LOW COST EROSION CONTROL

CASE STUDIES IN THE KYEAMBA VALLEY

By Cam Wilson *for* Kyeamba Valley Landcare Group

THE KYEAMBA VALLEY LANDCARE GROUP

NSW GOVERNMENT

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The information contained in this report is intended for general use by members of the Kyeamba Valley Landcare Network. The recommendations assume that the goals of the landholder have deemed addressing the erosion sites as a priority within their overall context. The information contained in this publication comprises general statements based on the author's knowledge and understanding of soil erosion processes, and has been produced specifically in relation to the case study properties. Readers are advised and need to be aware that this information may be incomplete or unsuitable for use in specific situations. Before taking any action or decision based on the information in this publication, readers should seek expert professional, scientific and technical advice. To the extent permitted by law, the author does not assume liability of any kind whatsoever resulting from any person's use or reliance upon the content (in part or in whole) of this publication.

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1. INTRODUCTION

1.1 A Brief History and Trajectory of Erosion in the Kyeamba Valley

Erosion is a natural process, with the resulting transport and deposition of sediment shaping the familiar landforms that we see. The interplay of erosion and deposition is reflected in a technical name given to the gently sloping, broad valley floors that are so common in the region: cut-and-fill landscapes. During the Holocene (last ~10,000 years), these settings have gone through long periods of stability - the ‘fill’ component - slowly accumulating sediment and building over time (3,000 to 6,000 years), followed by rapid phases of gully formation - the ‘cut’ component - during which significant sediment export occurs.

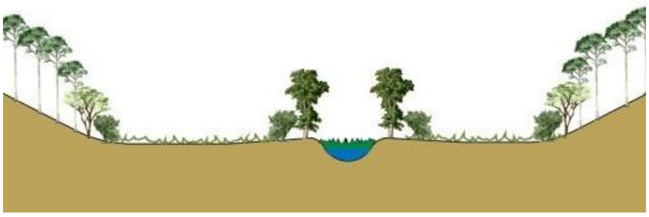
While periodic erosion within these landscapes is a natural process, the widespread and simultaneous occurrence of erosion across the region following the introduction of European land management practices had not been seen at any other time during the Holocene. The management-induced causes of this widespread gully formation have been extensively documented within the scientific literature, with catchment runoff significantly increased by a combination of native vegetation clearing and groundcover loss due to livestock proliferation, coinciding with reduced resistance to erosion caused by stock and vehicle tracks, ploughing and drainage for agricultural purposes. This process is described in the following section.

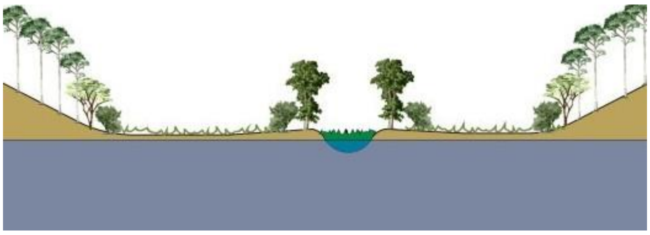
1.2 The Dehydration and Rehydration of the Australian Landscape

The following diagrams (from Wilson, 2011) provide a pictorial tour of the degradation and dehydration process that the Australian landscape went through following European settlement, along with one of the major aims of Peter Andrews' Natural Sequence Farming approach, namely the rehydration of the Australian landscape.

If you were one of the early explorers, walking into a wide floodplain system in the early 1800s, more than likely you would have found some form of discontinuous watercourse. One example is known as a 'chain of ponds', in which you'd find small bodies of open water, about a metre below the level of the floodplain, held in place and separated from the next pond by a marshy plug of reeds such as Phragmites (below left).

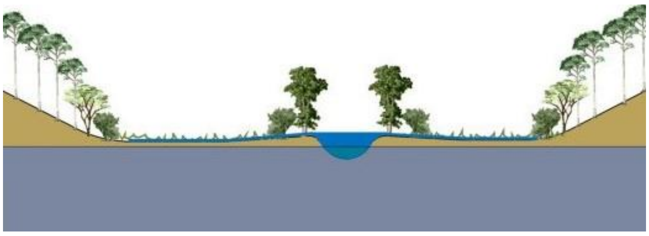
These ponds weren't the whole story though. They were just the tip of the iceberg and indicated the level of the water table under the rest of the floodplain-step, with moisture within a metre or so of the toes of all of the plants on the floodplain (below right).

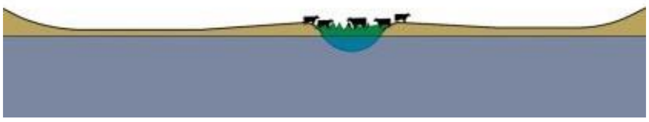




When a decent flow occurred, rather than it rushing downstream, the reed beds would slow the water, causing it to gently rise and flow over the banks onto the floodplain. This gave the water plenty of time to infiltrate and recharge the aquifer below - a wise move for a landscape to make when the next generous rain might be a few months away. You might also notice something strange - the banks of the creek are higher than the rest of the floodplain. This is because when the water spills over the banks, the largest sediment settles out first, building up a levee over time (below left).

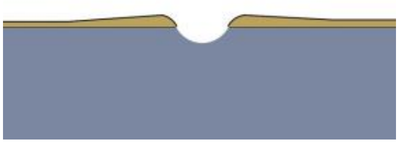
When settlers arrived with their animals, they ring barked many of the trees as they went. There weren't many stock troughs in those days, so of course the animals had to drink from the creeks (below right).

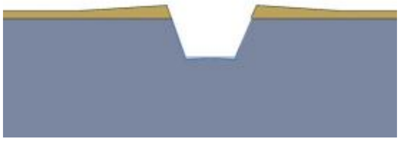


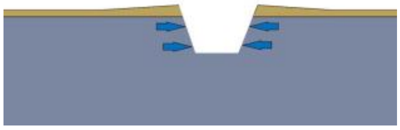


The hard hooves soon cut tracks into the reeds, and contributed to the killing off of the marshy plugs (below left). With the plugs gone, and the hillside up above the floodplain cleared, burnt and overgrazed, water could now build some momentum, and soon scoured out the deep erosion gullies we still see today (below centre).

With the ponds no longer in place, the gully turned into a really efficient drain (below right)…

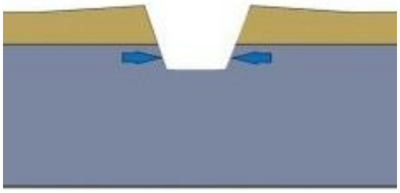


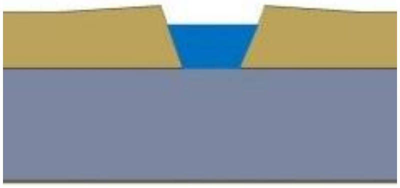


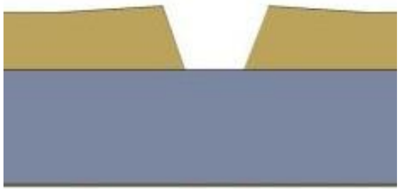


…lowering the alluvial aquifer (below left), down to the base of the incised channel (below centre). Once this occurred, rather than plants having moisture one metre below, they became high and dry, and at the mercy of the infrequent rainfall patterns experienced in much of the Australian landscape.

Once a channel is deeply incised, in many places even a large rainfall event is confined to the channel (below right). This deprives the floodplain of the soaking sheets of water and fertile sediment of yesteryear.



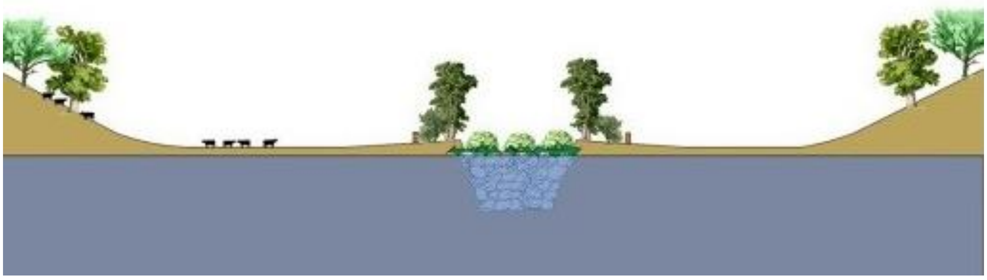




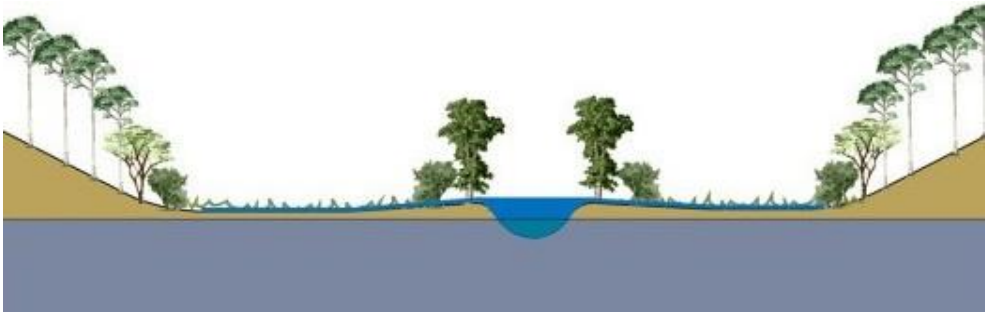
The Natural Sequence Farming approach is about replicating the job that wetlands used to do, by creating ‘leaky weirs’ using locally available materials. Vegetation is an important component of leaky weirs, with the fibrous root system of bioengineering plants helping to tie the boulders together. This approach results in structures that are a fraction of the cost of highly engineered structures. The exclusion of livestock is also important, except for periodic crash grazing.

The weirs enable chains of ponds to re-form. These ponds begin to raise the alluvial aquifer, particularly through buried old creek lines which act as gravelly intake areas along the banks (below left). The rehydration will obviously happen faster in sandy soils than it will in heavy clay, but slowly the aim is for the alluvial aquifer to be raised (below right). This is water harvesting in the form of reinstating a natural landscape process.

Eventually, the goal is to reinstate a drought-proof landscape.



At such time, flood processes become important once again, by creating a freshwater lens on top of the heavier, saline groundwater.



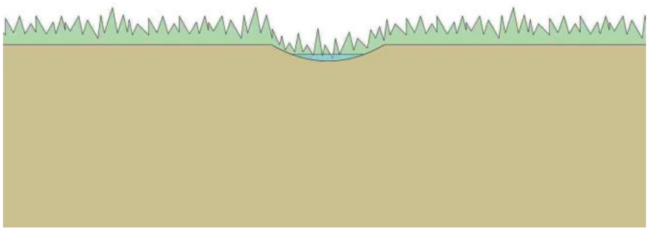
The majority of gully formation on the Slopes and Tablelands happened during a few key events, much of which occurred by the start of the twentieth century. Despite the ongoing and obvious presence of erosion gullies, improvements in land management have resulted in a period of relative stability since the mid-twentieth century. Research shows that the establishment of in-stream vegetation within many gullies represents the most recent channel 'fill' phase and, given sufficient time, all of the active erosion that we see will eventually stabilise and infill.

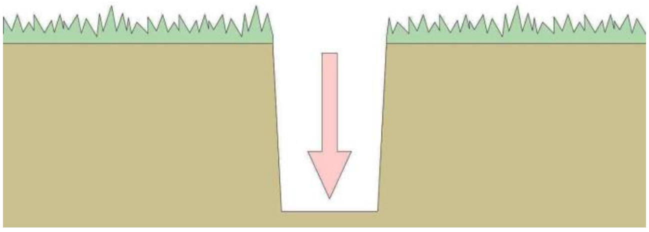
1.3 The Evolution of an Incised Channel

The following diagrams provide a pictorial description of the development and evolution of an incised channel.

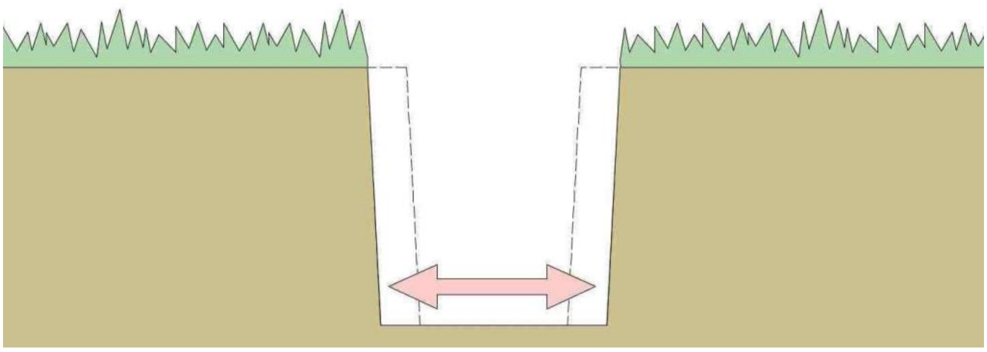
Stage 1: Intact (below left). This is a stylised example of an intact valley floor in the Southern Tablelands at the time of European settlement. The valleys were commonly characterised by a shallow and often discontinuous channel, with flows regularly inundating the adjacent floodplain. These conditions resulted in low energy flow, conducive to sediment accumulation.

Stage 2: Downcutting phase (below right). This stage is characterised by headwall erosion advancing upstream. At the time of European settlement, gully erosion was initiated by a combination of increased runoff due to clearance of native vegetation and/or overgrazing, and compromised groundcover due to stock and vehicle tracks, ploughing and drainage. Contemporary gully formation is generally related to the ongoing migration of headcuts that formed many years ago.



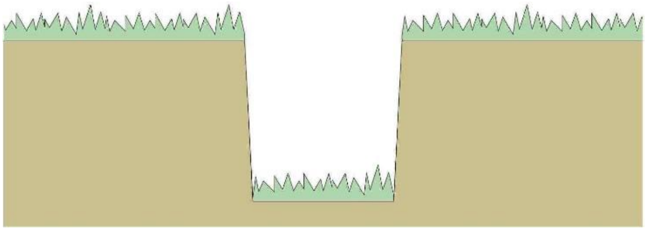


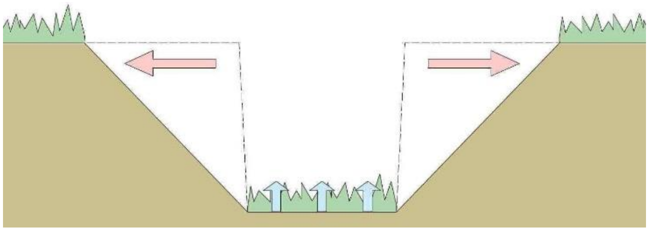
Stage 3: Widening process (below). When flows are confined within a recently incised channel, a high energy environment prevails. The energy is expended on the sidewalls of the channel resulting in widening over time.



Stage 4: Bed stabilization (below left). As the floor of the gully widens, the energy of the flow decreases, and conditions become more conducive to vegetation establishment. Species establishing under these conditions vary with increasing moisture availability, from pasture to Sedges (*Carex* spp) and Tussock Grasses (*Poa* spp), through to macrophytes such as Bulrush (*Typha* spp) or Reeds (*Phragmites* spp). High flows may strip vegetation out multiple times, and cause further channel widening until an equilibrium is reached under which permanent vegetation may establish.

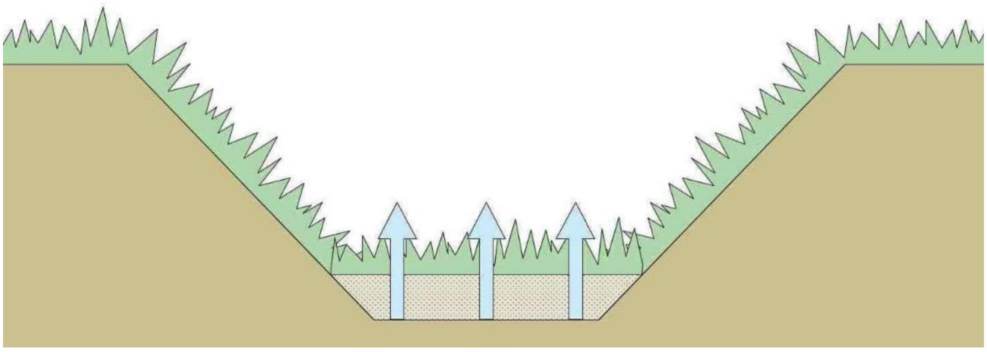
Stage 5: Sidewall erosion (below right). Following the lowering of the bed of a channel, the walls will erode and self-batter over time (red arrows), re-setting in relation to this new bed level. In general, this process is inevitable and a relatively low priority for intervention. The ongoing load of sediment can in fact be seen as an asset, with effective vegetation or small grade control structures helping to retain this sediment as close to the source as possible and raise the bed of the channel (blue arrows). Where tributaries enter, a newly eroded channel may be of greater concern, as they will tend to cut back at this new depth.





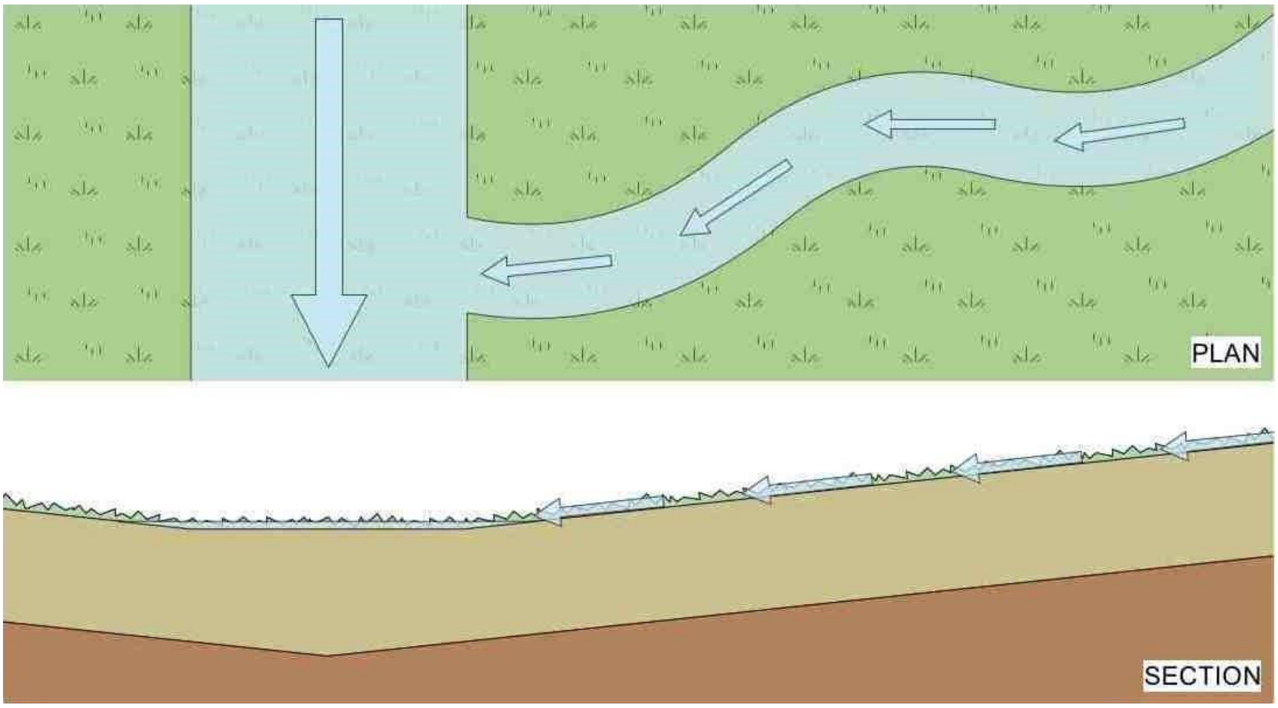
Stage 6: Sidewall stabilization (below). Eventually the sidewalls will reach a batter at which groundcover can readily establish. The gradient at which this will occur is dependent on a range of environmental factors, but can generally be determined from local observation. In the absence of further disturbance, the channel will raise over time through the capture and accumulation of sediment (blue arrows).

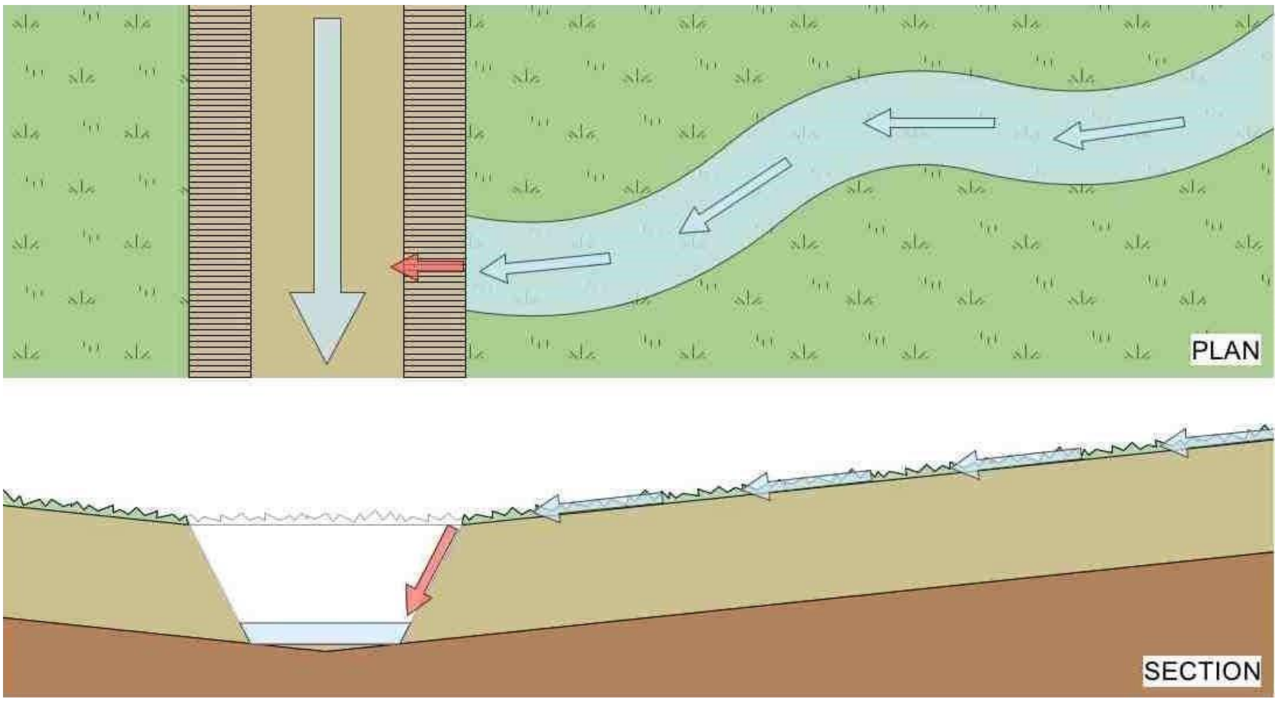
In contrast, a further lowering of the bed due to headwall migration from downstream may send the process back to Stage 2, possibly on multiple occasions.

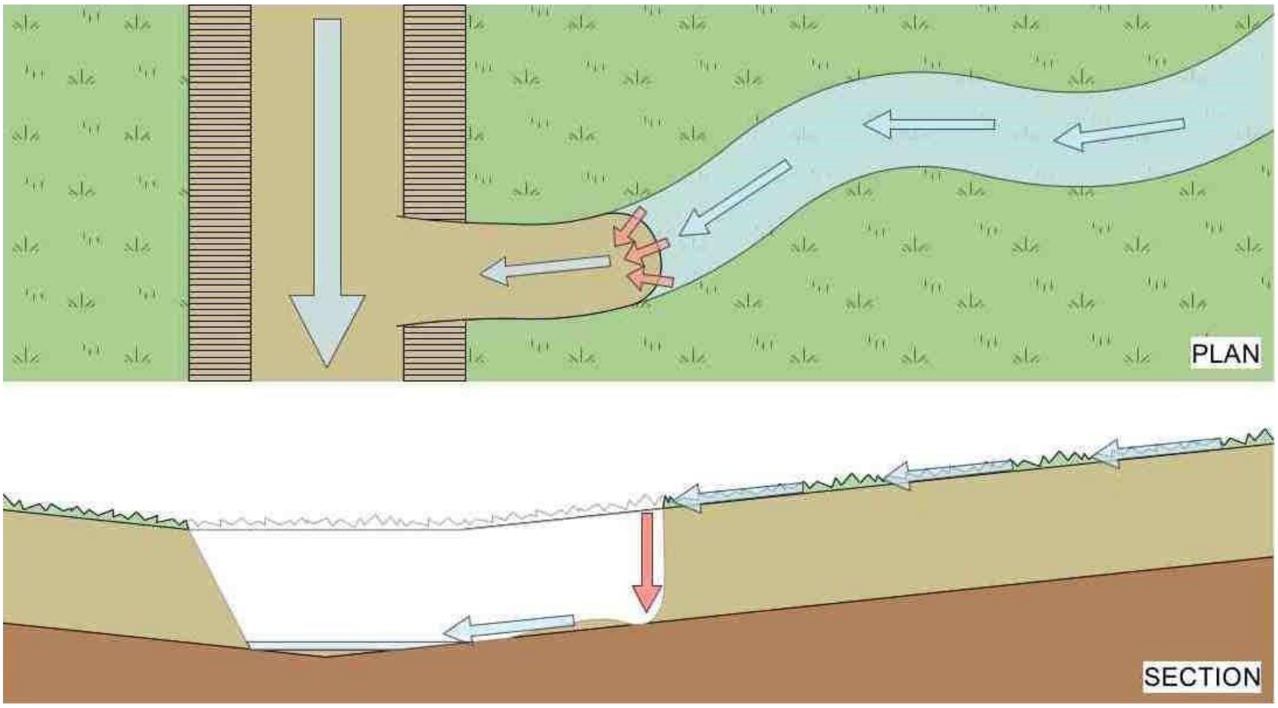


1.4 The Process of Tributary Erosion

The following diagrams provide a pictorial description of the process of tributary erosion.



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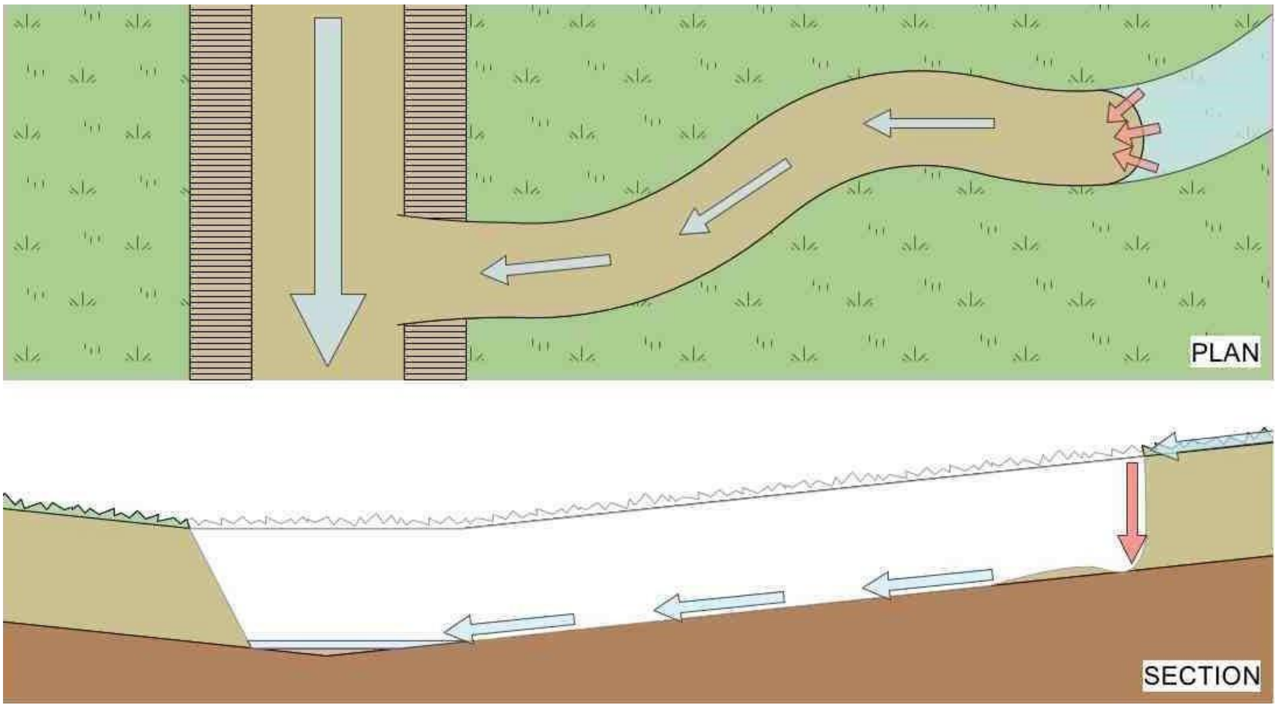
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2. STRUCTURES

All information and diagrams in this section are copyright of Cam Wilson, Earth Integral.

Note that where water flow is concerned, there are substantial risks involved. While the information and images are formulated in good faith, with the intention of raising awareness of landscape rehydration processes, the contents do not take into account all the social, environmental and regulatory factors which need to be considered before putting that information into practice. Accordingly, no person should rely on anything contained here as a substitute for specific professional advice.

2.1 Headcut Stabilisation Structures

Brush Ramp

Brush Ramps are suitable for treating low-energy headcuts. They are not suitable for use within a channel. The intention is to reduce the gradient of the headcut, and coat with topsoil and vegetation.

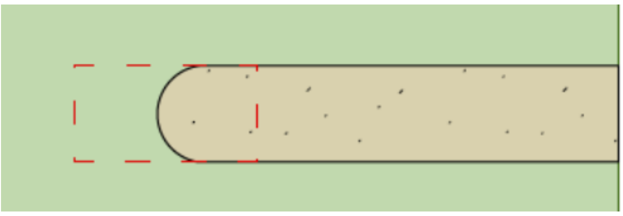
This structure can be utilised when a good volume of topsoil is available to coat the face prior to applying the brush.

Good contact between the brush and soil is the key, with heavier logs helping to weigh down the material. Planting above (and within, if pole planting) for long-term stabilisation is important, as the brush has a finite functional lifespan. The role of the layer of brush is to mimic a root system, holding the topsoil in place long enough for vegetation to establish.

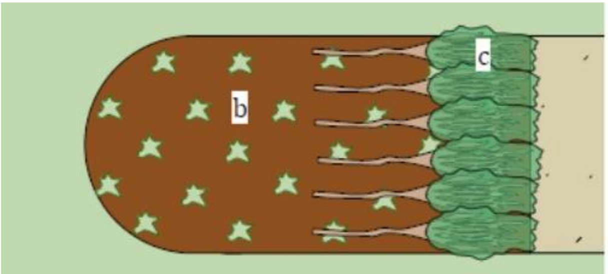
The photo at left shows an example of a Brush Ramp, with vegetation starting to push up through the material.

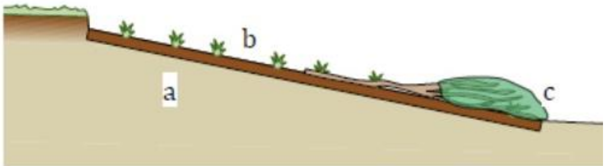
Construction notes

- The images below show the plan and section view of a 400 mm headcut. The red line indicates the batter location, aiming for a gradient between 3:1 and 6:1
- Before battering and compacting the subsoil, set the topsoil aside, preserving all vegetation in the process

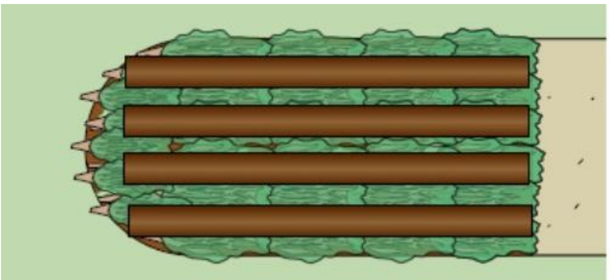


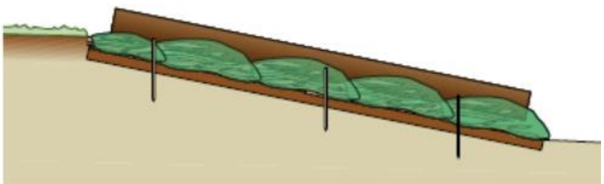
- Shape the subsoil with a slight depression in the centre (a). Then coat it with the retained topsoil, and return any sod you have preserved (b). Also divide and plant local tussocks if they are available (source from a low flow area)
- Some fertiliser can be helpful to give things a boost. In sodic soils, generously apply gypsum (or lime, if the soil is also acidic) on the ramp
- Start laying brush at the base of the ramp (c)





- When laying brush, orient with the branches downstream and butt up. Continue adding layers of brush, moving up the ramp. The aim is to get as much branch-soil contact as possible. This provides resistance and breaks the flow, reducing the opportunity for soil to wash away
- The brush can be held in place by weighing down with logs, or using small stakes lodged in the branch forks.



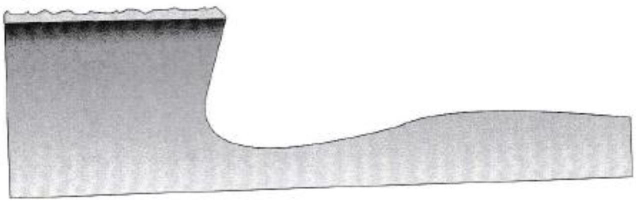


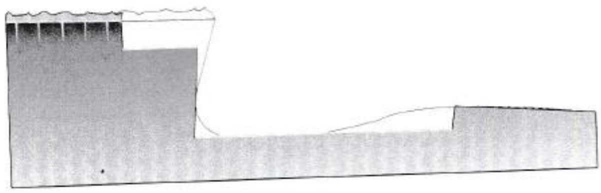
Log Step

Log Steps are suitable for treating headcuts up to one metre, or even greater with the help of machinery.

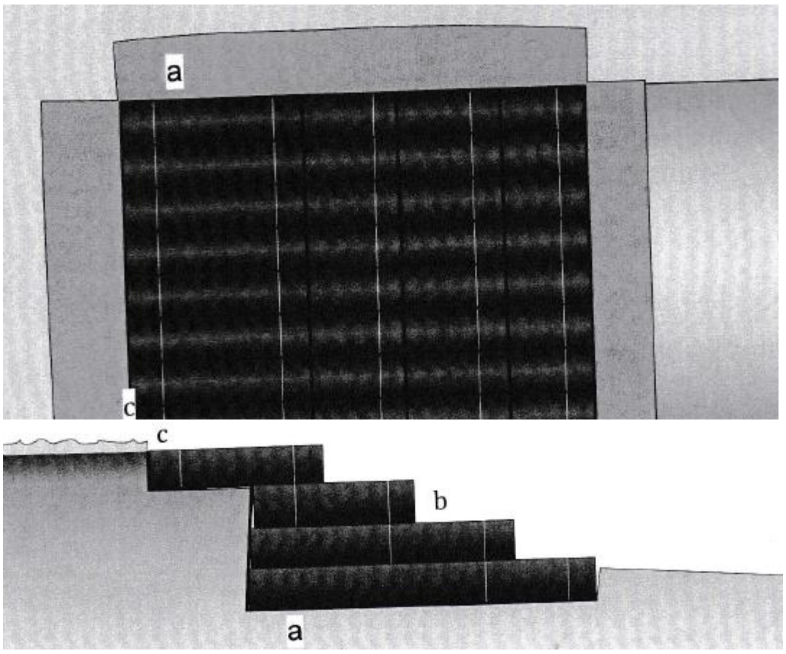
Construction notes

- The diagrams below show the side view of a 600 mm headcut, prior to any works (left), and during preparation for a Log Step (right)
- Preparation involves firstly squaring up the back and edges of the headcut. Any topsoil and sod removed can be put to the side to use later



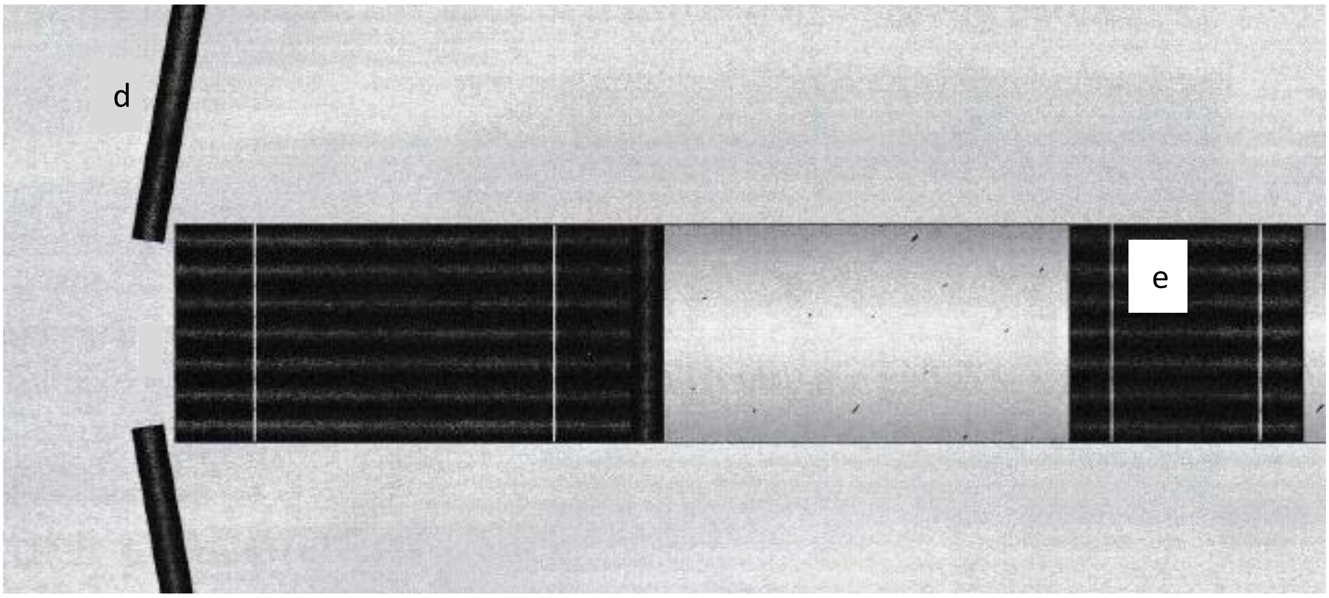


- If the soil is sodic, once the profile is battered, apply a generous amount of gypsum to the base and in a three metre radius above and beside the headcut, to stabilize the surrounding soil. A few slits with a shovel or mattock above the structure will help incorporate the gypsum more deeply



- Line the base, sides and rear wall with geotextile fabric, to protect the sodic soil from the flow of water (a)
- Select logs of 100 to 150 mm diameter for the job. Each successive layer needs to be bedded tightly against the back wall, and wired and stapled together (b)
- The plastic should be cut off flush with the soil level at the top edge (c), and any gaps filled with the sod removed during the preparation stage, and live grasses

- Log diversions at the entry to the Log Step (d) steer water down the structure, rather than over the still vulnerable sites
- A small Brush Mattress (e) can be included to protect the toe of the structure



- Grazing management should encourage greater recovery times and increased soil litter. This will improve overall soil health and reduce runoff amount and intensity
- The geofabric will deteriorate in time, but by the time this happens the gypsum will have altered the soil chemistry, organic matter will have accumulated between and underneath the logs, and windblown and/or waterbourne seed should result in good vegetation establishment.

Log Vee Drop

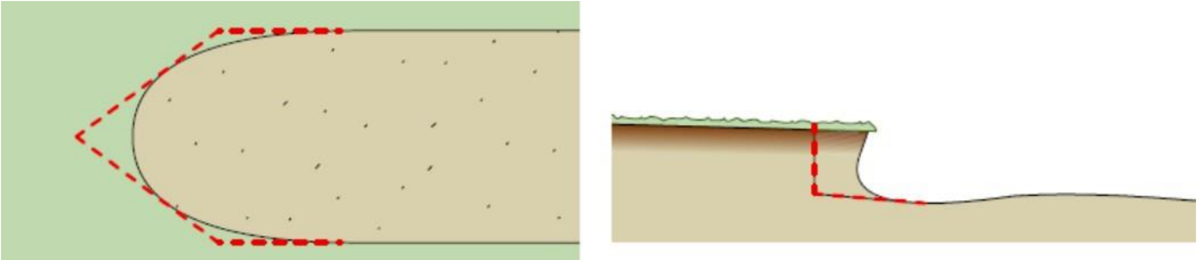
Log Vee Drops are suitable for treating small headcuts (less than 0.6 metres), in moderate flow situations where straight logs are available.

The photo below shows an example of a Log Vee Drop that has just been finished, with sod carefully placed up to the edge of the logs.

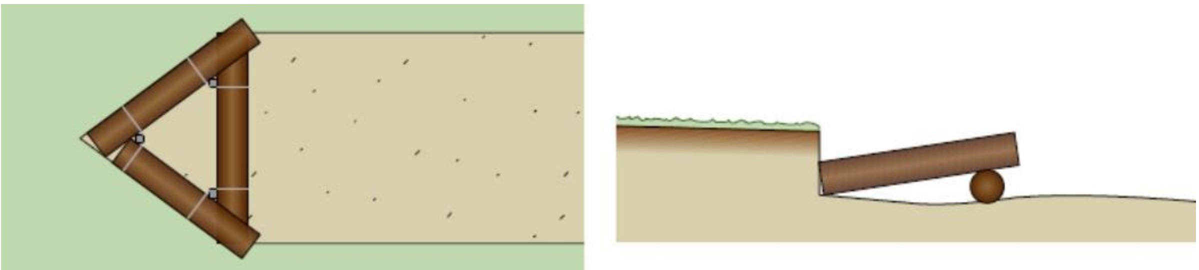
The logs in the Log Vee Drop shown below provide an armoured face for the flow to drop down, while the progressive increase in height out towards the gully walls ensures that flow heads over the centre of the structure in the biggest flow events.

Construction notes

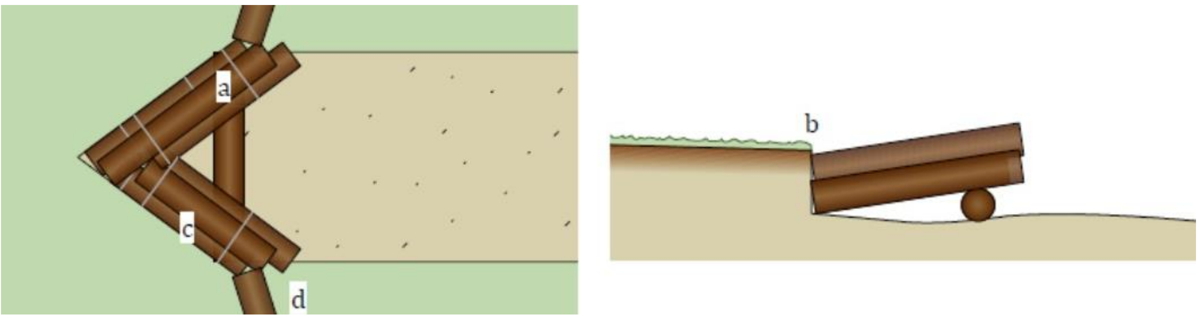
- The images below show the plan and section view of a headcut before and after construction of a Log Vee Drop. To begin, sit a couple of nice straight logs just above the existing headcut, angled at around 45 degrees (red dashed lines). Mark the position, then dig the soil back to this shape, setting aside any topsoil and preserving any live vegetation



- Place a log across the entire width of the channel, then rest the other two logs on top of the first and hard up against the face. The upwards slant (shown in the section view) is important to the final function, as it concentrates flow to the centre of the plunge pool
- Twitch and stake each corner of the triangle



- Add any wire and additional logs (a) until the centre of the structure matches the original spill height (b)
- Finish off by tightly packing woody biomass and soil between the logs and the face (c), carefully returning any sod and available tussock divisions
- In some situations, log or rock wings (d) may be required, to ensure that flow heads over the armoured face of the structure.



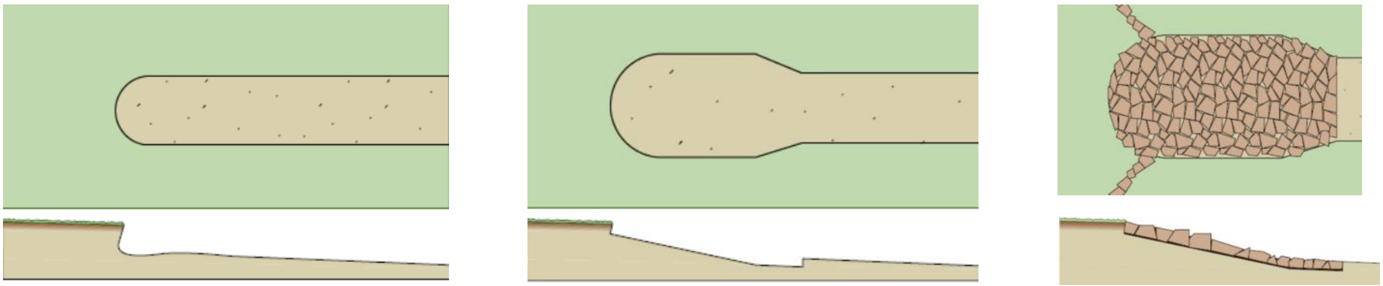
Rock Rundown

Recommended for use at Sites 1, 2, 3, 6, 7, 8, 9, 13, 15, 17, 19 and 21.

Rock Rundowns are suitable for treating small, low-energy headcuts. They are not suitable for use within a channel.

The photos below show examples of the flow path (blue arrows) on newly hand-built Rock Rundowns. The wings on the Rundowns help to ensure that the majority of flow heads down the armoured face. The One Rock Dam grade control structure below the Rock Rundown in the bottom photo creates a stilling basin to reduce energy at the bottom of the structure.

The images below show the plan and section views of a headcut prior to treatment (left), following battering of the face (centre), and after construction of a Rock Rundown structure with the inclusion of diversion wings (right).



Construction notes

- If the face is cut-and-filled, ensure the material is very well consolidated, otherwise it should be removed from the area
- Aim for a maximum gradient of 3:1 on the centre of the ramp, and around 2:1 on the sidewalls
- Ensure the centre of the ramp is slightly dished
- In erodible soils, line the prepared face with geotextile fabric to prevent undermining of the structure
- Start at the base of the structure with a splash apron that finishes level with the existing gully floor
- Work your way from the base up. Aim for snug fitting rockwork that keys into the materials below
- Angular rock works best. Appropriate rock diameter will depend on predicted flow volumes, but in general catchments smaller than 20 hectares can use rock of approximately 150 mm, while a 50 hectare catchment will require material of around 300 mm. Seek expert advice for catchments larger than 50 hectares
- Fill any gaps with pebbles and soil from the site. Set aside sod from the initial works, and use this to use to ensure there are no gaps between the grass and rock at the top and sides of the structure
- Diversion wings will help to ensure flow heads down the protected ramp face.

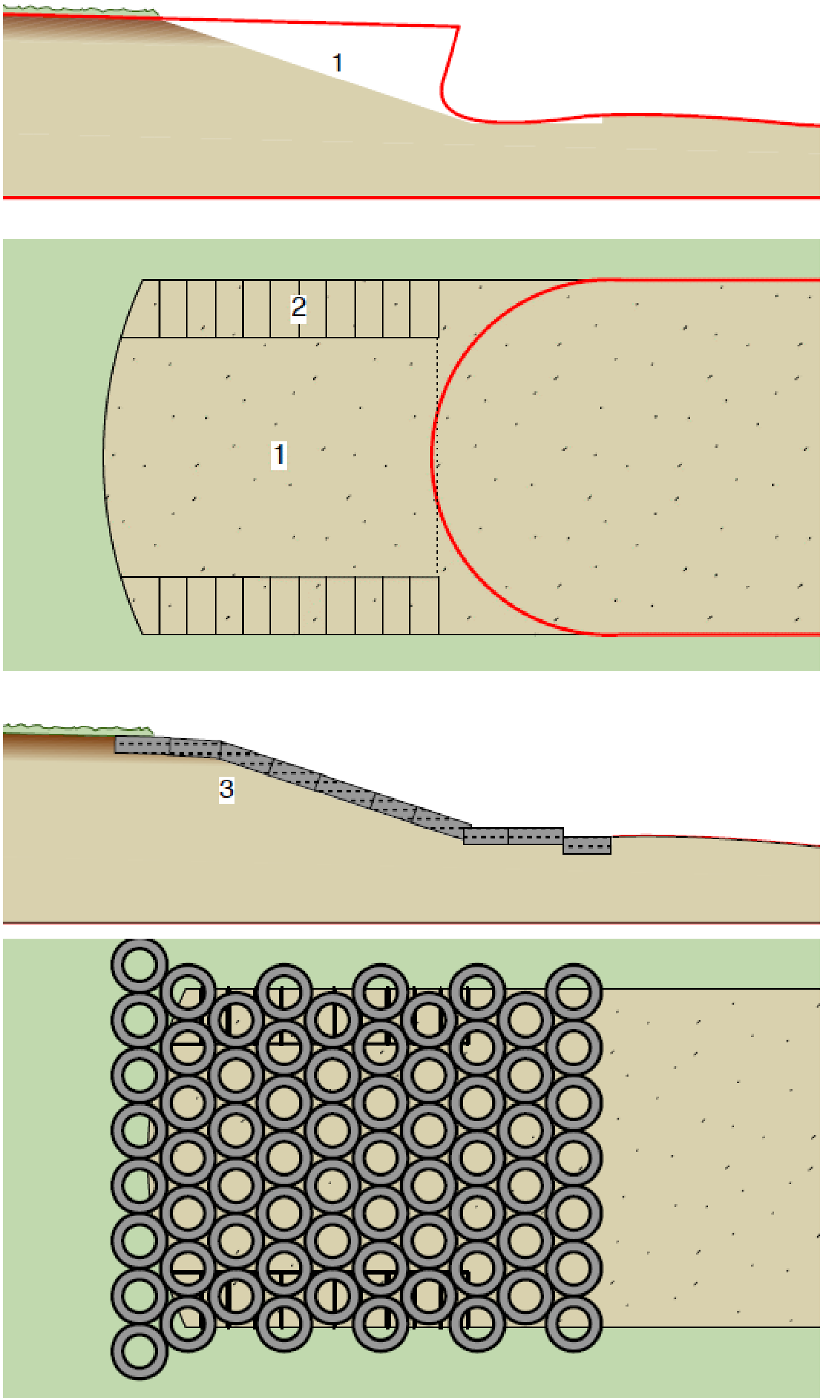
Tyre Mattress

Recommended for use at Sites 10 and 14.

This technique is suitable for armouring low (less than one metre) but wide, moderate-energy headcuts in ephemeral flow lines. The gravel- and/or rock-filled tyres fulfill a similar function to a gabion mattress.

The photos on this page show an example of a rock-filled Tyre Mattress, protecting a battered headcut. In the photo below, rocks can be seen in the tyres in the foreground, while grasses have grown through the tyres on the majority of this structure. The photo at right shows a close-up view of the way in which the roots of the sedge *Carex fascularis* fill and cover the tyres and rocks over time.

Construction notes



- Layback the original profile (shown in red in the diagram at top right) to around a 1:3 grade (1). The centre of the structure should be the lowest point
- The sidewalls can be battered to a steeper 1:2 grade (2)
- Cover the face with geotextile fabric and spread gypsum if soils are sodic, or lime if also acidic
- Lay the tyres out across the shaped face, butting up in an offset pattern. The tyres at the entry and exit points should be close to level with the existing soil profile
- Ensure that the tyres extend up the sidewalls to avoid outflanking (3)
- Once you're happy with the positioning, with reasonable contact across the structure, tech-screw the tread of the tyres together using a cordless drill
- The tyres can then be filled with large gravel and/or small rock (gabion rock is perfect). This can be dumped from a bucket, or hand placed. In high-flow situations, it is important to ensure tyres are adequately filled
- Ideally, interplanted clumping grasses will grow through the structure over time. The roots of trees and other flanking vegetation will also help to bind and reinforce the structure over time, if planted and managed accordingly.

Tyre Step

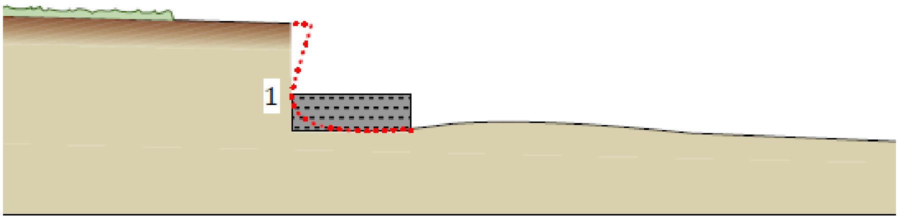
Recommended for use at Sites 6 and 10.

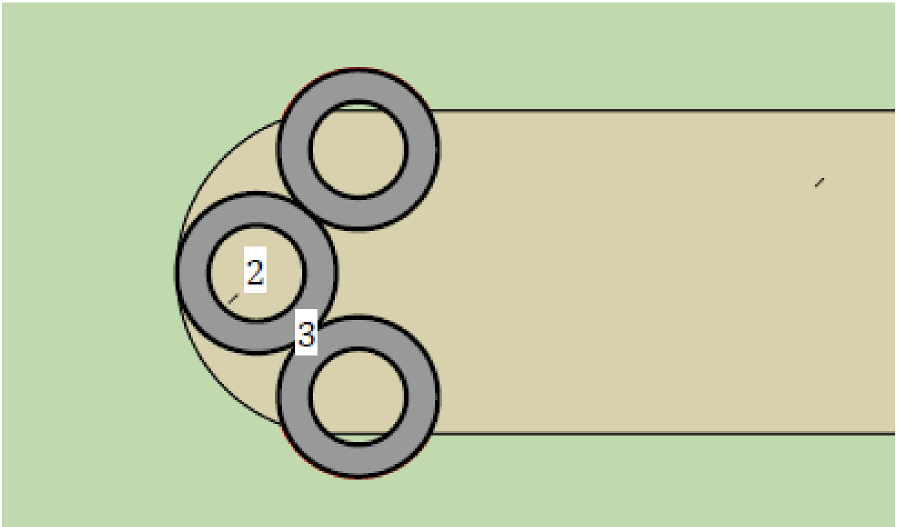
This structure is suitable for treating moderate-energy headcuts in ephemeral flow lines. Note that tyres should not be used in perennial watercourses or high-energy situations.

Tech-screws are necessary to secure tyres both horizontally and vertically, to form a more consolidated structure in the short term. Plant roots increase this function in the long term.

The photo at rights shows an example of a rock-filled Tyre Step, which is protecting a pool and instream wetland from active headwall erosion.

Construction notes



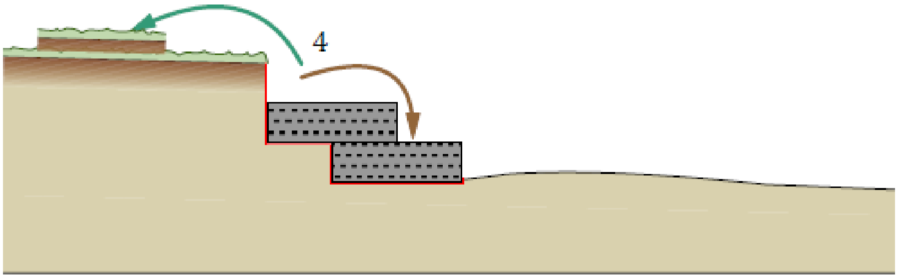


- Square up the face of the original profile (shown by the red dots in the diagram at right), and butt the bottom course hard up against the toe (1)
- Tech screw horizontally through the treads with a cordless drill to join the tyres together (3)
- While a V-shape is shown for the bottom course in this example (2), the shape is largely determined by that of the existing headcut. For wider gullies, it will look more like the second or third courses

shown in the following diagrams

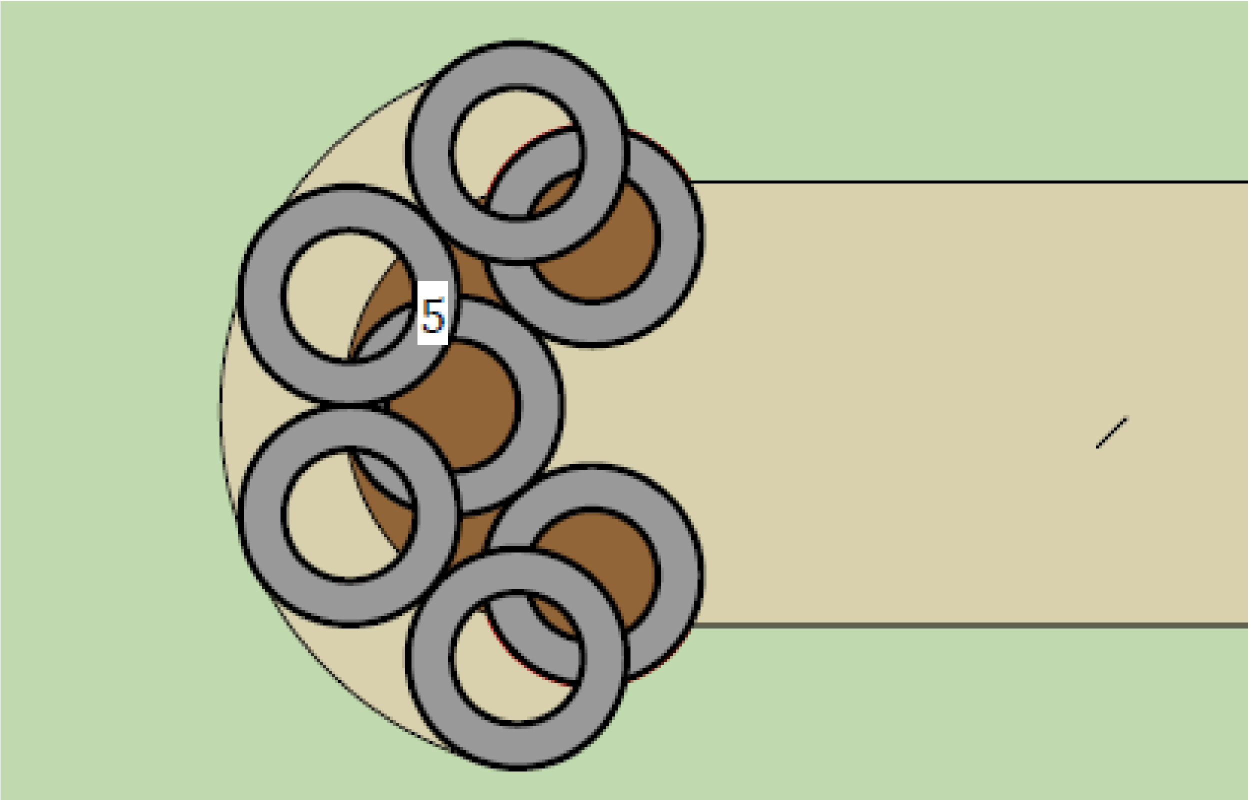
- Where soils are sodic, it is best to lay geotextile fabric under the structure. When doing so, it is easiest to cut the shape first, with the tyres placed loosely for measurement purposes. Once the shape is complete, remove the tyres, lay the fabric and continue

- When cutting the profile for successive courses (about half a tyre deep), place the sod aside for later use, and use the remaining available topsoil to fill the void inside behind the tyres below (4). If insufficient topsoil is available from the cut, additional material is best obtained from the top of the gully walls downstream (if steep, this will tend to erode and batter over time anyway)

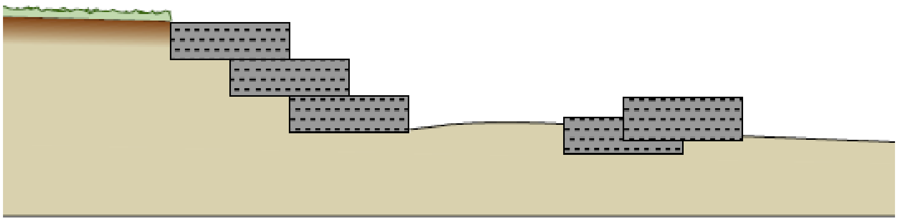


- On sites where flow is more consistent at times, small rock (up to around 100 mm) is more appropriate than soil to fill the tyres. Appropriate vegetation is still important to bind the fill

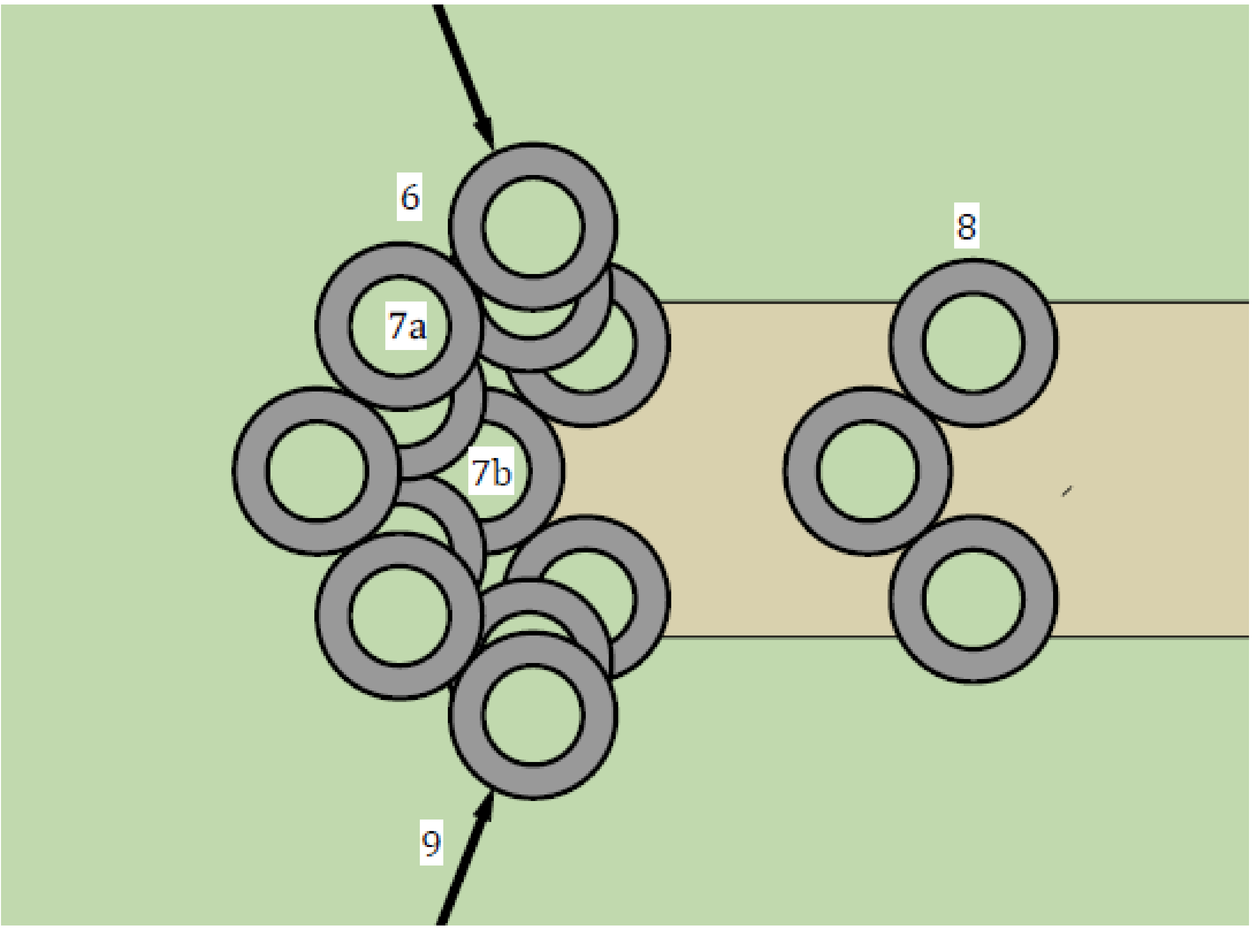
- For the second course and above (5), in addition to screwing horizontally, join the courses vertically by screwing through the tyre walls



- For the final course, ensure that the centre of the structure is flush with the existing soil level. Use wider tyres to ensure the pour-over gets slightly higher towards the edges (6)



- Finish filling the tyres with a layer of sod which, like the topsoil, can be obtained from the top of the walls downstream if required. If available, running grasses are particularly appropriate as they will cover the tyres over time (7a)
- Clumping grasses such as *Lomandra*, *Carex* or *Poa* can be planted in the lower courses as an alternative (7b), but flexible grasses are preferable for the top course to prevent flow diversion, which can increase the chance of outflanking
- As with most drop structures, a low grade control structure just downstream is useful for creating a stilling basin (8)
- Where flows are quite dispersed, a wing of tyres, rock or logs should be included upstream to direct the majority of flow over the armoured face (9).



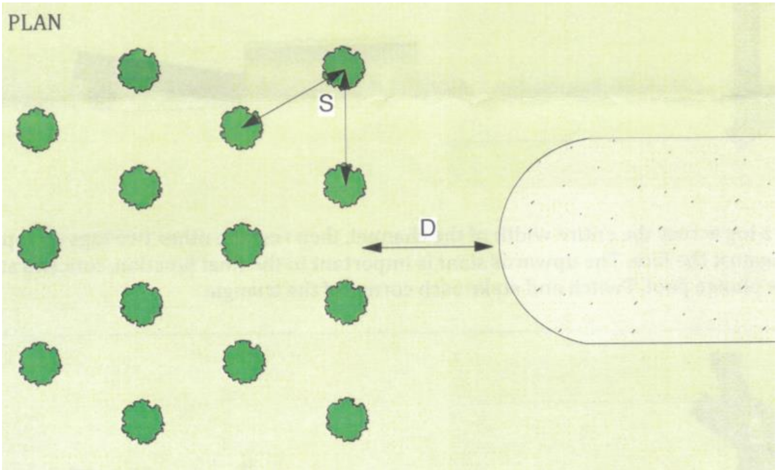
Poplar Headcut Armouring

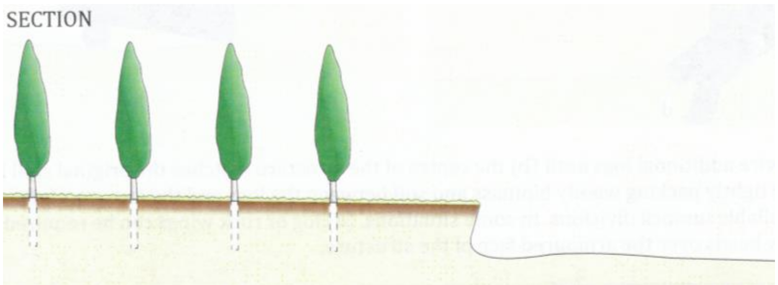
Recommended for use at Sites 16, 17 and 18.

For headcuts above waist height, human-scale techniques become a sizeable job. In these situations, the armouring of the zone above the headcut with a dense root system can be a more effective technique in terms of cost and effort.

While increasing native biodiversity should be the predominant focus when carrying out riparian plantings, some introduced species can also be considered a useful tool, in the same way that we may use concrete or rock (except that plants absorb carbon, as well). Studies have shown many poplar species to have excellent bioengineering and soil binding characteristics due to the dense, fibrous root system that develops. The habit of different species can easily be observed in mature stands in the region. Lombardy (*Populus nigra*) and White Poplar (*Populus alba*) are both quite suitable, but check local weed lists before planting.

Planting can be carried out in an offset grid pattern, as shown in the image below. Spacing (S) will depend on species, but two metres between plants is a good rule of thumb. Distance (D) from the top of the headcut will depend on how fast the cut is anticipated to move; for example, there's no point planting something that is likely to be undercut in around three to five years, before it has developed a strong root system.





Planting is best carried out in July or August, when soil moisture is high. Try to collect young, upright cuttings, greater than 25 mm in diameter. Rip prior to planting, or form pilot holes with a crowbar, and plant to around 500 mm deep. Ensure good bark-soil contact by tamping well after planting. As with most tree plantings, grass suppression is important, as is protection from browsing animals.

For further useful information, see the New Zealand guide '*Growing Poplar and Willow Trees on Farms*' (Charlton et al, 2007).

2.2 Grade Control Structures

Brush Mattressing

Recommended for use at Sites 12, 16, 18 and 20.

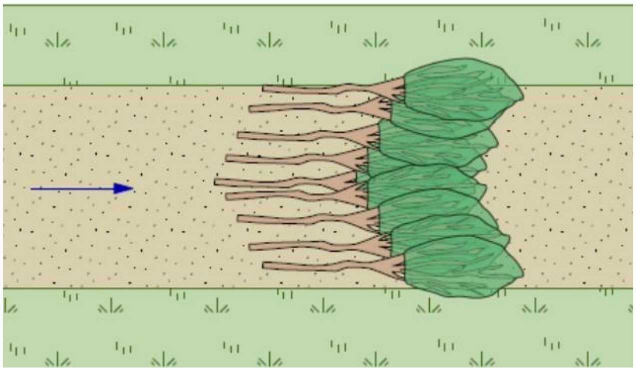
Brush Mattressing is a low-cost, low-risk structure that is quick to install. It is useful for raising the bed of minor incised gullies (less than two metres wide), when abundant woody weeds are available.

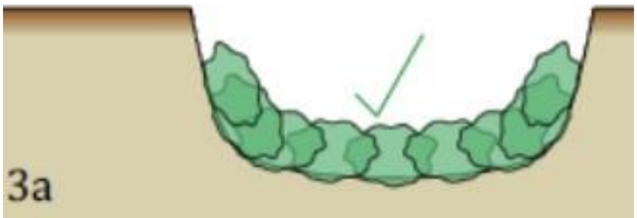
The structure slows channel flow and captures sediment, facilitating vegetation establishment that will drive the long-term repair process.

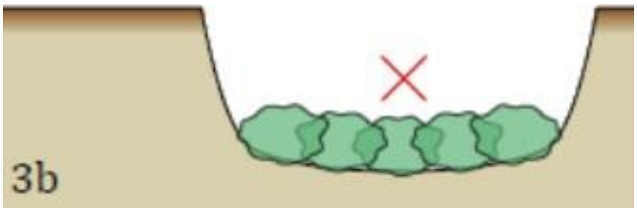
In the photo below, Brush Mattressing is being laid within a small gully to catch sediment in a low energy environment. Loppers are being utilised to ensure the centre of the structure is the lowest point, to avoid flow outflanking (gouging around the edges).

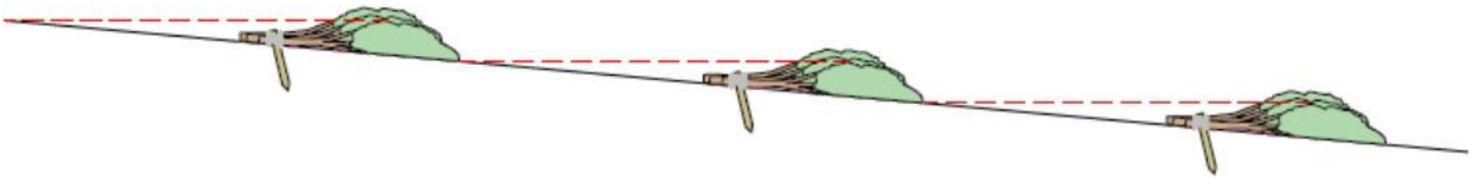
Construction notes

- Brush material should be laid with the butt upstream and branches downstream (1). A v-shape, as shown in the top image, is beneficial
- The size of material and anchoring requirements will depend on the prevailing flow, but once sediment accumulates, the brush beds in well
- As sediment accumulates over time, additional layers of brush can be added (2)
- While natural vegetation recruitment is likely once sediment has accumulated, the division and transplant of local tussocks from similar conditions can enhance the success of the long-term repair process
- It is important to maintain the profile of the channel (3a); if material is laid flat (3b), water can find its way around the edge and erode the banks. A pair of loppers is useful to ensure the centre is the lowest point of the structure
- Where meanders exist, the positioning of structures should be midway between the bends. Another possible approach where channels are reasonably straight is to take a 'crest to toe' approach, as shown in the image below.









Brush Weir

The photos below show a downstream view of three Brush Weirs, soon after construction (left), and the same site during a high flow event (right). The high energy flow that is entering from the bottom left of the photos is dissipated by the first structure, with significantly lower energy seen as a result of the series of structures.

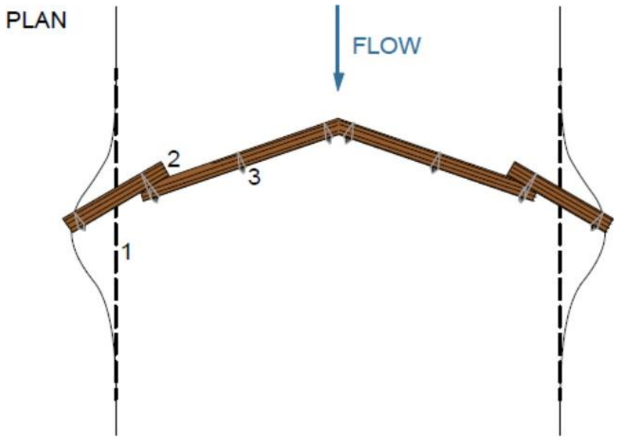
The photos below show a Brush Weir during construction, prior to cinching brush down onto the log foundation (left), and two years later, when the structure has developed into the vegetated mound in the centre of the image (right). The vegetation-protecting qualities of the brush material are clearly on display, with the increased biomass helping to further slow flows and accumulate sediment and debris.

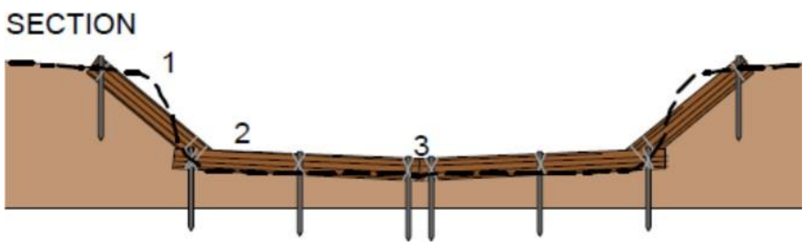
Construction notes

- Brush Weirs should be sited in a straight section of the channel, mid-meander. This reduces the risk of the structure outflanking
- The shallower the grade, the greater the potential volume of deposition.

Step 1 - Logs:

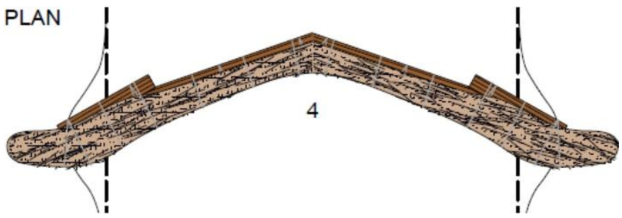
- If channel walls are steep, they should be battered to an appropriate grade (1)
- Logs of about 200 mm diameter should be arranged in a V-shape, pointing upstream (2), matching the channel and battered bank profile. This provides the footing for the structure
- For catchments larger than 50 hectares, logs on the walls can often be avoided
- Steel posts and wire should be used to keep the logs in place (3).





Step 2 - Brush:

- Brush material should then be arranged on the downstream edge of the logs, lowest in the centre and protecting the banks from outflanking (4). This should be wired to the footing logs
- Steps of less than 300 mm are recommended, to reduce the chance of scour undermining the structure.



One Rock Dam

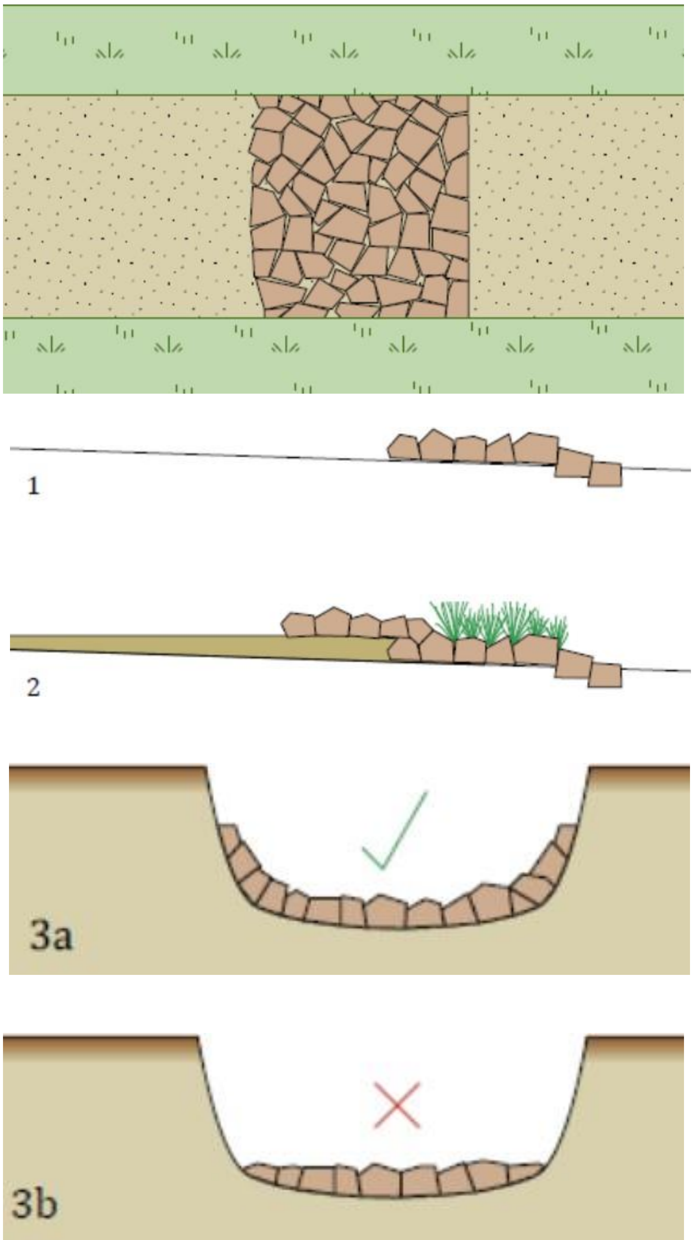
Recommended for use at Sites 6, 8 and 12.

One Rock Dams are low grade control structures, aimed at raising the bed of an incised gully. The structure slows channel flow, captures sediment and encourages infiltration, and in doing so assists with vegetation establishment.

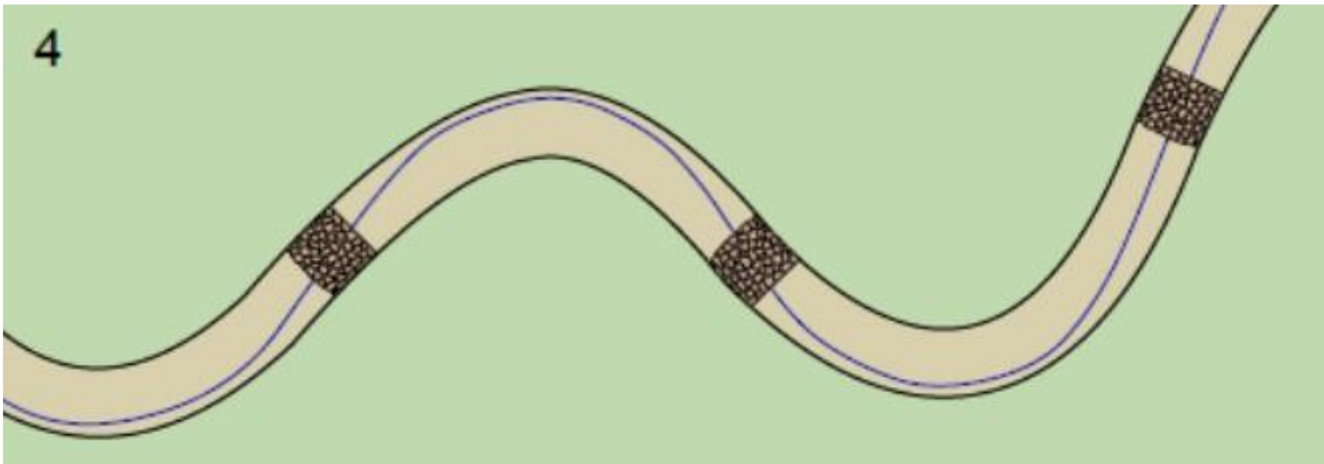
One Rock Dams are built with one layer of rocks, creating a small drop which results in a very low risk structure which can be progressively built up over time.

The photos below show examples of One Rock Dams, designed to mimic a natural riffle, slowing flow and capturing sediment above. A solid foundation level with the gully floor is an important starting point, with well keyed rockwork forming a sturdy structure.

Construction notes



- Start by digging a shallow trench across the base, and lay one or two layers of rock as a footer
- Work your way progressively upstream, keying into the rocks below (1)
- As the structure silts up over time, progressive layers of rock can be added, to continue the bed-raising process (2). An alternative option is to allow the vegetation which has established to take over and continue the aggradation process
- It is important to maintain the profile of the channel (3a). If the structure is built flat (3b), the water will find its way around the edge
- Where meanders exist, place structures midway between the bends (4). This is the place where sediment naturally accumulates, so this will be working with the natural processes.



Credit to Bill Zeedyk and Craig Spoonholtz

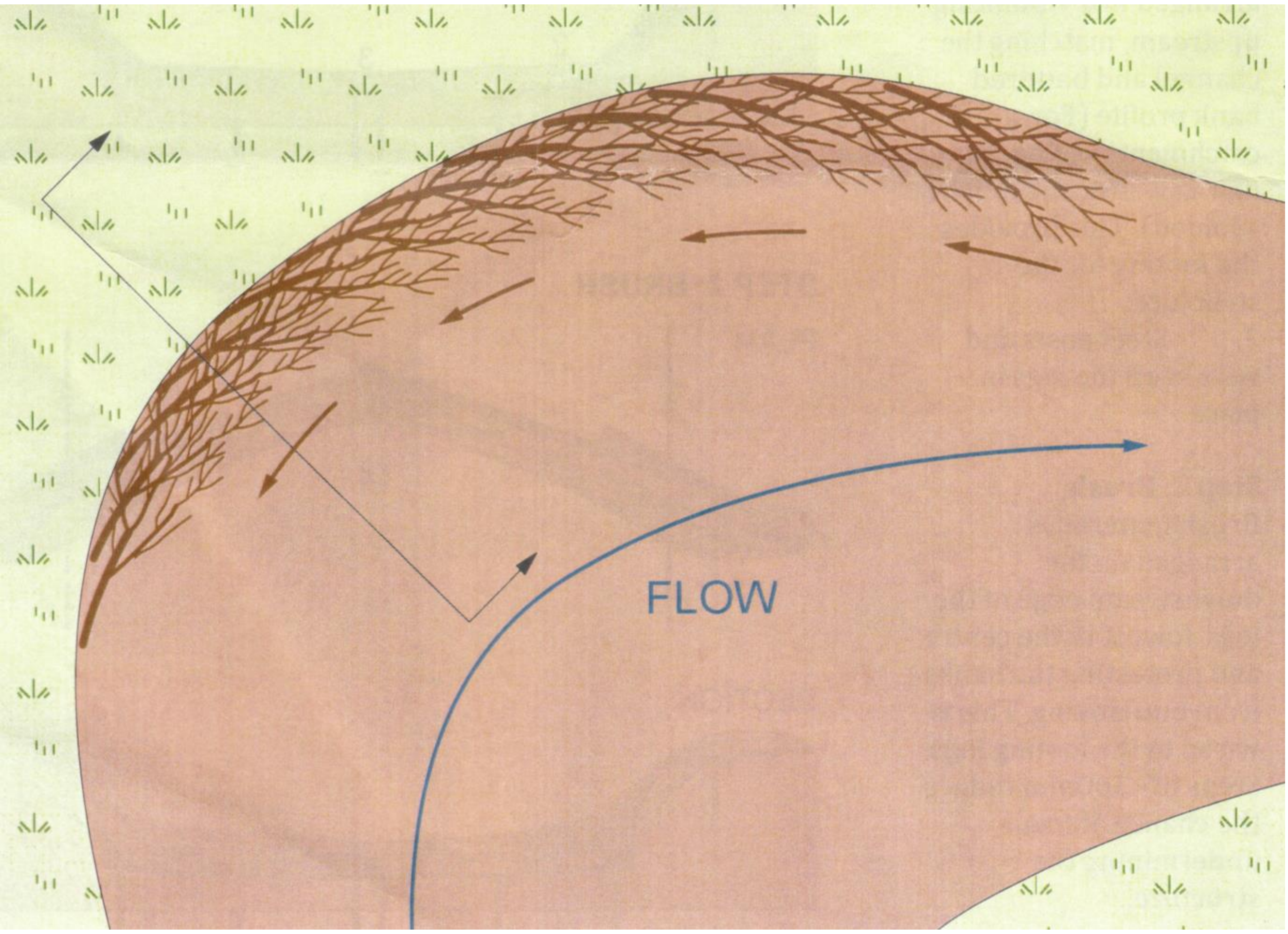
2.3 Bend Protection Structures

Brush Toe Protection

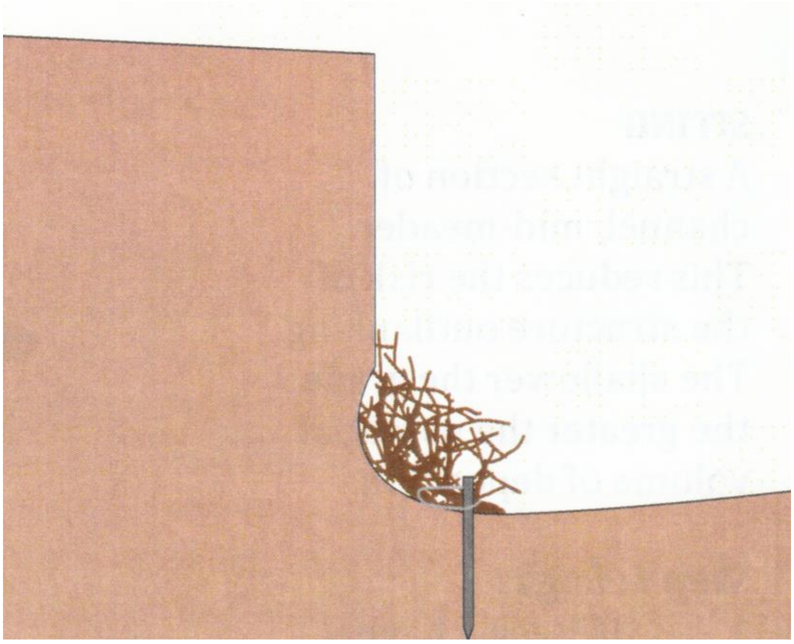
Brush Toe Protection can be used to protect an outside bend where scour is occurring.

The brush should be laid against the toe of the wall, with the butt end upstream, as shown in the diagram below (the blue line represents the direction of flow). Large stems with multiple branches are best for this structure.

Laying should begin at the downstream end, working upwards, as shown by the brown arrows in the diagram below.



Much of the force of the flow will be pushing the material into the wall, so staking every two metres is often sufficient (see the section diagram below). Twitch with wire regularly enough so that the material binds into a single unit.



2.4 Scald Rehabilitation

Recommended for use at Site 12.

The major goal in scald rehabilitation is to reinstate biological processes. The inhospitable conditions that exist following scald formation inhibit the establishment of functional biota. Retaining sediment and providing cover can help to improve conditions. This can be achieved using the technique of laying brush across the slope with good surface contact. This can help to capture actively moving sediment, which provides a seedbed and stores moisture for plant establishment. Brush can also provide an effective physical barrier to grazing, allowing young plants to gain a head start. Excellent results have been achieved using this technique, even in inhospitable rangeland conditions (Ludwig and Tongway, 1997).

Hay or straw mulch is another very effective way of re-establishing groundcover. The hay protects the soil from direct rainfall impact, provides biomass, and creates an improved environment for germination and soil biota.

On large sites where full mulch coverage is not possible, the material can be laid as strips on contour. If minor depressions are crossed, brush should be utilised in these locations to provide increased resistance to flow. Once bands of vegetation establish, the ongoing flow resistance results in sediment accumulation on the uphill side, with vegetation widening in a positive feedback loop. If a scalded site has a significant catchment area, the installation of a contour bank to intercept surface flow may also be required.

The photos at right show an active headcut, extending a small gully uphill (top). The image below right shows a downstream view of the same headcut following the construction of a Rock Rundown (mid-frame), and addition of brush material and hay to the floor of the rill.

Photo M Fitzpatric

In the photos below, minor headcuts have been armoured with Rock Rundowns, with a One Rock Dam for grade control below and Brush Mattressing above. Hay was later added along the contour at intervals of approximately three metres and scattered on the floor of the rills. The image at the bottom shows the same site ten months after the works were completed.

3. CASE STUDIES

3.1 Introduction to the Case Studies

As the previous sections have described, stabilisation of erosion is and will continue to occur. However in many cases this stabilisation won't necessarily happen in the time scales that humans are used to, and is of little comfort when valued natural and farm assets are threatened by active processes in the short term. In this context, this booklet presents case studies for a range of sites from properties in the Kyeamba Valley. All of the landholders included in these case studies expressed concern about a variety of erosion issues, and sought advice on how to remediate these issues.

The case studies offer a variety of erosion forms, scales, levels of severity and stages within the fairly predictable pathway that erosion processes take. Where possible, the intention has been to identify opportunities for landholders to tackle issues themselves. In some cases, available rock, logs, brush or vegetation can be put to effective use, while at certain scales professional advice and engineering is essential.

It is hoped that this booklet will help readers to identify similar repair opportunities for their own land, and where possible an attempt has been made to discuss general processes. However it is important to understand the context-specific nature of repair strategies, and to seek professional advice. The '*Gully Erosion Assessment and Control Guide*' (Glover et al, 2013) is highly recommended as a reference to help landholders to evaluate erosion priorities, and understand the management options that are available.

In terms of undertaking works to repair erosion, a top priority is to protect valuable parts of the landscape, such as where headcuts or bend-erosion threaten:

- Farm infrastructure,

- Good soils and high production zones, and/or
- Areas of high biodiversity value, such as wetlands, riparian zones or remnant vegetation.

Another high priority is to repair or enhance zones of high value. Past degradation has often resulted in the draining and dehydration of the land adjacent to erosion gullies - floodplains, which generally contain some of the better soils on a property. Works can help to raise the bed of the channel in targeted locations to rehydrate these productive zones, whether for enhanced agricultural or biodiversity goals.

Vegetation Management

While the focus of this document is largely on the physical tools for addressing specific erosion issues, it is important to note that in all cases vegetation management - both at the site and over the wider landscape - is a critical component of success.

Erosion is an energy-driven process and two of the key controlling factors are roughness and amount of flow:

- **Roughness** is a term for anything that provides flow resistance, including plants, woody material and rock. Roughness is particularly important for slowing flow velocity on valley floors and within channels. Grazing and weed management that allow water-loving plants such as rushes, sedges and reeds to proliferate will significantly increase the flow resistance, thereby reducing the erosive power available. Riparian shrubs and trees can also provide resistance during major flow events
- The **amount of flow** reaching the valley floor at any one time is a key factor in erosive power. The management of groundcover over the wider landscape provides landholders with the greatest tool for managing this amount of flow. The more consistent and 'rough' the groundcover in the paddock, the greater the flow resistance and the longer the time taken to reach the valley floor.

The adoption of a rotational grazing approach is one tool to facilitate enhanced groundcover from a hydrological perspective. A regional Landscape Functional Analysis study by Ampt and Doornbos (2011) indicated that the soil properties of infiltration, stability and nutrient cycling were all enhanced under rotational grazing management in comparison to set stocking neighbours. From a hydrological perspective, this means properties where rotational grazing was practiced had less flow down the creeks, and more water stored at the toes of the pasture.

3.2 Headcut Formation Due to Obstruction or Diversion of Flow

Site 1: Headcut initiated by obstruction in the flowline

Erosion Process

A large blackberry bush was present within the flow line during a major flow event. This deflected the flow sideways, and caused it to re-enter down a steep section, initiating a headcut (as shown in the photo below) that migrated around 10 metres upstream.

Property:	'Silver Springs', Big Springs
Erosion:	Headcut formation & migration
Causes:	Flow obstruction & diversion
Catchment:	50 ha
Proposal:	Rock Rundown

Recommendations

Rock bars were present not far upstream, meaning that the headcut could not migrate far. The vegetation close to the head of the channel also indicated that the cut had been relatively stable in recent times. As a result, this site would be considered a relatively low priority for intervention.

If such a headcut was threatening a valuable natural or farm asset, then armouring with a Rock Rundown would be the recommended strategy. With a catchment area of nearly 50 hectares, an average rock diameter of 300 mm would be recommended, with rocks placed carefully and in-filled with gravel and soil. If the material was just to be dumped in place, a larger rock diameter would be recommended. Geotextile fabric would also be required, with Bidim A24 standard the minimum grade.

Outcome

The landholders tapered the headwall using pick and shovel, then covered it with geofabric before armouring with a Rock Rundown. Rock was collected locally (on-property) with a front end loader. Gypsum was also added. The streamline was realigned to prevent the overflow from creating another channel in the same manner. The photo below shows the landholders undertaking the works, with the assistance of several other Landcare members as part of a working bee. The photo at right shows the completed works.

The landholders have found the completed works to be very successful, and believe the technique would be suitable for other sites on their property.

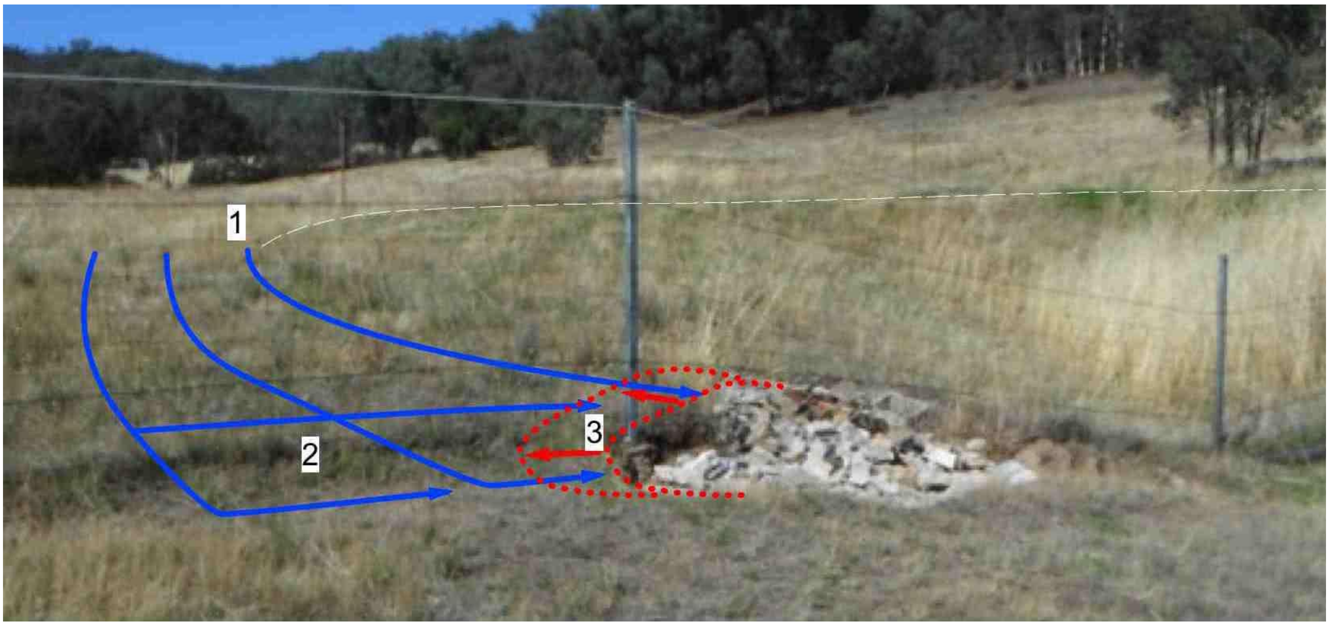
Site 2: Headcut initiated by flow concentration along a fenceline

Erosion Process

Property:	'Lanacoora', Big Springs
Erosion:	Headcut formation & migration
Causes:	Flow concentration & diversion, erodible soils and dam impacts
Catchment:	40 ha
Proposals:	Rock Rundown, Dam Spillway extension

This site was a small headcut located within the spillway of a dam. The catchment of the dam was around 40 hectares, and could expect a peak flow rate of around four cubic metres per second for a 1 in 50 year event, according to the procedure in Pilgrim (1987) and Lewis (2002).

During a large runoff event, flow along the spillway of the dam, shown at (1) in the photo below, was diverted and concentrated along both sides of a fenceline (2). This was caused by a combination of stock tracks, increased vegetation and organic-debris accumulation. The concentrated flow, in combination with the steep return slope, the sudden change in soil level on the downhill side of the fence and the minimal topsoil and vegetation along the fenceline due to tracking, resulted in a small headcut (3) commencing near the toe of the slope and migrating to its current location.

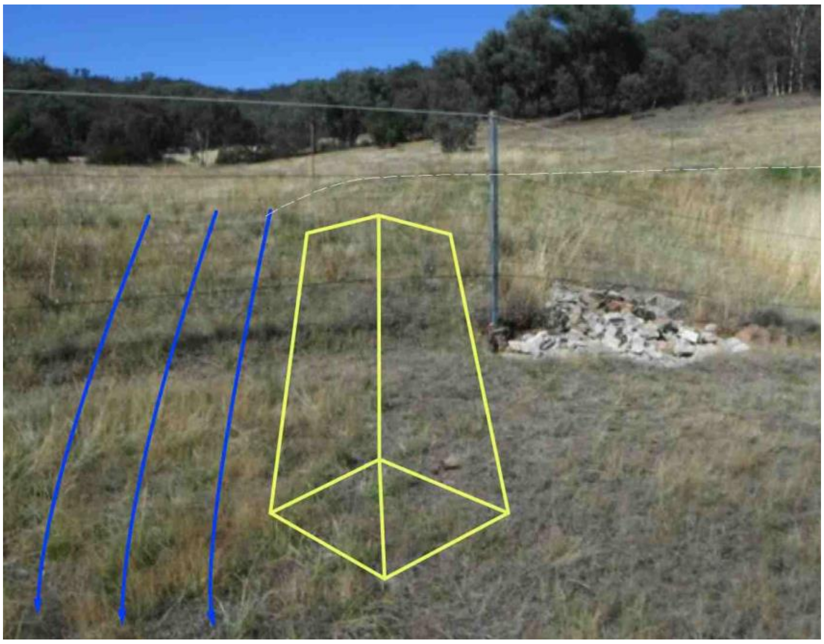


Rubble was added to the channel by the landholder. While this helped to slow the flow down within the eroded channel, the face of the headcut was still exposed and over time would still wash away and migrate uphill towards the dam, due to the highly erodible nature of the soils. This projected movement is shown by the red arrows in the photo above. Material of this size could also be transported by the peak flows that could be expected.

Recommendations

While careful shaping and armouring of this site to the point of safely allowing flows is possible, if an excavator or bulldozer is required on the property for any other purpose, the most economical approach would be to extend the spillway through the addition of a wing-wall (shown by the yellow lines in the photo below) to starve the site.

Any extension of the spillway should allow a minimum flow of six metres wide and 0.5 metres deep, to convey the peak flows (Lewis, 2002). The outlet should be located where a combination of good vegetation and the shallowest gradient is found. The old cut could easily be filled in at the same time.



If there is no other reason for having earthwork machinery on the site, then armouring of the headcut with a Rock Rundown would be recommended. An average diameter of 200-250 mm rock would be recommended on the upper surface.

Outcome

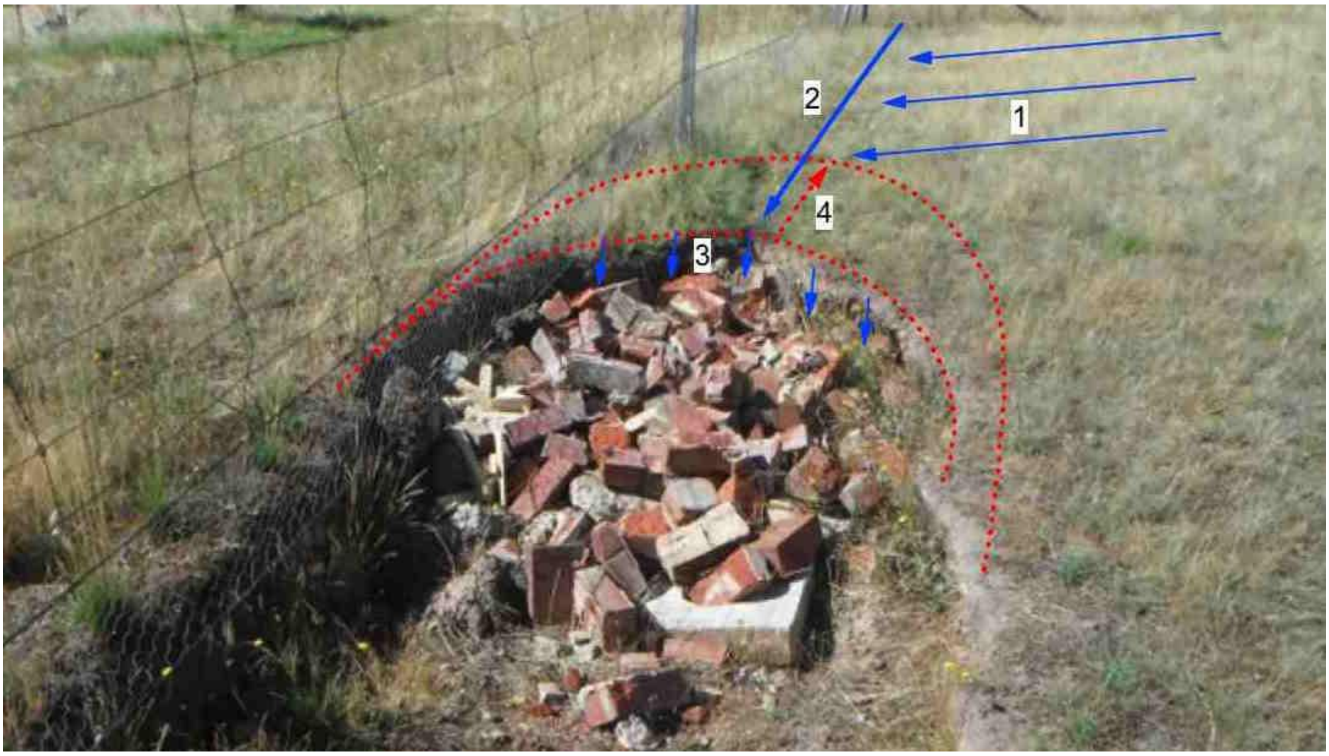
The landholders filled the site with rubble and covered with soil, added hay to encourage grass growth, and placed timber to deter stock tracking. The changes can clearly be seen in the before (left) and after (right) photos below. They then used a bobcat to form a low, 30 metre long diversion bank uphill of the site. This will help to protect both Site 2 and Site 3 (see following pages), by diverting future overflow from the dam spillway away from the two sites.

Site 3: Headcut initiated by flow concentration along a fenceline

Property:	'Lanacoora', Big Springs
Erosion:	Headcut formation & migration
Causes:	Flow concentration and erodible soils
Catchment:	40 ha
Proposals:	Rock Rundown, Rock / Earth Berm

Erosion Process

At this site, surface flows travelled in the direction shown by the blue arrows (1) in the photo below, and were channelled by stock tracks along the fence line (2). This resulted in the formation of a headcut during a major runoff event. While the bricks that were placed within the channel will slow the flow to some degree, flow will still cascade down the exposed face (3) of the highly erodible soils. The erosion could therefore continue to migrate uphill, in the direction shown by the red arrows (4).



Recommendations

The most economical approach for halting the migration of this cut is to shape and armour the face with a Rock Rundown, with the approximate upper extent indicated by the yellow curve in the photo on the following page. With the small catchment area, the material that is in the hole will be fine for doing the job, but it would be recommended to place a layer of 2 mm geotextile fabric underneath the rock/brick material, due to the dispersive nature of the soil on the site. If the hole was to be left open, an apron of netting on the opposite side of the fence would be the cheapest way of restoring function to the fenceline.

If filling of the hole was desired, then a small diversion around the top of the filled hole would be recommended to minimise surface flows. This could be achieved with a rock or earth berm placed a couple of metres above the cut that tips the flow safely to the downhill side, as shown in the graphic overlay of the photo at right.

Outcome

The landholders filled the holes with rubble, and covered this with soil and hay, as can be clearly seen in the photos at right of the site during (middle) and after construction (bottom). As described under Site 2, a low 4.5 metre long diversion bank was also constructed at the head of the site, providing further protection, while a scattering of timber has helped to deter stock from making another track along the fenceline.

Site 4: Headcut formed by concentrated flow from a spillway

Property:	'Aryshire Park', Big Springs
Erosion:	Headcut formation
Causes:	Flow concentration and dam impacts
Catchment:	160 ha
Proposal:	Dam spillway extension

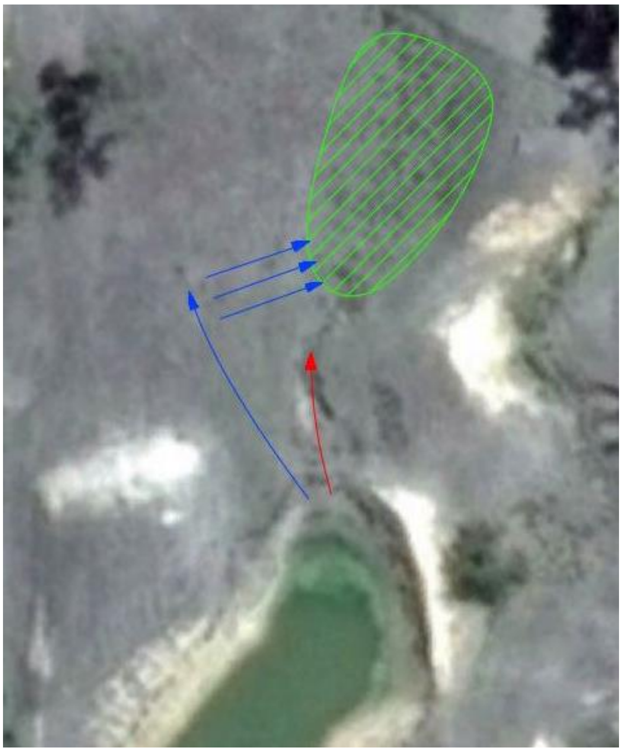
Erosion Process

This site is situated on a second order watercourse. Concentrated flow from the spillway of the dam formed a headcut during a major rain event. The headcut is five metres wide and one metre tall and, while the gully is quite short, it threatens to compromise the dam. The photos below show the upstream (left) and downstream (right) views of the headcut.

Recommendations

The floor of the valley is quite intact, and vegetated with a good cover of *Carex appressa* (Tall Sedge), as can be seen in the downstream view in the photo above, and also by the green hatching in the aerial photo on the following page. This feature, in combination with the gentle slope on the left bank, offers a safe re-entry zone.

Earthworks are therefore recommended as the most cost effective solution on this site, diverting the flow in a 1 in 400 channel to a level sill spillway. The earthworks should be designed to divert the flow from its current path, shown by the red line in the aerial photo, to the path shown by the blue lines, returning the flow to the well-vegetated valley floor indicated by the green hatching.



The catchment area has been estimated at 160 hectares from aerial imagery. This would result in peak flows of 5.4 cubic metres per second for an average recurrence interval of 50 years which, according to the table in Appendix Two, requires an outlet width of approximately eight metres for the low gradient setting.

Outcome

The landholders reshaped the cut and lined it with hay, then layered logs and brush on top of the hay. The photos below show the site during (left) and immediately following works (right).

Site 5: Gully formation from inappropriate siting of a dam

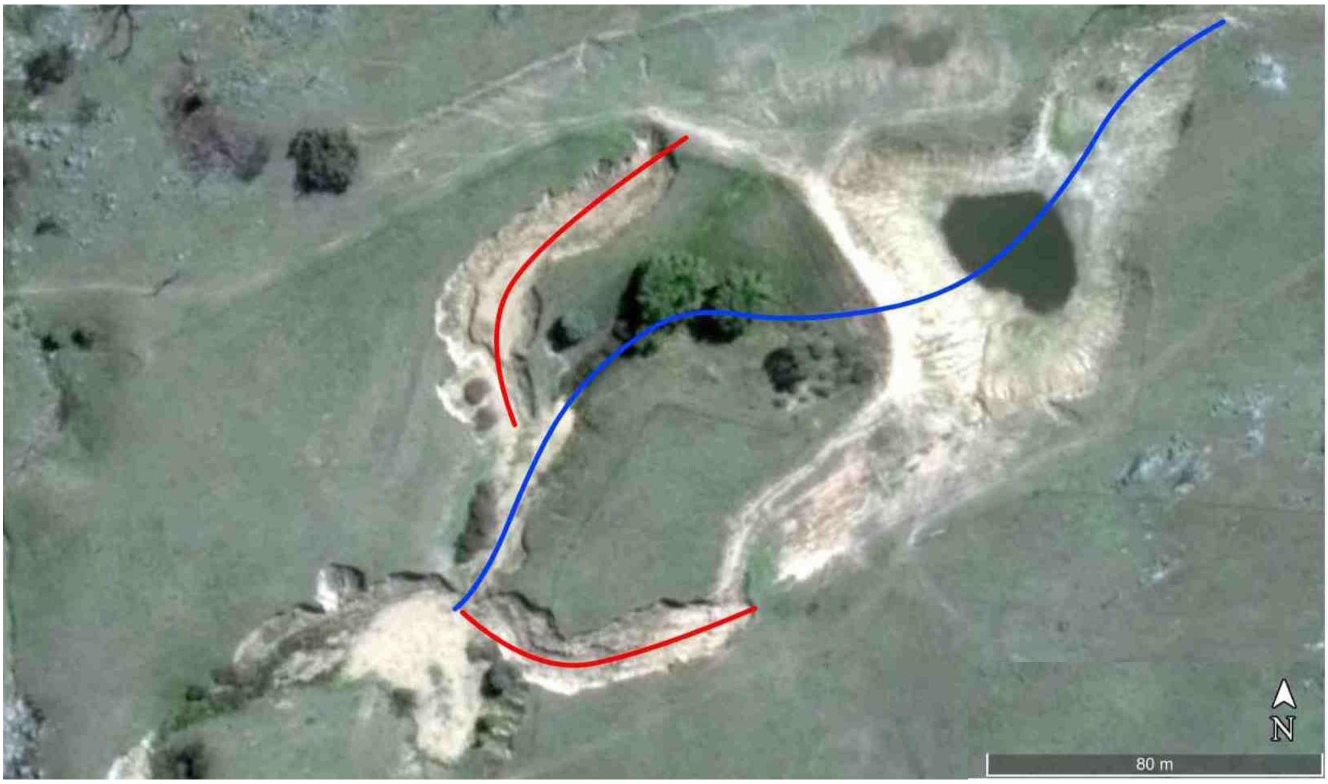
Erosion Process

Property:	'Silver Springs', Big Springs
Erosion:	Headcut formation, channel incision, and gully erosion
Causes:	Dam impacts and erodible soils
Catchment:	100 ha
Proposal:	Rock Flume

At this site, poor design and siting of a large capacity dam (by previous owners) has led to the formation of two gullies at the spillway outlets of the dam, threatening the integrity of the dam.

The condition of the reaches upstream and downstream from the dam site indicates that it is likely that the channel (shown by the blue line in the photo below) was well stabilised prior to the construction of the dam. The channel had undergone a historical phase of incision, with sufficient time to go through the full set of stages of the evolution of an incised channel.

However the construction of the dam resulted in peak flows returning to the channel floor over a considerably shorter distance (shown by the red lines in the photo below) compared with the prior conditions (blue line). This included the relatively steep sidewalls of the old channel. The steeper the slope, the greater the erosive power, and in this instance the binding power of the vegetation has been insufficient in relation to the inherent erodibility of the soils, resulting in the tributary erosion process commencing.



The result is large-scale erosion, as shown in the photos below, of the view downstream of the southern headcut (left), and upstream towards the southern headcut (right).

The photo below shows the upstream view of the southern gully from the original channel floor. The gully is setting itself to the 'base level' of the original channel floor.

Spillways should generally be designed for a 1 in 50 year event (Lewis, 2002), which is around 8.5 cubic metres per second for the 110 hectare catchment area feeding this dam. Based on this flow rate and a return slope of around 20% on the sidewall, the table in Appendix Two indicates that an outlet width in excess of 40 metres would be required to safely convey this flow to the valley floor. This would need to be even wider if groundcover was poor. Clearly this was impractical from the beginning, so the dam was always in trouble when a big flow eventuated.

If left unchecked, the end result will be the draining of the dam and a new erosion gully of a similar grade and dimensions to the blue line in the aerial photo.

Recommendations

Unfortunately, if the dam is to be protected in the long term, there is no cheap and easy solution for this site. A flume is required to safely drop flows from the southern spillway outlet to the original channel floor (a contour cutting flow off from the head of the northern spillway).

Concrete is generally the most cost effective solution for landholders who do not have rock readily available on the property. However at this property, rock is in abundance and machinery is available for collecting and transporting the rock, so this option would be the best option.

Careful sizing of rock is a must for a job of this size. A mean diameter of approximately 500 mm for angular rock and 700 mm for rounded rock is required, assuming an Annual Recurrence Interval 1 in 50 year peak discharge of 8.5 cubic metres per second, chute width of six metres, and 1-in-3 gradient (following the procedure in Catchments and Creeks, 2010). Subtle design and construction details are the keys to success for this site, and professional assistance should be sought.

Outcome

Given the size and cost of works required to successfully manage this site, no work has yet been completed.

Site 6: Erosion from diversion of flow over an existing gully

Erosion Process

Property:	'Tantanoola', Book Book
Erosion:	Headcut formation & migration and gully erosion
Causes:	Flow diversion, dam impacts and erodible soils
Catchment:	295 ha
Proposals:	Rock Rundown, Tyre Step, One Rock Dam

The diversion of flow following the installation of a dam on the neighbouring property is thought to have resulted in an abrupt drop over the sidewall of an existing gully, causing a headcut to form and subsequent retreat (the same as the tributary retreat process).

As can be seen in the below photo of the upstream view of the site, the landholder has already placed rubble against the face in an attempt to slow the erosion. However significant contact between flow and the erodible subsoil has continued, resulting in undermining and collapse of the topsoil/sod blocks and ongoing retreat.

Recommendations

Due to the large catchment area and considerable rate of discharge, a Rock Rundown would be the standard approach to prevent further migration. However in this case the landholder has a supply of tyres already present on site, so an approach that utilises this resource could be attempted. A schematic of what the proposed structure involves is shown in the image below, with a Tyre Step of screwed, soil-filled and vegetated tyres armouring the face. A low grade control structure built out of the rubble that is on site is also recommended, just below the structure (shown in yellow) to provide an energy reducing basin. This could be achieved using the approach for a One Rock Dam.

Outcome

The landholders constructed a Tyre Step with drainage rock. Geofabric was laid below the tyres, and gypsum spread after construction. Seed was also spread to encourage regeneration of vegetation.

The photos on the following page show the site immediately after construction (top), and working as planned following rain (bottom).

3.3 Headcut Migration

Site 7: Headcut migration

Property:	'Ayrshire Park', Big Springs
Erosion:	Headcut migration and gully erosion
Causes:	Erodible soils
Catchment:	170 ha
Proposal:	Rock Rundown

Erosion Process

An advancing headcut at this site was threatening the main floodplain crossing, approximately 10 metres upstream. As can be seen in the photo on the right, during a flow event a large proportion of the 600 mm tall head is drowned by a pool.

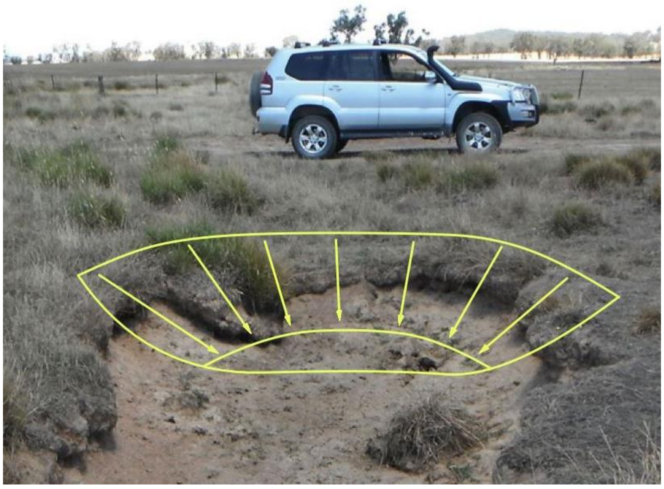
This pool is formed because the channel is discontinuous, with some of the eroded sediment deposited at the downstream end (see photo below right) in a cut-and-fill process.

Recommendations

Because of the threat to access, this site is a particularly high priority. The site has quite a large catchment area, around 170 hectares, with expected peak flows of four cubic metres per second (1 in 20 years) and 5.4 cubic metres per second (1 in 50 years). However the flow at the headcut itself is likely to be around two cubic metres per second due to a good proportion of the flow travelling across the floodplain to the east.

To stabilise the headcut, a Rock Rundown is recommended. To resist a peak flow of approximately 2.5 cubic metres per second, an average rock diameter of 400 mm should suffice, using angular rock, with voids filled with small rocks and soil.

The overhanging lip of topsoil (seen in the top photo on the following page), and the cloudiness of the water (seen in the photo above, top) indicate the dispersive nature of the subsoil. As a result, it is important to include a minimum of 100 mm of topsoil beneath the recommended geotextile fabric. This soil could be obtained both from the batter and around the lip of the pond. A schematic of the approximate batter for the Rock Rundown is shown by the yellow lines in the photo at right. Despite the large catchment area, the site is on a second order watercourse with intermittent flow and is therefore considered a Minor Stream from a legislative perspective, avoiding the requirement for approval.



Outcome

The landholders constructed a Rock Rundown as recommended, shown in the photos at right and below. They shaped the edges, covered the sodic soil with a topsoil layer, covered this with geofabric and then fitted rock of between 200 and 400 mm in size. Over this they scattered gypsum, and also sedge seed to encourage vegetation establishment. The site has had a small amount of rain since the works were completed, and has performed well.

Site 8: Headcut migration

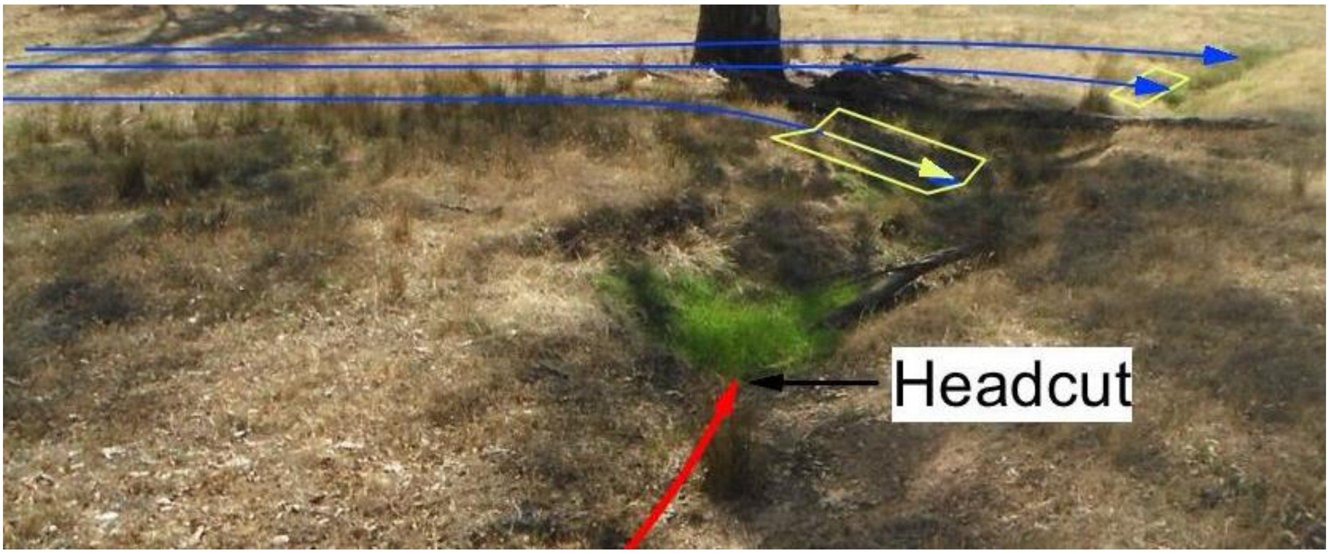
Erosion Process

A 600 mm high headcut is migrating towards a major access route at this site. The cut initiated well downstream, with this being the current location on its ongoing march upstream. The red arrow in the photo at right shows the downstream view of the existing flow pathway.

Property:	Palmers Road, Book Book
Erosion:	Headcut migration
Causes:	Concentrated flow and erodible soils
Catchment:	100 ha
Proposals:	Rock Rundown and One Rock Dam

Recommendations

There are plans to add gravel to the crossing just above this site. In doing so, levels can quite easily be adjusted to encourage flow to head to the eastern side of the valley floor, rather than to the west as it currently flows, thereby starving the headcut. The valley floor is more level to the east, so subtle upstream diversion would result in more dispersed flow and re-entry, as indicated by the blue lines in the downstream photo (below) compared to the concentrated flow driving the existing headcut (shown by the red arrow in the photo below).



Within the proposed re-entry zone, there are two vulnerable sites at which minor erosion has occurred, leading to soil in the sidewalls becoming exposed. Armouring these sites, shown by the yellow lines in the photo above, with a Rock Rundown would be recommended, along with One Rock Dams on the downstream side of these works, to create stilling basins along the re-entry zone.

Outcome

The landholders battered the washouts and lined them with geofabric, before armouring the site with rock, as shown in the photo below (left). They then added brush and timber tied together and secured to posts, as can be seen in the photo (below right). The aim was to slow the flow and divert some flow onto the floodplain. All materials used were sourced on farm.

The photo below shows the site two days after construction, following heavy rains. As can be seen, the work was very effective in directing the main flow along the rock structures to the bound timber structure, where the flow was slowed and energy dissipated, with much of the flow then being diverted onto the floodplain.

Site 9: Headcut retreat caused by dam overflow

Erosion Process

A standard headcut retreat process is occurring at this site, caused by overflow from the dam due to high rainfalls in recent years (see photo at top right). This has been exacerbated by the steep gradient down to the floor of Kyeamba Creek.

Property:	'Tantanoola', Book Book
Erosion:	Headcut migration and gully erosion
Causes:	Dam impacts
Catchment:	46 ha
Proposals:	Rock Rundown, fencing and revegetation

Recommendations

The gully is becoming progressively shallower as the distance from the Kyeamba Creek entry increases and, as can be seen in the upstream view of the headcut in the photo (below right), the gully floor itself is stabilising well. As the gradient decreases, the roots of the Eucalypts will start to play a more significant stabilising role. Therefore, if there is no immediate threat to access or infrastructure, this site could be left to see if it naturally stabilises. Fencing of the site would significantly improve the role of grasses in helping to stabilise the site.

If the erosion continues and looks like it will advance past the stand of trees, armouring with a Rock Rundown would be recommended. The catchment area of 46 hectares results in expected flows of 1.7 cubic metres per second for a 1 in 20 year event, and 2.6 cubic metres per second for a 1 in 50 year event, based on the data in Appendix One. To resist flows of this velocity, a rock structure with an average rock diameter of 300 mm is recommended.

Outcome

The landholders constructed a Rock Rundown (see photos at right and below), with geofabric lining below the rocks, and gypsum spread following construction. Seed was also spread to encourage establishment of vegetation at the site.

Site 10: Headcut retreat

Erosion Process

Property:	'Wongoonoo', Book Book
Erosion:	Headcut migration
Cause:	Flow concentration
Catchment:	80 ha
Proposals:	Diversion Bank, Tyre Mattress, Tyre Step

Primary and secondary headcuts are moving back through a major access route. As can be seen in the photos below of the upstream (left) and downstream (right) views, the headcuts are eating into the laneway.

The catchment is approximately 80 hectares, which will result in a peak discharge of 3.5 and 5.1 cubic metres per second for an Average Recurrence Interval of 20 and 50 years respectively.

Recommendations

Because of the height of the combined headcuts, and the significant flow rate at this site, rock armouring would require a large volume of material (over 15 cubic metres) and machinery-placement. As a result, starving the head with a dozer-built diversion bank will be a much more cost-effective solution. A channel five metres wide and 0.6 metres deep, set at a 1:200 gradient, will adequately convey a 1 in 50 year event. Design should be such that a level sill set 600 mm above the channel floor will allow larger flows to head around the northern flank.

If no other earthworks are planned on the property in the near future, and tackling the site by hand/tractor combination is desired, a Tyre Step could be adopted for the lower cut and a Tyre Mattress for the upper cut, which is already fairly well battered.

Outcome

The landholders constructed two Tyre Steps, using geofabric underneath and armouring the site with rocks. Gypsum was also spread over the site. While the process of construction of the Tyre Steps was a significant undertaking, the end result, as can be seen in the photos below, is a sound structure which continues to hold and perform well.

3.4 Channel Incision and/or Widening

Site 11: Ongoing channel widening and undercutting

Property:	Palmers Road, Book Book
Erosion:	Channel incision & widening and bend erosion
Causes:	Scour and stock grazing
Catchment:	100 ha
Proposal:	Fencing and revegetation

Erosion Process

This site is a second order watercourse with a catchment of approximately 100 hectares. The shape of the floodplain to the east of the channel indicates that it is likely that this creek was part of a swampy meadow at the time of settlement, but as has occurred in the vast majority of these settings, the channel incised deeply long ago. The shape of the floor and walls show that the channel has undergone an earlier phase of widening and stabilisation. The relatively uniform and mature age of the trees within the floor of the channel are an indication of the timing at which a more stable form was reached.

A further lowering of the bed has occurred more recently, that timing being indicated by the narrow profile and steep walls of the channel (following the downcutting stage). The ongoing bend erosion in multiple locations, such as that shown in the photo below, indicates that the widening process is still underway.

Undercutting caused by scour on the outside of the bend shown in the photo on the previous page has resulted in mass failure, with blocks of soil/sod sliding down the bank. This is a part of the ongoing widening process following a lowering of the bed. Vegetation within the channel and banks has been heavily grazed by stock, providing minimal flow resistance and preventing water loving plants from reaching their full potential

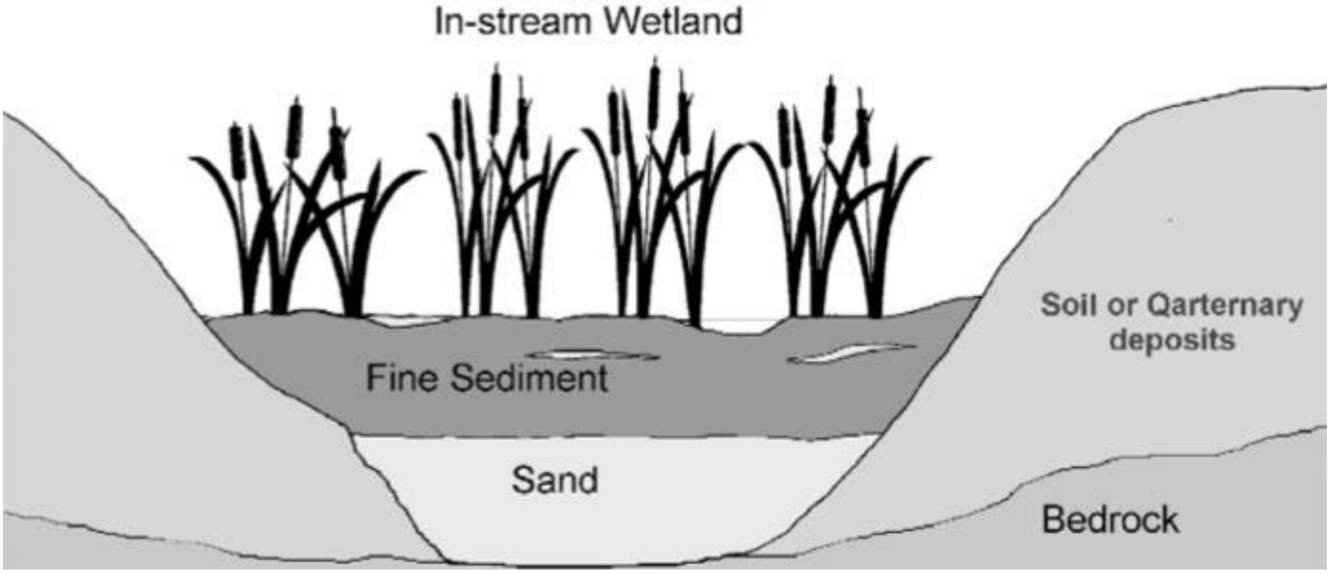
The formation of the meanders is actually moving the creek towards a more stable form. Bend erosion expends excess energy, while also increasing the length of the channel, which reduces the slope, thereby decreasing the velocity and erosive power over time.

Recommendations

Fencing is considered the most cost effective solution in this reach. Stock currently have regular access to the creek which, as seen in the photo below, resulting in minimal flow resistance from vegetation. In numerous locations, Cumbungi (*Typha* spp) has already established, but due to regular grazing the plants are only 50 to 100 mm tall as opposed to their two metre potential.

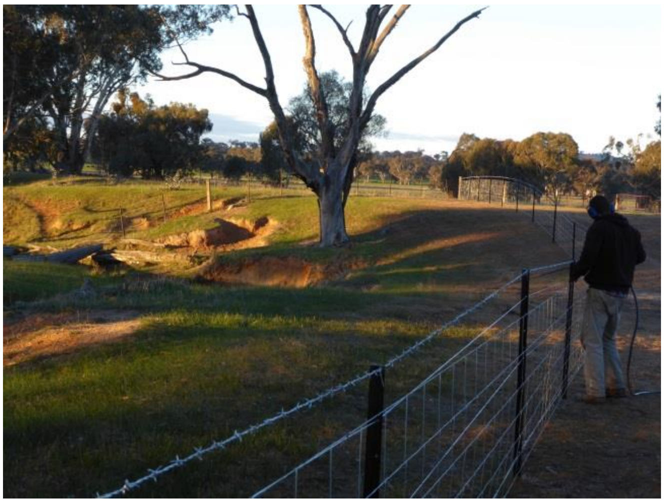
Removal of stock would see extensive stands of macrophytes such as *Typha* (and *Phragmites* if introduced) establish along this reach, as well as a variety of rushes and sedges, with a good chance of eventually forming what is known as an in-stream wetland (Zierholz et al, 2001).

Increased vegetation cover would significantly increase the roughness along the channel, thereby reducing stream velocity and the associated erosive power. Where erosion does continue as part of the ongoing widening process, the increased vegetation would help to retain that sediment as close to the source as possible. Once full in-stream wetland conditions establish, finer and finer sediment will begin to accumulate, which will offer multiple benefits to downstream waterways and ecosystems. This process of accumulation of fine sediments, following the establishment of dense in-stream vegetation, can be seen in the schematic below (from Zierholz, 2001).



Outcome

The landholders have fenced the site, as shown in the photo (below left), and revegetated with native tree, grass, sedge and rush seedlings. The seedlings have established well as can be seen in the photo (below right), taken two years after works were completed.



Site 12: Sidewall erosion in sodic soils

Property:	'Silver Springs', Big Springs
Erosion:	Channel incision & widening, gully erosion, scalding and sheet erosion
Causes:	Erodible sodic soils
Catchment:	58 ha
Proposals:	Brush Mattress, One Rock Dam

Erosion Process

This site exhibits scalding (ongoing areas of bare soil) adjacent to old erosion gullies. This situation represents an extreme version of the battering process in stage 5 of the evolution of an incised channel. While sidewalls will often naturally revegetate once a moderate batter has been achieved (leading to stage 6 of the evolution process), the soil properties at this site are perpetuating sheet erosion and inhibiting vegetation establishment on the sidewalls, as can be seen in the photo below.

The subsoil is sodic and highly erodible, becoming very unstable and boggy when wet, and hard-setting when dry. Once exposed, these soils are prone to capping and the ongoing presence of a scald, as can be seen in the photo below. This is caused by inherently unstable clay particles being dislodged by direct rainfall impact, and then clogging the soil pores at the surface. Once capping occurs, infiltration is restricted, and the conditions become inhospitable for seed germination and vegetation establishment.

Recommendations

When approaching a site like this, the first task is to stabilise the main gully floor, followed by any runnels or small gullies entering from the sides. This achieves two aims: preventing any further lowering of the bed minimises further sidewall erosion, and stabilising the floor will help to retain sediment as close to the source as possible until the scald itself is revegetated.

On this site, the channel floor is already well vegetated with sedge (*Carex appressa*), but the runnels off to the sides are still largely bare. Small grade control structures can be utilised to capture the sediment as close to the source as possible. These structures can also enhance vegetation establishment by creating a more stable bed for plants to take hold, in contrast to the regular smothering and undermining of seedlings that has been occurring.

While just throwing branches into the channel floor can achieve good results, the benefits of the available material can go further if a little more planning is employed. Of the grade control structure options, Brush Mattressing and One Rock Dams are the ideal structures at this scale.

The structures should be installed mid-way between bends, and in a crest-to-toe fashion.

Outcome

The landholders rolled out bales of oaten hay across the slope of the scald, and allowed sheep to graze and trample the hay for a short period (24 hours). This helped to break the crust of the scald, while the sheep also walked the hay (and sheep manure) into the surface as they moved across the area. The photos on this page show the site after these works, with the upstream view shown at right and the downstream view below.

The landholders feel that the process has worked well on this relatively level site. The channels have been stabilized and grass is growing where there is good cover of hay. A final application of hay was added around six months after the initial application, to complete the coverage.

Site 13: Channel formation on a floodplain

Erosion Process

Property:	'Aryshire Park', Big Springs
Erosion:	Headcut migration and channel incision
Causes:	Flow concentration and erodible soils
Catchment:	275 ha
Proposals:	Rock Rundown, fencing and revegetation

The justification of erosion control at this site relates to the economic trade-off between the estimated loss of return if the channel continues to migrate, compared with the price of the required rock and fabric to control the erosion.

The ramifications can differ considerably between grazing and cropping, with machinery access impacted far more than grazing. The photos below show the upstream view of the headcut and valley floor (left), and the downstream view of the channel that has formed (right), highlighting the impact on cropping area and access that is concerning the landholders.

The impact on hydrology is another interesting consideration to weigh up. The depth of the channel has a strong influence on groundwater in the surrounding area. From a cropping perspective, channel incision could in fact prove a positive on some sites during wet years, by increasing drainage and reducing waterlogging near the main flow lines. Local observation at incised and un-incised reaches would be required to gauge the relevance of this effect on a site-by-site basis.

Conversely, waterlogging may be less of an issue in a rotational grazing enterprise, since plans can be included as part of an overall grazing plan to skip wet areas during the wettest times, while capitalising on increased soil moisture compared to the rest of the landscape at other times.

Recommendations

If the landholder comes to a decision that stabilisation is to be carried out, the considerable catchment area, of approximately 275 hectares, means that armouring with rock and fabric is the only viable solution. With peak flows of approximately 5.4 and 7.5 cubic metres per second for 1 in 20 and 1 in 50 year events respectively, expert advice should be sought for design and construction. It should also be noted that the Pillagala Creek at this site is a third order watercourse, and would therefore be treated as a river from a legislative perspective, requiring approval before any works were carried out (see Appendix Three).

The outside of the bends, as seen in the downstream view on the previous page, are highly likely to scour and widen over time as a result of flow concentrating within the newly incised channel. Fencing of this section to maximise groundcover, particularly tussock and sedges, would significantly increase the roughness within the channel and thereby reduce channel velocity and erosive power. From a management perspective, both the widening of bends and fencing will have an impact on the area that is currently cropped. However the value of the fencing approach could be more justified if tree planting for wind shelter and shade are additional benefits.

Outcome

The landholders initially attempted to armour the site with two cardboard air conditioner pads at the erosion head. Unfortunately this was unsuccessful, as the pads were washed away in heavy rains approximately one year after installation.

Following this, the landholders decided to rip across the erosion head when quite wet, they then ripped and sprayed planting lines, fenced the entire area and planted with native seedlings. The result has been good stabilization of the site, with the fencing ensuring that stabilization and regeneration will continue. The series of photos above shows the site in May 2016 (top), October 2017 (middle) and July 2019 (bottom).

Site 14: Erosion into prior cut-and-filled gully

Property:	'Wongoonoo', Book Book
Erosion:	Headcut migration and gully erosion
Causes:	Flow concentration
Catchment:	70 ha
Proposals:	Rock Flume, Tyre Mattress

Erosion Process

This site is of concern because further erosion threatens a main access route. The site is midway along an old gully, the linear nature of which generally indicates that it was caused by either an old road or a drain. The gully section within the laneway has been cut-and-filled to improve access, but flow heading over the crossing is starting to eat back into the fill, as can be seen in the upstream view shown in the photo below.

The catchment for this site is approximately 70 hectares, which can expect peak discharge of 3.1 and 4.6 cubic metres per second for an Average Recurrence Interval of 20 and 50 years respectively.

Recommendations

Without downstream armouring to protect the fill, or an adequate culvert pipe to convey flows, cut and fill to provide improved access within a gully such as this is always going to be threatened when overtopped.

If a downstream inspection indicates that the gully floor is stabilising well at a particular grade, crossing works should aim to maintain this same longitudinal profile and width of the gully floor. The gradient of entry and exit batters will depend on soil type, but they should still aim to finish at the toe of the existing sidewalls.

The first option for downstream armouring is a traditional rock and fabric flume. Based on designing for an Average Recurrence Interval of 20 years, a gradient of 1 in 3, a width of three metres and height of 0.7 metres, approximately seven cubic metres of angular rock with an average diameter of 500 mm would be required to adequately armour the downstream face (Catchments and Creeks, 2010). A24 Geotextile fabric should underlie the rock, with the voids filled with gravel and soil. The construction approach is similar to that described in the Rock Rundown, but design and construction by someone with professional experience is recommended due to the rapid flow rate.

An alternative strategy for downstream armouring is a Tyre Mattress. Using tyres isn't everyone's cup of tea, but a Tyre Mattress provides a similar function to a gabion mattress at much lower cost. In short, tyres are joined together to create a consolidated unit and then filled with gravel to weigh it down. Much less material will be required than for the rock flume approach described above.

Outcome

The landholders constructed a Tyre Mattress, with geofabric beneath the tyres and rock armouring the tyres, as the photo below shows. The site was fenced and revegetated with native seedlings, helping to stabilize the site.

Site 15: Incision of creek leading to tributary erosion

Erosion Process

The incision of Kyeamba creek has resulted in an abrupt drop at the sites where the tributary enters the creek, as can be seen in the photo below. This has resulted in the retreat process of erosion up the tributaries.

Property:	'Tantanoola', Book Book
Erosion:	Channel incision, tributary erosion and gully erosion
Causes:	Flow concentration, erodible soils
Catchment:	311 ha
Proposal:	Rock Rundown

Recommendations

The priority of working on this site will be determined by the rate of retreat and the threat to either infrastructure (compromising a fence) or access.

One of the first tasks when stabilising a gully, whether large or small, is to ensure that the floor is stable. The well vegetated floor, as can be seen in the photo at right, indicates that this has been achieved at this site. The establishment of the Eucalypts on either side of the descent is also a positive sign for reducing the chance of a further lowering from this point down.

The main task is therefore to armour the face of the active headcut. The large catchment area of around 311 hectares means that considerable flows are possible at this site, with peak discharge of 5.5 and 8.0 cubic mnetres per second expected for an Annual Recurrence Interval of 1 in 20 and 1 in 50 years, respectively. A Rock Rundown would therefore be the recommended approach, with the appropriate rock size being dependent on the proportion of flow that is heading over the site. Assuming around half of the overflow heads over the site, and a 2.5 metre wide flume is constructed (equivalent to the approximate width of the channel downstream), an average rock diameter of 450 mm would be required to resist a 1 in 20 year event (Catchments and Creeks, 2010). If the rock is carefully keyed from the base up and voids are filled with smaller stone and soil, a slightly smaller average rock diameter of around 300 mm could be utilised.

Because of the flow volume and velocity, professional advice is highly recommended for this site.

Outcome

The landholders lined the site with geofabric, as shown in the photo at right, then armoured it with a Rock Rundown (below left) using rock of 150 - 300 mm diameter. As can be seen in the photo at below right, the structure has worked well in recent rains.

Site 16: Erosion of an old stabilised gully following a major storm

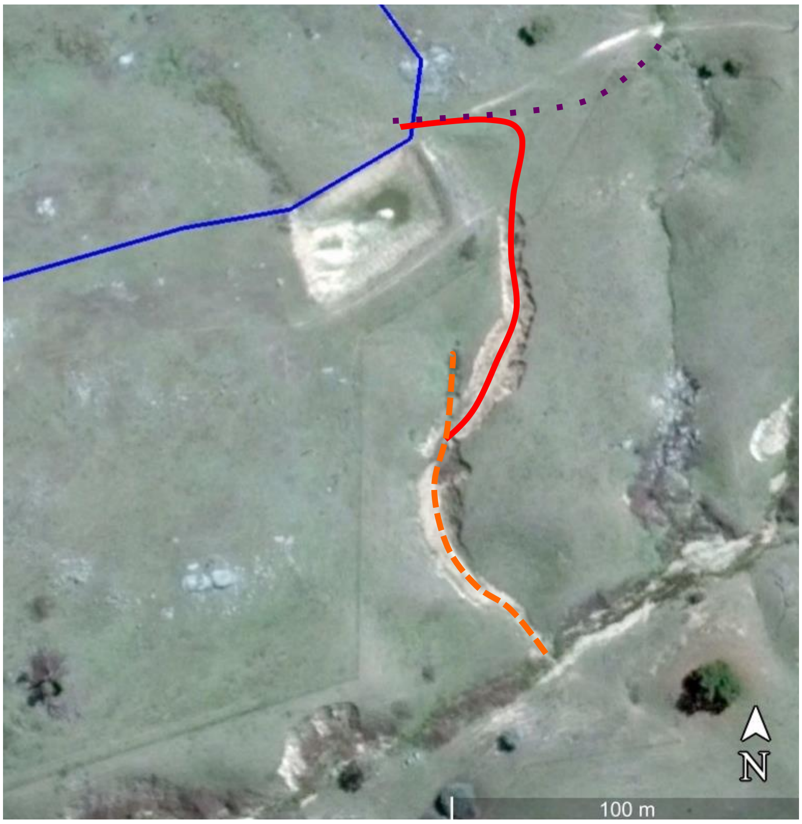
Erosion Process

A dam with a 14 hectare catchment overflowed during a major stormflow event, commencing a new sequence of gully erosion at the point that it re-entered an old stabilised gully. This resulted in the erosion gully seen in the upstream (left) and downstream (right) photos below.

Property:	'Silver Springs', Big Springs
Erosion:	Gully erosion
Causes:	Dam impacts
Catchment:	14 ha
Proposals:	Contour Bank, Poplar Armour, Brush Mattress, Fencing and Revegetation

The process by which this re-entry erosion occurs follows the standard tributary erosion stages, with the new gully setting itself in relation to the floor of the existing gully.

The aerial view of the site, at right, shows the process, whereby the major overflow event (shown by the red line) initiated a new headcut where it dropped down the sidewall into an old stabilised gully (indicated by the orange dashes).



Recommendations

The dam seen in the aerial view on the previous page does not overflow often; it leaks quite readily, which results in a reasonable proportion of the approximately three megalitres usually needing to fill before overflow occurs.

If a reasonable amount of human labour is available, one approach that could be adopted at this site is a combination of the Brush Mattressing method and reinforcement with vegetation. The aim would be to evenly spread the remaining blocks of topsoil, and supplement with manure. The Brush Mattressing helps to hold this material in place while vegetation establishes. For long-term stability, vegetation with a dense fibrous root system must create an interlocking 'hammock' under the surface, both on the face and above the existing cut.

Casuarina cunninghamiana, which is performing well over the hill (see photo at right), is the native tree species that has the most suitable root system for such purposes. Depending on species preferences, landholders in New Zealand have achieved good levels of success using poplar species as an erosion control tool in similar circumstances (see Charlton et al, 2007).

For the option described above to be successful, a sufficient period for root systems to establish without major flows would be required. If the headcut starts to rapidly migrate again, threatening the dam, then the installation of a contour to redirect flows across to the valley to the east is advisable. This valley has already incised as far as it can go, having hit bedrock and boulders in multiple locations. If a dozer were completing earthworks nearby, this would be a sensible piece of earthworks to complement the vegetation approach described above.

Outcome

The landholders battered the headwall at this site, treated it with gypsum and covered it with geofabric. The site was then armoured with leafy saplings cut from a nearby regenerating red gum patch. Brush Packing was used downstream of the site to collect the sediment as it moved into the gully floor. Star posts and fencing wire were used to secure the brush and sapling packing in the gully floor. Locally available rock was added to the headwall, as were old rolls of discarded hinge joint fencing, which was placed behind the brush packing.

During a rain event a few months after construction, the trickle pipe for the dam adjacent to the gully was blocked by a dead turtle. This caused the dam to overflow out into the active gully, tearing away the work which had been completed.

Despite this unforeseen turn of events, the landholders still consider the technique to be an effective method of rectifying this type of erosion.

The photos at right and below show the site one year after the overflow event, with many saplings still visible, and sediment capture evident.

3.5 Tributary Erosion

Site 17: Retreating gully erosion along tributary

Property:	'Aryshire Park', Big Springs
Erosion:	Headcut migration and gully erosion
Causes:	Dam impacts
Catchment:	100 ha
Proposals:	Rock Rundown, Poplar Armour, Fencing and Revegetation

Erosion Process

A five metre wide headcut is migrating back towards a stock dam. The headcut is active when the dam overflows. A further five metres of erosion will result in the dam spillway being lowered by the depth of the gully (around 0.5 metres), reducing the storage capacity of the dam.

This gully initiated as a result of historical erosion of the main creek. The lowering of the bed meant the re-entry point had to descend the steeper grade of the bed, resulting in the retreat of the erosion along the tributary. This process has resulted in the formation of a relatively stable bed, as shown in the sequence of photos at right.

The stability of the floor of the channel at this site is related to downstream conditions. The main creek is stable and well vegetated with sedges present (top right). The downstream end of the small gully enters the creek smoothly (middle right), while the rest of the channel is reasonably well vegetated with quite an even grade (bottom right). With conservative grazing, there is little risk of further lowering of the channel floor, other than the small island in the centre.

The walls of the gully have quite a visual impact, as can be seen in the photo on the following page of the upstream view of the headcut and gully (the edge of the dam is to the right of this photograph). However the appearance of the gully walls is predominantly a cosmetic feature and will naturally batter in relation to the channel floor and revegetate over time, following the natural sequence of the evolution of an incised channel. Addressing the head of the channel is the main requirement at this site.

Recommendations

The level of priority for stabilising the head is determined by how important this particular water supply is to overall grazing management. If the gully is left unmanaged, the overflow is not likely to lower more than the depth of the existing 0.5 metre deep gully, which represents a decreased storage volume of approximately 0.25 megalitres. One additional concern if this eventuates however, is that a lowering of the full supply level in the dam may cause a new phase of erosion to initiate upstream of the dam, due to a reduced 'drowning out' extent. Armouring of the site is therefore recommended.

Soft armouring above the cut could be attempted with plantings of species with interlocking fibrous root systems, such as *Casuarina cunninghamiana* (River She-Oak) or Poplar species (Charlton et al, 2007), depending on species preferences. For this approach to succeed, fencing and protection from stock is the first major consideration, the second being the risk that major flows would need to be absent until root systems were mature enough to provide sufficient protection; this is likely to be approximately eight years.

If the job is deemed a high priority, the large catchment area means that shaping and armouring with rock would be the most suitable approach. The catchment size has been estimated at approximately 160 hectares, which would result in peak flows of 3.8 and 5.4 cubic metres per second for an Average Recurrence Interval of 20 and 50 years respectively.

While this is only a second order watercourse and therefore doesn't require approval, due to the scale it would be recommended that professional advice be sought in designing and constructing such works. As a ballpark, a five metre wide chute (equivalent to the width of the current face) with a 1-in-5 grade would require an average rock diameter of around 400 mm if angular, and 550 mm if rounded. Approximately nine cubic metres of rock would be required.

If such work was to be carried out, sufficient freeboard along the western dam wall would be required, to ensure flows head over the armoured zone, as stock tracks have impacted and potentially lowered the wall in this area.

Outcome

The landholders initially attempted to repair this site by rolling out bales of hay (top right) and allowing sheep to graze and trample the hay, to walk the hay into the surface. Larger tree prunings and woolen dags were also added to the site, to further promote conditions suitable for regeneration of vegetation. This appeared to work for some months, before larger rain events washed the hay and dags away (middle right).

The landholders then undertook works to incorporate the eroded site within the dam itself, effectively solving the problem (bottom right).

Site 18: Tributary retreat

Erosion Process

This site is a very large-scale example of the tributary retreat process. The main channel is approximately four metres deep. As can be seen in the photo at right, the subsoil on the walls is sodic and highly erodible. The sloping sod in the foreground of the photo indicates that flow is running across the floodplain surface, over the lip of the more resistant topsoil (A horizon) and then onto the subsoil (B horizon) which is dispersing and washing away underneath, causing the sod to progressively collapse in.

Property:	Palmers Road, Book Book
Erosion:	Tributary erosion and gully erosion
Causes:	Erodible soils
Catchment:	7 ha
Proposals:	Poplar Armour, Brush Mattress

Recommendations

This is a very challenging site to address. The cost of hard engineering, such as with a rock or concrete flume, would be very difficult to justify at a site like this due to the scale and episodic nature of the movement - it takes a very wet period for sufficient runoff to occur.

A bioengineering approach offers the most cost effective chance of success. Although not everyone’s preference, similar sites have been successfully stabilised using upright white poplar (*Populus alba* 'Pyrimidalis') which suckers at close spacing, creating a dense fibrous root system below the surface. For the best chance of success, pole planting should be carried out at one metre spacings along the base of the channel, two metre spacings on the sloping sidewalls and three metre spacings in a six metre diameter range above the head itself. A wet winter provides the perfect opportunity for propagating cuttings. If native species are preferred, close planting of *Casuarina cunninghamiana* offers the best chance of success.

While root systems are establishing, laying dense brush along the floor of the channel using the Brush Mattressing technique, can help to retain the topsoil and sod as close to the source as possible, while also providing additional protection from grazing for groundcover plants.

Outcome

Due to the scale of the issue at this site, the landholders have not yet undertaken works.

Site 19: Erosion where flow re-enters the channel

Erosion Process

Property:	'Aryshire Park', Big Springs
Erosion:	Headcut migration, tributary erosion and gully erosion
Causes:	Dam impacts
Proposals:	Rock Rundown, Diversion Bank, Fencing and Revegetation

Multiple active headcuts are retreating within the overflow zone of a dam on Pillagala creek. The photos below show the upstream view of the active erosion face in the dam overflow zone (below left), and the downstream view from one of the active headcuts (below right).

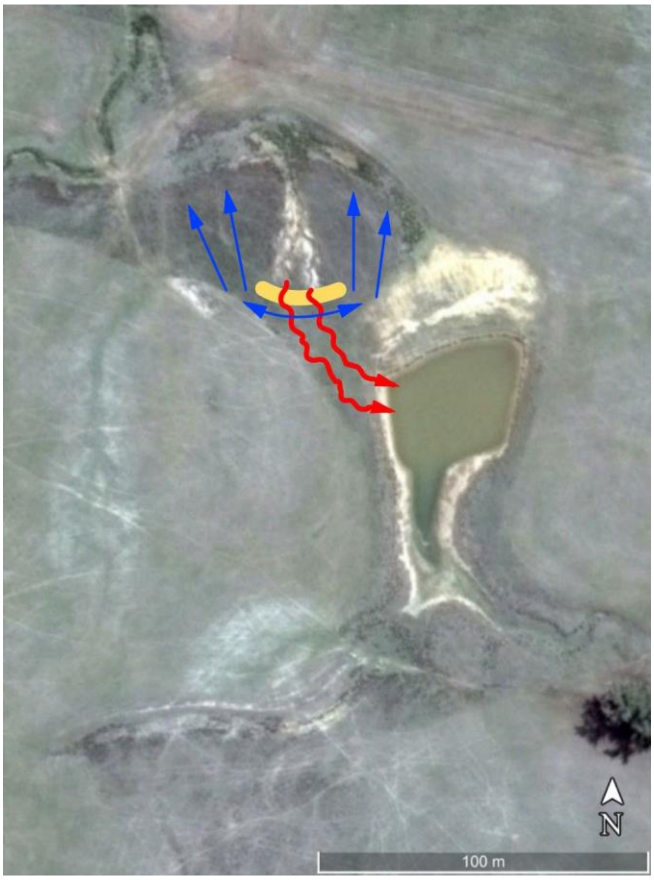
The headcut initiated at the site where flow re-enters the original channel. The aerial image on the following page shows the path that the erosion will take if left unmanaged (shown by the red arrows), continuing to migrate back towards the dam. There are multiple active headcuts within the channel itself, which threaten to further lower the bed over time

Recommendations

The topography within the dam overflow zone is quite subtle, resulting in a dispersed flow. While the lower erosive power of dispersed flow is desirable on an intact floodplain setting, once the small gully commenced it resulted in numerous entry points with associated active erosion, both at the head and sides of the channel.

Rather than trying to armour every active site, the most economical approach in this instance would be to starve the active erosion zone by installing a diversion bank. As shown in the aerial photo on the following page, the bank (shown by the yellow bar) should be pushed uphill to retain an intact valley floor above.

The adjacent floodplain to the east and west is in good condition, as is the majority of the main channel. Reinstating dispersed flow across the zones indicated by the blue arrows in the aerial photo will help to give this area the best chance of long-term stability. This would best be achieved in combination with the strategies of groundcover management and early intervention.



The landholders have plans to use this area as a tree plot. While the roots of the trees will play a role in binding the soil, the groundcover is of more importance from an erosion perspective. Sedges in particular, such as *Carex appressa*, if allowed to reach their full potential within this zone, will help to significantly increase the 'roughness', or flow resistance of the surface, which will reduce the velocity and hence erosive power at the re-entry sites.

Ongoing observation and early intervention are also critical. Due to the steeper gradient on the walls of the channel, it is possible that even with significant groundcover, a new headcut may commence at an alternative re-entry site. Early detection and intervention will make the job far easier than if the cut is allowed to progress and widen as has occurred on the existing site. A Rock Rundown would be the recommended approach, with rock sizing depending on how much flow is concentrating in that particular location (professional assistance is advised).

Outcome

The landholders initially filled erosion heads with dags and crutchings, as can be seen in the photo at right. They found this to work relatively well, although they believe more time is needed for seed germination and growth before heavy rains, as this tends to wash away the wool.

The landholders subsequently fenced the site out, and planted it out to make a wetland tree plot, as can be seen in the photos below. The dam bank can be seen on the left of the shot in the photo at the bottom of this page.

Site 20: Gully formation where tributary enters a creek

Erosion Process

A minor gully has formed at this site, where a small tributary enters Kyeamba Creek. The ongoing battering and revegetation of the walls indicates that the rate of retreat is relatively slow at this site, and that existing root structures are doing a good job of maintaining stability, as can be seen in the photos below.

Property:	'Tantanoola', Book Book
Erosion:	Tributary erosion and gully erosion
Causes:	Flow concentration, erodible soils
Catchment:	311 ha
Proposals:	Brush Mattress, Fencing and Revegetation

Recommendations

Works would only be recommended if a period of high runoff was to result in a sudden increase in the rate of retreat. As with similar sites, fencing and only periodic grazing would significantly improve the stability of the site. From a hydrological sense, opportunistic and occasional grazing is preferable over set stocking or regular rotations.

To assist the existing vegetation, the staking of brush along the floor of the small channel using the Brush Mattressing technique would help to slow flow velocity and reduce erosive power by increasing the ‘roughness’. While not essential at this point in time, 150-200 mm rock could also be added just below and against the face of the small steps that have formed, as a bit of insurance.

Outcome

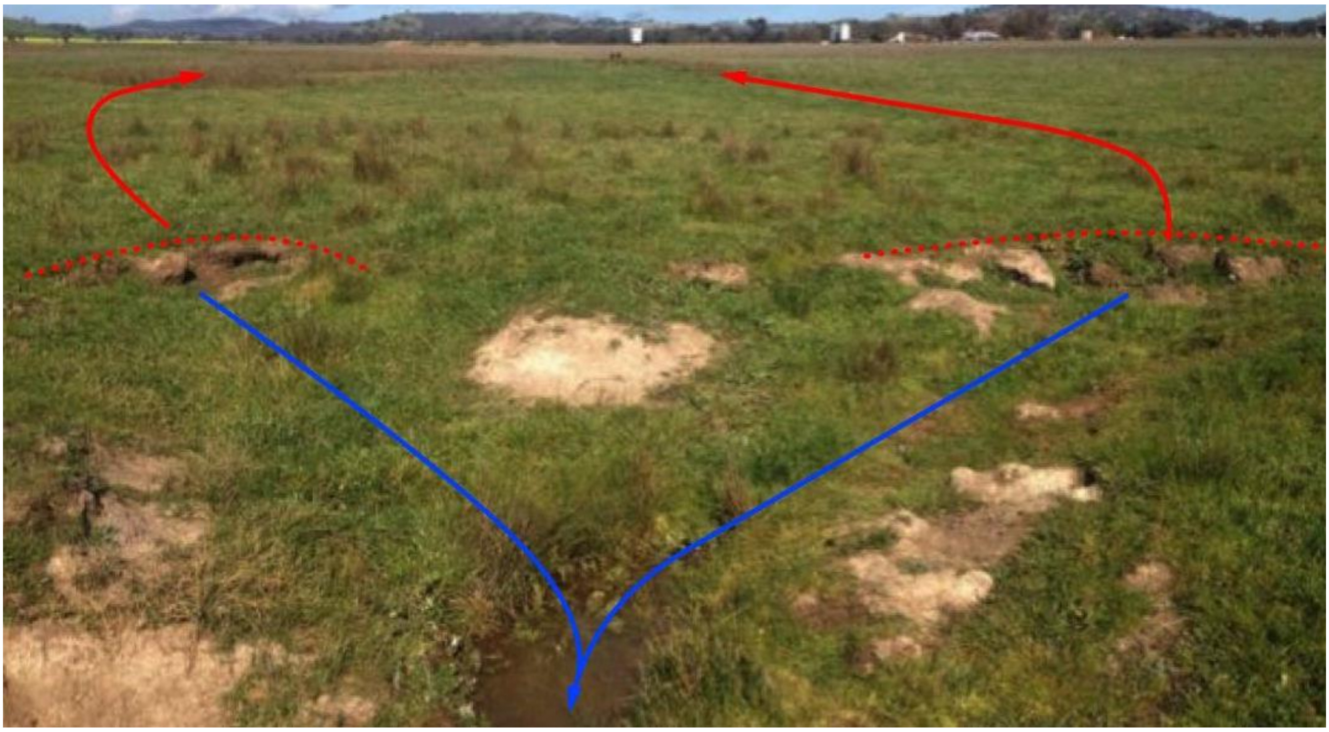
A Rock Rundown was constructed, with the assistance of a number of Landcare members as part of a working bee. As the photos below show, the site has stabilized well.

Site 21: Headcuts initiated at the rear of a dam

Erosion Process

The two headcuts at this site initiated at the rear of a dam. The photo below shows the upstream view towards the two active faces, indicated by the red dotted lines. The erosion trajectory is indicated by the red arrows.

Property:	'Aryshire Park', Big Springs
Erosion:	Headcut formation & migration
Causes:	Dam impacts
Catchment:	160 ha
Proposal:	Rock Rundown



The photo at right of the downstream view shows the erosion pathway. The channel itself is well stabilised and of no concern.

Recommendations

A Rock Rundown is recommended at the head of each of the two active cuts. Armouring the upstream edge of the pool at the confluence is also suggested as this depression could start migrating in either direction in a large flow event.

Based on the catchment area, 200 mm rock is recommended if it is well keyed and in-filled with gravel/soil. The image at right shows a schematic of the approximate batter for addressing each of the cuts at this site.

Outcome

The landholders shaped the edges of the headcuts, covered the sodic soil with a layer of topsoil and covered this with geofabric. A series of Rock Rundowns were then constructed, as can be seen in the photo at right, using rock of 200 - 400 mm diameter. Gypsum was scattered over the top, as was seed of sedge and prickly tea tree. The site has performed well in the rainfall received since these works were completed, as can be seen in the photo below. The landholders have found the area to be very stable, with water trickling slowly through the structure, depositing sediment and allowing grasses and shrubs to germinate and establish well. The paddock has now been stocked on and off, with no impact on works.

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5. APPENDICES

Appendix One: Flow Rates in the Kyeamba Valley

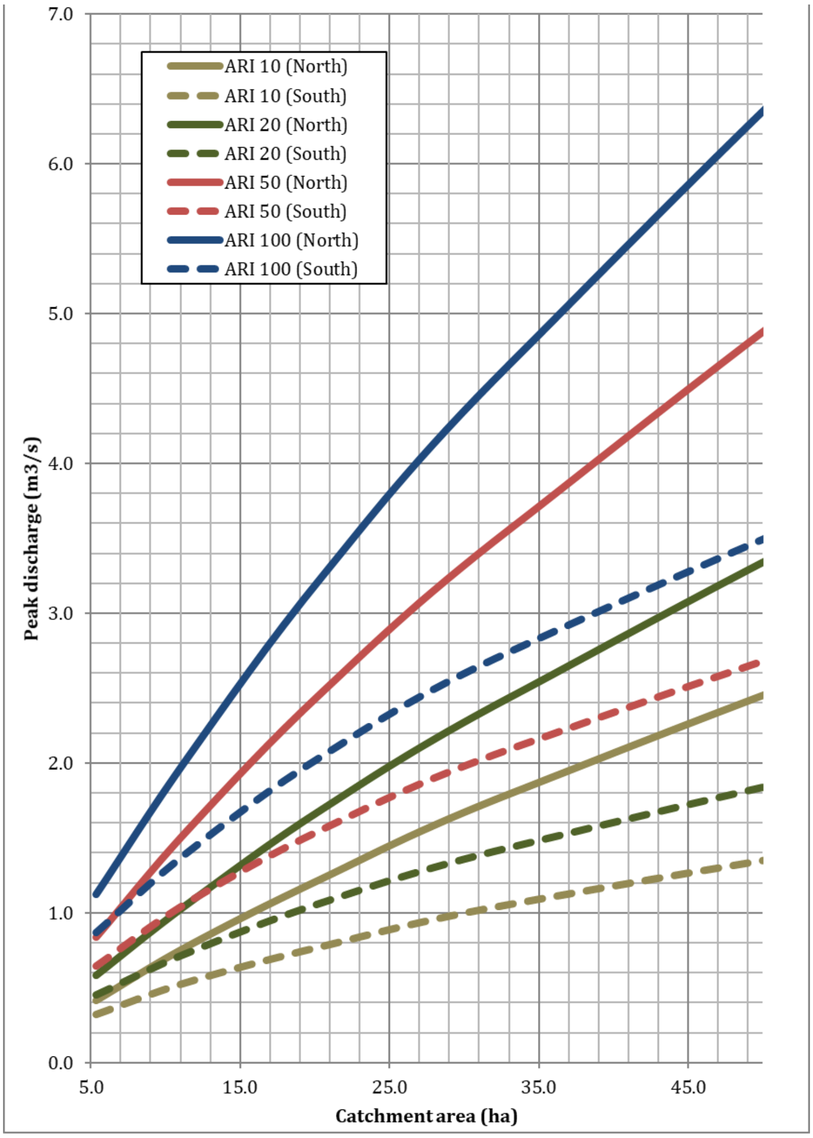

Figure A1: Peak discharge by catchment area (5-50 hectares) for an Average Recurrence Interval of 10, 20, 50 and 100 years following AR&R87 procedure (Pilgrim, 1987)

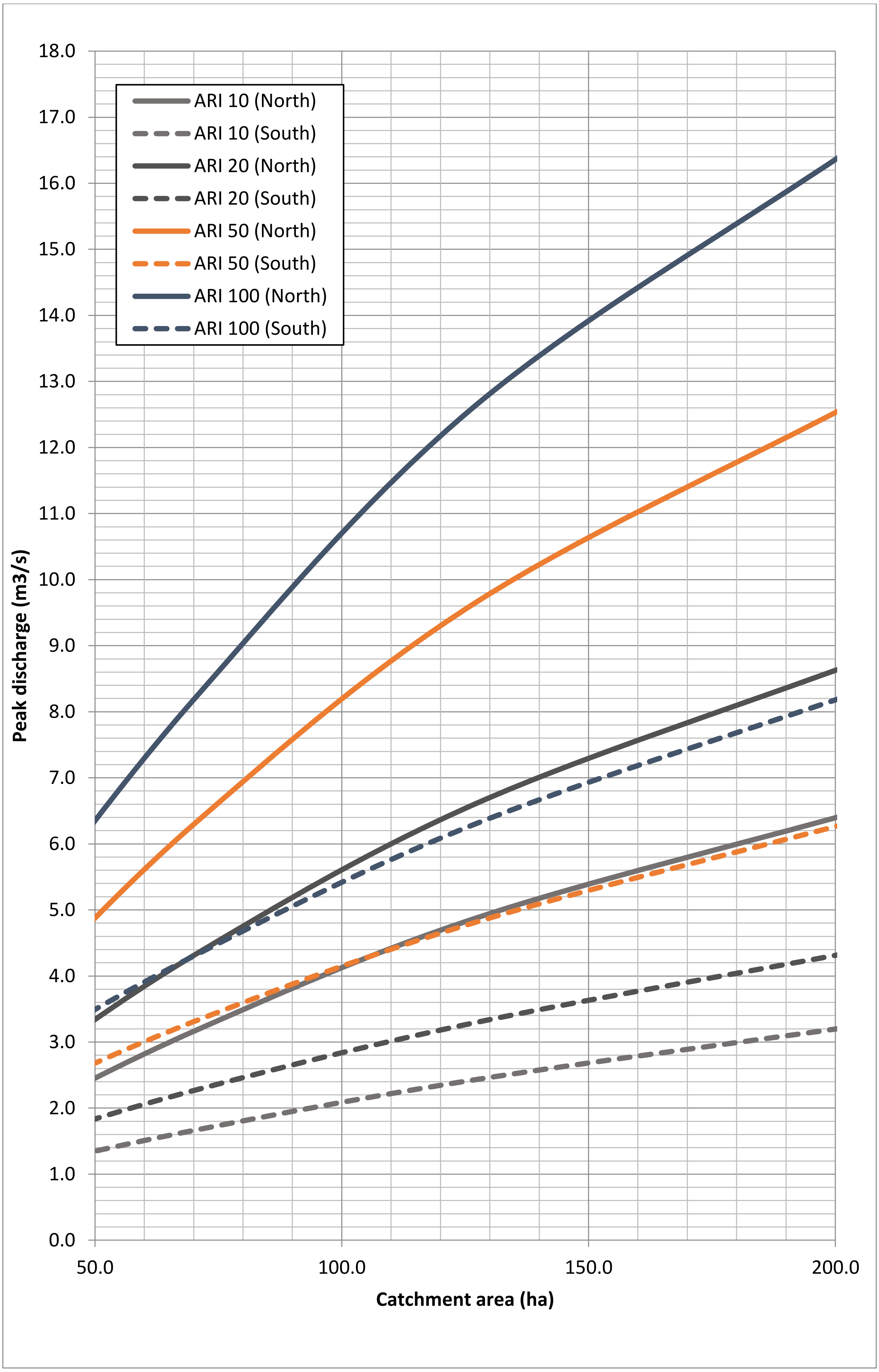

Figure A2: Peak discharge by catchment area (50-200 hectares) for an Average Recurrence Interval of 10, 20, 50 and 100 years following AR&R87 procedure (Pilgrim, 1987)

Appendix Two: Dam Spillway Design

The gradient of the return slope is a key factor in designing the dimensions of a dam spillway; the greater the slope, the wider the outlet of the spillway needs to be.

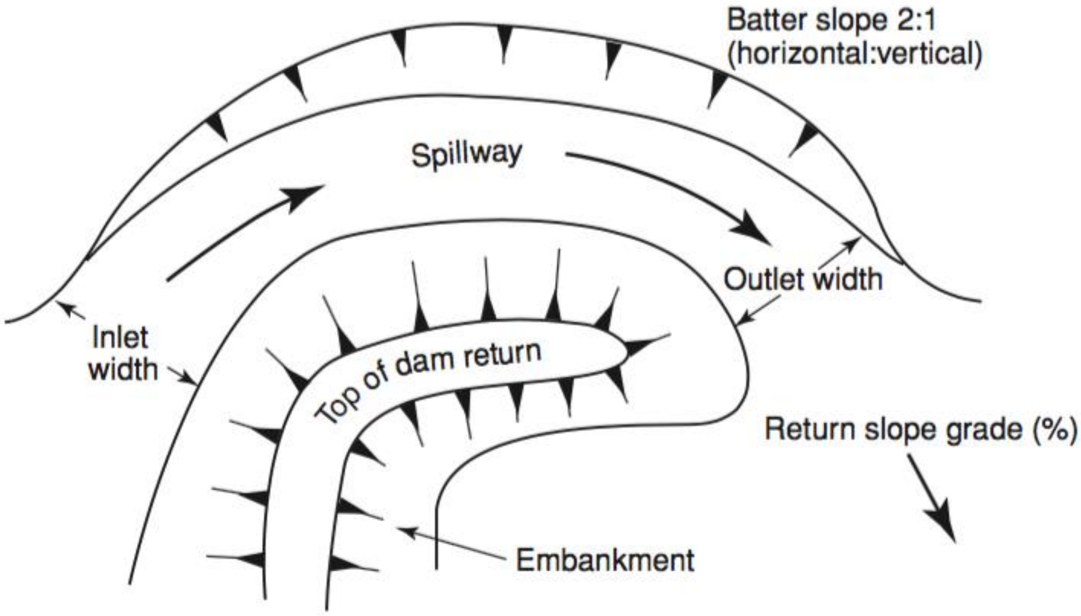

Figure A3: Spillway design features

Table A1: Minimum outlet widths of spillway based on rate of discharge (from Lewis, 2002)

Spillway discharge (m3 / sec)	Return slope (m)									
	3%	4%	5%	6%	7%	8%	9%	10%	15%	20%
	Outlet width (m)									
1	6	6	6	6	6	6	6	6	6	6
2	6	6	6	6	6	6	6	6	7	9
3	6	6	6	7	8	8	9	10	14	18
4	6	6	8	9	10	11	13	14	19	23
5	6	8	10	11	13	14	16	17	23	29
6	8	10	12	14	16	17	19	20	28	35
7	9	12	14	16	18	20	22	24	33	41
8	11	13	16	19	21	23	25	27	37	47
9	12	15	18	21	24	26	29	31	42	
10	13	17	20	23	26	29	32	34	47	
12	16	20	24	28	31	35	38	41		
14	19	24	28	33	37	41	45	48		
16	22	27	33	38	42	46				
18	25	31	37	42	47					
20	27	34	41	47						
22	30	38	45							
24	33	41	49							
26	35	45								
28	39	48								

Source: Modified WAWA, 1991

Notes:

- These widths are for well grassed spillways. Poorly grassed spillways should be wider
- Lined spillways may be more economic in the range above 47 m

Appendix Three: Stream Classification and Water Storage

Stream classification as set by the Water Act 1912:

'Minor streams' determined by Schedule 1 (NSW Government, 2006):

- Represented in 1:25,000 NSW topographic maps as a first or second order under the Strahler system
- Does not maintain a permanent flow of water
- Does not at any time carry flow from a third order watercourse or higher
- Any stream or part of a stream not represented on the 1:25,000 NSW topographic maps.

'Rivers' determined by Schedule 2 (NSW Government, 2006):

- Represented in 1:25,000 NSW topographic maps as a third, fourth or higher stream order under the Strahler system
- First or second order stream which maintains a permanent flow of water or at any time carries flow from a third order or higher watercourse.

Water storage regulations:

- For minor streams, dams may be built without a licence up to the volume stipulated by the harvestable rights of the property. The harvestable rights are equal to 10% of the average regional runoff from the property. More information on how to calculate the harvestable rights, including dams that are exempt is available through the NSW Office of Water website: http://www.water.nsw.gov.au/water-licensing/basic-water-rights/harvesting-runoff
- Dams and other works conducted within a 'river', as defined above, require approval through the NSW Office of Water. More information is available through the NSW Office of Water website: http://www.water.nsw.gov.au/water-licensing/approvals

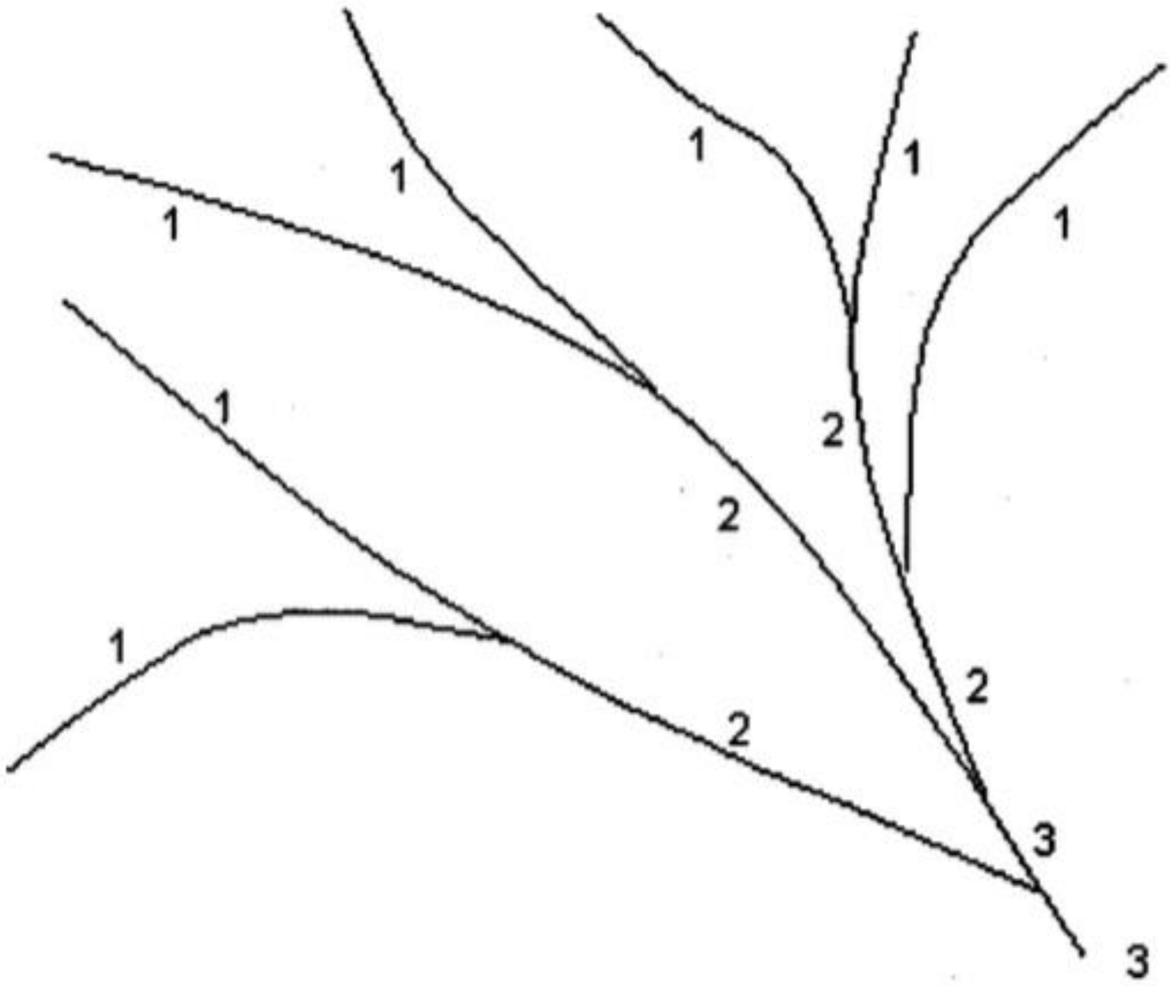

Figure A4: The Strahler system of stream classification as it relates to the classification of minor streams and rivers

This booklet was produced through the project "Slow the Flow: Erosion Control in the Kyeamba Valley" funded by the NSW Environmental Trust

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