



FINAL REPORT:

An assessment of the impact of riparian revegetation on stream erosion during floods in Victoria

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Key findings

- Flood related channel change damages public and private infrastructure and river health. The cost of flood related river restoration work in Victoria has amounted to \$80 million (net present value) over the past 20 years (approx). In addition to this river restoration cost, the cost of repairs to public infrastructure (such as roads and bridges) has been an order of magnitude greater again.
- Where very similar reaches of stream experience large floods, the reaches that have been cleared of native vegetation experience much greater erosion damage than corresponding reaches that have been revegetated over several years.
- Quality native riparian vegetation, established via a revegetation program reduced erosion at the vegetated sites in each of the five paired site assessments undertaken for this project, by between 80% and 95% (Figures 1 and 2).



Figure 1. Paired site assessment for Black Range Creek, north east Victoria (the site with bare banks (left) experienced widespread erosion while the revegetated site (right) incurred only minor channel change in the same flood event

- Native riparian vegetation must be of high quality and contain diverse structural elements comprising instream, bank and floodplain vegetation including sedges, reeds, ground covers, shrubs and trees suitable to address the range of erosion mechanisms present in stream systems.
- It may take between 10 and 15 years for a reach subject to a well-managed revegetated program to acquire the characteristics necessary to achieve the stabilising capacity of high quality, structurally diverse vegetation.
- The occurrence, scale and extent of channel change that arises as a result of an absence of high quality, structurally diverse native riparian vegetation is greatest in the Northeast and East and West Gippsland regions.

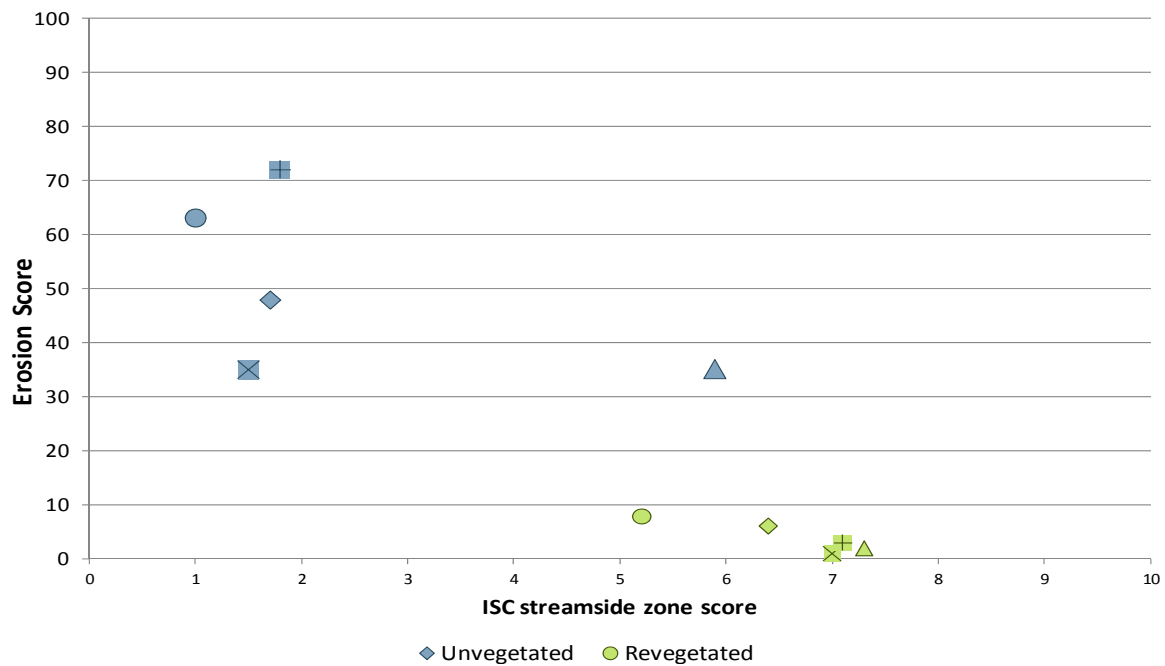


Figure 2. Results showing the relationship between erosion score and the ISC streamside zone score for all five of paired sites analysed in this study

- Structural works may be required in addition to native quality riparian vegetation to provide an appropriate level of protection to public infrastructure from flood related stream erosion.
- The establishment of continuous corridors of high quality structurally diverse native riparian vegetation is reliant upon:
 - The implementation of ongoing programs and works based on established industry standards. This included assessment, design, implementation and maintenance of structural stream management works, fencing and revegetation.
 - The application of activities and works at a reach scale. This comprised management of stream reaches over a minimum of several meander wavelengths as opposed to management of isolated sites of erosion.
 - The provision of policy support for land management agreements with adjoining landholders. This included provision of state and regional policy, and administrative arrangements that enabled the CMA to establish riparian land management agreements with adjoining landholders over both private and crown lands. These agreements include arrangements associated with land management, repairs to fencing, access by stock and crown frontage licence terms and fees.

Executive summary

Widespread flooding occurred across Victoria in the spring of 2010 and the summer of 2010/11. This flooding caused major channel change and associated flood related damage. This study investigates the role of native vegetation established through revegetation programs on the extent of flood related channel change. The investigation has been based on relevant Australian and international literature, and recent investigations in North East Victoria by the North East Catchment Management Authority (NECMA) and in East Gippsland by the East Gippsland Catchment Management Authority (EGCMA). The investigation has also included a set of paired site assessments to test the hypothesis that riparian vegetation established through a revegetation program can be the controlling factor that limits flood related channel change.

In Victoria, a substantial investment has been made in waterway management programs, including streamside vegetation establishment and complimentary works (community engagement, fencing, stock exclusion etc.). The use of native vegetation in such waterway management programs commenced in the late 1980s and early 1990s. These programs were focussed on the establishment and maintenance of stream stability. The past 10 to 12 years have been dominated in Victoria by drought conditions and much of the investment and research over this period has been in the field of waterway health. The programs of native vegetation establishment have continued with a broader objective of achieving improvements in waterway health.

There has been a renewed interest in stream erosion and channel change following recent flood events and, in particular, renewed interest in the role of native vegetation in limiting such channel change in flood events. Through the investigation described in this report, comprising literature and study reviews and paired site assessments (field investigations and hydraulic analysis), we have compiled an extensive body of evidence associated with the role of native riparian vegetation on flood related channel change. We found:

- Flood related channel change causes major damage to public and private infrastructure and river health. The cost of flood related river restoration works has amounted to over \$80 million (net present value) over the past 20 years (approx). The cost of repairs to public infrastructure (such as roads and bridges) has been an order of magnitude greater than the cost of river restoration works.
- The absence of high quality, structurally diverse native riparian vegetation increases the occurrence extent and scale of flood related channel change and associated flood related recovery costs in Victoria.
- High quality, structurally diverse native riparian vegetation, established through revegetation programs such as those undertaken by Victoria's catchment management authorities, can be effective at reducing the occurrence, extent and scale of flood related channel change.
- Native riparian vegetation must be of high quality and contain diverse structural elements comprising instream, bank and floodplain vegetation including sedges, reeds, ground covers, shrubs and trees suitable to address the range of erosion mechanisms present in stream systems.

The paired site assessments revealed a strong inverse relationship between erosion and the presence of high quality, structurally diverse native vegetation, established from a revegetation program (Figure 2). The results of the paired site assessment support the hypothesis that riparian vegetation established through a revegetation program can be the controlling factor that limits flood related channel change. At the paired sites, we found negligible channel change at sites that had been the subject of revegetation programs resulting in the establishment of high quality, structurally diverse native riparian vegetation. We found high rates of flood related channel change at sites that did not have high quality, structurally diverse native riparian vegetation.

The characteristics of riparian vegetation in streams that are resistant to flood related channel change include:

- Vegetation corridor structural diversity: the vegetation should be structurally diverse (contain instream vegetation, bank ground cover, shrub species and trees). This diversity will take many years (potentially 10 to 15 years) to establish, dependent upon local conditions;

- Vegetation corridor width: native vegetation riparian corridors need to be an appropriate width to ensure they are ecologically and physically functional. The scientific literature is clear that the appropriate width varies across sites and for the specific function that needs to be achieved (Hansen et al. 2010). This study demonstrated that sites with well-developed riparian corridors (generally 10 to 30 m wide on each side) were effective in providing for resistant and resilient streams.
- Vegetation corridor longitudinal connectivity: Native vegetation riparian corridors should be continuous (or largely continuous).

Some of these characteristics are shown in the right hand panel of Figure below.



Figure 3. Paired site assessment for Barwidgee Creek, north east Victoria (the site with bare banks (left) experienced widespread erosion while the revegetated site (right) incurred only minor channel change in the same flood event

The establishment from revegetation programs of continuous corridors of high quality, structurally diverse native riparian vegetation that meets the above criteria is reliant upon:

- The implementation of ongoing programs and works based on established industry standards. This included assessment, design, implementation and maintenance of structural stream management works, fencing and revegetation.
- The application of activities and works at a reach scale. This comprised management of stream reaches over a minimum of several meander wavelengths as opposed to management of isolated sites of erosion.
- The provision of policy support for land management agreements with adjoining landholders. This included provision of state and regional policy, and administrative arrangements that enabled the CMA to establish riparian land management agreements with adjoining landholders over both private and crown lands. These agreements include arrangements associated with land management, repairs to fencing, access by stock and crown frontage licence terms and fees.

Native riparian vegetation corridors will reduce the extent and scale of flood related channel change. However, where there are public assets located near stream systems, additional structural works may be required. The integration of road, bridge and culvert design with the dynamics of stream systems is complex. In most instances, it is not feasible to rely on vegetation alone to provide protection for major infrastructure such as roads and bridges where they intersect with stream systems. Some complimentary structural works in the vicinity of the asset, such as rock revetment, may also be required. In the long-term and through the majority of stream length, the control on flood related channel change can be provided by high quality, structurally diverse native riparian vegetation.

Historically, the majority of flood related damage to Victoria's public infrastructure has occurred in the eastern regions of the state. This has been illustrated by the history of flood recovery investments undertaken in Victoria over the past 35 years. Nonetheless, native vegetation can be a controlling influence on flood related channel change, as well as play an important role in stream processes and health in all alluvial stream systems across Victoria.

There are some cautions associated with the investigations and results from this study. The relationship between rivers and their accompanying floodplains is complex and requires careful consideration and management. This investigation has focussed on in-channel processes and not floodplain processes. As a consequence, the results should be used with some care and in conjunction with consideration of broader floodplain processes. In this respect, revegetation of riparian zones should be undertaken in association with the management of the broader floodplain.

The investigation has identified the circumstances or conditions where high quality structurally diverse native vegetation provides the critical influence on flood related channel change. It should not be interpreted that native riparian vegetation is not required where these circumstances are not met. High quality, structurally diverse native riparian vegetation is required on all stream systems for the protection and maintenance of aquatic and riparian ecological values. However there are some systems and flood events where this vegetation plays a more important role in erosion control than other systems and events.

Methods now exist to predict reaches of rivers, and areas of floodplains, that will be at greatest risk from severe erosion during floods. High resolution remote sensing techniques (e.g. LIDAR), combined with hydraulic modelling, allow managers to predict those sections of stream that will be subject to the greatest bed and bank erosion. The same is true for predicting the areas of floodplain that are most likely to have avulsions. Identifying these areas at risk will help to guide managers in planting riparian vegetation. At the same time, the hydraulic effect of vegetation should be investigated to understand the implications of revegetation programs on flood risk.

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1 Introduction

Widespread flooding occurred across Victoria in the spring of 2010 and the summer of 2010/11. This flooding caused major channel change and associated flood related damage. This study investigates the role of native vegetation established through revegetation programs on the extent of flood related channel change. This investigation has been based on relevant Australian and international literature, and recent investigations in north East Victoria by the North East Catchment Management Authority (NECMA) and in East Gippsland by the East Gippsland Catchment Management Authority (EGCMA). The investigation has included paired site assessments from Victoria.

In Victoria, substantial investment has been made in waterway management programs, including streamside vegetation establishment and complimentary works (community engagement, fencing, stock exclusion etc.). These programs were undertaken in the late 1980s and early 1990s for stream stability purposes. The past 10 to 12 years have been dominated by drought conditions in Victoria and much of the stream investment and research over this period has been in the field of waterway health. The programs of native vegetation establishment have continued over this period as part of programs to improve the health of Victoria's waterways.

There has been renewed interest in channel change following recent flood events and in particular renewed interest in the role of native vegetation in limiting the extent and scale of channel change in flood events.

The investigation addresses the role of revegetation on flood related channel change but does not address the many other roles of vegetation and revegetation programs on stream processes and health.

2 Flood impacts – the cost of repairing flood related damage

Flood events cause major damage across Victoria. This damage is associated with the direct inundation (flooding) of property and indirect impacts associated with erosion and deposition (channel change). This investigation addresses the second of these issues, focussing on the damage associated with flood related channel change.



Figure 4. Temporary bridge construction over Macalister River following loss of Cheynes Bridge in the 2007 flood event.

The damage associated with flood related channel change includes erosion that leads to loss of private and public infrastructure such as bridges, culverts, roads, water supply systems and power and telecommunications systems. Flood related channel change causes the loss of agricultural land through erosion of stream beds and banks. In addition, large floods can produce meander cut-offs and avulsions where the river abandons one channel and occupies a new one across a floodplain. This causes major disruption to communities and infrastructure (Figure 5).



Figure 5. Floodplain flow and site of potential avulsion of King River in north east Victoria (View looking downstream, King River is on the right, floodplain scour path is in centre of image)

Flood recovery works are expensive and result in unscheduled cost burdens on the public and private sectors. Table 1 outlines the costs associated with flood recovery works undertaken by catchment management authorities and their predecessor organisations across Victoria over the past 45 years. These costs only include the cost of stream restoration works and do not include the costs of reconstruction of private and public infrastructure. Since 1990 these flood recovery works have required flood recovery grants of approximately \$80 million (historical flood recovery grants converted to \$AU 2011), equivalent to approximately \$4.0 million per year.

Table 1. Cost of stream based flood recovery programs in Victoria

Year of flood	Catchment/Region	CMA Region	Grant/Region (Flood Year \$ NPV 2011)	Grant/Event (Flood Year \$ NPV 2011)
2010/11	Ovens, King, Kiewa, Upper Murray, Upper Goulburn, Campaspe, Loddon	North East, Goulburn Broken and North Central	\$23,000,000	\$23,000,000
Jun-07	Tambo/Nicholson, Snowy, and Mitchell Rivers	East Gippsland	\$3,300,000	\$11,200,000
	Macalister, Avon and Thomson Rivers	West Gippsland	\$7,900,000	
Sep-06	Upper Mitta, Upper Murray	North East	\$200,000	\$200,000
Jun-98	East Gippsland Region-wide	East Gippsland	\$18,800,000	\$19,800,000
	Avon River	West Gippsland	\$1,000,000	

Year of flood	Catchment/Region	CMA Region	Grant/Region (Flood Year \$ NPV 2011)	Grant/Event (Flood Year \$ NPV 2011)
Sep-98	North East Region-wide	North East	\$6,300,000	\$7,300,000
	Wonnangatta and Wongungarra Rivers	East Gippsland	\$1,000,000	
June 1995 & October 1996	King/Ovens/Kiewa Rivers	North East	\$2,300,000	\$4,800,000
	Bruthen Creek	West Gippsland	\$900,000	
	Avoca River	North Central	\$100,000	
	Upper Goulburn River	Goulburn-Broken	\$200,000	
	Lake Wellington Rivers	West Gippsland	\$1,000,000	
	Surf Coast	Corangamite	\$300,000	
Oct-93	Ovens River	North East	\$6,400,000	\$8,400,000
	Broken River	Goulburn-Broken	\$1,100,000	
	Merrimans Creek	West Gippsland	\$500,000	
	Upper Goulburn River	Goulburn Broken	\$400,000	
Apr-90	Mitchell River	East Gippsland	\$2,100,000	\$6,500,000
	Thomson \$ Latrobe Rivers	West Gippsland	\$600,000	
	Avon-Macalister Rivers	West Gippsland	\$3,700,000	
	Bodmans Creek	West Gippsland	\$100,000	
Oct-85	Avon-Macalister Rivers	West Gippsland	\$900,000	\$900,000
Jul-84	Avon-Macalister Rivers	West Gippsland	\$100,000	\$100,000
Jun-78	Avon-Macalister Rivers	West Gippsland	\$1,800,000	\$1,800,000
Oct-76	Avon-Macalister Rivers	West Gippsland	\$600,000	\$600,000
			Total	\$84,600,000 (approx \$85,000,000)

The full cost of flood recovery, including bridge replacement as a result of channel widening and meander migration, is estimated to be an order of magnitude higher than the cost of the stream related flood recovery works. Following the 2010 flood events in Victoria, the State Government budgeted \$141.5 million for roads, bridges and railway repairs alone (pers. comm. Kishor Melvani). Other examples of infrastructure losses as a result of flood related channel widening and meander migration include:

- Loss of Cheynes Bridge and the Licola Bridge (and their approaches) on the Macalister River in 2007
- Loss of the Great Alpine Road adjacent to the Tambo River in 1998
- Loss of Pratts Lane Bridge across Black Range Creek in 1993
- Loss of numerous (three) road bridges across Morses Creek near Bright in 1993,
- Loss of the Dargo Road at Waterford adjacent to the Mitchell River in 1990
- Loss of the Princes Highway Bridge across the Genoa River in 1985.
- Threat of loss of Princes Highway bridge in Bairnsdale in 1990

3 Factors affecting flood related channel change and floodplain erosion

A substantial body of scientific and grey literature has been published on the subject of flood induced channel change. 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 degradation (stream power) to all the factors that if increased would favour aggradation (defined as resisting power).

The 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.

This concept of specific stream power can also 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 and a reduction in channel change in flood events. 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.

As outlined above the extent to which flood related stream power results in major channel change, 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 that 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 above channel change is also influenced by vegetation.

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:

$$\Omega = \rho g Q S$$

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

The units for mean specific stream power are Watts/m²

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/m². 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.

3.1 The influence of vegetation on flood related channel change – the processes at work

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. Accelerated rates of erosional channel change can damage public assets (bridges, culverts, road embankments, power lines etc) and result in degradation of, and damage to, river health through, for example, infilling of pools by large sediment loads, erosion of bank habitat niches (e.g. under cut banks) and loss of large wood.

Erosion is the process by which alluvial sediment is removed from the bed, banks or floodplain. There is a range of erosional processes that can occur independently or in unison resulting in channel change. Abernethy and Rutherford (1999) define three erosion categories as:

1. **Subaerial erosion** – erosion by processes external to the stream (i.e. cattle pugging, desiccation, groundwater seepage)
2. **Fluvial scour** – erosion resulting from the entrainment of bed and bank sediments due to hydraulic forces exceeding the resistance force (e.g. cohesion, gravity etc)
3. **Mass failure** – erosion caused when large volumes of bank material slide or topple from the bank into the channel.

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 Rutherford (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 2.

Table 2. Vegetation and its influence on each of the three erosional processes (adapted from Abernethy and Rutherford, 1998)

Erosion process	Vegetation interaction
Mass failure	<p>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 Rutherford 2000)</p> <p>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 Rutherford 2000)</p>
Fluvial scour	<p>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).</p> <p>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 Rutherford 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.</p>
Sub-aerial preparation	<p>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.</p> <p>Desiccation – Dry and cracking banks are more susceptible to mass failure. Vegetation can reduce desiccation by binding the substrate together. (Wynn and Mostaghimi 2006).</p>

Importantly, and as outlined in Table 2, for these different forms of erosion, vegetation plays two critical roles in limiting channel change:

1. Hydraulic (frictional) resistance: According to Anderson and Rutherford (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
 - inchannel 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 .
2. Structural protection to the stream bank: The vegetation provides structural reinforcement to the bank material increasing the cohesive properties of the soil.

These roles in limiting erosion and channel change are rarely provided by a single species. A suite of vegetation types is required to fulfil these various roles in limiting channel change. This suite of vegetation includes instream vegetation, stream bank ground covers, shrub species and trees. This suite of vegetation is typical of

south east Australia's remnant native riparian vegetation. For the purposes of this report we refer to high quality, structurally diverse native riparian vegetation as being of 'remnant quality'.

3.2 The influence of vegetation on flood related channel change – examples from the literature

Over the past 20 years much attention has been devoted to conserving remnant native vegetation on rivers and revegetating degraded rivers with native species. These practices have been primarily driven from past learnings and a broader understanding of riparian zone function (Webb and Erskine 2003). Beyond the contribution toward limiting the rate and extent of channel change, there is a good understanding and widespread acceptance of the role of native riparian vegetation in the provision of shade and shelter for aquatic and terrestrial fauna and as a source of carbon and large wood to stream systems. High quality structurally diverse, native riparian vegetation is essential for waterway health and for the protection and maintenance of instream and riparian ecological values.

In terms of channel change there is now a good understanding on how different vegetation types limit erosional processes and as a result there is widespread agreement that riparian vegetation limits excessive erosion in alluvial systems.

Riparian vegetation influences channel morphology through modifications to near bank hydraulics and bank properties. The influences on morphology can be varied, depending on which erosional processes are dominant. Consequently, the influence of riparian vegetation on morphology can be related to the position in the catchment, as different processes become more dominant (Abernethy and Rutherford 1998). Abernethy and Rutherford (2000) found alluvial channels, supporting well-developed riparian vegetation, to be deeper, narrower and to migrate more slowly than channels without such vegetation. Alternatively, McBride, Hession et al. (2010) propose that the re-forestation of river banks can result in initial deepening followed by widening as a result of changes in the local hydraulics and bank-resisting forces. However, any minor changes associated with revegetation are likely to be offset by the riparian vegetation's ability to resist major channel change during large floods events.

Large floods can exert large forces on river banks. Hubble and Rutherford (2010) observed substantial channel widening in reaches of the Nepean River that had banks cleared of vegetation after periods of unusually large and frequent floods. During periods of low flood magnitude, limited erosion was observed even in reaches with cleared banks. Similarly Geyer, Nepl et al. (2000) reported on the impacts of woody riparian vegetation on stream bank erosion following an extreme flood in 1993 on the Kansas River (ARI in the 100-500 year category). Their study found lateral streambank erosion was related to vegetative cover; erosion rates were far higher on cropland and only nominal on forested streambanks. It was concluded that cultivating land next to alluvial streams should be avoided because of the large acreage lost during flood events. The economic impact of having unvegetated stream banks was also highlighted by Webb and Erskine (2003) who discussed the large cost involved in stabilising unvegetated streams following major floods in eastern Australia.

Similar findings were also reported following major flooding in British Columbia in 1990 (Beeson and Doyle 1995). Meander bends devoid of riparian vegetation were nearly five times as likely to be eroded as vegetated bends. Furthermore, major bank erosion was 30 times more prevalent on non-vegetated bends as on vegetated bends. A longer term study by Micheli, Kirchner et al. (2004) on migration rates and bank erodibility on the Sacramento River, California USA, was conducted between 1949 and 1997. It was found that agricultural floodplains are 80 to 150% more erodible than riparian forest floodplains. These studies are some of the few that provide quantitative information on the ability of vegetated reaches to resist major channel change during large flood events.

Due to the limited availability of quantitative, reach-based studies, much of our learning of the importance of riparian vegetation in Australia comes from past experiences. Land clearing and the removal of riparian vegetation, combined with large flood events, have resulted in extreme channel change throughout south-eastern Australia (Fryirs and Brierley 2001; Webb and Erskine 2003). The erosion has led to loss of cultivated land, damage to public assets and the smothering of riverine and estuarine ecosystems in sediment.

An example of extreme erosional channel change following European settlement is the Cann River in East Gippsland, Victoria (Brooks, Brierley et al. 2003). After riparian vegetation clearance in the twentieth century, the Cann River system transformed from a highly sinuous system to a relatively straight river which is now more than three times wider and twice as deep. These changes in morphology have resulted in a 45 fold increase in bank full discharge. In contrast, the highly sinuous Thurra River in the adjacent catchment retained its riparian vegetation. Despite a similar flow regime, no major channel change has occurred in the Thurra River, which still maintains a similar morphology and function to the Cann River prior to settlement.

Burston and Good (1996) discuss a similar case of extreme erosional channel change in the Inman River on Fleurieu Peninsula, South Australia. Prior to riparian vegetation clearance it was possible to leap from one bank to another. It has now incised to a depth of 5m and a widened to approximately 20 m. These examples may seem extreme but similar levels of erosional channel have occurred across south-eastern Australia. It should be noted that although removal of riparian vegetation is a key driver of these erosional changes, other factors such as landuse change and desnagging would have also contributed to channel change.

3.3 Review of flood recovery programs in East Gippsland

In East Gippsland, an area with high flood variability and consequently prone to extreme flood events, flood recovery programs incorporating native vegetation establishment have been in place since the late 1980s. The flood recovery programs consist of revegetation programs as well as on-ground works (grade control, alignment training, and bank protection).

In 2011, an evaluation of flood recovery programs in East Gippsland was undertaken for the East Gippsland CMA and the Department of Sustainability and Environment to address three specific questions:

1. Have flood recovery works increased the resilience and resistance to the next flood? (refer to definition below and accompanying text box for a discussion on resistance and resilience)
2. Do flood recovery works contribute to stream health?
3. Do flood recovery works at individual sites contribute to increasing the resilience and/or resistance of stream reaches for the next flood?

For the purpose of the evaluation resistance was defined as the ability to prevent flood related channel change and resilience defined as the ability of the system to recover to a condition similar to that prior to the flood.

Study approach

The Federal Government's Natural Resource Management, Monitoring, Evaluation, Reporting and Improvement Framework (MERI) was used to guide the evaluation of the flood recovery programs in East Gippsland. The evaluation was based on the analysis of 37 sites of flood recovery works located within six flood impacted stream systems. These flood recovery sites and programs sought to achieve broad integrated river health and infrastructure protection outcomes. A further two sites were assessed comprising isolated works with a more narrow aim of protecting major public infrastructure at or near the site. The evaluation methods and indicators used are set out in Table 3.

Table 3. Proposed evaluation method and indicators

Evaluation question	Sub questions	Indicators	Scale	Approach
1. Have flood recovery works increased the resilience and resistance to next flood?	To what extent have the flood recovery works prevented damage from occurring in subsequent flood events?	Vegetation (resistance)	Site	<ul style="list-style-type: none"> Field assessment of vegetation for resistance
		Physical works	Site	<ul style="list-style-type: none"> Field assessment of current function and condition of physical works Post-hoc comparison of current vs. intended role of physical works
		Damage records	Site	<ul style="list-style-type: none"> Desktop analysis of EGCMA flood damage request database to determine whether the site has been subject to flood damage in subsequent flood events and if so the scope and cost of rework
	In what ways have flood recovery works sites recovered following subsequent flood events?	Vegetation (resilience)	Site	<ul style="list-style-type: none"> Field assessment of vegetation for resilience
		Trajectory assessment	Site	<ul style="list-style-type: none"> Field assessment of current conditions Ranking of degree to which system is on intended trajectory
2. Do flood recovery works contribute to River Health?	Has there been a change in stream health where flood recovery works have been undertaken?	Condition assessment	Site Reach	<ul style="list-style-type: none"> Field assessment of current condition using 2004 ISC method for streamside zone and physical form Review of EGCMA data from ISC assessment at 1998 program sites Review of statewide 1999 and 2004 ISC assessments
	What, if any, unanticipated (positive or negative) stream health outcomes have occurred due to flood recovery works?	Trajectory assessment	Site Reach	<ul style="list-style-type: none"> Reframe the site based assessments to investigate the reason for any decline in stream health
3. Do flood recovery works at individual sites contribute to increasing the resilience and/or resistance of stream reaches for the next flood?	To what extent have flood recovery works contributed to a reduction in damage from the next flood at a reach scale?	Vegetation (resistance)	Reach	<ul style="list-style-type: none"> Reframe the site based assessments to reach scale
		Physical works		
		Damage records		
		Channel change		
	In what ways have stream reaches recovered following subsequent flood events?	Trajectory assessment	Reach	<ul style="list-style-type: none"> Reframe the site based assessments to reach scale
		Vegetation (resilience)		

Study findings

Alluvium (2011a) found that the establishment of native vegetation was the common, essential element in achieving reach scale stream resistance and resilience to flood events and long term improvements in stream health. Post-flood assessments undertaken in 2011 found the vegetation established under the 1998 flood recovery programs had provided resistance to erosion associated with major flooding (approx. 25 year ARI) in previously unstable systems. The revegetation program in East Gippsland provided resistance to erosion associated with major floods after only 13 years. Conversely Alluvium (2011a) found ongoing flood related channel change in systems where vegetation establishment had not been successful.

Stream resistance and resilience

The terms stream resistance and resilience were used in the investigation by the East Gippsland Catchment Management Authority. The following definitions were adopted for the purpose of that investigation.

Stream resistance: This refers to the ability of the stream system to prevent or limit channel change. This resistance may be provided by the bed and bank materials and vegetation. Stream resistance can be provided through structural measures such as rock beaching.

Stream resilience: Stream resilience refers to the ability of a stream system to return to a pre-existing condition (including level of resistance) following a major flood and or some level of channel change. Stream systems with a wide native riparian vegetation corridor are typically resilient i.e. can readily return to a pre existing condition following some channel change. Conversely streams with structural protection may have low resilience with the system not able to return to a pre-existing level of resistance following damage to the structural works.

This investigation into flood related channel change is primarily associated with stream resistance.

This resistance to channel change, should not be confused with 'hydraulic resistance'. Hydraulic resistance refers to the roughness of a stream system and the role that this roughness has on the velocity of moving water. Hydraulic resistance can be provided by large bed sediments, large instream timber, vegetation and variable stream form such as meanders and changes in cross sectional area.

The success of waterway management programs in obtaining increased stream resistance, resilience and health was found to be associated with the success of activities such as vegetation planting, weed control, fencing and physical works to create an environment suitable for vegetation establishment. Alluvium (2011a) found three factors that governed the success or otherwise of the vegetation establishment and the establishment of resistant, resilient and healthy stream systems. These factors were:

- The implementation of ongoing programs and works based on established industry standards. This included assessment, design, implementation and maintenance of structural stream management works, fencing and revegetation.
- The application of activities and works at a reach scale. This comprised management of stream reaches over a minimum of several meander wavelengths as opposed to management of isolated sites of erosion
- The provision of policy support for land management agreements with adjoining landholders. This included provision of state and regional policy, and administrative arrangements that enabled the CMA to establish riparian land management agreements with adjoining landholders over both private and crown lands. These agreements include arrangements associated with land management, repairs to fencing, access by stock and crown frontage licence terms and fees.

The success factors that govern each influence activity are illustrated in Figure 6.

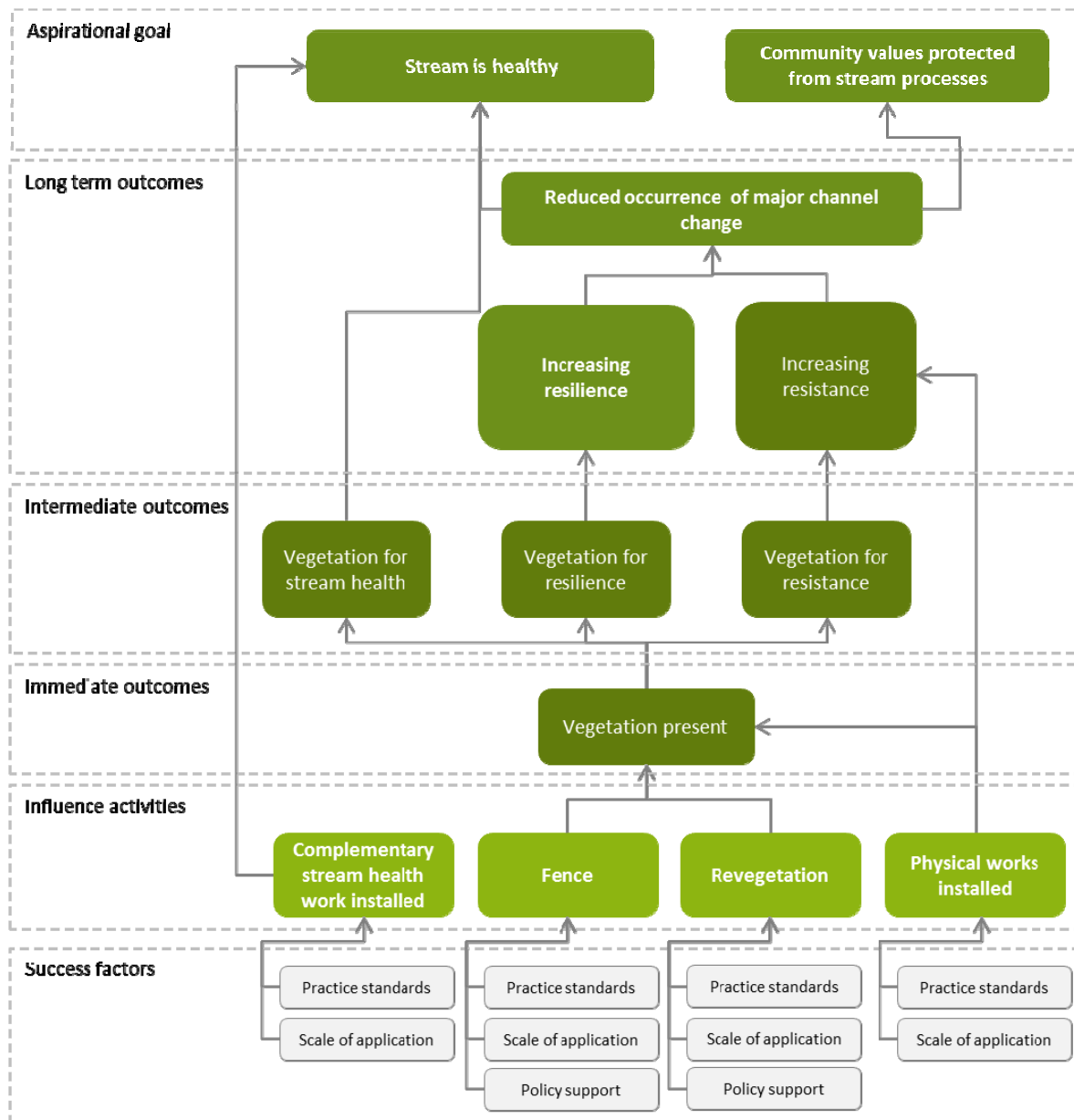


Figure 6. Program logic linking the three success factors to attainment of long term outcomes and the aspirational goal. 'Practice standards' refer to the implementation of ongoing programs and works based on established industry standards, 'scale of application' refers to the application of activities and works at a reach scale, and 'policy support' refers to the provision of policy support for land management agreements with adjoining landholders.

3.4 Study of factors influencing channel change in the 2010 / 2011 floods in North East Victoria

In late 2010 and early 2011, intense, widespread rainfall in north-east Victoria led to three major flood events. The flooding inundated large areas of floodplain and a number of settlements in the region. Widespread damage to property, bridges and farmland was observed by staff from the North East Catchment Management Authority (NECMA) and more than 500 reports of flood related damage were reported to the NECMA by the community.

The floods that occurred in north-east Victoria were of variable magnitude, impacting on streams of different morphologic character and vegetation condition. The variability of the vegetation conditions included varying degrees of willow presence and control on the subject stream systems. The floods had varying impacts in terms of channel change. Some streams had limited channel change, while others were subject to major in channel and floodplain erosion.

Following the floods, the NECMA commissioned a study to investigate and explain the distribution of erosion observed. Prior to the commencement of the study there was no clear understanding of the relationship between the magnitude of the floods, the vegetation conditions and the extent of channel change arising as a result of the floods. The objectives of the investigation into the factors influencing channel change in the 2010/2011 floods in north-east Victoria were to:

- Understand and describe the flood events in different systems in the north-east
- Understand and document the type, magnitude and spatial distribution of channel and floodplain erosion across the north-east
- Identify the factors relating to the physical form of the channels, waterway management activities and the characteristics of the flood events to explain the spatial variability of channel and floodplain erosion across the north-east
- Identify any management implications.
- The investigation included a review of the role of willow control on channel change.

Study approach

The concept of the *sensitivity* of a river to erosion was suggested by Piegay et al. (2005) as a useful tool for predicting erosion. The scientific literature suggests there are multiple factors that can influence the sensitivity of a river to erosion in a flood, including the presence of a remnant native riparian zone, the dominance of riparian vegetation by willows (*Salix* spp. and hybrids), the removal of willows, active erosion prior to the flood, erodibility of bed and bank sediment, sinuosity, channel bed slope and valley confinement.

Alluvium (2011) investigated the influence of these *channel factors* and a set of flood factors on channel and floodplain erosion across the north-east through a series of questions:

- Did the dominant riparian vegetation type (i.e. remnant, willow or pasture grass) explain the distribution of channel or floodplain erosion?
- Did reaches that were actively incising or widening before the floods erode more than those that were stable?
- Did reaches that were more sinuous (winding) erode more than straighter rivers?
- Was there more erosion in reaches with a steeper longitudinal bed slope?
- Was there more erosion in reaches with a floodplain than reaches where a floodplain is not present?
- Did the occurrence of bushfires in some of the catchments of the flooded rivers exacerbate erosion?
- The method developed to address the questions posed is illustrated in Figure 7.

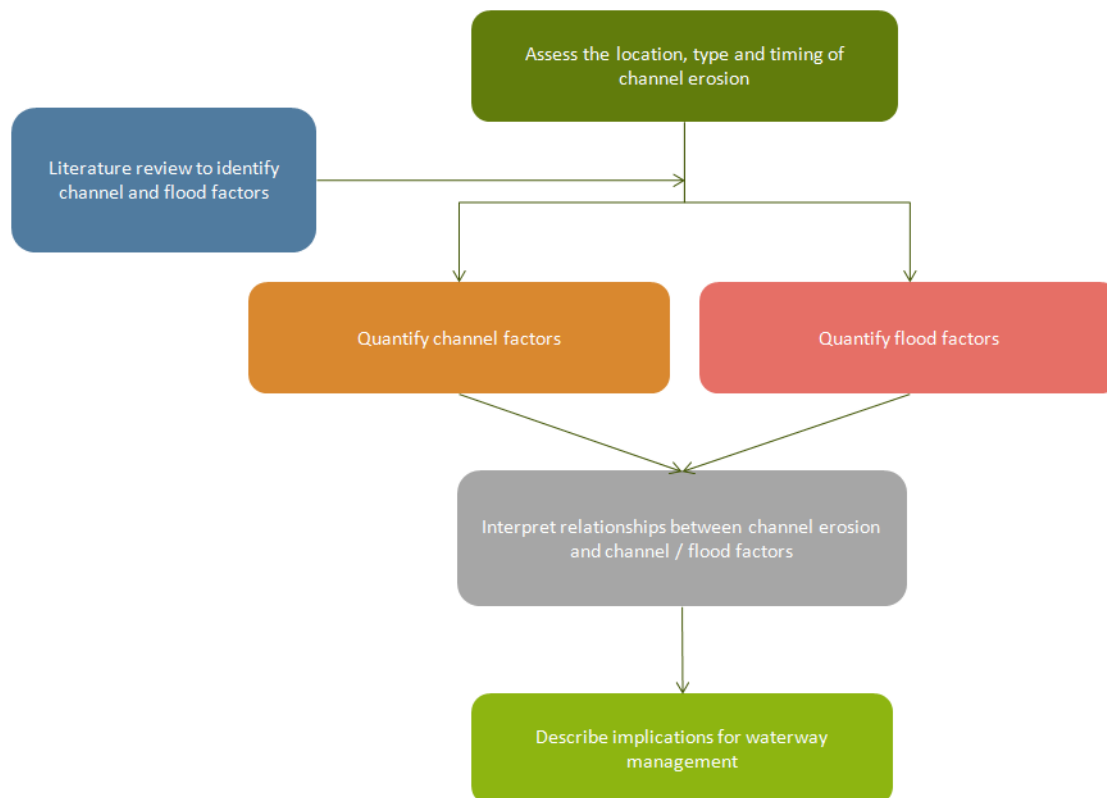


Figure 7. Outline of the north-east Victoria flood evaluation study method

The approach to the analysis of data collected was to:

- Carry out a broad analysis of the association between erosion and all of the channel and flood factors to identify those with most explanatory power and discard those not associated with erosion
- Carry out more detailed analysis and interpretation of factors most associated with erosion.

Alluvium (2011) used a statistical technique termed ‘random forest’ to analyse the entire dataset and model the relationship between erosion presence and channel and flood factors. The random forest technique is a popular tool for the discovery of important, but otherwise hidden, patterns within large volumes of data and has recently been applied in several geomorphology investigations (Eustace et al., 2011).

The output from the random forest analysis was a shortlist of the factors most closely associated with channel or floodplain erosion in the floods. A series of analyses was then carried out on these factors to understand their influence on erosion both as individual factors and in combination.

Study findings

The study found there are many factors (channel and flood) that influence erosion. The shortlist of factors included 11 channel factors (describing vegetation type and channel / floodplain geometry), three flood factors and two factors describing the hydraulic predisposition of the system to erosion.

The detailed analysis found that no single factor explains erosion but some factors are more important than others. Indeed, no relationship between a single variable and erosion presence was able to adequately describe and predict the occurrence of erosion. This finding was not unexpected. There are important interactions between many of the variables, meaning that more than one of the variables was needed to fully understand the occurrence of channel or floodplain erosion.

The presence and absence of major channel change (erosion) was best explained by considering the interrelationship between the following factors:

- Flood factors: the relative size of the flood event,
- Channel factors:
 - the predisposition of the reach to erosion
 - the type of dominant vegetation

The following indicators were used for a more detailed analysis of these factors:

Factor	Indicator
Flood factor	The peak specific stream power for the largest flood event that occurred over the 2010 spring and 2010/11 summer
Channel Factor: Predisposition to channel change	The literature review identified systems with steep and narrow channels as having a greater predisposition to channel change than broad and low-gradient systems. 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 2 year ARI specific stream power and the potential or predisposition for channel change (Alluvium, 2011, Hardie 2005, Bledsoe 2002). The 2 year ARI specific stream power provides a standardised, comparable metric that helps identify reaches of stream that may be predisposed to channel change. The 2 year specific stream power was adopted as the indicator of the predisposition of a reach to channel change.
Channel Factor: Vegetation condition	The presence or absence of a continuous corridor of high quality, structurally diverse native riparian vegetation on both stream banks was one of a number of vegetation condition indicators adopted for the assessment

High quality, structurally diverse native riparian vegetation comprises a suite of vegetation with similar structural elements and provides similar hydraulic control and resistance to erosion as remnant native vegetation. Such vegetation does not necessarily have the same density of each structural component as remnant vegetation however large trees, mid-storey shrubs, understorey low shrubs, rushes, sedges and grasses are all present and substantially established.

A combination of hydraulic modelling and information provided by the staff of the NECMA was used to identify the 2 year ARI specific stream power, peak event specific stream power and the quality of native vegetation at nearly 800 reaches of 500m in length across the north east Victoria (Alluvium 2011). This information was then used to help identify why certain systems experienced channel change.

Figure 8 provides a plot of reaches subject to different combinations of flood factor, and predisposition to channel change, for reaches with less than remnant quality riparian vegetation on one or both banks. The x axis represents the predisposition of the reach to erode, based on the 2 year specific stream power. Increasing 2 year specific stream power is associated with an increased likelihood of erosion due to less stable channel characteristics. The y axis in this figure represents the size of the flood event, based on the peak event specific stream power. The peak event specific stream power is a measure of the forces exerted by the biggest flood in 2010/2011 for each reach. Increasing peak event specific stream power is associated with an increased likelihood of erosion. Each point in the figure represents the mean results for a series of cross sections within a 500metre reach of stream.

Channel change did not occur in reaches with less than remnant quality vegetation for events with specific stream power less than 100 W/m^2 . Channel change occurred in reaches with less than remnant quality native riparian vegetation when these values were exceeded.

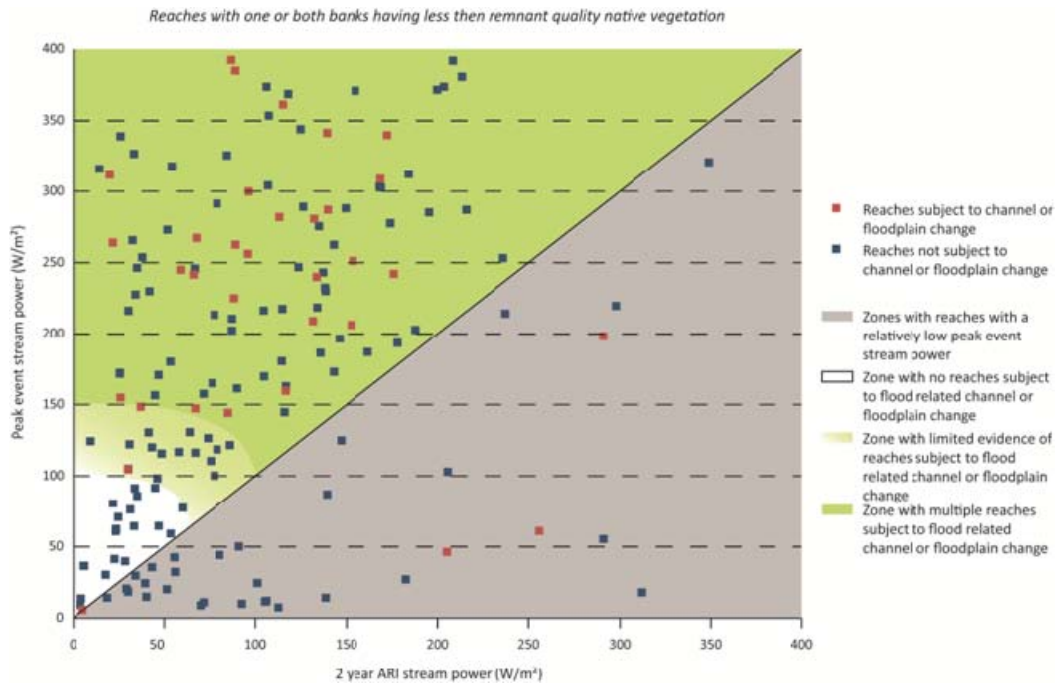


Figure 8. Scatter plot showing the relationship between predisposition to channel change, flood hydraulics and erosion in reaches with less than remnant quality vegetation.

Figure 9 provides a plot of reaches subject to different flood factors, and predisposition to channel change for sites with remnant quality riparian vegetation. Channel change did not occur in reaches with remnant quality vegetation where the predisposition to channel change (the 2 year ARI specific stream power) was less than $100 W/m^2$.

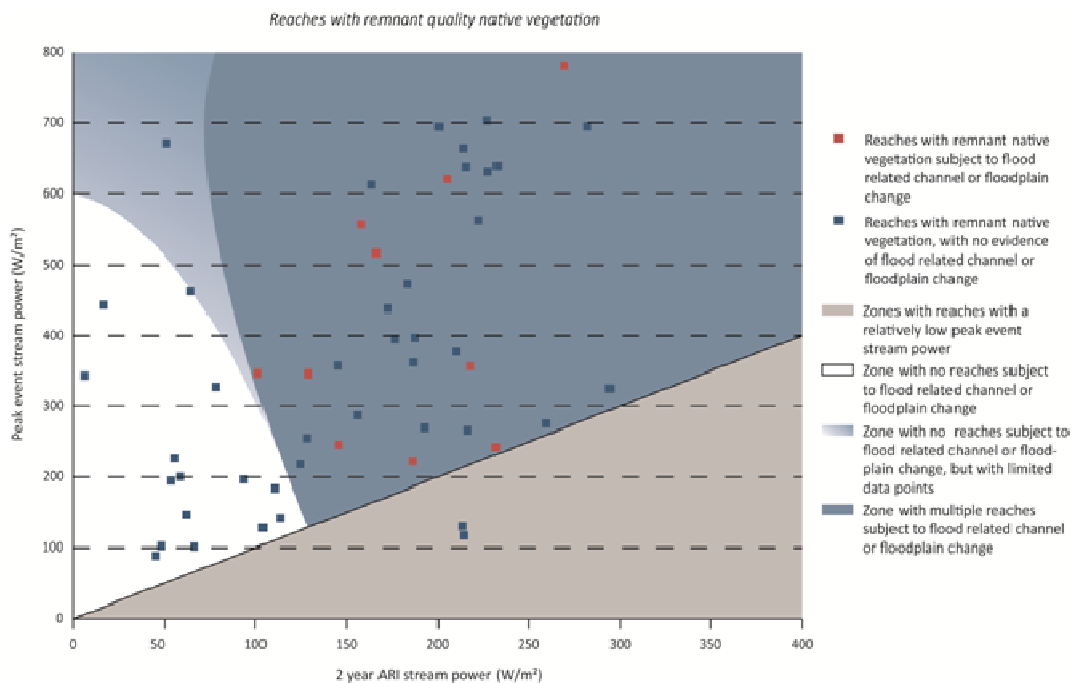


Figure 9. Scatter plot showing the relationship between predisposition to channel change, flood hydraulics and erosion in reaches with remnant quality vegetation

From these two graphs a third figure can be developed that identifies a set of zones where remnant quality vegetation does and does not have an influence on flood related channel change. The zones represent a combination of flood and channel factors. Figure 10 illustrates a critical zone where remnant quality vegetation provides the additional resisting power to oppose channel change. This figure also illustrates a zone (or set of circumstances) where the combination of the flood event and the channel characteristics create circumstances that flood related channel change is unlikely even in the absence of riparian vegetation. These circumstances occur when the stream power in the flood event and or the predisposition to channel change is very low. Similarly there is a zone (or set of circumstances) where channels are so predisposed to erosion, or the flood event is so large, that channel change will occur even with remnant quality vegetation.

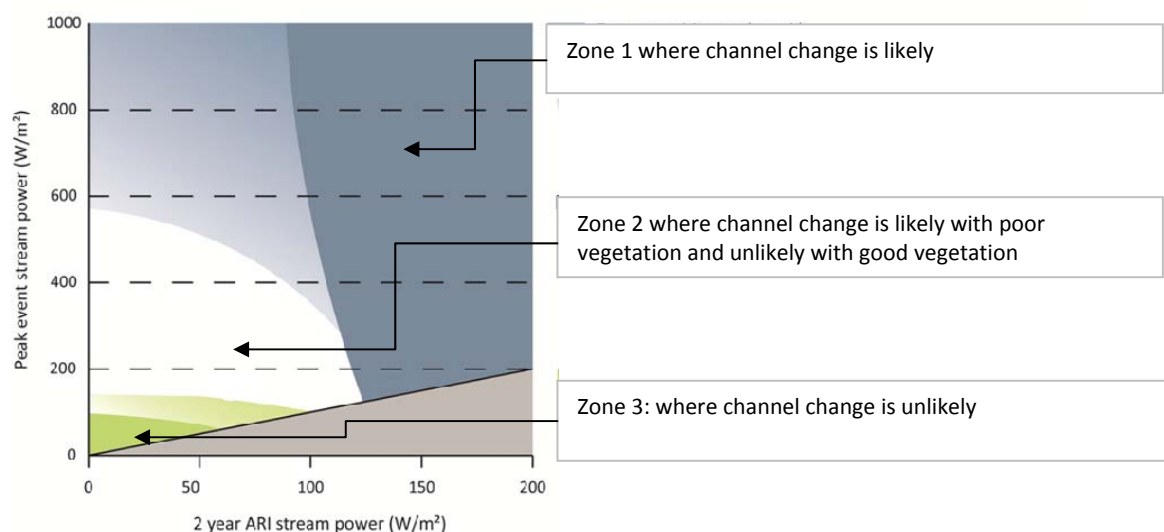
These three zones are represented graphically in Figure 10. The boundaries of the three zones in the graph are indicative only and based on interpretation of the data from the NECMA study. As such the boundaries should not be considered as absolute thresholds and have abutting areas of reduced confidence. The three zones comprise:

Zone 1 within which flood related **channel change is likely** regardless of the vegetation condition and type. The presence of native vegetation may limit the extent of channel change within this zone

Zone 2 where erosion occurs at sites with poor vegetation, and where no (or very limited) erosion occurs where there is good vegetation. This is the zone within which high quality, structurally diverse native riparian vegetation provides the **critical resistance** to flood related channel change.

Zone 3 where flood related **channel change is unlikely** to occur. The presence or absence of high quality, structurally diverse native riparian vegetation does not influence on the outcome.

Depending on the relief, climate and geology, the distribution of these three zones will vary for different



regions and flood events.

Figure 10. Zones of erosion resistance based on predisposition to channel change, scale of event and vegetation type

4 The influence of native riparian vegetation on flood related channel change: paired site assessments from Victoria

There is a good understanding on how different riparian vegetation classes (tall trees, shrubs, grasses) reduce erosion rates for each of the erosional processes described in Section 3.1. As a result, there is general acceptance that a wide, continuous, high quality, structurally diverse suite of native vegetation is required to reduce erosional channel change in flood events. This vegetation suite would include large trees, mid-storey shrubs, understorey low shrubs, rushes, sedges and grasses. However, little information is available on the precise age, composition and specific width of riparian corridors required to provide protection from erosion.

The reason for this was well summarised by McBride, Hession et al. (2010) who state that riparian vegetation eludes simple quantification or description because of variation in density, species diversity, maturity, and rates of growth. Furthermore, the influence of riparian vegetation on stream channel morphology is complicated by variations in background conditions including, but not limited to, discharge and sediment regimes, bank material composition, climate, and anthropogenic modifications.

4.1 Approach adopted for paired site assessments in Victoria

A series of paired site assessments have been conducted in order to assess the applicability of the findings of the literature review i.e. to assess the extent to which revegetation of alluvial rivers in Victoria with an appropriate suite of native species reduces channel change in moderate to large flood events. A paired-site approach was used to test this hypothesis. The pairs comprised a 'control' site that had not been subject to a revegetation program and an 'intervention' site that had been subject to a revegetation program.

The paired-site approach was based on controlling (as far as possible) for the variables that drive channel change between the paired sites, so that the only difference is the revegetation. Obviously it was not feasible to completely control for the range of factors (flood and physical channel factors) that influence channel change. Confidence in the findings depends to some extent on the level of comparability between paired sites.

The analyses were constrained to sites affected by floods since July 2010. Preference was given to paired sites within the same stream system, with similar geomorphic characteristics and that incurred the same flood event. These sites were described as being spatial pairs. Where such sites were not available we undertook a temporal analysis, comparing a revegetated site subject to recent flooding against its performance during previous major flooding.

4.2 Paired site identification

The primary constraints on the assessment were the identification of sites that had been subject to recent major flooding, but that also contained a pair of sites, one site with mature stands of vegetation established from a revegetation program, and a second comparable site that had bare banks or only grass cover.

Based on the literature review, we found that the establishment of high quality, structurally diverse native riparian vegetation through a revegetation program takes several years. There is some evidence to suggest that revegetation in south-east Queensland takes 5 to 10 years to achieve this standard (Rutherford pers. comm.). Based on recent investigations, we found that in East Gippsland it takes 10 to 15 years to establish high quality, structurally diverse native riparian vegetation through a revegetation program.

Sites in the higher rainfall areas of Victoria would require a similar time to establish as those of East Gippsland. However, we suggest that it may require 15 to 20 years to establish high quality structurally diverse vegetation in dryer landscapes and in drought conditions.

Large scale streamside revegetation programs with native vegetation commenced in Victoria in the late 1980s. In the Goulburn Broken, North East and East Gippsland regions, this coincided with the formation of whole-of-catchment waterway management authorities in the early 1990s. Few whole-of-catchment waterway

management programs comprising reach scale native vegetation establishment programs were operating elsewhere in Victoria (other than in the Melbourne Water Region) prior to the late 1990s.

As a consequence of the time required to establish riparian vegetation with remnant qualities through a revegetation program, and the necessity to find sites subject to recent flooding, we were only able to locate suitable paired sites within the East Gippsland, and the North East regions of Victoria. The paired study sites are set out in Table 4.

Table 4. Paired sites used to test hypothesis

Stream	Commencement of revegetation program / age of program	Region	Location	Paired site type	Flood event	Comment / assessment type
Genoa River	1993/ 18 years	East Gippsland	Downstream of Princes Highway	Temporal	1988 and 2011	Qualitative
Black Range Creek	1995/ 16 years	North East Victoria	Near Pratts Lane	Spatial	2010	Qualitative/ quantitative
Barwidgee Creek Reach 1	1998 / 13years	North East Victoria	Near Myrtleford-Yackandandah Rd	Spatial	2010	Qualitative/ quantitative
Barwidgee Creek Reach 2	1998 / 13years	North East Victoria	Near Browns Lane	Spatial	2010	Qualitative
Cann River/	1998 / 13 years	East Gippsland	Upstream from Princes Highway	Temporal	1998 and 2010	Qualitative/ quantitative

4.3 Qualitative and quantitative assessments

The investigations comprised both qualitative and quantitative assessments. The qualitative assessments comprised field assessments of the vegetation and scale and extent of post flood event erosion at the sites. The quantitative assessments comprised hydrologic and hydraulic analysis to identify specific stream power for the sites. Not all paired sites had sufficient information to allow the quantitative assessments to be undertaken. The purpose of the hydrologic and hydraulic assessments was to;

1. confirm that the two sites or two events that made up each pair were suitably comparable for the purpose of the assessment, and
2. identify whether the pairs were within the zone where the presence or absence of native vegetation had a critical influence on the presence or absence of flood related channel change

The qualitative and quantitative, site and desktop assessments comprised:

1. Background investigations and research for each site to identify the age of revegetation works, the flood history and to obtain any historic and relevant photography and surveys for the sites.
2. Site assessments of the extent of damage (channel change) and the quality of vegetation at both control (unvegetated) sites and treatment (revegetated) sites.

Damage (channel change): A definition of flood related damage was developed for the project, along with a means by which damage could be consistently and repeatedly assessed at sites. Flood damage as a result of flood inundation (such as drowned crops) was not included. Flood damage was defined as that associated with erosional channel change. Erosional channel change processes included bank retreat, meander migration and bed degradation.

Each site assessment included a field inspection to assess the extent of post flood erosional channel change. An erosion score metric was developed for the study. The score was the product of the scale of erosion within the reach and the longitudinal spatial extent of erosion within the reach (Figure 11). The spatial extent of

erosion was defined as the percentage of bank length that was impacted on by erosion. Two examples are provided in Figure 12. It is important to remember that under pre-disturbed conditions some erosion would be expected, similar to that in the photo on the left.

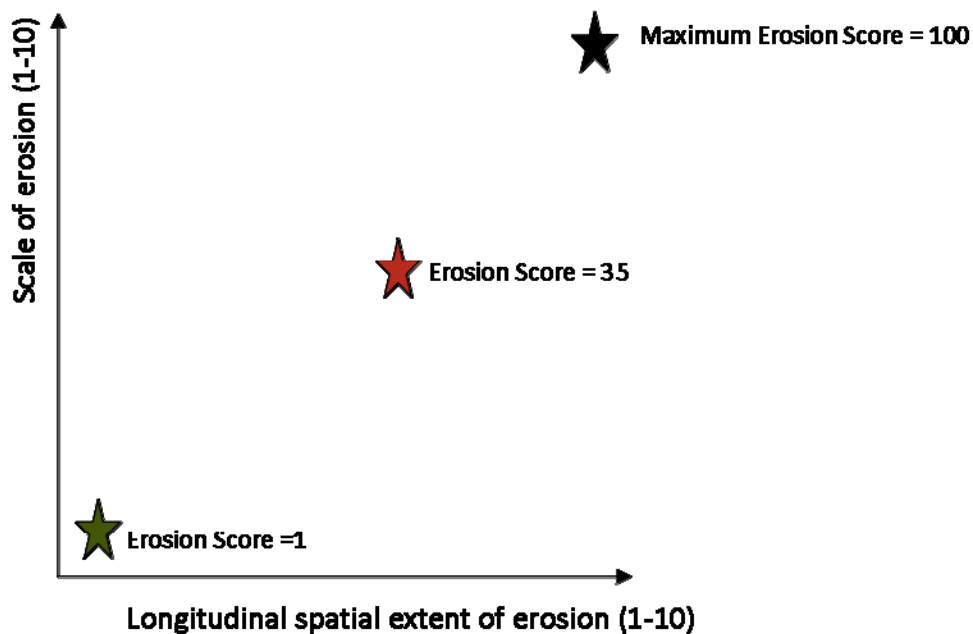


Figure 11. Hypothetical example of the Erosion Score developed to assess the extent of erosion at each of the sites



Figure 12. Examples of two sites with differing longitudinal spatial extent of erosion scores. The site on the left received a low score as erosion is localised and limited to one bank on the outside of a meander, the site on the right received a high score as erosion occurred through the reach on both banks

Within each reach, the scale of erosion was assigned a score of between one and ten. A score of one indicated that there was only minor erosion of surface sediment with no change in bank morphology, whereas a ten indicated that the bank had retreated such that the channel had increased its width by 50% or more. All the erosion within the reach was given one score that was indicative of the overall scale of erosion observed within the reach.

The longitudinal spatial extent of erosion was also assigned a value between one and ten which represented the percentage of the reach where erosion was observed. Consequently a maximum erosion score of 100 would represent a reach where both banks retreated throughout the entire reach length such that the channel width increased by at least a factor of two.

Vegetation condition assessment: Two standard methods are commonly implemented across Victoria to assess vegetation, particularly riparian vegetation. These two methods are the Index of Stream Condition (ISC), developed by the Department of Sustainability and Environment (Office of Water); and the Habitat Hectare (HH) or Vegetation Quality Assessment (VQA) approach, also developed by the Department of Sustainability and Environment (Arthur Rylah Institute). Both are standard methods, developed by the State Government, and are designed to be consistently applied by different practitioners in different regions. Both methods are applied widely across the state and the results are accepted and used in planning and policy decision-making by the State Government.

The ISC was developed specifically for measuring riparian and river health. The only relevant component applicable to the assessments undertaken as part of this project is the 'Streamside Zone' sub-index. This is a measure of riparian vegetation condition and structure. The 'Streamside Zone' component of the ISC was developed using the Habitat Hectares method and has many similarities in its application.

For this project, the ISC 'Streamside Zone' sub-index was selected to provide representative data relating to the quality and structure of riparian vegetation at the paired sites. This method provides an accepted and standard approach to the assessment of riparian vegetation, and was specifically designed for this purpose. It is strongly related to the HH or VQA methodology and therefore encompasses many of the benefits of these methods as well.

Field Methods: A full ISC vegetation assessment was undertaken at each subject site visited. This assessment included the completion of three transect assessments, and a full 'measuring site' assessment (over 430m) at each of the selected sites (with and without riparian vegetation). This 430m measuring site was located in a representative part of the reach. A detailed description of the ISC methodology can be found within DSE (2006).

Supporting Data: Data to support the standard ISC methods was also collected at each of the subject sites. The density of woody vegetation at various points within the site were collected provide an assessment of the physical structure of vegetation at different locations on the stream bed and banks along a given cross section.

The quantification of amount of vegetative material in various sizes classes, as well as plant density within a defined area, provides a picture of the hydraulic resistance or roughness provided by the vegetation at various points within a study site.

Supporting vegetation density data was collected using a 4m² quadrat to count woody stems of various heights at various points within the stream channel and riparian zone. Three separate cross sections were selected, located approximately every 200m along the subject reach. Each of these transects was located within one of the three zones used to assess the ISC Streamside Zone sub-index within the reach.

The 2m x 2m quadrat was placed on the ground (to collect a representative sample) at three points along the selected cross section;

- in the stream bed, or as close to the toe of the bank as possible
- on a bench or terrace
- on the high bank.

Individual stems of woody vegetation were counted within the quadrat at three height thresholds:

- 0.3m but < 0.5m
- 0.5m but < 1.0m
- 1.0m.

Desktop assessments: An investigation into factors influencing channel change in recent flood events in north east Victoria (discussed in Section 3) identified that the occurrence of erosion is best explained by considering the interrelationship between:

- Flood factors
- Channel factors
 - Predisposition to channel change
 - Dominant vegetation type.

For the purpose of this assessment, we used the same indicators as that used for the recent work undertaken for the NECMA to assess these factors influencing flood related channel change in north-east Victoria. This approach allowed us to assess the applicability of the results to sites beyond those assessed in the study for the NECMA and to assess the influence of vegetation among the other factors that influence flood related channel change.

The following indicators were used for these factors:

- | | | |
|----------|-----------------------------------|---|
| 1 | Flood factor: | Peak event specific stream power |
| 2 | Predisposition to channel change: | Specific stream power in the 2 year ARI flood event |
| 3 | Dominant vegetation: | As determined from field assessment |

The results of this assessment were plotted for each paired site to confirm the comparability of the sites / events that make up each pair and to identify the extent to which the vegetation was a controlling influence on the presence or absence of channel change at the sites.

4.4 Results from paired site assessment

The results for each of the paired site assessments are provided in Appendix 1. Based on the quantitative analyses, we found the paired sites to be geomorphically similar and suitable for comparative analysis.

Further, we found each of the sites for which a quantitative analysis was undertaken to be within the zone where vegetation was expected to play the critical role in the presence or absence of flood related channel change. The Cann River paired sites are illustrated graphically in Figure 13.

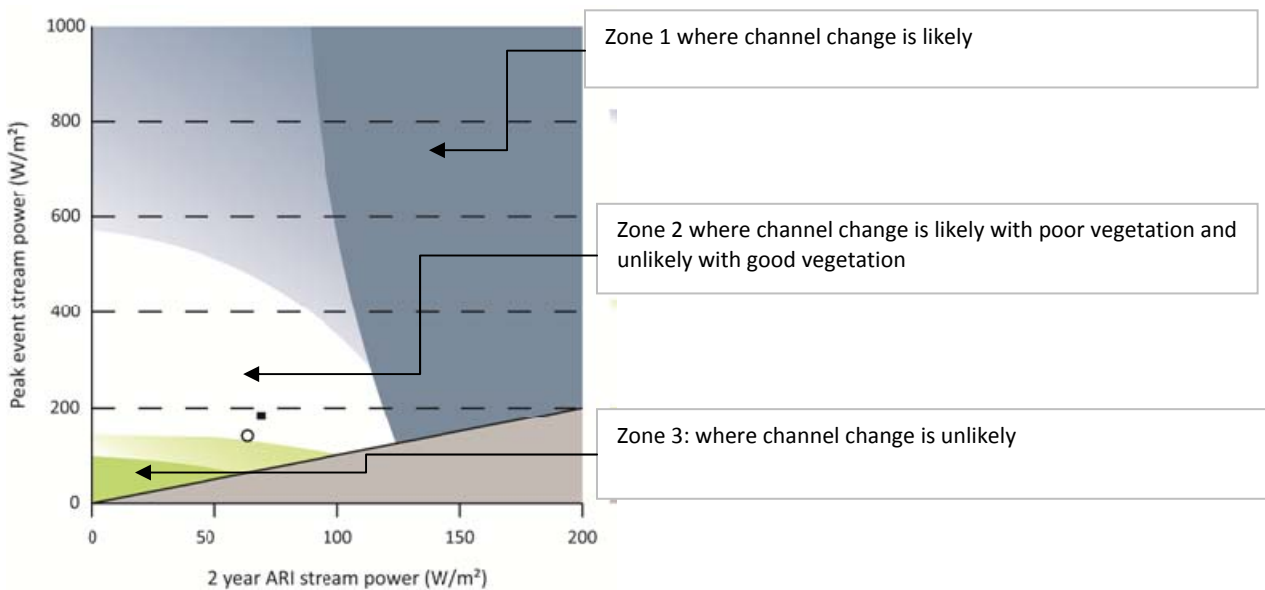


Figure 13. Results from the hydraulic modelling for the Cann River paired sites

The paired site assessment revealed a strong inverse relationship between the presence of revegetation works resulting in high quality, structurally diverse native riparian vegetation and erosion at all five case study sites (Figure 14). We found a low rate of erosion at sites that had been the subject of revegetation programs resulting in the presence of high quality, structurally diverse native riparian vegetation. We found high rates of flood related channel change at sites that did not have high quality, structurally diverse, native riparian vegetation.

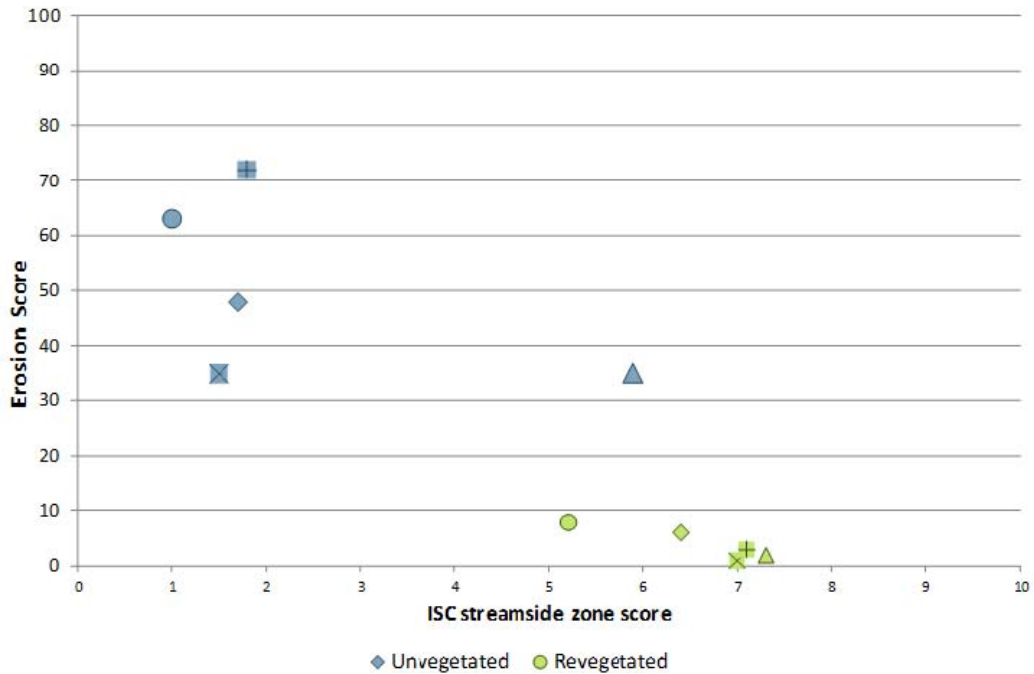


Figure 14. Results showing the relationship between erosion score and the ISC streamside zone score for all five paired sites

The difference in the scale and extent of channel change at a pair of sites on a tributary of Barwidgee Creek in north east Victoria is illustrated in Figure 15.



Figure 15. Paired site assessment for tributary of Barwidgee Creek, north east Victoria (the site with bare banks (left) experienced widespread erosion while the revegetated site (right) incurred only minor channel change in the same flood event

We found that high quality, structurally diverse, native riparian vegetation, established via a revegetation program,

- was the key factor that limited the extent and scale of channel change at each of the five paired site assessments
- resulted in negligible channel change at each of the five paired site assessments (Figure 14)
- reduced the scale and extent of erosion at the five paired site assessment by between 80% and 95% (Figure 14).

In the absence of revegetation works we would have expected channel change of a similar extent and scale at each of the 5 revegetation sites as their paired unvegetated sites (Figure 14).

The results of the qualitative and quantitative paired site assessments support the hypothesis that high quality, structurally diverse native riparian vegetation can provide a critical role in limiting channel change in alluvial stream systems.

4.5 Implications of the paired site assessments for Victoria

As outlined above the paired site assessment support the hypothesis that high quality, structurally diverse native riparian vegetation can provide a critical role in limiting channel change in alluvial stream systems. In this respect the paired site assessment confirms the model that there are circumstances where the combination of channel characteristics and flood event create the conditions within which high quality, structurally diverse native vegetation provides the critical resistance to flood related channel change. The results of the paired site assessment support the application of the model to alluvial stream systems across Victoria.

Most of the flood recovery funding in Victoria has been spent in east and west Gippsland and in north east Victoria. The streams in these regions have the characteristics identified by Kochel (1988) and Fuller (2008) to be associated with channel change including high channel gradients, abundant coarse substrate, relatively low bank cohesion and low width/depth ratios

The reason for this is both geological and climatic. The east of Victoria is divided by the mountainous alpine region of the Great Dividing Range (Figure 16). As the waterways emerge from the bedrock confined valley settings into more alluvial settings the floodplains and channels have high gradients. Consequently the relief on the eastern side of the state creates channel characteristics with high stream power. While these systems may not exhibit major channel change with the presence of continuous corridors of resistant native vegetation, these systems have demonstrated major channel change in flood events following the removal of vegetation. Further the east of the state has much higher annual rainfall than the west leading to a denser network of waterways and more sites at which channel change is likely to be observed.

As previously discussed, clearing of the riparian zones in the east of the state has resulted in major channel metamorphoses with major flood damage and recovery costs. However in extreme flood events channel change can occur in any alluvial system within Victoria. While the spatial distribution of streams with a high pre-disposition to channel change and subject to high stream power during major flood events increases in an easterly direction across the state, high quality, structurally diverse native vegetation has the potential to play a critical role in limiting channel change and support other elements of river health across Victoria.

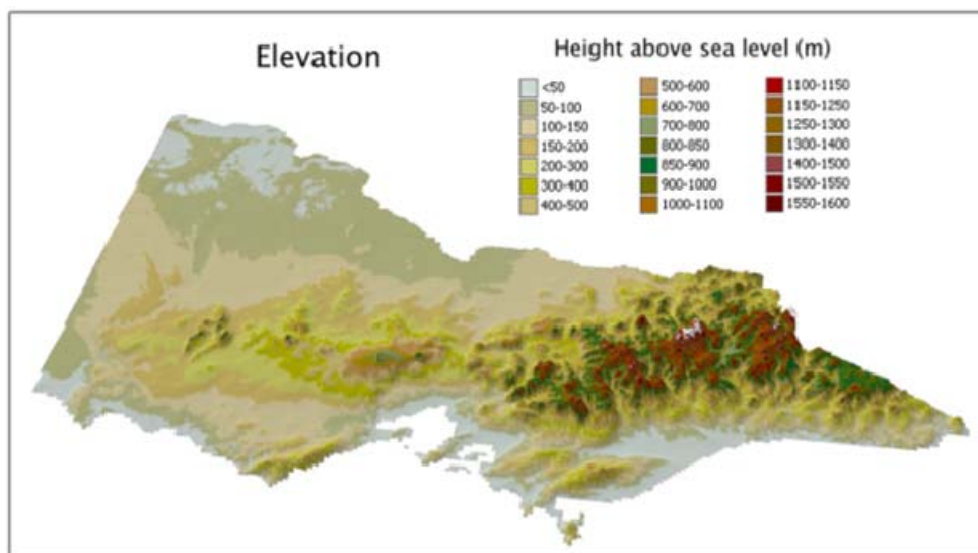


Figure 16. Victoria showing the relief across the state

5 Conclusions and implications for management

The investigation found flood related channel change to cause major damage to public and private infrastructure and river health. The cost of river repair works have been estimated to be over \$80 million (net present value) over the past 20 years (approx), with the cost of repairs to public infrastructure being an order of magnitude greater than the cost of river repair works.

The occurrence, scale and extent of flood related channel change is a function of a combination of channel and flood factors. Flood factors include the scale of the flood event. Channel factors include the composition of the bed and bank material, the physical channel characteristics such as the bed grade and channel width, and importantly, the vegetation condition.

The literature review also revealed that there is a combination of channel characteristics and flood events that create circumstances where high quality, structurally diverse native riparian vegetation provides the critical factor that limits gross channel change in flood events. These circumstances can present themselves on alluvial systems across the state. The highest occurrence and frequency of such circumstances is in the east of Victoria.

Of significance, the paired site assessment undertaken for this investigation has confirmed the model that there is a zone (a set of flood and channel circumstances) within which high quality, structurally diverse native vegetation plays the critical role in the presence or absence of flood related channel change. Importantly, the paired site assessment supports the applicability the 'model' of flood related channel change developed for north east Victoria. The paired site assessment confirms the applicability of this model for alluvial stream systems across Victoria.

Further and also of significance, the vegetated site within each pair was a site of a revegetation program. The results of the paired site assessment confirm that revegetation programs can be used to create a suite of high quality, structurally diverse riparian vegetation that can reduce the occurrence, extent and scale of flood related channel change across Victoria.

Based on this investigation comprising literature review and paired site assessment we have found:

- The absence of high quality, structurally diverse native riparian vegetation increases the occurrence extent and scale of flood related channel change and associated flood related recovery costs in Victoria

- High quality, structurally diverse native riparian vegetation, established through revegetation programs such as those undertaken by Victoria's catchment management authorities, is effective at reducing the occurrence, extent and scale of flood related channel change.
- High quality, structurally diverse native riparian vegetation must be at or near remnant quality and contain instream, bank and floodplain vegetation including sedges, reeds, ground covers, shrubs and trees suitable to address the range of erosion mechanisms present in stream systems.

The paired site assessment revealed a strong inverse relationship between the presence of high quality, structurally diverse native vegetation, established from a revegetation program at all paired sites assessed, and flood related channel change. The results of the paired site assessment support the hypothesis that riparian vegetation established through a revegetation program, can be the controlling factor that limits flood related channel change. At the paired sites, we found negligible channel change at sites that had been the subject of revegetation programs resulting in the establishment of high quality, structurally diverse native riparian vegetation. We found high rates of flood related channel change at sites that did not have high quality, structurally diverse native riparian vegetation.

We found that high quality, structurally diverse native riparian vegetation, established via a revegetation program,

- was the key factor that limited the extent and scale of channel change at each of the five paired site assessment undertaken for this project
- resulted in negligible channel change at each of the five paired site assessments undertaken for this project (Figure 14).
- reduced the erosion at the five paired site assessment undertaken for this project by between 80% and 95% (Figure 14).

In the absence of revegetation works we would have expected channel change of a similar extent and scale at each of the five revegetation sites as their paired unvegetated sites (Figure 14).

The characteristics of native riparian vegetation in streams that are resistant and resilient to flood related channel change include:

- Vegetation corridor diversity: the vegetation should be of high quality and structurally diverse (contain instream vegetation, bank ground cover, shrub species and trees). This diversity will take many years (potentially 10 to 15 years) to establish, dependent upon local conditions;
- Vegetation corridor width: native vegetation riparian corridors need to be an appropriate width to ensure they are ecologically and physically functional. The scientific literature is clear that the appropriate width varies across sites and for the specific function that needs to be achieved (Hansen et al. 2010). This study demonstrated that sites with well-developed riparian corridors (generally 10 to 30 m wide on each side) were effective in providing for resistant and resilient streams.
- Vegetation corridor longitudinal connectivity : Native riparian vegetation corridors should be continuous (or largely continuous)

The establishment of continuous corridors of high quality, structurally diverse native riparian vegetation, which meet the above criteria, from revegetation programs is reliant upon:

- the implementation of ongoing programs and works based on established industry standards
- the application of activities and works at a reach scale
- the provision of policy support for land management agreements with adjoining landholders

Native riparian vegetation corridors will increase the resistance and resilience to flood related channel change, however where there are public assets located near stream systems additional structural works may be

required. The integration of road, bridge and culvert design with the dynamics of stream systems is complex. In most instances it is not feasible to rely on vegetation alone to provide protection to major infrastructure such as roads and bridges where they intersect with stream systems. Some complimentary structural works in the vicinity of the asset, such as rock revetment, may also be required. However in the long-term and the majority of stream length the resistance to channel change can be provided by high quality, structurally diverse vegetation.

Historically the majority of flood related damage to Victoria's streams and public infrastructure has occurred in the east of the state. None the less, native vegetation can provide the controlling influence on flood related channel change on all alluvial stream systems across Victoria.

However there are some cautions associated with the investigations and results. The relationship between rivers and their accompanying floodplains is complex and requires careful consideration and management. This investigation has focussed on in channel processes and not floodplain processes. As a consequence the results should be used with some care and in conjunction with consideration of broader floodplain processes. In this respect revegetation of riparian zones should be undertaken in association with the management of the broader floodplain.

The investigation has identified the circumstances or conditions where high quality structurally diverse native vegetation provides the critical influence on flood related channel change. It should not be interpreted that native riparian vegetation is not required where these circumstances are not met. High quality, structurally diverse native riparian vegetation is required on all stream systems for the protection and maintenance of aquatic and riparian ecological values. However there are some systems and flood events where this vegetation plays a more important role in erosion control than other systems and events.

Methods now exist to predict reaches of rivers, and areas of floodplains, that will be at greatest risk from severe erosion during floods. High resolution remote sensing techniques (e.g. LIDAR), combined with hydraulic modelling, allow managers to predict those sections of stream that will be subject to the greatest bed and bank erosion. The same is true for predicting the areas of floodplain that are most likely to have avulsions. Identifying these areas at risk will help to guide managers in planting riparian vegetation. At the same time, the hydraulic effect of vegetation should be investigated to understand the impact of revegetation programs on flood risks.

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Appendix 1

Results of paired sites assessment

Paired site assessment No. 1: The Genoa River

Introduction

The Genoa River rises in the alpine region of New South Wales before flowing into far eastern Victoria. The lower reach, which flows through the township of Genoa, is an unconfined sand bed stream. The floodplain and riparian zone was largely cleared of vegetation during the twentieth century for agricultural pursuits. Major flooding in 1976 and 1985 resulted in substantial channel widening in the floodplain reach which was largely devoid of riparian vegetation (Figure 17).



Figure 17. *Genoa River following major flooding in 1985 (Photos courtesy of EGCMA)*

The program of management

Since the 1985 flood, an extensive program of river restoration has been undertaken within the floodplain reach of the Genoa River. The East Gippsland Catchment Management Authority (EGCMA), and its predecessor the East Gippsland River Management Board (EGRMB), have undertaken a suite of works focussing on increasing the resistance and resilience of the stream system to accelerated channel change (erosion and sedimentation). These works include indigenous riparian vegetation establishment and introduction of large wood to help stabilise sand bars.

By 2009, the outcomes of the restoration works were independently reviewed and reported by Erskine as one of the best examples of river restoration in Victoria

1986



2009



1986



2009



1986



2009



2002



2009



Figure 18. The Lower Genoa River before and after an extensive rehabilitation project downstream of the Princes Highway in Genoa (Photos courtesy of EGCMA)

Assessment of the 2011 flood event

In March 2011 a gauge on the Genoa River approximately 8 km upstream from the Princes Highway recorded a flood peak of 83,000 ML/day, which exceeded the level of the 1985 flood (80,000 ML/day). The event was the second largest since gauged records began in 1972 (the largest event was in 1978 at approximately 130,000 ML/day) and had an annual recurrence interval of approximately 20 years. In July 2011 the rehabilitated floodplain reach downstream of the Princes Highway was assessed for resistance and resilience to the preceding flood event.

Qualitative assessment

Unvegetated reach

Using the available aerial imagery, a temporal analysis was undertaken between 1986 and 2011. Prior to the flooding in 1985, the reach downstream of the Princes Highway was largely devoid of native vegetation. There were some scattered small trees along the bank line, though species identification is not possible from the imagery. The site was dominated by introduced pasture species. The site was given an ISC streamside zone score of 1.8 (Figure 22).

From the aerial imagery and anecdotal evidence, widespread channel widening and meander migration occurred as a result of the 1985 flood event. For the erosion assessment, it was assumed 90% of the reach underwent severe erosion. The site received an erosion score of 72 (Table 5).

Revegetated reach

The vegetation observed was of good condition, given the recent flood history at the site, and showed a reasonable level of diversity, particularly in understorey species. A good cover of native vegetation was found both along the stream banks and within the bed. An immature canopy was present with a more diverse understorey of medium and small shrubs. A good cover and diversity of emergent and macrophyte species were also observed. The site was given an ISC streamside zone score of 7.1 (Figure 22).

The reach was for the most part, highly resistant to the March flood event. Prior to the flood, the system had developed a well-defined low flow channel within the over widened macro channel. The alternate sand bars were well vegetated with a range of terrestrial species. Following the flood there was no major realignment, or infilling, observed in the low flow channel. A large amount of deposition, up to 2m, had occurred on some of the sand bars. In certain locations, the sand bar elevation was now approaching the floodplain elevation. The deposition on the sand bars is consistent with the narrowing observed during the recovery from stream incision and should not be seen as negative outcome, but a positive contribution to system recovery. The vegetation on the sand bars provided favourable conditions for deposition and helped maintain the alignment of the low flow channel (Figure 19).



Figure 19. Looking downstream from the Princes Highway before and after the March 2011 flood. Note the same alignment of the low flow channel and the recent deposition on the bar (Photos courtesy of EGCMA)

The riparian vegetation on the bars and bank limited any major fluvial scour. The force of the floodwaters was so high that mature trees were flattened, however they still protected the bank material from scour (Figure 21).



Figure 20. Photos of flood damaged trees on the left and right banks. The force of the floodwater was enough to flatten the 4-5 m trees however the vegetation was still able to protect the banks from scour

At two locations, localised minor bank erosion had occurred. Both these locations had limited riparian vegetation as the banks were used for stock watering access (Figure 21). The dense riparian vegetation upstream and downstream of the stock access point appeared to have reduced the near bank velocities sufficiently to limit fluvial scour at these locations.



Figure 21. Banks that exhibited localised erosion were limited to areas cleared for stock watering access.

Table 5. Erosion score assessments for the paired sites of the Genoa River

Reach	Scale of erosion (1-10)	% of reach impacted by erosion	Erosion score
Unvegetated	8	9	72
Revegetated	3	1	3

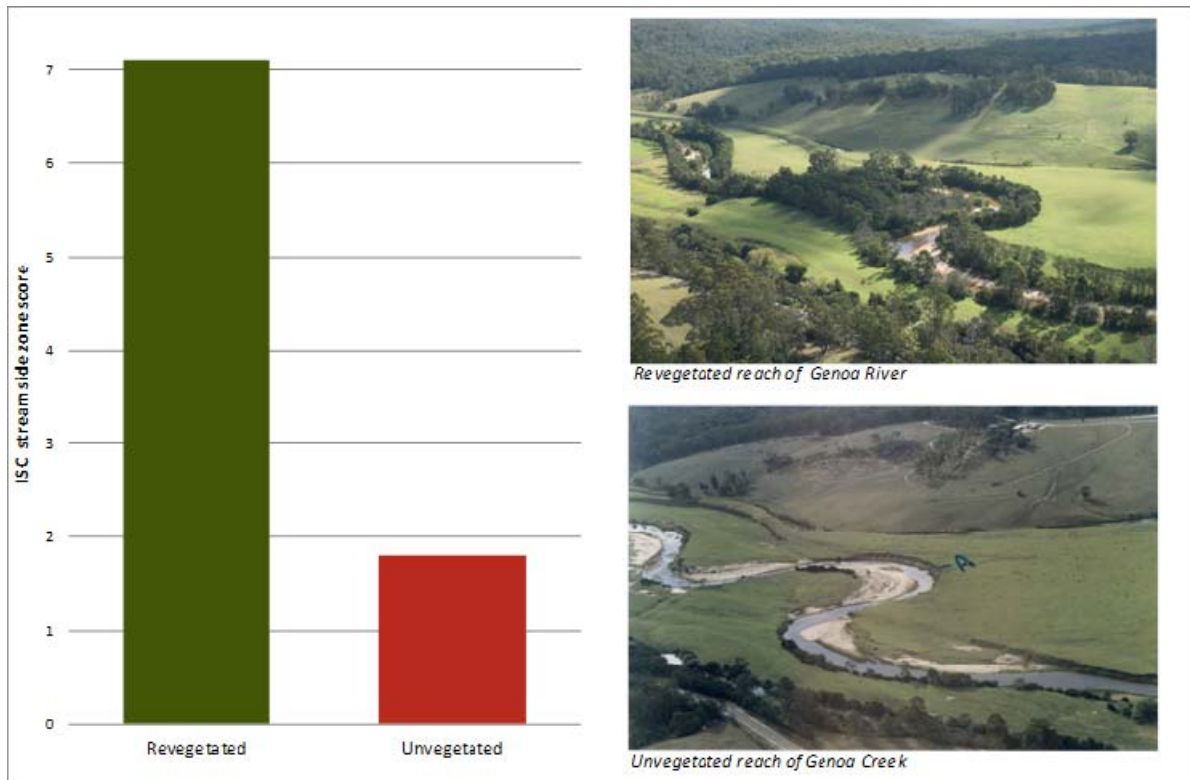


Figure 22. *ISC streamside zone scores for the paired sites of Genoa River*

Quantitative assessment

No topographic data was available from 1986 to undertake a quantitative assessment of the paired sites.

Conclusion

The floodplain reach of the Genoa River was highly resistant to the major flood event that occurred during March 2011. Only minor erosion was observed, and there was no loss of land or damage to public assets. This outcome contrasts to the major channel change observed in the same reach following the 1978 and 1985 flood events, when there was limited riparian vegetation. That previous channel change required substantial investments in the restoration of public assets and in-stream stabilisation. The 2011 event was of a similar magnitude to the 1985 flood event and it can be concluded that the presence of native vegetation at the site was a dominant influence on the absence of major channel change in the most recent flood events.

Paired site assessment No. 2: The Cann River

Introduction

The Cann River is located in East Gippsland with headwaters in NSW and the Victorian Alps. The region was subject to land clearing and drainage associated with agricultural development and this clearing and drainage work led to channel incision post European settlement. The river discharges into Tamboon Inlet before entering Bass Strait and the most actively eroding reach is located within the floodplain of the river near the township of Cann River.

Up to and immediately following the 1998 flood event, the floodplain reach of the Cann River was one of Victoria's largest actively incising (eroding) stream systems. Much of the subject reach was in the early stages of channel incision with active and large scale channel change. The subject reach required up to 9 metres of grade control works (streambed had to be raised by 9 m over a number of kilometres), amounting to more than \$1,000,000 of investment. The limited funding available to the East Gippsland Catchment Management Authority and predecessor organisations prevented the implementation of the necessary grade control program to control the incision process. As a consequence, prior to the 1998 flood event, the Cann River was predisposed to major channel change.

A program of management was undertaken on the Cann River under the 1998 East Gippsland Flood Recovery Program. The program was aimed at halting the incision process and initiating a phase of system recovery to increase the resistance, resilience and health of the river.

The program of management

A major grade control program was undertaken through the subject reach under the 1998 flood recovery program. The grade control program cost in excess of \$2,000,000, and was undertaken to protect private and public infrastructure and limit sediment production. The grade control program comprised construction of rock chute style grade control structures and complementary vegetation establishment.

Grade control programs rely on the provision of instream vegetation to reduce stream power and velocity in major flood events. This vegetation is reliant on the grade control structures to provide sufficient system stability between and during flood events to enable both establishment and retention. Stock exclusion is required for the vegetation establishment and retention and is fundamental to the long term success of grade control programs.

Cann River immediately following 1998 works



Cann River prior to 2011 flood event



The Cann River had been the subject of past management interventions including stock exclusion prior to the 1998 flood recovery program. While landholders understood the role of vegetation in reducing near bank velocity and providing protection to bed and bank material, they also understood the potential impact of vegetation establishment programs and other instream blockages on the occurrence of flood inundation.

Landholders sought to limit the impact of the program of management on flooding by including flood inundation criteria into a community agreement to accompany the development of the grade control program.

An ongoing program of management and maintenance has been implemented through the Cann River by the EGCMA in association with local landholders. The ongoing program has been undertaken since 1998 to achieve the objectives sought under the flood recovery program and agreed with the community.

Assessment of the 2011 flood event

In July 2011, the Cann River was subjected to a major flood, nearing a 30 year event. This was the largest flood in the Cann River since the 1998 floods. The Cann River was assessed for damage during and following the flood event and was compared to the damage following the 1998 event.

Qualitative assessment

Unvegetated

The Cann River was subjected to major flooding in 1998. This flood event was equivalent to a 30 year ARI event and resulted in major channel change including incision and widening. The incision threatened public assets such as water supply pipelines and bridges. In addition, the incision and sediment liberation resulted in a continuation of the decline in condition of the lower reaches of the river, including the estuary (Tamboon Inlet). Assessments undertaken by current Alluvium staff gave the system an erosion score of 35 following the 1998 flood (Table 6). An ISC streamside zone assessment undertaken at the time gave the site a score of 5.9 (Figure 23).

Revegetated

The damage incurred as a result of the 2011 flood event was assessed as negligible and not requiring funding support under Natural Disaster Funding programs. The Cann River was also assessed immediately prior to and following the 2011 flood event for system resistance, resilience and health. The system was found to be resistant to the 2011 flood. Channel change in the system was limited to localised erosion and sediment deposits. However the coverage of instream vegetation was reduced by the flood. Despite this reduction in coverage, the diversity of vegetation was still largely preserved, indicating high rates of recovery are likely (high resilience). The assessment also revealed the Cann River to be in good condition.

Assessments undertaken following the 2011 flooding gave the system an erosion score of 2 (Table 6). The site was given an ISC streamside zone score of 7.2 (Figure 23).

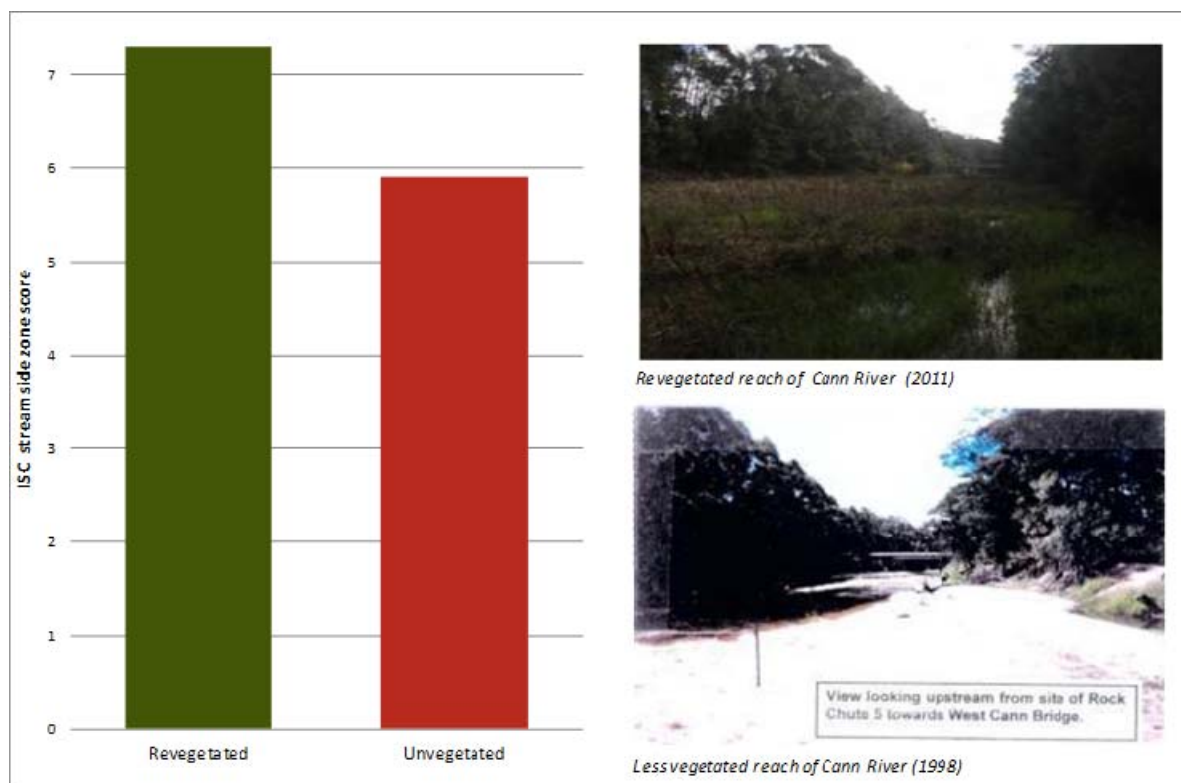


Figure 23. ISC streamside zone scores for the paired sites of the Cann River

Table 6. Erosion score assessments for the paired sites of the Cann River

Reach	Scale of erosion (1-10)	% of reach impacted by erosion	Erosion score
Unvegetated (1998)	5	70	35
Revegetated (2011)	2	10	2

Quantitative assessment

We found 80% of cross sections assessed on the Cann River to be currently within Zone 2 (Figure 10) with most having stabilising vegetation i.e. most of the Cann River was found to be within a zone that would erode if there was no vegetation. The remainder of cross sections were in Zone 3 and unlikely to undergo channel change in the subject flood event with or without native riparian vegetation. Based on the assessment, and subject to the continuing presence of high quality, structurally diverse native vegetation, the system is now effectively protected from gross channel change in major flood events. At the time of the 1998 flood event, we found over 90% of the system to be within Zone 2 and in the absence of effective stabilising vegetation was subject to gross channel change.

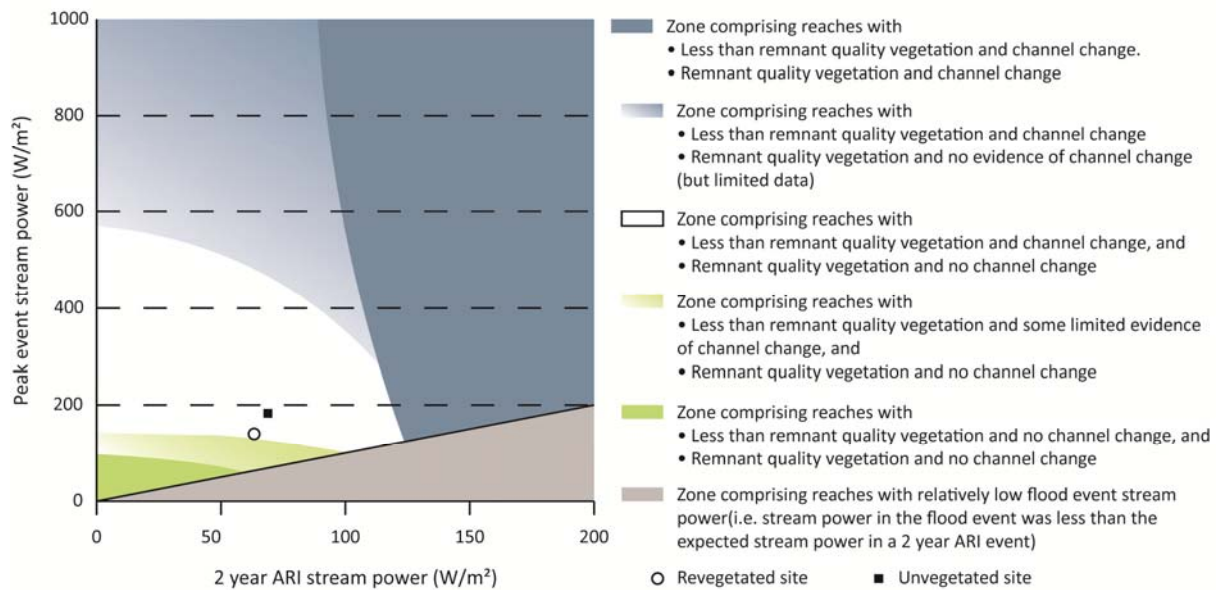


Figure 24. Results from the hydraulic modelling for the Cann River paired sites

Conclusion

The qualitative analysis has revealed that the subject reach of the Cann River was the subject of major channel change in the 1998 flood event. The quantitative analysis revealed that the reach was within the zone within which flood related channel change could be expected to occur in the absence of high quality, structurally diverse native riparian vegetation.

The qualitative analysis also revealed that the Cann River did not undergo major channel change as a result of the 2011 flood event, despite this event being of similar magnitude to the 1998 event. The quantitative analysis revealed the hydraulic conditions within the subject reach to be similar in the 2011 as that in the 1998 event and that it was the presence of high quality, structurally diverse native riparian vegetation that provided the additional resilience in the 2011 event, preventing major channel change.

The 1998 flood recovery program contained many elements of a successful flood recovery program. These included the application of works with a strong track record of success, the development of a program of management at a reach scale to achieve reach scale outcomes, and the development and implementation of the program with strong landholder support and buy-in. These elements have resulted in the establishment of a robust and resilient stream system with good and improving river health outcomes. The 1998 flood recovery program, together with a commitment to ongoing management, has resulted in a long term reduction in the government investment in post flood repair to this previously unstable stream system.

Paired site assessment No. 3: Black Range Creek

Introduction

Black Range Creek rises on the northern slopes of the Great Dividing Range, emerging into an unconfined valley setting (floodplain reach) before its confluence with the King River near Edi. The floodplain reach is primarily used for grazing and the riparian vegetation was largely removed during the twentieth century. An extreme flood event of an unprecedented scale occurred in 1993. As a result, the system experienced severe channel change including channel widening and floodplain stripping.

The program of management

Following the 1993 flood, a program of works was undertaken to stabilise an approximately 1 km reach of Black Range Creek upstream of Pratts Lane. The works included some alignment training, but primarily the focus was on using native vegetation to increase the resistance and resilience of the stream system. Further downstream, works were not implemented and the riparian zone was left unfenced and devoid of vegetation.

For the paired site assessment the revegetated reach located upstream of Pratt Lane was compared with an unfenced grazed reach located upstream of Pettifers Rd (**Figure 25**).

Assessment of the 2011 flood event

In late 2010, widespread rainfall in north-east Victoria led to two major flood events in the King River catchment. No gauge data for Black Range Creek were available for this study, but the King River at nearby Edi experienced a 17 year ARI event in September and a 35 year ARI event in December. Consequently, for the quantitative assessment it was assumed that Black Range Creek experienced events with a similar ARI.

Qualitative assessment

Unvegetated reach

The site was largely devoid of native vegetation, with only scattered indigenous plants, mainly tufted graminoids, and one remnant large tree observed. The site was dominated by introduced pasture species. Woody weed species including blackberry and willow were also observed in some locations. The site was given an ISC streamside zone score of 1.5 (**Figure 26**)

Bank retreat was widespread in the unvegetated reach with approximately 70 % of the reach having undergone moderate scale erosion. The site received an erosion score of 35 (**Table 7**).

Revegetated reach

The vegetation observed was of good condition, with areas of moderate to high species diversity. A good (to excellent in parts) cover of native vegetation was found along the high stream banks and toe, with areas of emergent vegetation within the stream bed also observed. The diversity of understorey species was limited, however the cover of medium and small shrubs was high across most of the site, and very high in places, particularly in close proximity to the stream. The site was given an ISC streamside zone score of 7.

Erosion rates in this reach were typical of natural rates of erosion in remnant streams, only minor bank undercutting and mobilisation of surface sediments was observed. No obvious post flood erosion was observed. The site received an erosion score of 1 (**Table 7**).

Table 7. Erosion score assessments for the paired sites of Black Range Creek

Reach	Scale of erosion (1-10)	% of reach impacted by erosion	Erosion score
Unvegetated	5	70	35
Revegetated	1	10	1



Figure 25. *The paired sites for Black Range Creek (The revegetated reach on the left, and the unvegetated reach on the right*



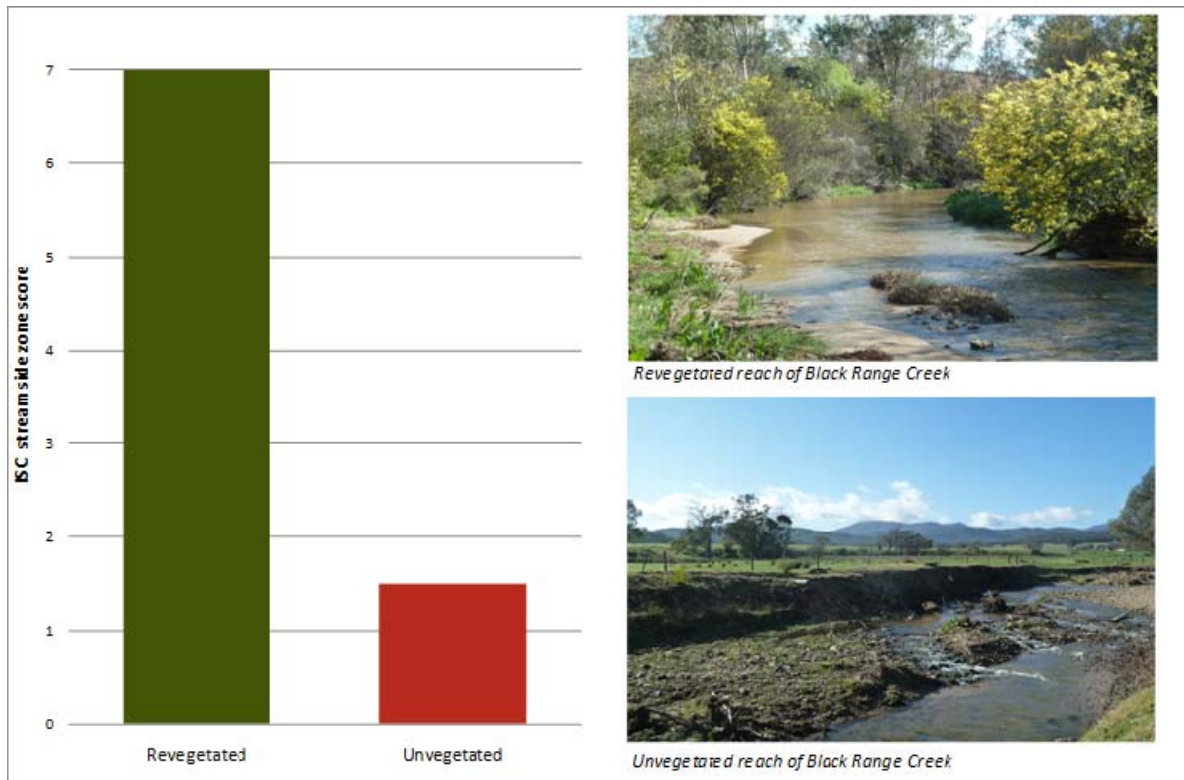


Figure 26. ISC streamside zone scores for the paired sites of Black Range Creek

Quantitative assessment

The hydraulic modelling indicated that the revegetated reach experienced much higher peak stream powers during the December flood event than the unvegetated reach and that both reaches had a similar predisposition to channel change (Figure 27). Despite the increased peak stream power, the revegetated site was found to be largely intact, with only minor erosion arising from the 2011 flood event. In contrast, the unvegetated reach experienced relatively widespread moderate erosion. Both sites were located within the zone within which native vegetation is expected to play a critical role in the presence or absence of flood related channel change. The critical difference between the erosional outcomes at the two sites was the presence or absence of native vegetation and its resisting power.

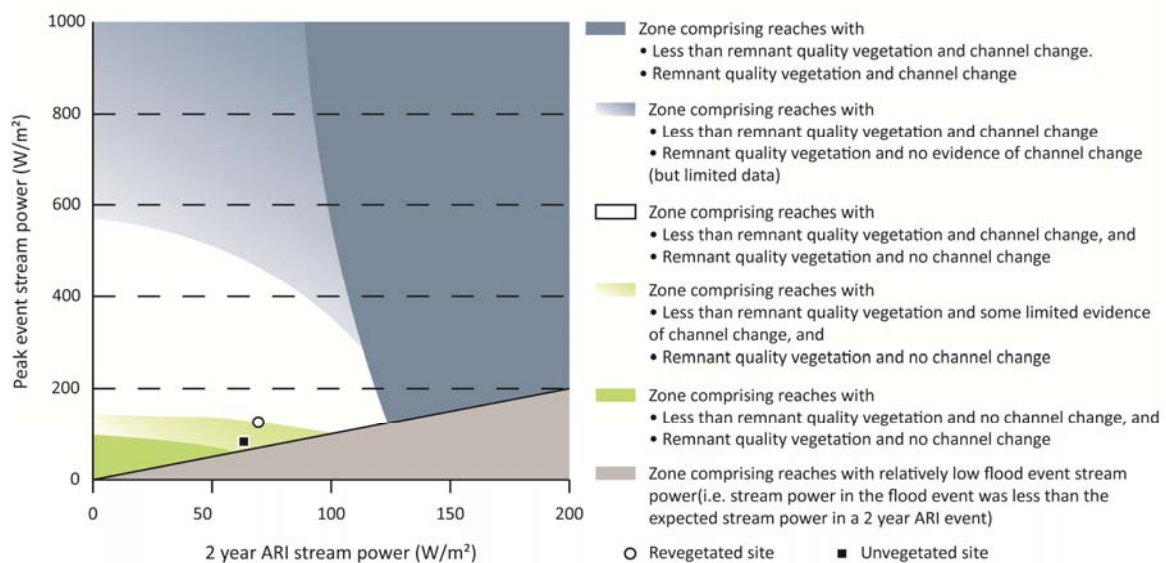


Figure 27. Results from the hydraulic modelling for the paired sites of Black Range Creek

Conclusion

Black Range Creek has a history of erosional channel change. The results from this study indicate that the revegetation program that was undertaken in 1993 was the critical factor in limiting erosional channel change at the site upstream of Pratts Lane. The presence of channel change upstream of Pettifers Lane can be attributed to the absence of native vegetation. The presence of high quality, structurally diverse native vegetation at the unvegetated site upstream of Pettifers Lane would have limited the extent of channel change at that site.

Paired site assessment No. 4: Barwidgee Creek site 1

Introduction

Barwidgee Creek rises on the eastern slopes of Mount Cook. A number of other streams rise in the surrounding hillslopes of the Great Dividing Range before converging with the main stem near Mudgegonga. The streams have created a large alluvial plain in this area. Downstream of this zone, the Barwidgee Creek enters a partly confined valley setting before converging with Happy Valley Creek and the Ovens River near Myrtleford.

The program of management

Following major flooding in the early 1990s, a program of works was undertaken on a 1 km reach upstream of Myrtleford-Yackandandah Rd. The works were undertaken in 1997 and consisted of some limited and isolated rock bank stabilisation and fencing and revegetating the riparian zone. Further downstream, works were not implemented and the riparian zone was left unfenced and devoid of vegetation.

For the paired reach analysis, the rehabilitated reach upstream of Myrtleford-Yackandandah Rd was compared to the unfenced grazed reach immediately downstream of the road (Figure 28).

Assessment of the 2010/11 flood event

In late 2010, widespread rainfall in north-east Victoria led to two major flood events in the Ovens River catchment. No gauged data from Barwidgee Creek were available for this study. The return periods for the events in the adjacent gauged Happy Valley Creek in 2010 were assumed for the Barwidgee Creek. Happy Valley Creek had a 4 year ARI event in September and a 20 year ARI event in December.

Qualitative assessment

Unvegetated reach

The site was largely devoid of native vegetation and was dominated by introduced pasture species. At one location, woody weed species including blackberry and willow were observed. The site was given an ISC streamside zone score of 1.0 (Figure 29).

Channel widening was found to have occurred throughout the reach. Approximately 90% of the channel was assessed as having severe erosion. The site received an erosion score of 63 (Table 8).

Revegetated reach

The vegetation observed was of moderate to good condition, but showed only a low level of diversity, particularly in the understorey. An adequate cover of native vegetation was found along the high stream banks and toe, with some emergent vegetation within the stream bed. The site was given an ISC streamside zone score of 5.2.

Moderate erosion still occurred at this site with bank retreat and slumping observed for approximately 20 % of the reach length. The erosion was localised and confined to high energy zones such as the outside of meanders. The site received an erosion score of 8.



Figure 28. *The paired sites on the main stem of Barwidgee Creek (on the left is the unvegetated reach, while on the right is the revegetated reach*



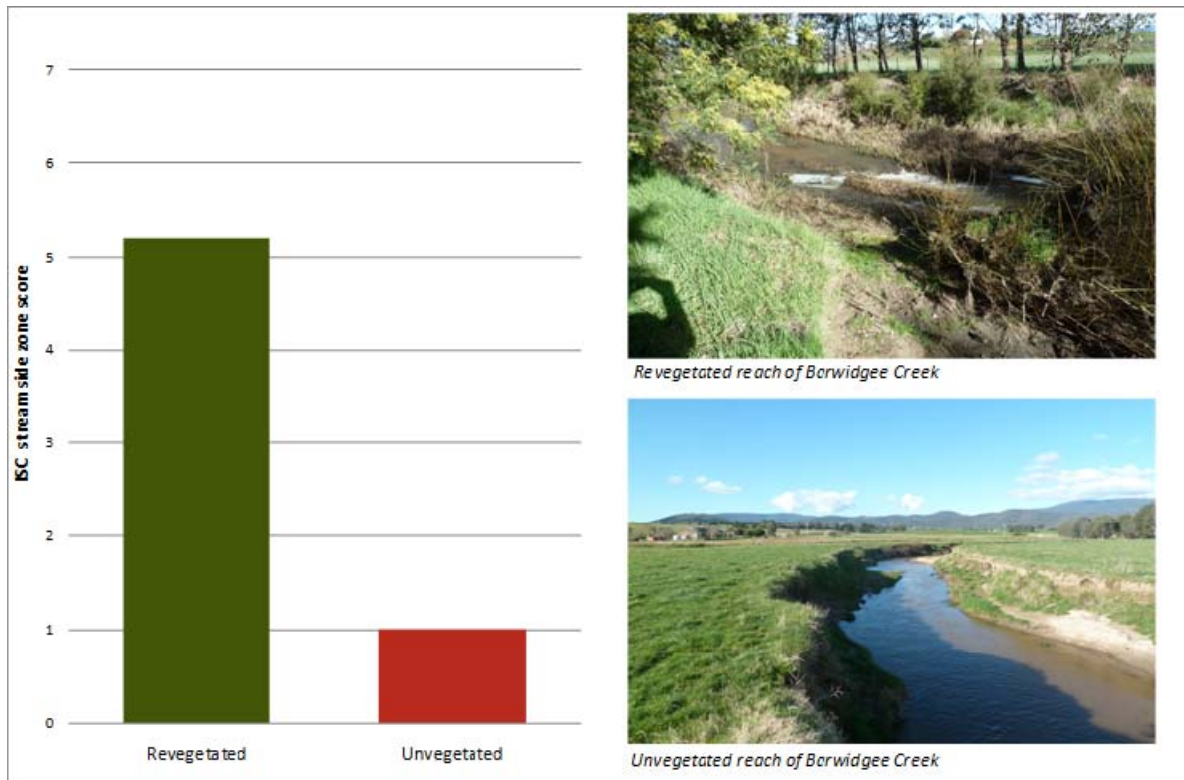


Figure 29. ISC streamside zone scores for the paired sites of Barwidgee Creek

Table 8. Erosion score assessments for the paired sites of Barwidgee Creek

Reach	Scale of erosion (1-10)	% of reach impacted by erosion	Erosion score
Unvegetated	7	90	63
Revegetated	4	20	8

Quantitative assessment

The hydraulic modelling revealed the two reaches to be sufficiently similar to enable comparison. The hydraulic modelling also revealed the subject reaches to be subject to events that placed them within the zone where the presence of high quality, structurally diverse native riparian vegetation would be the critical factor in the presence or absence of flood related channel change.

The hydraulic modelling indicated that the revegetated reach experienced higher peak stream powers during the December flood event and had a much higher predisposition to channel change (Figure 30). Despite this, the revegetated site was found to be largely intact, with only moderate erosion observed in approximately 20% of the reach. In contrast, the unvegetated reach experienced widespread severe erosion. The critical difference in resisting power appeared to be the revegetation works.

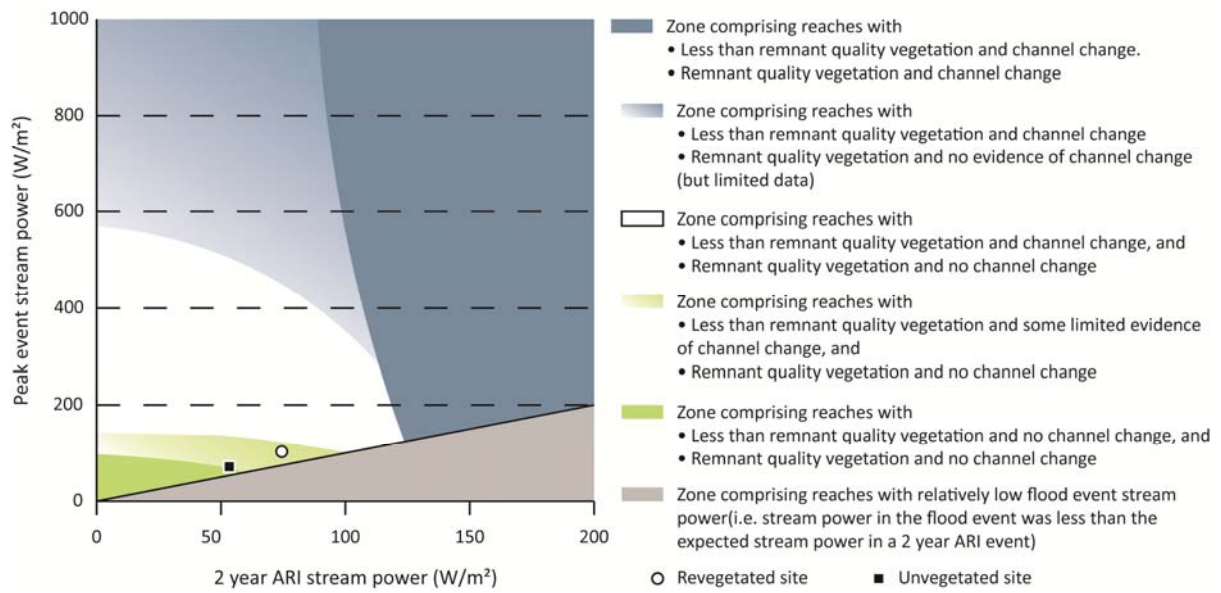


Figure 30. Results from the hydraulic modelling for the paired sites of Barwidgee Creek

Conclusion

Barwidgee Creek has a history of erosional channel change. The results from this study indicate that the revegetation program that was undertaken in 1997 was the critical factor in limiting erosional channel change. The presence of channel change at the unvegetated site can be attributed to the absence of native vegetation. High quality, structurally diverse native vegetation at the unvegetated site would have limited the extent of channel change.

Paired site assessment No. 5: Barwidgee Creek tributary

Introduction

The Barwidgee Creek tributary rises on the eastern escarpment of Mt Stanley before flowing south to meet the main stem of Barwidgee Creek near Mudgegonga. Downstream of this zone, the Barwidgee Creek enters a partly confined valley setting before converging with Happy Valley Creek and the Ovens River near Myrtleford.

The program of management

Following major flooding in the early 1990s, a program of works was undertaken on a 1 km reach downstream of Browns Lane. The works started in 1993 and additional works were undertaken in 1997 and 1998. Grade control works was undertaken in the upper 400 m while fencing and revegetating the riparian zone occurred throughout the reach. Further downstream, works were not implemented and the riparian zone was left unfenced and devoid of vegetation.

For the paired reach analysis, the lower 600 m of the rehabilitated reach, which was not under the influence of grade control, was compared to the unfenced grazed reach immediately downstream (Figure 31).

Assessment of the 2011 flood event

Qualitative assessment

Unvegetated reach

The site was largely devoid of native vegetation and was dominated by introduced pasture species and localised woody weed species including blackberry and willow. The site was given an ISC streamside zone score of 1.75 (Figure 32).

The reach had previously incised, and an inset channel had formed with the macro-channel. Flood related channel widening had occurred throughout the reach in both the inset channel and the macro channel. Approximately 90 % of the reach was assessed as having moderate scale erosion. The site received an erosion score of 48 (Table 9).

Revegetated reach

The vegetation observed was of moderate to good condition, but showed only a low level of diversity in the understorey. A good cover of native vegetation was found along the high stream banks and toe, with a good cover of emergent vegetation within the stream bed observed in some areas. An immature canopy was present and a sub-canopy community was also developing. The diversity of understorey species was limited, though cover of medium and small shrubs was good. The site was given an ISC streamside zone score of 6.5.

The reach had also previously incised (hence the upstream grade control), however the inset channel was narrower than downstream with only localised bank erosion observed. No erosion was observed in the macro channel which was well vegetated. Approximately 20% of the reach was assessed as having minor erosion.



Figure 31. *The paired sites on the tributary of Barwidgee Creek (on the left is the unvegetated reach, while on the right is the revegetated reach)*



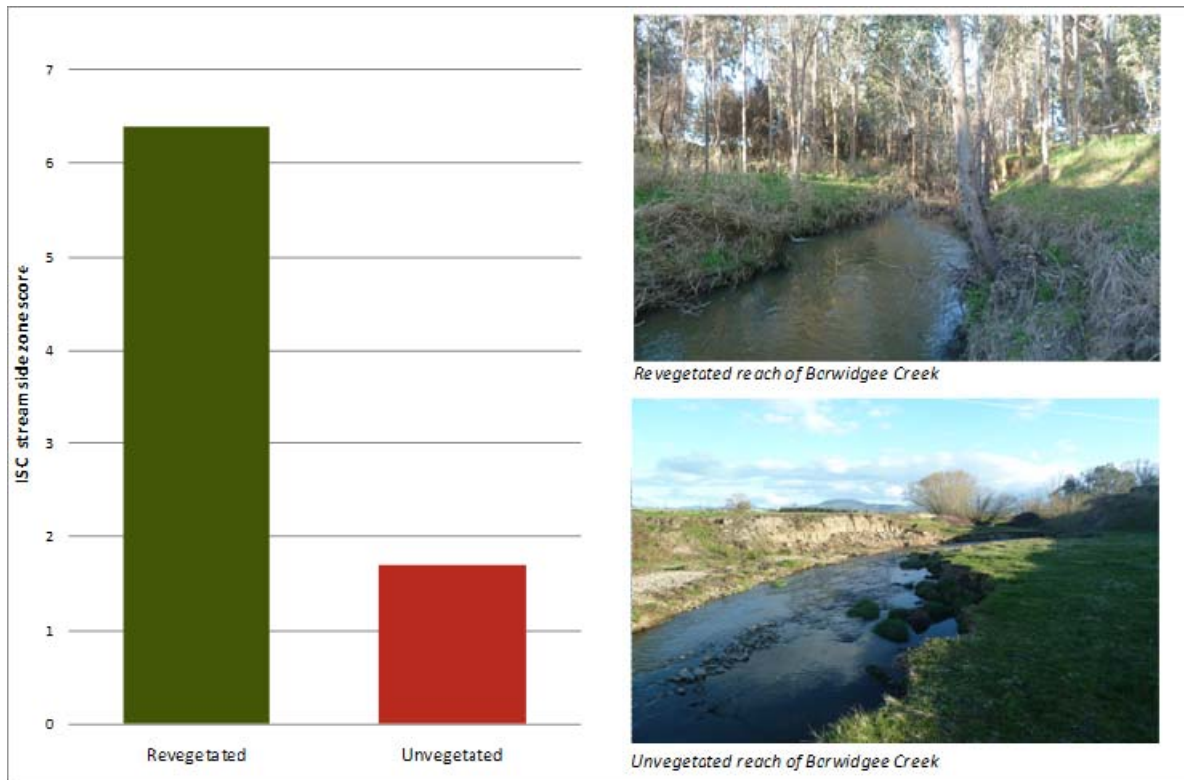


Figure 32. ISC streamside zone scores for the paired sites of the tributary of Barwidgee Creek

Table 9. Erosion score assessments for the paired sites of the tributary of Barwidgee Creek

Reach	Scale of erosion (1-10)	% of reach impacted by erosion	Erosion score
Unvegetated	6	8	48
Revegetated	3	2	6

Quantitative assessment

No topographic data was available to undertake a quantitative assessment of the paired sites.

Conclusion

Barwidgee Creek has a history of erosional channel change. The results from this study indicate that the revegetation program was the critical factor in limiting erosional channel change at the revegetation site. While the results of the assessment cannot be as definitive as the results at sites with a quantitative analysis, the site was similar to the other Barwidgee Creek paired sites and the presence of channel change upstream at the unvegetated site can be attributed to the absence of native vegetation. Based on the assessment of the sites and similarity to the other Barwidgee Creek paired site assessment, it can be concluded that high quality, structurally diverse native vegetation at the unvegetated site would have limited the extent of channel change.