Literature Review: Vegetation Effects on Channel Morphology and Bank Stability – for use in designing catchment works

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Executive Summary

This literature review examines the effects of vegetation on channel morphology and bank stability. It briefly describes geomorphic processes in relation to stream channel morphology and evolution and summarises the role of riparian vegetation in channel form stability and associated instream water quality. The following points are highlighted as relevant areas of research, knowledge gaps and proposed research questions to inform the design of catchment works and long term investment of significant funds in stream rehabilitation:

• Studies of pre and post-European vegetation extent studies have shown approximately 43% of native vegetation remains in SEQ following European settlement. These data also show rainforest and vine thicket that was present in moist gullies and riparian zones was reduced to a third of its original extent, post-European settlement.
• Channel morphology is strongly influenced by vegetation composition and several studies across Australia have shown a sensitivity of channel width to different forms of riparian vegetation.
• There is still disagreement in the literature as to the most appropriate vegetation composition to be used for channel stability management.
• The effect at the catchment scale that riparian revegetation has on channel morphology, sediment and nutrient export, water yield and aquatic ecosystem health is largely unknown.
• Knowledge gaps include specific revegetation techniques for sub-tropical regions; appropriate riparian zone width and length; vegetation species; species composition on a transverse and longitudinal profile; and planting techniques for flood prone areas and following catastrophic channel changes.
• Monitoring of management action effectiveness and efficacy is untested in sub-tropical catchments and the design and evaluation of monitoring programs on a catchment scale is a significant knowledge gap.
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1 Introduction

The word “riparian” is derived from the Latin word *ripa* meaning river bank and the term “riparian zone” is now widely used to describe the interface between the terrestrial landscape and waterways. Riparian zones are connected to their landscape and riparian vegetation is a fundamental component of landscape systems (Simon et al., 2004). In order to understand their development and function it is, therefore, important to understand the processes that exert direct and indirect effects on these landscape features.

This literature review will briefly describe geomorphic processes in relation to stream channel morphology and evolution and summarise the role of riparian vegetation in channel form stability and associated instream water quality. The main focus of the literature review is to describe what information exists in relation to the use of riparian revegetation methods, the knowledge gaps surrounding this area of interest and the proposed research questions that need to be answered in order to maximise the use of this method.

The role of riparian revegetation in stabilising the landscape and reducing pollutant loads entering the waterways has been extensively described in the literature with a global application (Kondolf, 1996; Jenkinson et al., 2006; Bernhardt and Palmer, 2011). This literature review will focus on the studies that are applicable to sub-tropical regions to develop research questions relevant to Southeast Queensland (SEQ).
2 Fluvial Processes

2.1 Sediment/water discharge balance

The river network and channel morphology are determined by interactions between the landscape and the flow of water through the catchment from higher to lower elevations (Knighton, 1984). The interaction involves the entrainment, transport and deposition of erodible material from the channel boundaries and is shaped by the inherent potential energy in the river system created by the change in elevation from the top to the bottom of the system (Schumm, 1984). This potential energy develops a complex fluvial network as the river moves through the landscape. Excess energy is dissipated by many means, including: contact with instream and channel bank vegetation, turbulence in the river profiles, erosion at meander bends and most importantly through the transport of sediment (Kondolf, 2002).

Sediment production is influenced by many factors, and the watershed through which the river flows influences the type and amount of sediment produced. Vegetation type and cover, land use, soil type, climate and erosion rates are important in sediment production and transport and the weighting of their influence may change along the longitudinal profile of the river system (Knighton, 1984). Sediment transport capacity and sediment load are also key factors that influence channel form and process (Lane, 1955). Sediment transport capacity is strongly influenced by flow velocity and water depth and velocity itself is controlled by the channel slope, geometry, discharge and channel roughness. Any changes to these parameters would influence the capacity of the river to transport sediment and riparian vegetation plays a role in many of the processes controlling these parameters. Sediment load is the total amount of sediment being transported and can exist as dissolved, suspended and bedload (Knighton, 1984). Bedload is considered the form of sediment most influential in channel morphology and stability.

The balance of sediment and hydrologic loads and channel morphology was conceptually represented by Lane in 1955 (Figure 1). This model and channel equilibrium theories (Leopold, 1957; Hupp and Osterkamp, 1996) were the key underlying concepts that helped determine the relationships between landscape features and processes and channel responses to anthropogenic changes in the landscape. For example, if sediment loads are increased, the scale will tip towards aggradation. In order for quasi-equilibrium to return to the system, changes to channel slope, geometry and/or hydrologic load would need to occur. The rate of change to any of these parameters is influenced at some point by catchment and riparian vegetation. For example, channel width may change at a faster rate at sites with no riparian vegetation in comparison to those with good vegetation cover.

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It is important to set this context in order to fully appreciate the role of riparian vegetation, and its involvement in the response of a river system to change.

### 2.2 Erosion processes through the catchment

Sediment and associated nutrients originate through soil erosion from hillslope (rill and sheet) and channel (streambank and gully) sources. At the local level, it is common for either hillslope or channel erosion to be the dominant source and the management of these erosion processes differs (Olley et al., 2006). Sediment tracing studies for SEQ have shown channel erosion processes result in the majority of non-urban diffuse pollutant loads entering the waterways and receiving waters of Moreton Bay (SEQHWP, 2007) and sediment loads to Moreton Bay are now 30 times the pre-European rates (NLWRA, 2001). More recent work also confirmed the increased delivery of sediment to waterways was a consequence of increased streambank erosion following significant flow events (Saxton et al., 2011; Burton et al., in preparation). Increased non-urban pollutant loads pose many economic and ecological problems for the region including impaired water quality and downstream aggradation and sedimentation of water storages (Pollen et al., 2004).

Streambank retreat occurs as a natural process along the longitudinal profile of the river system but disequilibrium occurs in unstable river channels when bank erosion outstrips bank construction increasing the channel cross-sectional area. Streambank instability can lead to loss of valuable land, destabilisation of structures such as bridges and river crossings, and loss of instream habitat due to increased sediment loads transported through the system. There are three...
types of streambank erosion processes that have been described in the literature: subaerial preparation, fluvial entrainment and mass failure (Lawler, 1992). Although these processes can act along the whole of the system, there exists a spatial zoning of dominance for each process. It was suggested by Abernethy and Rutherfurd, 1998 that upper reaches of the river were dominated by subaerial preparation, mid-basin by fluvial entrainment and lower reaches by mass failure. Other groups have also found a spatial dominance of erosion patterns for fluvial entrainment and mass failure (Croke et al., 2012). Given river restoration has significantly increased globally and nationally in Australia (Brooks and Lake, 2007; Kondolf et al., 2007), it is important to know where along the river these activities will most effectively achieve their goals. Understanding the underlying processes driving erosional activity will be pivotal to this success.

Subaerial processes directly deliver bank sediment to the stream or prepare the bank for removal of sediment by fluvial entrainment. Examples of this include rainsplash, rilling and frost action. Fluvial entrainment describes the process where sediment is removed from the boundary surfaces and transported by the flow within the channel. During this process, the hydraulic shear forces acting on the channel boundary are greater than the soil shear strength, which is strongly influenced by soil characteristics and the presence of vegetation (Simon and Collison, 2002). Mass failure often leads to large blocks of bank material slumping into the channel to be deposited at the toe of the bank or entrained in the flow. Mass failure is more closely related to soil moisture and the effects of drawdown stresses on the bank material when flows recede than to flow conditions (Knighton, 1984). Riparian vegetation may affect each dominant erosion process in a different manner and consideration must be given to how vegetation interacts with the channel boundaries to determine the most effective use of revegetation as a management action through the catchment.

2.3 Degraded systems and channel evolution

Geomorphic responses to channelisation have previously been described by a six-stage model of channel evolution (Simon and Hupp, 1986; Simon, 1989; Hupp and Simon, 1991; Figure 2). Field and experimental investigations of fluvial landform development suggest geomorphic thresholds and complex responses of drainage systems also support the concept of dynamic equilibrium as depicted by channel evolution models (Schumm, 1979).

Following disturbance, eg channelisation of a stream (stage II) channel and bank processes initially react vertically through downcutting (stage III). Bed-degradation and subsequent channel widening progress as the system responds to an increase in stream power and in-channel discharge capacity (stage IV). A depositional surface forms on banks once bed-degradation and heightened bank mass wasting processes have eased or slowed (stage V). Dominating lateral processes, characteristic of stable or natural channels, return during the
formation and expansion of the in-channel features. Characteristic woody riparian vegetation begins to grow as this depositional surface develops and becomes part of the process and form of restabilizing banks (stage VI). Bank accretion and vegetative regrowth appear to be amongst the most important processes involved in channel bank recovery from channel disturbance. The point, both temporal and spatial, at which these processes have their maximum benefit, is still not well documented. If revegetation is a key management action, it is important for land managers to understand where in the catchment and at what point along the channel evolution timeline is investment in these actions most effective in order to achieve channel stability with limited budgets.

A significant number of streams and rivers have degraded across SEQ since European settlement and now contain a bankfull discharge > 1-10 RI. Disconnection of the channel with the floodplain has altered the hydrological and hydraulic processes across the catchment and systems are still responding to these initial disturbances. The role of vegetation in the subsequent evolution of channels in SEQ or in sub-tropical climates post-disturbance has not been widely documented in the literature. The following questions are relevant to this area of research:

*Can we use space for time substitution methods to predict the effect of revegetation intervention on subsequent channel recovery?*

*Can we use this output to inform further investment in the revegetation of streams from the top to the bottom of the catchment?*

Figure 2: Channel Evolution Model Hupp and Simon (1991)
3 Role of Riparian Vegetation

3.1 Distribution of vegetation across South East Queensland

Historical accounts of European settlement in south east Queensland and Moreton Bay detail significant vegetation clearing for grazing of domestic animals and urban settlement. After the penal colony was abandoned in Brisbane and free settlement was allowed in the region in 1842, sheep and cattle numbers steadily rose to approximately 3,500,000 sheep and 433,000 cattle in 1861, (Powell, 1998). Timber was increasingly removed from riparian forests and exported overseas or transported to Sydney with significant wastage in the process (Bolton, 1992). Ringbarking and burning of trees across the catchments was a standard practice in order to clear the land for crops and grazing animals. Pre and post-European vegetation extent studies have shown approximately 43% of native vegetation remains in SEQ following European settlement (NVIS, 1997). These data also show rainforest and vine thicket that was present in moist gullies and riparian zones was reduced to a third of its original extent, post-European settlement.

Datasets (including both native and exotic vegetation) show SEQ has on average 68% woody vegetation landcover across the region (DERM, SLATS 2008/9). However, there are limited studies and validated datasets at appropriate scales that detail the extent and condition of existing riparian vegetation in SEQ. The State of the Environment Report examines the condition of environmental categories across Queensland (Qld Gov, 2007). The last report was collated in 2007 and the inland waters and wetlands chapter briefly discussed the condition of riparian vegetation in Queensland. The report concluded that the upper Brisbane River (one of three catchments sampled) had riparian vegetation in poor (45%), moderate (13%) and good (13%) condition. However, these ratings were not expressed in a spatial manner across the catchment. A regional statement of river condition suggested the SEQ region has a rating of “potentially of concern” given the water quality and ecological parameters that were measured. On a regional assessment scale, the State of the Rivers Reports detail catchment scale vegetation condition and associated bank stability for 7 of the 14 major catchments of SEQ (DERM, 2000). These reports use qualitative descriptors of condition, such as poor, good etc, but field derived datasets are available at a reach scale. These datasets include quantitative data in regards to channel geometry, vegetation extent and condition and qualitative descriptions of bank erosion processes. An example of the findings from Lockyer Creek show the riparian vegetation throughout the catchment was in very poor to poor condition. Stream lengths with very good to good ratings generally occurred in the Western Tributaries, and Lake Clarendon and Buaraba Creek subcatchments. On average the riparian zones had been cleared to the edge of
the stream bank for agricultural purposes and grass was the dominant vegetative structural type in the reach environs (average ground cover at sites of 70%).

The Ecosystem Health Monitoring Program (Healthy Waterways Ltd, EHMP) has site specific datasets that detail the extent and condition of channel habitat and riparian vegetation 100 m upstream of the freshwater EHMP sites in the upper catchments (S Bunn and F Sheldon, per. comm.). Peterson et al., 2011 analysed aerial photographs to distinguish the extent of vegetation in the riparian zone close to EHMP sites in the upper catchments. These datasets maybe useful to determine riparian vegetation extent and condition at sites that have been monitored for ambient aquatic ecosystem health values since 2002. This dataset would also include vegetation extent and condition during the last significant drought in SEQ and for the more recent wet periods in 2010/2011.

3.2 Channel morphology and riparian vegetation

Channel morphology is strongly influenced by vegetation composition and several studies across Australia have shown a sensitivity of channel width to different forms of riparian vegetation (Huang and Nanson, 1997; Brierley et al., 2005; Abernethy and Rutherfurd, 1998; McBride et al., 2008). However, there is conflicting information in the literature in regards to the selection of vegetation type for stream channel stability outcomes (reviewed in Trimble, 2004; McBride et al., 2008). Importantly, the studies reviewed differ in their descriptions of non-vegetated, grassed and vegetated, forested sites. Davies-Colley (1997) showed forested riparian zones give rise to wider, shallower channel geometries; whereas grassed channels are deeper and narrower in width. Huang and Nanson (1997) showed the opposite. There is some suggestion that discrepancies between grassed and forested channels may be linked to instream processes of sediment deposition or bank destabilisation as a consequence of the riparian vegetation type in smaller streams (Zimmerman et al., 1967). Alternatively, Huang and Nanson (1997) concluded the effect of channel bank vegetation on channel geometry was less than the influence of channel bed vegetation. The theoretical considerations of how trees or grass affect channel geometry and channel erosion processes is reviewed by Trimble (2004) and lists the advantages and disadvantages of both vegetation types. It seems the impact of vegetation on channel form is hydroclimatic and spatially influenced (in a downstream direction). Floodplain material was also problematic in determining the change in channel form in response to vegetation change. Possible research questions to further knowledge in the response of channels to vegetation type would be:

*What is the effect of changing riparian vegetation from a grass/non-vegetated to treed/vegetated state on channel morphology in SEQ, and*
What parameter is strongly correlated to any change in channel morphology, eg discharge, vegetation age and condition, vegetation placement across the channel?

There are limited studies that detail channel responses to increased vegetation and in channel roughness in sub-tropical systems. However, one site specific study in Echidna Creek, SE Queensland, showed an initial release of sediment from the trial site and channel widening before stabilisation of the channel geometry over time (Claridge, 2005; Marsh et al., 2004). The timescale for channel adjustment is generally outside the scope of a typical research study and most studies must rely on the space for time substitution approach with paired catchments that have similar characteristics. A recent study by Hardie et al., (2012) showed revegetated reaches fared better than non-vegetated reaches following flood events but there was no data to determine changes to channel geometry following revegetation of the reaches (full report is to be released by the Victorian Government in April 2012). This area of research is clearly important in order to predict and manage stakeholder expectations if degraded, non-vegetated streams are to be rehabilitated on a catchment scale. A valid research question to address would be:

Can we model channel responses to predict sediment deposition and erosion from the top to the bottom of the catchment?

The effect of revegetation of riparian zones on channel planform is also an area of interest. Channel avulsion (where the channel abandons its present course for a new one) and meander cut-offs on floodplains are normal geomorphic processes in single threaded and anastomosing streams. Evidence of these events is prevalent across the SEQ region, predominantly in the lower floodplain areas of the catchments. Tree growth and logjams along with sediment deposition, slope reduction and increased sinuosity are influential in these processes (Schumm et al., 1996). There have been no studies in sub-tropical regions that detail the planform response of channels over time as a consequence of catchment scale revegetation. Again, this area of research is important in managing stakeholder expectations, particularly stakeholder groups using the lower floodplain areas of the catchment. The following research question would further our knowledge in this area:

Can we use historical floodplain features and dendrochronology methods to predict changes in channel planform as a consequence of changed vegetation patterns?

3.3 Effects of riparian vegetation on streambank erosion

The most documented role of riparian vegetation in the literature is its effect on the stability of stream channels. Many factors of stream health are compromised
when a channel is unstable, making channel stability a high priority for site rehabilitation (Brooks and Lake, 2007). Bank stability algorithms and associated analysis models have been developed to evaluate and quantify bank stability with input parameters that focus on soil characteristics, bank geometry and the absence or presence of riparian vegetation (Pollen-Bankhead and Simon, 2009a; Simon et al., 2009; De Baets et al., 2008; Eaton and Giles, 2009). Most of these studies have used vegetation variables that are relevant to northern hemisphere tree species ((Simon and Collison, 2002; Gray and Barker, 2004; Simon et al., 2006; Piercy and Wynn, 2008). However, studies in the southeastern region of Australia have developed relevant model parameters for Australian tree species, albeit limited (Abernethy and Rutherfurd, 2000; Abernethy and Rutherfurd, 2001; Docker and Hubble, 2008; Docker and Hubble, 2009; Hubble et al., 2010).

Briefly, the literature suggests vegetation reduces bank erosion through soil reinforcement, bank drainage and reducing near-bank flow velocities (reviewed in Thorne, 1990; Pollen-Bankhead and Simon, 2009b). Vegetation root networks add tensile strength to soil matrices and increase soil elasticity. Soils are known to be strong in compression and weak in tension, where as roots are the reverse (Vidal, 1969; Pollen et al., 2004). In combination, the soil-root matrix increases soil shear strength, which gives the channel boundary material an increased resistance to the driving forces of instream flow and near bank velocities and reduces bank erosion potential. However, soil reinforcement only extends down to the rooting depth of vegetation. Root architecture is thought to be important in the reduction of bank erosion as grasses, whilst responsible for some of the highest root matrix strength readings (Simon and Collison, 2002), typically occupy only the top 30 cm of soil (Wynn et al., 2004). Trees and shrubs penetrate much deeper into the soil and reinforce a much larger amount of soil throughout the profile (Docker and Hubble, 2009). A combination of both types of root structures are thought to offer the greatest stability to a stream bank as surface soils where erosion initially occurs will be strongly reinforced by shrubs and grasses, whilst the deeper soils which are exposed at the toe of the bank through erosion are protected by the roots of large woody plants (Simon and Collison, 2002).

Vegetated banks are thought to be drier and better drained, which improves their stability in regards to mass failure (Thorne, 1990). Several processes are involved in influencing bank hydrology as a consequence of riparian vegetation: interception of rainfall, evapotranspiration, and infiltration. These processes reduce pore water pressure in the soil and increase matrix suction through abstraction of water from the soil profile through the roots (Simon and Collison, 2002; Langendoen et al., 2009). The presence of vegetation also lowers antecedent moisture levels in the soil and reduces the frequency of bank saturation. This in turn reduces bulk unit weight of soil and increases cohesive forces in the soil matrix (Thorne, 1990). By reducing pore water pressure and antecedent moisture levels the trigger for bank collapse through mass failure following high stream flows is reduced and bank stability is increased. The
following research questions will increase our knowledge on this subject for subtropical SEQ:

**What are the relevant attribute values of SEQ riparian tree species for bank stability modelling inputs, and**

**What are the hydrological attributes of different bank soil types in vegetated and non-vegetated riparian zones in SEQ catchments?**

An increase in channel roughness associated with riparian vegetation can increase resistance to near bank erosive forces by displacing the flow away from the bank (Thorne, 1990). Studies have shown dense vegetation increased this resistance to erosion by 1-2 orders of magnitude compared to non-vegetated banks (Carson and Kirkby, 1972; Kirkby and Morgan, 1980) as cited in Thorne (1990). Mechanistically, it is thought vegetation near the toe of the bank can reduce the rate of bank retreat by impeding fluvial scour and the subsequent steepening of the bank, which would normally occur if the toe of the bank was scoured during high velocity flows (see a review in Simon and Collison, 2002). A study by Kean and Dungan Smith, 2004 showed boundary shear stress in channels with woody vegetation was affected by a reduction in friction along the bank as well as a reduction of flow near the bank through increased drag forces associated with the vegetation structure (hummocks, root balls, stems, branches etc). This study also highlighted the constraints of current flow modelling using a single Manning’s n value to determine the channel roughness coefficient for the whole channel as this cannot be related to important characteristics of the vegetation such as stem spacing.

There is limited data in the literature that measures the effects of spatial configurations of vegetation in the field and so complex models have been developed to help determine stem spacing effects on drag and turbulence patterns (Lopez and Garcia, 1997; Nepf, 1999). One study in south eastern Australia did investigate erosion patterns around large single trees on the Acheron River and found trees tend to fail by toppling into the river as the undercut structure (abutment) beneath their root ball reaches a critical threshold (Rutherfurd and Grove, 2004). This suggests roots from a single tree can increase the resistance of impinging banks in a semi circle centred on the trunk. However, single trees on the top of banks were unable to alter the long term migration rate of the river bend. The following research question is warranted to further our knowledge:

**Can we effectively link instream flow responses to bank stability models in SEQ systems, particularly in reference to vegetation placement within the channel?**

There is some information in the literature as to the effect of riparian vegetation on channel meander and bank erosion rates (Pizzuto, 1984; Beeson and Doyle,
1996; Rutherfurd, 2000; Brooks and Brierley, 2004; Micheli et al., 2004; Bartley et al., 2008). Micheli (2004) found agricultural floodplains along the Sacramento River, California, USA were 80-150% more erodible than riparian forested floodplains and Beeson and Doyle, 1996 found river bends without riparian vegetation are nearly 5 times more likely to exhibit erosion during flood events and 30 times more likely to suffer major erosion. Bartley et al., 2008 showed that mean erosion rates of vegetated banks in a tropical catchment, Australia were 6.5 times lower than banks without vegetation. None of these studies showed maximum streambank erosion rates associated with a given flood event but determined the average erosion rate over a given timeframe. This lack of information on stream bank erosion rates and the environmental factors controlling them has led to the confirmation that streambank erosion is the most uncertain of the sediment source terms in the development of a river budget model (Olley et al., 2009). The following research questions are pivotal to our current understanding:

What are the streambank erosion rates for vegetated and non-vegetated channels in SEQ, and

What is the effect of discontinuity of riparian vegetation along the catchment on sediment loads at the catchment outlet?

3.4 Influence of riparian revegetation on catchment water yields and flooding patterns

Best et al., 2003 reviewed past studies that have assessed changes to water yield from catchments as a consequence of changes to vegetation cover. Most of these studies are focussed on catchment area cover rather than specifically riparian vegetation. Most of the studies concluded that a reduction in catchment vegetation resulted in an increase in water yield and base flow in the stream network. They also showed the increase in water yield was greatest in catchments with high rainfall. Other conclusions from this review are: overland flow or quick flow is less likely to be affected by vegetation cover than baseflow; changes in water yield as a result of changes in vegetation, particularly permanent vegetation changes are likely to be reflected as changes to baseflow and the main process responsible for changes in water yield as a result of vegetation changes at the mean annual scale is evapotranspiration (Zhang et al., 2001). Under most climatic conditions, evapotranspiration from forests will be greater than from grasses. The effects of catchment scale revegetation of riparian zones on stream baseflow have not been widely researched and no specific studies were found in the literature. This may have significant implications for ephemeral streams as the further reduction of low flows in some areas of SEQ following revegetation of the riparian zone could result in the crossing of a threshold of ecological importance.

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Following significant floods, there is often a call from the community to “clean out the creeks” removing vegetation, debris and silt in order to quickly convey flood waters and prevent inundation of low lying areas (Tate et al., 2012). Recommendations from the Queensland Floods Commission of Inquiry-Interim Report following the 2010/2011 floods suggested “Lockyer Valley Regional Council should immediately develop a plan for the removal of debris, man-made and natural, from waterways in the Lockyer Valley and put it into effect so as to minimise the risk should flooding recur in the coming wet season.” Yet there has been no clear cut evidence to suggest vegetation or logjams within the streams exacerbate flooding on a catchment scale. If anything, data would suggest increased roughness in the channel due to channel bed and bank vegetation and large woody debris (LWD) reduces the peak flood height and channel flow velocities (Lovett and Price, 2007). Adding vegetation and LWD to streams has little effect on the height and duration of large floods and the effect of increased vegetation on flood heights diminish as the width of the channel increases downstream. Past removal of instream vegetation was related to flood management and drainage and it is not unexpected that landholders would question the re-introduction of vegetation into the channels on future flooding. There is very limited data to confirm or deny these fears of increased flooding and no peer reviewed literature in relation to this subject in subtropical SEQ. The following research questions would address some of the knowledge gaps in the above areas of interest:

*Can we use instream flow and bank stability models to predict changes in water yield for the catchments, and*

*Can we use these models to assess changes in flooding patterns throughout the catchment as a consequence of revegetation on a catchment scale?*

### 3.5 Riparian vegetation and aquatic ecosystem health

The ecology and management of riparian zones is extensively reviewed in Naiman and Decamps (Naiman and Decamps, 1990). Riparian zones are effective as reducers of flood effects, natural filters against diffuse pollution from the draining catchment landscape and also provide a source of organic matter to the aquatic system through the movement of riparian plant and animal material (Naiman and Decamps, 1990; Vannote et al., 1980). Established riparian vegetation can influence organic production in the system by shading out light penetration into the water column. The lack of projecting vegetation can have detrimental impacts on water quality through increased photosynthesis and oxygen depletion (Mosisch et al., 2001), while higher water temperatures increase metabolism, decomposition of organic matter and the solubility of gasses which all further deplete oxygen levels. The physical presence of instream vegetation and large woody debris is also important as it provides
habitat for aquatic organisms and increases the biodiversity of sites (Gurnell et
al., 1995; Abbe and Montgomery, 1996).

Monitoring of aquatic ecosystem health has been undertaken in SEQ since 1998
and has expanded to now include over 135 monitoring sites (Healthy Waterways
Ltd, EHMP). Analysis of the EHMP datasets in conjunction with riparian zone
extent and adjacent landuse practices has shown a decline in aquatic ecosystem
health rating with cleared riparian areas and proximity to agricultural landuse, eg
grazing (Peterson et al., 2011). The following questions are valid to build on our
current knowledge in this area:

What are the riparian buffer trapping efficiencies for sediment and nutrients
in sub-tropical SEQ, and

What are the riparian buffer trapping efficiencies for sediment and nutrients
with specific adjacent landuses?
4 Revegetation as a management action

4.1 Revegetation methods and success rates

Riparian management is a common method employed in river restoration projects and includes stock exclusion, installation of off-stream watering points, weed management and revegetation of the riparian zone with native species (Sweeney and Czapka, 2004, Roni et al., 2008; Rutherfur et al., 2000 Bernhardt et al., 2007). A survey in Victoria, Australia by Brooks and Lake, 2007 showed the majority of river restoration projects (49%) undertook these methods as the main output for the project, followed by bank stabilisation and instream habitat improvement. The rationale for using revegetation techniques is commonly based on scientific literature that has defined the function and processes inherent in riparian zones (Gregory et al., 1991, Naiman and Decamps, 1990, Baxter et al., 2005). Such functions include stabilization of banks and channel, reducing flow velocity, providing in-stream habitat, assisting the movement of organisms, filtration of inflows, energy input and moderation of instream production. However, there is very limited scientific evidence to suggest riparian management will re-instate riparian zone ecological functions and processes to a sustainable level.

Actual methods for undertaking riparian management activities are often presented in local manuals that are specific for local conditions (BCC, 2000; ICC, 2009), national guidelines (Rutherfurd et al., 2000; Abernethy and Rutherfurd, 1998; Lovett and Price, 1999; Price and Lovett, 1999) and rudimentary bush regeneration methods and factsheets (Bradley, 1988; MRCCC, 1996). The majority of the methods in local revegetation manuals and factsheets describe species composition and its suggested location in the riparian zone at a transverse scale for the waterway. The suggested species lists are usually endemic to the local area and its associated climatic conditions and often based on remnant vegetation mapping guides (Queensland Government Herbarium). Webb and Erskine, 2003 detailed a practical approach to stream rehabilitation in Australia and proposed some of the following questions in reference to revegetation techniques that have not been answered in regards to sub-tropical regions:

*What are the requirements for specific vegetation communities in association with in channel features and landforms, eg depth to groundwater, flood disturbance, vegetation succession, substrate composition,*

*Do we require specific planting techniques on a transverse basis as well as along the longitudinal profile of the stream,*

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Has the hydrology of the catchment changed and will remnant vegetation communities be the most suitable species selection, and

Do we require specific planting techniques following catastrophic floods and channel adjustment?

There are limited studies that describe the revegetation methods applicable to the longitudinal profile of the stream and Abernethy and Rutherfurd, 1998 is the only Australian based study that suggests the placement of vegetation in association with specific geomorphic processes. In terms of sub-tropical regions the following research question is warranted:

In SEQ, what is the most effective vegetation species composition for the management of dominant erosion processes located along the longitudinal profile?

There is good evidence to suggest that revegetation of riparian zones can improve instream water quality and increase habitat complexity, trap fine sediment and nutrients from overland inflows and reduce instream water temperature and is a good source of large woody debris for the system. However, there is a paucity of data to confirm the reduction in streambank erosion as a consequence of riparian zone revegetation, which may be due to the time required to measure change (Feld et al., 2011). Rutherfurd et al., 2004 concluded that some inherently variable parameters would need to be monitored for significant periods of time (eg. 80yrs for turbidity) to confidently measure a change in condition. Monitoring the success of riparian rehabilitation projects is complex and time consuming, yet still some of the more basic questions relating to revegetation of a riparian zone have not been addressed in the literature. The following research question requires urgent attention:

What widths and lengths of riparian vegetation are required to restore stream bank stability and ecological function to the riparian zone?

4.2 Monitoring, evaluation and learnings

River restoration is a relatively young study area and a surge of activity occurred across Europe and US in the 1990s (Palmer et al., 2007). Most of the literature around this subject has been written over the last decade. In terms of investment, in the US one billion dollars is spent annually on river restoration projects (Bernhardt et al., 2007) and worldwide it is a multibillion dollar industry (Brooks and Lake, 2007). Yet there are few well documented cases that determine the actual success rate of these activities in achieving their intended project goals. Palmer et al., 2007 summarised data from over 37,000 projects included in the National River Restoration Science Synthesis project database to assess why restoration activities are undertaken, how are they monitored and what lessons
can be learnt for future investment. The conclusions from this paper and related articles in the special section of Restoration Ecology (vol 15(3), 2007) are sobering. Most restoration projects are based on an object/ive/s that is/are irrelevant to the processes underpinning the perceived problems. Monitoring of ecological outcomes from the restoration activities is also under resourced with less than half of the projects setting measurable success criteria. Actual monitoring of post-project performance is on average 10%. Kondolf, 2007 and Brooks and Lake, 2007 highlighted our lost opportunities to learn from past restoration efforts due to the lack of post-project evaluation. A key recommendation from the Palmer et al., 2007 report was the need for “specific restoration design and the implementation of watershed planning guidelines for prioritizing stream and river restoration projects that are based on the distribution and extent of environmental degradation coupled with watershed planning and scientific information on which problems are feasible to address via restoration”. Globally and in Australia, there is a paucity of monitoring in association with stream rehabilitation projects on both a catchment and reach scale. The following question is proposed primarily to address the lack of knowledge associated with monitoring techniques and management efficacy:

What key parameters can be monitored to assess the effects of revegetation on streambank stability and how can they be related back to research?

The need for assessment of waterway restoration costs and benefits is globally mirrored throughout the literature (Kondolf, 1995; Kondolf and Micheli, 1995; Bash & Ryan 2002; Downs and Kondolf, 2002; Palmer et al., 2005). In Australia we have good guidelines to address the whole process of stream restoration (Rutherfurd et al., 2000). However, there is a real knowledge gap for restoration practitioners in the development of relevant success criteria and key parameters that are valid for adaptive management purposes. Bunn et al., 2010 and Reich et al., 2011 suggest large scientific projects relating to waterway restoration should be undertaken in key landscapes and used to inform project planning in an adaptive management framework. These research questions are relevant to the above described knowledge gaps:

What are the success criteria to assess the effectiveness of specific revegetation methods?

What site specific attributes are critical in site selection for monitoring activities, particularly in paired site analysis?

Post-project evaluation in waterway restoration activities is a broad knowledge gap, yet it underpins all of the more specific areas of knowledge where we lack good robust data to inform restoration effectiveness and efficacy. The time frame required to address some of these knowledge gaps is longer than our current funding and evaluation cycles and so predictive modelling has been developing
over the past decade to substitute space for time in riparian restoration evaluation. Most of these models link erosional processes with vegetation attributes (e.g., root architecture, stem flexibility) yet the variability of tree species characteristics between continents and at a local scale can prevent generalised application of such models (Piercy and Wynn, 2008). Although predictive modelling is a useful tool in determining the effect of revegetation on bank stability and erosion and deposition responses to this management action, it still has significant knowledge gaps relating to Australian vegetation tree attributes, placement of vegetation on the bank face and the hydrological response of riparian zones along the longitudinal and transverse profiles in relation to revegetation on both catchment and reach scales. These are critical questions that have been raised in the above text.

Much has been learnt over the past decade on where to rehabilitate the catchments in regards to erosion sources and processes, yet still little information exists as to how to revegetate these areas on a landscape scale (Olley et al., 2009; Olley et al., 2010b; Olley et al., 2010a; Reich et al., 2011).
5 Summary

The literature review has described key areas of interest in regards to the effects of vegetation on channel morphology and bank stability and has touched on the associated topics of catchment hydrology and aquatic ecosystem health. The effectiveness of revegetation methods in the management of stream bank erosion and increased channel stability has not been well documented in peer reviewed literature. Post-project evaluation specific information may be available from catchment management groups and State Departments (Victoria has been developing a database to describe position and brief descriptions of on ground works-Brooks and Lake, 2007). However, the current funding structures for stream rehabilitation, both globally and in Australia, does not allow for adequate monitoring and evaluation activities. The scientific rationale for using revegetation methods to address streambank erosion is well researched and there are Australian design guidelines to assist in the development of stream rehabilitation projects. However, there are still considerable knowledge gaps in the practical application of this research and the design of monitoring methods to assess the effectiveness of revegetation methods. The use of predictive models in conjunction with field trials at relevant scales is required to clarify which methods are most cost effective in the sub-tropical region of SEQ and the assessment of landscape scale change in response to significant investment of funds in the rehabilitation of streams.

There is currently sufficient expertise and datasets to trial appropriate catchment works on SEQWater operated lands in order to address sediment export from streambank erosion sources. The proposed research questions should be used to assist in the development of these field trials on a sub-catchment scale and to develop robust monitoring methods to assess the efficacy of these management actions.
6 Potential research questions

The main focus of the literature review was to describe what information exists in relation to the use of riparian revegetation methods, the knowledge gaps surrounding this area of interest and the proposed research questions that need to be answered in order to maximise the use of this method. The proposed research questions are again summarised here;

What widths and lengths of riparian vegetation are required to restore stream bank stability and ecological function to the riparian zone?

What is the most effective vegetation species composition for the management of dominant erosion processes located along the longitudinal profile?

Can we use space for time substitution methods to predict the effect of revegetation intervention on subsequent channel recovery?

Can we use this output to inform further investment in the revegetation of streams from the top to the bottom of the catchment?

What is the effect of changing riparian vegetation from a grass/non-vegetated to treed/vegetated state on channel morphology?

What parameter is strongly correlated to any change in channel morphology, eg discharge, vegetation age and condition, vegetation placement across the channel?

Can we model this response to predict sediment deposition and erosion responses from the top to the bottom of the catchment?

Can we use historical floodplain features and dendrochronology methods to predict changes in channel planform as a consequence of changed vegetation patterns?

What are the relevant attribute values of SEQ riparian tree species for bank stability modelling inputs?

What are the hydrological attributes of different bank soil types in vegetated and non-vegetated riparian zones in SEQ catchments?

Can we effectively link instream flow responses to bank stability models in SEQ systems, particularly in reference to vegetation placement within the channel?
Can we use these models to assess changes in flooding patterns throughout the catchment as a consequence of revegetation on a catchment scale?

Can we use these models to predict changes in water yield for the catchments?

What are the requirements for specific vegetation communities in association with in channel features and landforms, eg depth to groundwater, flood disturbance, vegetation succession, substrate composition?

Do we require specific planting techniques on a transverse basis as well as along the longitudinal profile of the stream?

Has the hydrology of the catchment changed and will remnant vegetation communities be the most suitable species selection?

Do we require specific planting techniques following catastrophic floods and channel adjustment?

What key parameters can be monitored to assess the effects of revegetation on streambank stability and how can they be related back to research?

What site specific attributes are critical in site selection for monitoring activities, particularly in paired site analysis?

What are the success criteria to assess the effectiveness of specific revegetation methods?

What are the streambank erosion rates for vegetated and non-vegetated channels in SEQ?

What are the riparian buffer trapping efficiencies for sediment and nutrients in sub-tropical SEQ?

What are the riparian buffer trapping efficiencies for sediment and nutrients with specific adjacent landuses?

What is the effect of discontinuity of riparian vegetation along the catchment on sediment and nutrient loads at the catchment outlet?
7 References


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