority of sediment was released from floodplains. Stabilising terraces is likely to cost prohibitive (due to their height) and not result in similar sediment reduction compared with treating unstable banks along floodplains.

Management recommendations for each reach are outlined in Table 4. A long-term target for all active floodplain areas should be to establish a healthy riparian corridor with a suite of native species including large trees, shrubs, ground cover and grasses to protect against bank erosion. In some locations bank reprofiling and revetment will also be required – particularly on the outside of bends.

Despite the land use changes and threats identified in this study the O'Connell River still maintains a diversity of physical habitat. A program of riparian restoration along the O'Connell River has the potential to significantly improve the river health of the system, reduce sediment export to the marine environment and protect agricultural land from stream bank erosion.

7 Next steps

Based on the findings of this study it is recommended that Reef Catchments undertake landholder consultation to select sites for stream bank stabilisation and vegetation establishment. The program should focus on Reach 1 and Reach 3. These reaches

- have stream power within the range that allows revegetation programs to be implemented with limited structural intervention
- are in close proximity to the coast and have the capacity to supply the most sediment for transport to the coast
- Have high value agricultural land use and thereby an active interest from landholders to limit active bank erosion

Within these two reaches we have we suggest that Reach 1 is the highest priority for program implementation as a result of its low stream powers (simplest programs), highest volumes of past sediment release and closest proximity of the reach to the estuary and coast.

Once sites have been selected for program implementation it is recommended that:

1. Objectives and performance standards are developed and agreed upon with the landholder
2. Design of stream bank protection works (i.e. toe protection, pile fields, large wood installations engineered log jams and revegetation etc) are designed to a level that meets the agreed performance standards
3. Programs be implemented to agreed standards
4. Ongoing monitoring and maintenance program be implement to ensure the successful establishment of riparian vegetation

Table 4. Key recommendations for each reach

Reach	Threat	Recommended management action	Priority of action
1	Ongoing meander migration in zone of aggradation	Reprofile banks, establish toe protection and revegetate with a suite of native species including trees, shrubs, ground cover and grasses to protect against bank erosion.	Very high
	Bank erosion along where the channel abuts floodplains	Establish a healthy riparian corridor with a suite of native species including large trees, shrubs, ground cover and grasses to protect against bank erosion.	Very High
2	High stream power throughout the reach will maintain high rates of sediment delivery to Reach 1	Undertake a program to reduce in-channel stream power. This could include large wood installations or pile fields (if feasible) to facilitate instream vegetation establishment and stabilise sediment. Reducing the stream power will reduce the volume of sediment transported to reach 1	Low
3	Ongoing meander migration throughout the reach where the apex of the meander abuts an area floodplain	Reprofile bank, establish toe protection and revegetate with a suite of native species including large trees, shrubs, ground cover and grasses to protect against bank erosion.	High
	Bank erosion along where the channel abuts floodplains	Establish a healthy riparian corridor with a suite of native species including large trees, shrubs, ground cover and grasses to protect against bank erosion.	High
4	Bank erosion along where the channel abuts floodplains	Establish a healthy riparian corridor with a suite of native species including large trees, shrubs, ground cover and grasses to protect against bank erosion.	Moderate
	A cutoff developing near the Porter's Road crossing	The vegetation community on this section of floodplain should be maintained and enhanced to reduce the risk of a meander cutoff occurring.	Moderate
5	High stream power throughout the reach will maintain high rates of sediment delivery to Reach 4	Undertake a program to reduce in-channel stream power. This should be based on vegetation establishment, but may require large wood installations or pile fields to facilitate instream vegetation establishment. Reducing the stream power will reduce the volume of sediment transported to reach 5	Low
	Stock access is limiting the recovery of riparian vegetation community. There is generally good connectivity between the adjacent bushland and the riparian zone in this reach.	Exclude stock to allow riparian vegetation to recover.	Low

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Attachment A
Hydrological assessment

The O'Connell River catchment has a total area of approximately 410 km ³ upstream of the Andromache River confluence. Within the catchment there are three active or historical gauges along the O'Connell River (Table 5 and Figure 42). The length of stream flow records range from 36.75 years at Caping Crossing to 6.67 years at Forbes Road.

For the purpose of this study six defined locations have been selected as flow points, where a set of unique design flows will need to be selected for the hydraulic modelling. Three of these are at the location of the stream flow gauges, while the other three locations have been selected because large increases in catchment area occur at that location. A combination of the Queensland Rational Method and flood frequency analyses will be used to determine design flows at each of the six flow points.

There are other approaches that could have been adopted including calibrating a rainfall runoff model or calibrating against adjoining catchments. However, for the purposed of this study where design events are required to assess reach average stream power this approach is suitable. Further development of hydrologic analysis may be required for more detailed investigations and will be required for projects requiring higher level of accuracy and confidence in the results (i.e. a flood study).

Table 5. Stream flow gauges along the O'Connell River

Gauge	Catchment area (km^2)	Start date	End date	Length of record (years)
Caping Crossing 124001A	363	31-January-1969	02-November-2005	36.75
Staffords Crossing 124001B	342	03-November-2005	24-October-2013	7.92
Forbes Road 124005A	167	31-May-2007	18-February-2014	6.67

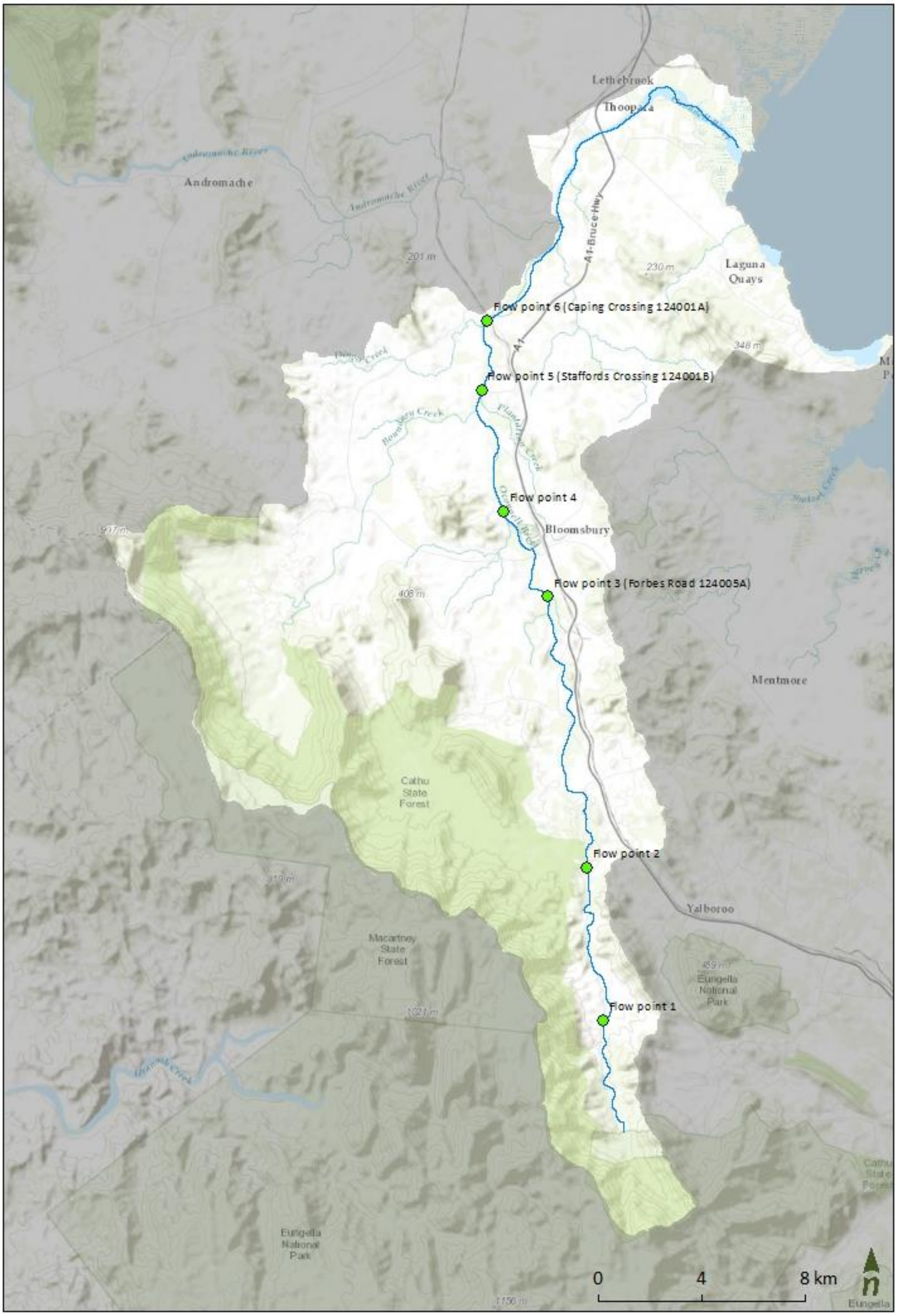

Figure 42. *O'Connell River catchment showing stream flow gauges and two points in the upper catchment used in the rational method*

Flood frequency analysis

The results from the annual series flood frequency analysis at the Caping Crossing gauge (36.75 years of data) are presented in Table 6 using peak daily flow. The annual series approach is generally used for events with an Average Recurrence Interval (ARI) greater than 10 years.

Table 6. Results from the annual series flood frequency analysis at Caping Crossing (124001 A)

ARI (years)	2	5	10	20	30	50	75	100
Discharge (m^3/s)	939	1780	2352	2914	3242	3658	3992	4230

The results from the partial series flood frequency analysis at the Caping Crossing gauge are presented in Table 7. Three different peaks above threshold values were used which ranged from n = 37 to n = 111. The number of peaks over the threshold is recommended to be between n and 3n (where n is the number of years of the record). The partial series approach is generally used for events with an ARI less than 10 years.

Table 7. Results from the partial series flood frequency analysis at Caping Crossing (124001 A)

ARI (years)		**2**	**5**	**10**	**15**	**20**	**25**
Discharge (m^3/s)	n=37	1214	2050	2644	2899	3016	3066
	n=74	1243	2120	2472	2572	2627	2674
	n=111	1155	2169	2773	2975	3042	3053

The Stafford Crossing and Forbes Road gauge only had short records so only partial series analysis was undertaken. Given the short length of record there would be low confidence in the predicted design events with larger recurrence intervals (i.e. 10 years, 20 years, 50 years etc) from the annual series method. The results of the partial series analyses are presented in Table 8 and Table 9 respectively.

Table 8. Results from the partial series flood frequency analysis at Stafford Crossing (124001 B)

ARI (years)		**2**	**5**	**10**	**15**	**20**	**25**
Discharge (m^3/s)	n=8	1329	2029	2661	3058	3347	3571
	n=16	1357	2163	2704	2927	3025	3063
	n=24	1376	2191	2698	2877	2935	2937

Table 9. Results from the partial series flood frequency analysis at Forbes Road (124005 A)

ARI (years)		**2**	**5**	**10**	**15**	**20**	**25**
Discharge (m^3/s)	n=7	806	1114	1422	1641	1816	1964
	n=14	753	1155	1595	1928	2204	2446
	n=21	740	1242	1837	2309	2717	3081

Rational Method

The Queensland Rational Method was also used to estimate design flows at each of the six flow locations. The Queensland Rational Method uses rainfall Intensity Frequency Duration (IFD) data from BoM with stream (slope, roughness, hydraulic radius) and catchment (relief, storage, ground cover) properties to determine design flow events. Results for each flow point are presented in Table 10.

Table 10. Results from the Queensland Rational Method at each of the six flow points

		ARI (years)					
Flow point	**Catchment area (km ²)**	**2**	**5**	**10**	**20**	**50**	**100**
1	28.5	369	468	528	642	794	890
2	53.7	383	495	639	742	880	1047
3 (Forbes Road 124005A)	146.6	536	770	891	1048	1264	1639
4	191	673	969	1121	1320	1593	1810
5 (Staffords Crossing 124001B)	341	1153	1664	1927	2271	2744	3119
6 (Caping Crossing 124001A)	363	1223	1765	2045	2410	2912	3310

Comparison between methods

There is increased confidence in the results from the flood frequency using the Caping Crossing data (compared to the other gauges) given the 36.75 years of record. The other gauges have short records that may not be representative of the long term flow regime. A comparison between the flood frequency analysis and the rational method results at Caping Crossing is presented in Table 11. Apart from the two year ARI event results, which are very similar, the rational method under predicts the flood frequency analyses results by approximately 20 -30 %.

Table 11. Comparison between results at Caping Crossing using both flood frequency analysis and the rational method

	ARI (years)					
Method	**2**	**5**	**10**	**20**	**50**	**100**
Flood frequency analysis	1243	2120	2472	2914	3658	4230
Rational Method	1223	1765	2045	2410	2912	3310
% difference	1.6%	20.1%	20.9%	20.9%	25.6%	27.8%

There is less confidence in the flood frequency analysis results at Staffords Crossing and Forbes Road however these are also greater than the rational method results (Table 12 and Table 13)

Table 12. Comparison between results at Stafford Crossing using both flood frequency analysis and the rational method

Method	**2**	**5**	**10**
Flood frequency analysis	1357	2163	2704
Rational Method	1153	1664	1927
% difference	17.7%	30.0%	40.3%

Table 13. Comparison between results at Forbes Road using both flood frequency analysis and the rational method

Method	**2**	**5**	**10**
Flood frequency analysis	753	1155	1595
Rational Method	558	801	925
% difference	34.83%	44.23%	72.44%

Summary
This hydrologic assessment was undertaken to determine design events for a stream power assessment. Given the available data it is an appropriate level of assessment for this purpose as some margin for error is allowed without significantly impacting the reach stream power results.

There is a higher confidence in the flood frequency results at Caping Crossing due to the length of record. As a result these values will be used at this flow point. For the remainder of the flow points the results from the rational method have been increased by 25% to reflect the observed trend of under prediction by the rational method. The adopted results which will be used for the hydraulic modelling and stream power assessment are presented in Table 14.

Table 14. Summary of adopted design flows for each defined flow point

		ARI (years)					
Flow point	**Catchment area (km^2)**	**2**	**5**	**10**	**20**	**50**	**100**
1	28.5	461	585	660	803	993	1112
2	53.7	478	618	798	927	1100	1308
3 (Forbes Road 124005A)	146.6	698	1001	1156	1359	1636	2122
4	191	841	1211	1402	1650	1992	2262
5 (Staffords Crossing 124001B)	341	1442	2080	2409	2839	3430	3899
6 (Caping Crossing 124001A)	363	1243	2120	2472	2914	3658	4230