Refining river works techniques through one of Australia's largest river works programs

Bowman H.H.[1], Berry, B.[2], Crawford, T. [2], Martin, J.[3] & Hughes, V.[1]

1. Murray Darling Basin Authority (MDBA), 51 Allara St Canberra, 2602. Email: Hugo.Bowman@mdba.gov.au
2. NSW Office of Water (NOW). Dean St Albury, NSW. Email: Ben.Berry@Water.nsw.gov.au
3. Water Technology. Wangaratta Victoria. Email: Julian.Martin@Watertech.com.au

Key Points

- River works programs sympathetic to their morphologies and geomorphic behavior are critical to maintain and enhance the condition of working rivers.
- Understanding of the processes resulting in erosion is critical to inform a suitable remedial works program.
- Log revetment is an effective way of affording protection to the river bank through physical armouring.
- Rock beaching is effective but does not consider erosion in the context of the geomorphic evolution of the channel and its anabranches.

Abstract

While the water of Australia's rivers are utilised to meet demand for irrigation, critical human water needs and recreation, it is inevitable that they will continue to experience adverse impacts arising from regulation. Appropriate river works programs are critical to maintain and enhance the condition of working rivers, such as the River Murray, to ensure they continue to provide this vital nexus into our uncertain future.

The Hume Dam to Lake Mulwala River Works program is the largest of its kind undertaken in the Murray Darling Basin and one of the largest in Australia. To date, over $20M has been invested in physical works along a 200 km reach downstream of Lake Hume. The program was implemented to mitigate the detrimental geomorphic impacts of regulation arising from Hume Dam; the powerhouse of the regulated River Murray system. The program extends as far back as 1959, making it the longest running major river works program of its kind.

The scale and continuity of the program, together with contribution and strategic direction from a range of experts in the field, has allowed a considerable body of knowledge to be developed. The program has refined a range of established river works techniques and construction methods through extensive trials including engineered logjams, log revetment, pile fields, re-snagging and revegetation. This is significant given that the majority of other river works programs within Australia are short-term reactive programs, limited in geographic scope and funding. This paper outlines and evaluates these techniques in detail, and presents other practical advice for project managers, providing river managers with a way of accessing this information for practical implementation within a geomorphic context.

Keywords

pile fields, log revetment, rock beaching, re-snagging, revegetation

Introduction

The Hume Dam to Lake Mulwala River Works program is the largest of its kind undertaken in the Murray Darling Basin and one of the largest in Australia. The program commenced on a part time basis in1959, with a focus on removing impediments to maximise flow conveyance. By 1988 through to 1998 the program was undertaken on a full time basis and engaged 4 people utilising 2 front end loaders. The program reached its zenith around 2006, when it was employing 12 people, with a backhoe, 3 front end loaders, winch, log grabbers, post drivers and dump truck. Recent funding constraints have resulted in a current works crew of 6 full time staff. The program has also evolved in its approach, since 1998 the program changed from a focus on rock beaching to a vision to manage the river in '*a manner that is consistent with its laterally migrating, anabranching morphology*'. Hard engineering techniques like rock beaching are not sympathetic to this vision. Instead preference is now given to a range of innovative erosion control techniques utilising timber and revegetation.

The Murray is a meandering, anabranching river. This means that it is formed by lateral erosion of meander bends, but that these local erosion processes are set within the broader context of anabranch development. Thus, even under natural conditions, the pattern of erosion in the reach would be highly variable.

Regulation has resulted in an additional 12% of average annual discharge being conveyed by this reach, a result of water transfer from Snowy Hydro (Erskine *et al.* 1993). In addition most small to moderate floods are captured by Hume Dam. The bulk of this water is now conveyed within channel, drastically reducing minor overbank flow frequency. Much of this water is released from Hume Dam as long-duration relatively steady flows to deliver water for irrigation. This has resulted in river banks being saturated and exposed to movement of water for considerably longer periods than under pre-regulated conditions (Thoms *et al* 2000).

The main types of erosion associated with current regulated conditions include horizontal notch cut into the upper bank, which leads to retreat by the cantilever failure of blocks of material that are undercut by this notch. The height of this notch typically occurs at the same elevation (stage) as the water level of the artificially long-duration regulated flows released from Hume Dam. However many of the banks are undergoing parallel retreat, with the full bank profile retreating at the same rate. This is due to the bank sediments exhibiting a tendency to slake, where they experience decreased strength when wetted. The long-duration regulated flows arising from regulation thus cause erosion at even low velocities and lead to bank retreat. This retreat undermines the upper bank leading to cantilever failure. This is a critical observation as it demonstrates that erosion cannot be treated at the notch alone.

The lessons learnt from the application of several methods of erosion mitigation are outlined here. Results from this assessment demonstrate that appropriate river works programs sympathetic to their morphologies and geomorphic behaviour are critical to maintain and enhance the condition of working rivers.

Pile fields

Pile fields are permeable structures composed of rows of vertical timber poles constructed in the stream bed projecting from the bank into the flow (Dyer et al., 1995a, Dyer et al., 1995b). Pile fields are designed to prevent erosion either through lateral migration or channel widening. They act as an artificial form of flow resistance which would originally have been provided by large woody debris and vegetation. They reduce bank erosion by slowing flows and creating a depositional environment which produces favourable conditions for the establishment of vegetation, an essential element to the success of pile field sites. Pile fields comprised the predominant bank erosion mitigation technique as part of this program from 1998 until 2007, when log revetment became the favoured technique. Approximately $5M was spent constructing pile fields at 95 sites, representing 14 km of treated river bank. Timber piles are typically driven into the stream bed and banks in a straight line (in plan form) angled downstream using an excavator equipped with a hydraulic vibrating plate.

Figure 1. Pile fields are intended to act as drag structures, facilitating sediment deposition and encouraging vegetation colonization. They have had mixed success rates on the River Murray.

With consideration of the design intent, pile fields have had mixed success rates in the Hume to Mulwala reach. Whilst pile fields have generally been successful in unregulated river systems, the success rate on this regulated reach of the River Murray has been constrained by:

- The characteristics of the river banks means that when they are saturated they are subject to erosional processes from slaking, dispersion, fluvial scour and entrainment even at very low velocities (Rutherfurd *et al.* 2007).
- Sustained regulated flow releases preventing vegetation establishment between the pile field rows below the full regulated flow height.
- Construction limitations (length of excavator arm) result in rows that are too short to intercept bedload sediment which are primarily transported further into the channel, beyond the influence of the pile fields.
- Suspended load sediment conveyed through this reach is extremely fine. It requires velocities to approach zero before it will settle out, which is difficult to achieve with pile fields.
- High regulated flows do not provide the fluctuation in discharge and stage that facilitates sediment settling out on the receding limb of the hydrograph.
- The millennium drought coincided with the major phase of pile field implementation. The dry bank conditions and lack of regulated flow variation is thought to have significantly retarded vegetation establishment during this period skewing the apparent success. This was demonstrated also by the very low levels of natural recruitment during this time.

Refined pile field construction techniques include:

- Timber durability is a major consideration as it is a critical determinant in the design life of the structure. The timber used for many of the pile fields was comprised of moderate durability classes of 3 & 4. Many of these deteriorated rapidly through fungal decomposition and termites, leading to structural failure. Only durability class 1 or 2 timber is recommended. This extends the design life helping to achieve the design intent of the structure. Sourcing suitable class 1 or 2 timber for pile fields that is the right size, straight and without imperfections can be challenging. Ideal pole dimensions are 4-6 m long and 150 – 300 mm wide.
- Success has been higher on straight sections of channel and on inside bends compared to outside bends. The relatively lower velocity conditions in these planform locations can be reduced further through pile fields to facilitate sediment deposition of bed and suspended load material. The sustained higher velocity conditions on outside bends is more difficult to reduce to below the sediment entrainment threshold.
- Parallel pile fields have been trialed, where piles are driven into the bed parallel to the flow instead of right-angles to the flow. These appear effective at reducing near bank velocities however sediment capture and subsequent colonisation of vegetation is still low.
- Pile fields are ineffective at sites with vertical banks as vegetation, a critical component to their success, it is too difficult to establish within embayments.
- Pile fields are ineffective in areas of high boating activity as boat waves travel parallel to the bank resulting in very little of the wave energy dissipated by the pile fields.

Log revetment

Log revetment involves the placement and pinning of single or multiple rows of logs either parallel to the banks or at <45 degree angle (deflector logs) to the direction of flow. Log revetment effectively armours the bank, diverts flow and reduces near bank velocities while revegetation is established. Since 2007, log revetment has become the most used technique to address erosion as part of the River Works program, partially due to the proactive sourcing of suitable timber. Over $3.3M has been spent constructing log revetment at 115 sites, representing 11 km of armoured river bank.

Instream timber forms an essential component and provides an important function in Australian river systems. The logs ultimately return to the river as snags increasing hydraulic roughness, hydraulic diversity under a range of flows and improve instream habitat.

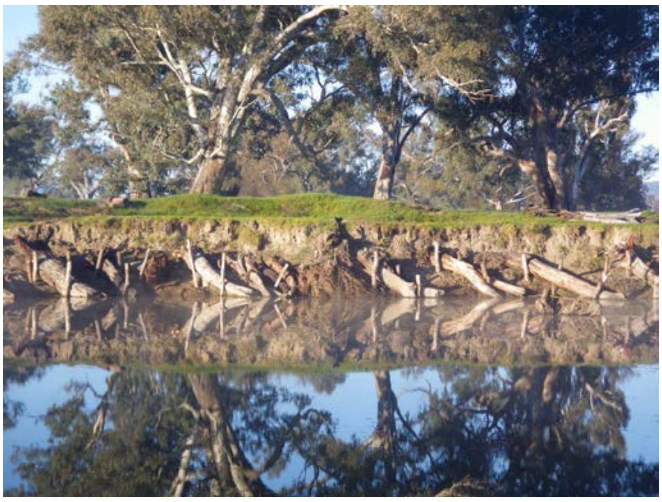

Figure 2. Log revetment involves pinning logs to the river banks, helping to reduce erosion through armouring. Here deflector logs have been placed to divert flows and assist reducing near bank velocities while vegetation becomes established.

Key findings in relation to the log revetment works include:

- It is a very effective technique for protecting the upper bank face and reducing bank retreat.
- Deflector logs effectively reduce erosion on concave banks as they divert flow from the erosional zone. Logs are placed with the root balls pinned to the banks with the trunks projecting into the flow downstream. This maximises roughness and minimises near bank velocities.
- Log revetment can be effective at armouring against effects of vessel wash from powered boating in moderate boat use areas, however high boat use areas require rock to be placed in between logs.
- Logs can also be used as stock exclusion fences across flood runners, anabranches or sections of river exposed during low flow stages.
- Where water levels permit access to the lower bank profile, double or multiple lines of logs can be pinned in place to protect the whole bank profile to address parallel bank retreat.
- When water levels prevent access to the lower bank profile, log revetment can be used to protect the upper bank face in conjunction with rock beaching to protect the toe. This may mitigate different erosional processes acting across the whole bank profile and provide sufficient time for vegetation establishment.
- Log revetment structures withstood flows in excess of 60,000 ML/day without failing.

Refined log revetment construction techniques include:

- Machine planted Phragmites rhizomes propagate successfully between the logs, even during sustained high regulated releases. Phragmites assists to stabilise the banks and further reduces near bank velocities.
- Where full bank armouring is not required, such as to protect against boat wash, single rows of logs can be used effectively with less logs and at reduced construction time.
- Pro-active sourcing of timber from locations such as storm damaged fallen timber, development sites, road construction and approved farmland clearing. Development corporations, local government and other authorities are contacted to ensure that trees felled as a result of such developments are stockpiled for later use. Dead timber in the riparian and floodplain zones plays important ecological and geomorphological roles and is not considered a desirable source of timber for log revetment.

- Log stockpile sites need to be selected carefully, as they pose a significant risk in fire prone areas and also have the tendency to be cut for firewood if in secluded environments.
- Only timber of durability 1 or 2, generally red gum (*Eucalyptus camaldulensis*).
- Logs are transported on flat-bed trucks with bolsters. Access considerations include bridge capacities and soil moisture which can lead to bogging.
- Logs capture soil from cantilever bank failure creating a niche environment for vegetation establishment.
- Pins need to be vibrated or driven into place using a large excavator. Pin placement must be carefully thought out so that pins can be driven over the logs at an appropriate angle to lock them into place. The smallest end of the pin needs to be driven into the river bed to reduce the piles vibrating in the water column.
- Ensure that piles ordered are to a spec that will allow the largest end of the pile to fit into the vibrating head on the excavator. If not they all need to be manually cut down which can become very expensive.

Engineered Log jams

Engineered Log jams (ELJs) are permeable in-stream structures that have been used as a component of the River Works program in an attempt to prevent anabranches from capturing increasing proportions of flow from the River Murray. ELJs reduce flow conveyance in an anabranch through increasing flow resistance and reducing the cross sectional area in a discrete location. Prior to 2010, full stream width pile fields (bed control structures) were used. Their design objective was to slow velocities below entrainment thresholds, encouraging deposition therefore reducing the cross sectional area of the offtake channel of anabranches reducing the flow capacity. However, design limitations to permit vessel navigation required these structures to protrude less than 0.5 m above the bed. This design constraint reduced the effective functioning of the structure. Since 2010 four ELJs have been constructed on anabranches, including the largest in Australia, at a cost of $300,000. A detailed concept design was prepared for the first ELJ, incorporating a detailed hydraulic investigation. The design has been replicated although scaled as appropriate to suit channel dimensions at other locations.

Figure 3. Engineered log jams are used to reduce flow conveyance through anabranches by increasing flow resistance and reducing the cross sectional area in a discrete location.

Anabranches with low sinuosity and steep gradients are more hydraulically efficient than the main channel of the River Murray and as such, threaten to capture an increasing proportion of flow from the main channel. Somewhat counter intuitively, erosion control work on anabranches that prevent lateral bend migration can have the adverse effect of retarding the natural anabranch evolution processes, thus retaining more hydraulically efficient channels. This can accelerate erosion and the process of flow capture from the parent channel. The most appropriate anabranch management strategy involves allowing anabranches to migrate laterally, whilst undertaking works to dissipate energy and manage channel width (Martin and Judd 2007). The ELJs reduce flow velocities, shear stress and stream power exerted on the channel thereby reducing the potential for erosion to occur. Key findings include:

- The ELJs have been effective at influencing flow conveyance in the anabranch and main channel, reducing flow conveyance by more than 10% through the anabranch channels.

- ELJs have been constructed at both the offtake and confluence where anabranch's leave and re-enter the main channel. This mitigates erosional processes migrating in both up and downstream directions known to be important factors in anabranch initiation and development in this reach (Judd 2005).

Refined ELJ construction techniques include:

- The basal logs of the structures which span the channel can be seated and raised slightly from the bed to permit fish passage during low flows.

- Very large root balls can pinned in place immediately upstream of the structures to dissipate flow velocities and stream power. They can also intercept debris which may damage the structures during floods.

- Ideal logs for the main structure are relatively straight with a good root wad double the radius of the trunk. This allows them to be manoeuvred by the excavator grab, keyed into place and pinned, making them very difficult to dislodge during high flow events.

- Rock pads constructed in the channel can provide a platform from which an excavator can operate. This can be removed as construction progresses and the rock utilised to create bed armouring and aprons on the bank to prevent scour and outflanking.

Rock beaching

Rock beaching is a layer of rock (generally blasted and sorted angular quarry rock) placed against a stream bank to protect it from erosion. Since 1998 over $7.3M has been spent implementing rock beaching on vulnerable river banks at 185 sites, equating to 19.6 km of treated banks. Rock beaching is the favoured management approach by many landholders as it is usually a quick, successful tool for halting further bank retreat when compared to approaches that are more sympathetic to the alluvial environment such as pile fields and revegetation (Martin and Judd 2007). However large scale rock beaching of banks is not considered compatible with the evolution of a laterally migrating, anabranching river system such as the Hume to Yarrawonga reach of the Murray River (Judd, 2005; Schumm *et al*., 1996).

The medium term consequences of rock beaching include:

- Prevention of natural adjustments in channel width. Channel width is an important determinant of sediment transport rates (Bagnold, 1977) and is important to the formation of pool-riffle sequences (Wilkinson *et al*., 2004).

- Anabranching on the Murray River involves the sinuosity of evolving channels increasing until the channel is abandoned in favour of an alternate course (Schumm *et al*. 1996). Hence, rock beaching of the outside banks of meander bends is likely to lead to fundamental changes to the development of anabranches and the overall channel pattern.

- Meander bends not only extend laterally towards the edge of the floodplain, they are also translated downstream over time. Hence, the rock beaching of the outside bank of a bend will prevent one bend from moving whilst the remaining meander train moves downstream. Over time the sinuous plan form of the channel alters, eventually cutting off the rock beached meander bend. This would take a long time on the River Murray.

- The erosion of the outside banks of meander bends, leading to meander extension and an increase in sinuosity, facilitates a reduction in channel slope that may lead to a reduction in the width of the channel. Preventing bank erosion and an increase in sinuosity within a reach using rock beaching is likely to result in a net increase in erosion (Judd, 2005)

These implications of rock beaching may prevent or retard the natural development of in-stream features and, in the long-term, the laterally migrating nature of the anabranching system. Despite these implications, rock beaching is still the preferred method for certain locations. Generally these are where a high value asset is threatened by bank erosion or other methods are considered not suitable.

Refined rock beaching implementation techniques include:

- Ensure that the size of the rock is suitable for bank characteristics, erosional processes, stream power and position of the bank on the planform of the river to be protected. The median size of the rock beaching should be designed to prevent the rock from moving in response to the local energy of the flow. If the rock is too small, the rock may be mobilised in a large flood. If the rock is too large, sediment may be removed from the bank face in between the spaces by fluvial scour and attrition. A hydraulic analysis may be required to determine rock size.

- Ensure that the rock is sufficiently angular to form an interlocking matrix.

- Ensure the rock is durable, as weathered rock may decompose. Dark rock, such as basalt, tends to blend in with the natural colour of the river banks, whereas lighter rock, such as granite, stands out more.

- Quantities of rock used can be reduced by placing with an excavator rather than dumping rock onto river banks with a tip truck or pushing rock in with a bulldozer.

- It is difficult to always estimate the volume of rock required at a site, particularly if the water levels are reasonably high. A fishing rod with an echo sounder can assist. Insufficient rock placed at the toe of the bank may result in slumping. In order to ensure structurally stable beaching, a ledge of rock can be placed on to the stream bed that will collapse into any scour that develops.

- Where log revetment or other structures are difficult to implement, buckets of rock can be placed instead using an excavator.

- Rock aprons have been placed at terminal points of developing anabranches or flood runners to successfully halt initiation and development of knick-point erosion. Including preventing potential channel avulsions.

- Without exception revegetation should be undertaken behind the rock beaching.

- Identifying whether the toe of the bank requires protection at every works site is critical. Rock is generally the best option for this task. Depending on the bank profile, rock may be used in conjunction with log revetment, where the rock is used to protect the toe and log revetment is used to armour the upper bank profile.

- When placing rock, the larger rock should be placed at the bottom of the bank to reduce the likelihood of slumping.

Submerged Woody Habitat Restoration (Re-snagging)

Trees, branches and root masses found in rivers are called snags and are natural long-term features of the riverine landscape. They perform a number of hydraulic, geomorphic and ecological functions. Hydraulically, they reduce the mean velocity of flow and divert areas of high velocity away from the bank enhancing bank stability. At the same time they increase the complexity of the hydraulic environment by increasing the range of horizontal and vertical flow velocities, and flow directions (Hughes, 2011). These hydraulic changes reduce the overall rate of bank erosion and also produce a more complex geomorphic environment, with the development of features such as scour holes in the river bed. Snags also retain sediment and removal can lead to sediment mobilisation with the re-deposition further downstream. Removal can also lead to enlargement of river channels. The hydraulic changes around snags also include the presence of areas of very low velocity which provide hydraulic refuge for stream dwelling biota such as plants and fish.

Removal of snags from rivers of the Murray-Darling basin has been widespread since European settlement. Over 3 million snags were removed from the Murray and Murrumbidgee Rivers from 1855 and the late 1960s (Treadwell *et al.*, 1999). Over 24,000 snags were removed from the Hume to Mulwala reach between 1976 and 1987 to improve hydraulic conveyance for irrigation flows (Murray-Darling Ministerial Council 1987). Despite the prior perceptions of snags, they do not significantly decrease channel capacity or lead to increased flooding. An investigation in 2004 identified only 5,000 snags remaining in this 200 km reach (Department of Primary Industries 2004).

In recognition that too much instream habitat had been removed, a project between the MDBA The Living Murray and the Native Fish strategy was commenced in 2003 to restore submerged woody habitats to three priority areas along the reach. By the conclusion of the program in 2008 a total cost of $4.3M had been spent. The distribution, character and function of snags in different riverine settings are highly variable spatially and are dependent on stream size and power and the characteristics of the wood itself (Chen *et al.* 2006; Baillie *et al.* 2008). The areas identified for re–snagging were selected based on a 'snag assessment' which recorded the location, size, complexity, alignment and depth of snags. In this reach large snags are concentrated on the outside of meander bends, where stream energy is highest (a result of their being recruited by meander development).

The assessment also recorded the associated riparian vegetation communities for presence/absence and connectivity. Knowledge of the number and location of snags previously removed were also included. This assessment allowed a target 'instream woody habitat load' to be calculated. The 'instream woody habitat load' estimates the level at which snags should occur to maintain native fish populations within the reach. The selection process incorporated the above assessment results and also considered connectivity with existing healthy instream habitat and logistics associated with re-snagging. This included sourcing and transporting woody habitat and access to re-snagging sites. The method used to reinstate snags employed a cable dragging technique developed by Nicol *et al* (2002).

When undertaking a re-snagging project, it is important to consider the following;

- Understand the natural relationship between snags and the river in your area of interest.
  - What would the natural character (number, size, type, shape, quantity, channel position, alignment to flow) of snags have been?
  - Were snags naturally a long term feature of the river, or were they moved quickly through it?
- Complex timber is more desirable than straight timber. Root balls and branches will increase the hydraulic complexity, increasing the ecological and geomorphic outcomes.
- If increasing fish habitat is the primary aim, the optimal location for snag placement depends on the target species. Murray Cod prefer snags within 15m of the bank, whereas re-snagging the mid-river area will preferentially benefit Trout Cod.
- Ensure the type and size of timber is sufficient to resist mobilisation during large flows.
- Creation of woody habitat in depositional zones of meanders had lower rates of utilisation by fish in comparison to other zones.
- Fencing of riverbanks from stock access and re-establishment of riparian vegetation will provide the snags of the future.

Revegetation

A major component of all work sites is fencing and revegetation. Since 1998 over 108 km of river bank has been revegetated at a cost of $890 000 with an average success rate of around 80%. Vegetation plays a complex role in stabilising stream banks. A primary objective of this program is to realise the value of vegetation in managing rates of channel change, improving aesthetics and landscape values and improving ecological values of the river and floodplain. Lessons learnt implementing revegetation include;

- Planting lines are ripped using a backhoe. They are discontinuous and multidirectional. A specialised ripper head was developed that breaks clods and compresses with a roller. Root zones of existing trees are avoided.

- The backhoe used is a small manoeuvrable 50 Horsepower road registered vehicle. This allows floating costs to be avoided.

- Common Reed (*Phragmites australis*) is adapted to inundation in low energy conditions. Machine placed rhizomes have been successfully transplanted and established within a range of settings below long-duration flow level where other plants could not establish. Establishment can assist to protect the exposed banks from slaking and attrition. They have been particularly successful in conjunction with log revetment. In some locations Phragmites has been successfully used to stabilise the bank toe. They have been moderately successful within pile field embayments. They have not been successful in conjunction with rock beaching, where peak summer temperatures resulted in high rates of mortality.

- Drought conditions made revegetation extremely challenging, particularly on north facing banks. Water carting had to be undertaken at significant cost.

- Water crystals are useful but using too many can push plants out of the ground.

- A jetting lance or water spear was used extensively early in the program for long stem planting, however this technique is now only seldom used where ground conditions are extremely hard.

Conclusion

The long term nature of this river works program has allowed a range of lessons to be learnt. In the context of this regulated reach with banks vulnerable to erosion under saturated and low velocity conditions, pile fields have had mixed success. Log revetment appears to be an effective way of affording protection to the river bank through physical armouring. Rock beaching is effective but does not consider erosion in the context of the geomorphic evolution of the channel and its anabranches. Engineered Log Jams can be used to mitigate erosion through anabranches by reducing flow conveyance and slowing the rate of evolution. Re-snagging influences the hydraulics of rivers in complex ways and constitutes a form of geomorphic restoration that improves instream habitat for freshwater biodiversity and increases species resilience. Fencing can be undertaken in a range of innovative ways that minimise detrimental impacts to native wildlife and improve habitat whilst being effective at managing stock. Revegetation is a critical component to any river works program to achieve pro-active erosion control and enhance environmental values.

An understanding of the processes resulting in erosion is critical to inform a suitable remedial works program. Working with the natural behaviour and evolution of rivers is critical to ensuring long term success. With ongoing implementation and critical review it is hoped that programs such as these will continue to provide ongoing lessons to guide other shorter programs constrained by funding sources and management constraints. This will assist us to manage these important systems sustainably into the future.

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