Forested headwater riparian areas – functions and benefits

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Riparian area in a New Zealand planted forest

Abstract

Riparian areas occupy a unique location within the landscape as transitional areas between aquatic and upslope terrestrial ecosystems. These areas are valued for their high biodiversity and the wide range of functions, processes and ecosystem services they provide. Hence, their importance often exceeds the proportion of space they occupy within the landscape. While afforestation of steep and highly erodible catchments provides the opportunity to enhance both the financial and non-financial benefits from this land, the riparian areas have the potential to contribute to non-financial ecosystem services. Headwater areas have the highest density of stream and riparian areas and comprise a large percentage of total stream length in many catchments. This paper outlines some of the key functions and benefits provided by forested riparian areas in steep headwater catchments.

Because of their location in the landscape, forested riparian areas also have the potential to deliver a range of beneficial ecosystem services to downstream users. Also, well-planned riparian areas established at the afforestation stage will assist in minimising the impacts of forest management activities on waterways, particularly during end-of-rotation harvesting operations. Under the National Environmental Standards for Plantation Forestry (NES-PF) (New Zealand Government, 2017), afforestation is prohibited within certain distances of a waterbody and setback distances are outlined in the Standards. Possible options for forest restoration for protection purposes within these setback riparian areas in steep headwater catchments are discussed.

Introduction

Afforestation of steep erosion-prone land has the potential to provide additional non-economic benefits beyond the traditional financial returns from timber (e.g. sediment and nutrient reduction, improved water quality and enhanced biodiversity). Forest restoration within the riparian areas in steep headwater catchments provides an opportunity to contribute to these wider non-economic benefits.

Riparian areas are considered the transitional areas between the aquatic and upland terrestrial ecosystems. They often form natural boundaries defined by a combination of changes in slope, vegetation, soil characteristics, surface hydrology and flood-plain borders. As a result, the widths of riparian areas are naturally highly variable. The importance of riparian areas is often greater than the proportion of area that they occupy because of their location within the landscape, their unique biophysical features, ecosystems, disturbance regimes and biodiversity, and the range of functions, processes and environmental benefits they provide (Gregory et al., 1991; Richardson & Danehy, 2007).

Headwater streams and their riparian areas make up a large percentage of total stream length in many catchments (Gregory et al., 1991; Richardson & Danehy, 2007). In steep headwater catchments these riparian areas may be quite narrow. The linear nature and high edge-to-area ratio of riparian areas increases their susceptibility to edge effects from upslope management activities. This, in turn, increases their vulnerability, and response and recovery time, to both upslope and in-stream disturbances such as droughts, floods, landslides and debris flows.

Riparian management zones differ from natural riparian areas in that they are usually defined by set widths, within which a range of management activities may be undertaken under certain conditions to meet defined management objectives (e.g. the National Environmental Standards for Plantation Forestry (NES-PF)) (New Zealand Government, 2017). These widths may extend well beyond the natural boundaries of the riparian area and can vary from a few metres to several hundred metres (Gregory et al., 1991; Neary et al., 2011; Verry et al., 2004).

Benefits from forested riparian areas

Forested riparian areas provide a broad suite of functions, processes and ecosystem services, as outlined in Figure 1.

Shade and stream temperature

The benefit of stream shade and cooler stream temperatures provided by forested riparian areas is maximised in smaller headwater streams, but will be influenced by the riparian vegetation characteristics and stream width (Richardson & Danehy, 2007). In smaller-sized streams, re-establishing forest cover can reinstate shade and water temperature regimes typical of those in native forests.

Streambank stability

The root reinforcement provided by forested stream margins contributes to maintaining bank stability (Collier et al., 1995; Hubble et al., 2010), reducing bank erosion and sedimentation, and enhancing the habitat diversity provided by undercut banks and tree roots.

Filtration/trapping of diffuse/fine sediment, nutrients and other contaminants

Riparian areas are uniquely situated in the landscape to intercept *diffuse* sources of sediments, nutrients and microbial contamination from upland areas before they enter the stream system. Their effectiveness will depend on the incoming contaminant loads, and the characteristics of the catchment and the riparian areas (Collier et al., 1995; Parkyn 2004). For example, riparian areas in headwater catchments tend to be narrow, and high shade from afforestation may restrict undergrowth, limiting their filtration capacity. Greater gains in nutrient, microbial and fine sediment reductions will most likely result from the removal of stock and afforestation of the upslope catchment areas. Afforestation of agricultural land has been shown to improve water quality, mainly through the reduction of agricultural contaminants, and is particularly effective in smaller-sized catchments (Baillie & Neary, 2015).

Riparian areas in steep headwater catchments are less effective at intercepting and storing *point sources* of sediment channelled along concentrated flow paths, given the high connectivity between the upslope generation point and the receiving stream environment (Neary et al., 2011; Phillips et al., 2017; Richardson & Danehy, 2007). However, riparian areas on flatter topography can be effective at trapping some of the sediment and woody debris transported off-slope and downstream during floods and debris flows.

Channel roughness

The root systems and stems of riparian vegetation increase channel roughness. This slows the speed of floodwaters during bank overflow, particularly in small-to-moderate flood events, which decreases the erosive capacity of floods and aids the retention of sediment, debris and floodwaters.

Organic matter inputs

Forested riparian areas provide a diverse range of food resources for both aquatic and terrestrial ecosystems and are the main source of food (i.e. litter, terrestrial insects) in small shaded headwater streams. The availability of this food resource is highly dependent on the capacity of the stream system to retain and process the organic material, sediment and dissolved nutrients for biological uptake.

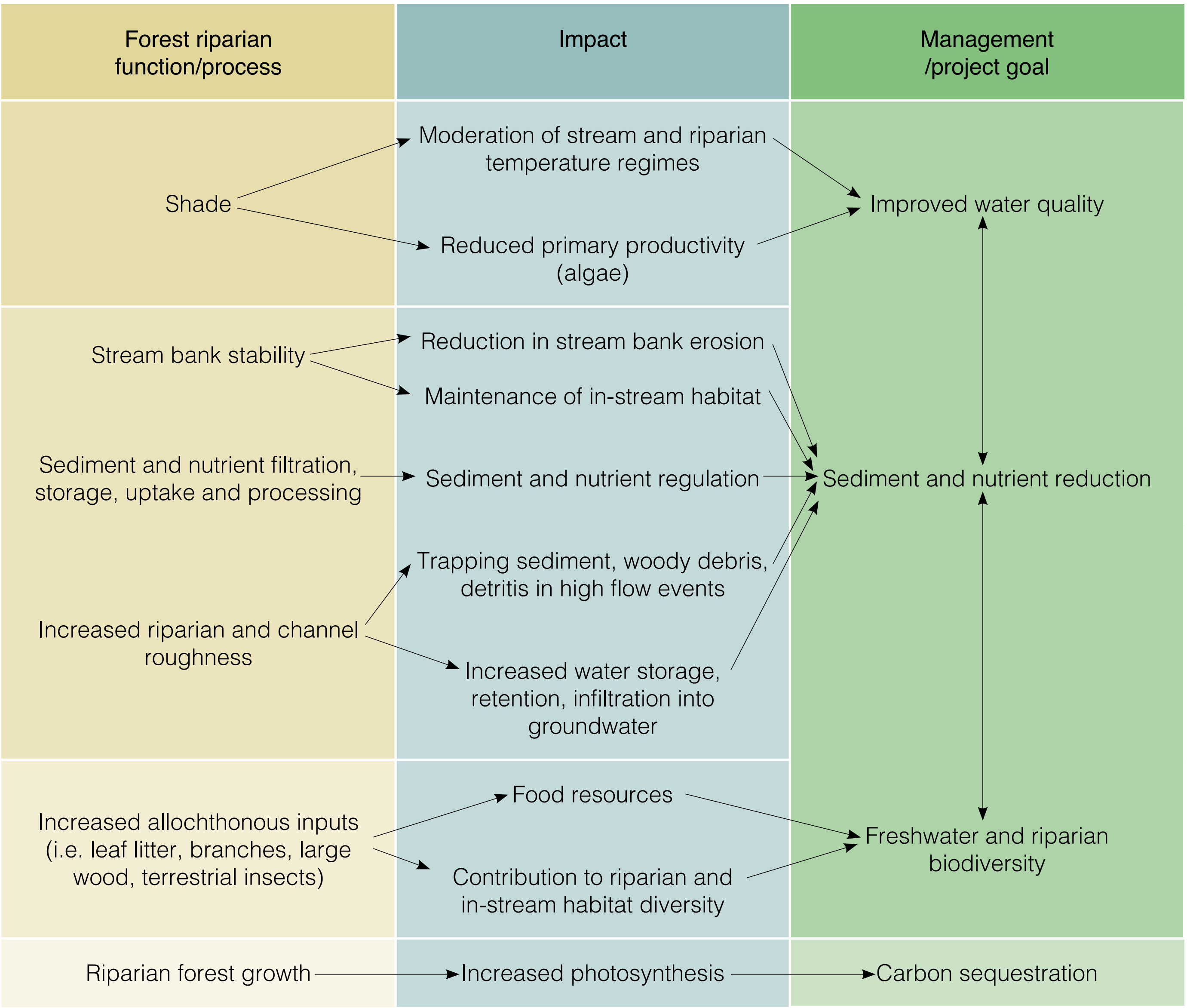

Figure 1: Selected key functions and processes in forested riparian areas

Forested riparian areas are also key providers of larger pieces of wood to stream systems. These pieces are an important component of forested stream ecosystems, influencing stream flow characteristics, habitat provision and the retentive capacity of streams (Gomi et al., 2002; Gregory et al., 2003; Gregory et al., 1991; Richardson & Danehy, 2007) (see photo). Over time, afforestation of headwater riparian areas will re-establish a source of wood supply to streams.

Forest carbon sequestration

Afforestation of riparian areas will increase carbon sequestration in these areas, as the vegetation transitions from pasture to woody vegetation and the active planting of trees can accelerate this process (Dybala et al., 2018). However, as riparian areas comprise a small portion of the total land area, the highest gains in carbon sequestration are likely to come from plantings in the remainder of the catchment.

Terrestrial and aquatic biodiversity

Indigenous forest riparian areas in headwater streams are a source of high biodiversity and species richness. The variability in topography, microclimate, soil moisture, disturbance regimes and spatial extent (both longitudinally and laterally) and high edge effects supports structurally diverse plant and animal communities. Their location and extent within a headwater catchment facilitates movement, dispersal and (re-)colonisation pathways for both terrestrial and aquatic plants and animals (Gregory et al., 1991, 2018; Richardson & Danehy, 2007). Also, woody debris inputs have a strong influence on aquatic biodiversity in small headwater streams, as they are major determinants of both the food resources and habitats of aquatic invertebrates and native fish (Baillie et al., 2013, 2019).

One study in the Waikato region illustrates the potential for the afforestation of headwater catchments to improve aquatic biodiversity. The pasture catchments

An example of large wood in a forested stream retaining sediment and organic matter, modifying stream flow and creating habitat

were planted in mainly *Pinus radiata* and the riparian areas were fenced off and either left to naturally regenerate or planted with poplars or indigenous vegetation. After six years, the invertebrate community composition in these streams was trending toward those in indigenous forest streams. The most rapid recovery in stream conditions was associated with the riparian areas planted in indigenous vegetation (Quinn et al., 2009).

Importance of headwater streams in landscape

Headwater stream and riparian systems occupy a high point in the landscape. Because of this, headwater stream systems influence the delivery of water, sediment, nutrients and organic matter to downstream reaches. This provides a range of possible beneficial ecosystem services to downstream users such as high water quality, reduced nutrient and sediment loads, cooler water temperatures and sources of biota for re-colonisation. These combined processes and inputs from upstream tributaries influence physical and biological processes in the downstream reaches and the composition of the biological communities living within them (Gomi et al., 2002; Richardson & Danehy, 2007).

The benefits of establishing forested riparian areas in smaller headwater streams are more readily identifiable. These benefits can be seen within a shorter timeframe compared to larger downstream river systems, where the influence of riparian areas declines and riparian effects can be compromised by multiple land-use stressors (that dilute or override the benefits of riparian management interventions). Therefore, there are benefits in prioritising the establishment of forested riparian areas when undertaking afforestation projects in highly erodible headwater catchments before progressing their implementation downstream (Gomi et al., 2002; Parkyn 2004; Richardson & Danehy, 2007). For example, in the Hawke's Bay region, the potential stream length available for riparian reafforestation is estimated at 4,375 km where erosion rates are greater than 1,000 t km^{-2} yr^{-1}, and nearly doubles in length when taking into consideration areas with lower erosion rates (8,095 km; >500 t km^{-2} yr^{-1}).

Connectivity to indigenous remnants in the landscape

The re-establishment of indigenous vegetation in the riparian areas of steep erosion-prone land provides the opportunity to assess potential linkages with nearby indigenous terrestrial and aquatic areas that would maximise beneficial ecosystem service and biodiversity outcomes. An example is the broad-scale assessment and prioritisation of the remaining indigenous biodiversity in terrestrial, lake and river ecosystems undertaken by Leathwick (2017) in the Hawke's Bay region. This assessment also looked at connectivity, highlighting the opportunities between stream and riparian areas and existing remnants of indigenous vegetation that can be leveraged throughout an entire river system.

End-of-forest rotation benefits

Well-planned and established riparian zones that promote forest restoration at the afforestation phase can provide significant protection to waterways during the rest of the forest rotation. As harvesting is the forest management activity having the largest impact on headwater streams and their riparian areas (Baillie & Neary, 2015), most studies have assessed the effectiveness of differing forested riparian widths in minimising harvest impacts. The results are understandably variable, given the range of site and riparian conditions and different harvesting practices.

However, Table 1 shows that in general forested riparian buffers less than 10 m in width are limited in the extent of their ability to mediate harvesting impacts. The greatest benefits are associated with shade retention, channel bank stability and limiting the transport of logging slash into streams. While there is a progressive gradient on increasing benefits to riparian and stream functions and processes with increasing buffer width (as shown in Table 1), studies on forest management activities have suggested widths up to 30 m or more on both sides of the stream to limit the effects of harvesting and to maintain both riparian and stream ecosystem function and biodiversity (Davies & Nelson, 1994; Kiffney et al., 2003; Phillips et al., 2017).

Depending on a range of criteria, under the NES-PF compulsory 5 m and 10 m planting setbacks are required from perennial rivers, wetlands and lakes to provide protective riparian margins (New Zealand Government, 2017). These setback planting boundaries may need to extend beyond the natural riparian edge into wider riparian management zones, particularly in steep V-shaped headwater stream systems where natural riparian areas can be quite narrow. As headwater streams are particularly sensitive to harvesting, buffer widths of greater than 10 m may be necessary to meet management goals and regulatory standards for water quality and riparian and in-stream biodiversity.

The development of a harvesting plan prior to afforestation would assist with this process (Visser & McConchie, 1993). Different widths are needed to achieve different outcomes for stream and riparian

Table 1: Ability of riparian areas to mediate impacts of clear-fell harvesting

Riparian width	Effect	Reference
5 m and 30 m	Whangapoua Forest, Coromandel Peninsula: Median daily air temperatures were 3.2°C lower in the 5 m wide forested riparian buffer and 3.4°C lower in the 30 m buffer, compared with an open clear-fell area.	(Meleason & Quinn, 2004)
10 m	Venlaw, Southland: The 10 m forested buffer reduced inputs of logging slash, and provided partial shade and a limited capacity to filter fine sediment and nutrients. There was an increase in algal growth and a decrease in-stream substrate size. Changes in aquatic invertebrate communities resulted in a decrease in sensitive taxa and an increase in taxa utilising algae and organic matter. Overall, the narrow riparian buffer reduced some of the physical and biological changes in the Venlaw site compared to sites without riparian buffers.	(Thompson et al., 2009)
Harvested pine: width <10 m (mean = 5.4 m); width >10 m (mean = 19.6 m). Mature pine: width <10 m (mean = 3.6 m); width >10 m (mean = 18.5 m)	Whangapoua Forest: Harvested sites without a riparian buffer or a narrow buffer (<10 m) averaged 33.3% and 63.4% native species cover, respectively. The wider buffers (>10 m) averaged 83.9% cover, similar to mature pines (narrow and wide riparian buffers) and native forest sites (range 81.6–99.8% cover). The mean number of adventive species was highest in the harvested sites with no or narrow riparian buffers (particularly where harvest disturbance was high), followed by the wider riparian buffers, and significantly lower in the mature pine (narrow and wide riparian buffers) and native forest sites. The percentage of pioneering species was also highest in the harvested sites with no or narrow riparian buffers. Vegetation community composition and structure in the harvested sites with wider riparian buffers was often (but not always) similar to the mature pine (narrow and wide buffers) and native forest sites. The authors note that adventive species are likely to be shaded out by the next rotation of trees.	(Langer et al., 2008)
Mean width 18 m	Whangapoua Forest: Riparian buffer of native shrubs and trees. Total fish numbers were highest at the logged sites (with and without riparian buffers) compared with the mature pine and native forest sites. The abundance of all fish species was highest at the logged sites with buffers. The abundance of banded kokopu (*Galaxias fasciatus*) was significantly higher at the logged sites with buffers compared with logged sites without buffers. The abundance of longfin and shortfin eel (*Anguilla dieffenbachii* and *A. australis*) was not influenced by the different site treatments.	(Rowe et al., 2002)

Riparian width	Effect	Reference
Range 6.5–27 m	Whangapoua Forest: Bank erosion was highest at the harvested sites with no buffer compared to harvested sites with buffers and the reference mature pine and native forest sites. Stream lighting was highest at the clear-cut sites and influenced by riparian vegetation and stream size. Periphyton (algae) biomass was highest in the harvested sites, followed by harvested sites with riparian buffers, and lowest in the pine (with and without native riparian buffers) and the native forest sites.	(Boothroyd et al., 2004)
Harvested pine: continuous riparian buffers (range 8–27 m); discontinuous riparian buffers (range 6.5–25 m)	Whangapoua Forest: Invertebrate community composition and a range of biotic integrity indices in harvested sites without riparian buffers differed from harvested sites with a continuous riparian buffer and the mature pine (with and without native riparian buffers) and native sites. Invertebrate communities at the harvested sites with a discontinuous buffer were intermediate between these two groups. Logging impacts were strongly influenced by increasing periphyton biomass, water temperature, channel instability and fine sediment. Intact riparian buffers were effective at mediating the impacts of harvesting.	(Quinn et al., 2004)
Initially ≈150 m reduced to 30 m as harvesting in the catchment progressed	Golden Downs, Nelson: Harvesting to the stream edge increased sediment and logging slash loads in the stream, increased water temperature extremes, and there was a decline in the more sensitive aquatic invertebrates and a reduction in native fish abundance (*Galaxias divergens* and *A. dieffenbachi*). The downstream death of brown trout (*Salmo trutta*) was attributed to upstream harvest practices. The riparian buffer mediated harvest impacts with minor changes in the physical habitat and aquatic fauns.	(Graynoth, 1979)
Harvested sites: 0–50 m (analysis 0–10 m, 10–30 m and 30–50 m); unharvested sites >50 m	Tasmania, Australia, *Eucalyptus* forest: Increased volume of woody debris, periphyton cover, length of open stream and stream temperature at harvested sites with buffers <10 m. Increase in superficial silt where buffers were ≤30 m compared with wider buffers and unharvested streams. Significant differences in aquatic invertebrate community composition occurred at sites with buffers <30 m wide, including community composition, total abundance, abundance of *Ephemeroptera* (mayflies) and *Plecoptera* (stoneflies). The abundance of brown trout declined where buffers were <30 m, but no significant differences were found in biomass.	(Davies & Nelson, 1994)
Harvested sites: 30 m, 10 m buffers and clear-cut to the stream edge	British Columbia, Canada, coastal western hemlock biogeoclimatic zone: Significant reductions in light reaching the stream surface from clear-cut – 10 m to 30 m buffer – unharvested control. Mean daily water temperatures decreased with increasing buffer width in winter, spring and summer, and similarly for maximum water temperatures in spring and summer. There were no significant differences in dissolved nutrients (N and P) between the treatments after harvesting. Periphyton biomass decreased with increasing buffer width. Chironomidae abundance decreased with increasing buffer width, as did mayfly abundance, although it was not statistically significant. Overall, ecological impacts were greatest in the clear-cut and 10 m buffer treatments.	(Kiffney et al., 2003)

health, and riparian widths advocated for larger river or agricultural systems may not necessarily be appropriate for smaller headwater streams (Parkyn 2004; Richardson & Danehy, 2007). A further complicating factor is the establishment of a riparian area to meet regulatory requirements and non-timber objectives in headwater systems, where a high density of stream networks may reduce the area for timber production to the point where it is no longer economically viable.

Options for re-establishing native vegetation in steepland riparian areas

The re-establishment of native vegetation in steepland riparian areas has the potential to provide a range of non-economic benefits. The most cost-effective option for converting pasture riparian areas to native vegetation cover is to implement setback distances from the stream edge and let natural regeneration take its course (Martin et al., 2019; Norton et al., 2018). However, this option is only viable if there is a readily available seed source within or nearby to the riparian area.

An example is kānuka, a hardy, native pioneering species that re-establishes readily in some regions of New Zealand when pasture is left to revert to native vegetation. This species provides an ideal nursery cover for other regenerating native vegetation. Naturally regenerating mānuka fulfils a similar role, although it has a shorter lifespan than kānuka and may collapse before successional species have had time to fully establish (Martin et al., 2019). Even so, weeds may re-establish within the riparian area and either out-compete or slow down the natural regeneration of indigenous vegetation.

Another option is to establish a nursery shade crop to facilitate natural regeneration. However, in the absence of any naturally regenerating native vegetation, Horgan et al. (2019) recommended planting a high proportion of faster growing shrubs to provide a nursery crop along with a lower proportion of tree species. When assessing the overall costs of this option, the higher costs of planting at high densities to assist with weed control and to achieve canopy closure in a shorter timeframe need to be compared with the reduced costs of lower planting density, along with additional costs for weed control and any other management interventions needed until canopy closure is achieved (Horgan et al., 2019; Martin et al., 2019; Norton et al., 2018). This may be expensive in steepland riparian areas where the major benefits are associated with non-economic ecosystem services and environmental outcomes. The synergies in undertaking riparian planting in conjunction with planting the remainder of the catchment may assist in reducing these costs.

In catchment areas identified as unsuitable for timber production and that are managed for other purposes, such as carbon sequestration and reversion to continuous indigenous forest cover, the riparian areas would be an integral component of the overall restoration and planting design. Given the complexities involved, and the limited information available on the afforestation of riparian areas in steep headwater catchments, a multi-disciplinary approach to riparian design would be advantageous.

Conclusions

Afforestation of steep erodible headwater catchments can potentially provide multiple benefits to society. Afforesting riparian areas in these headwater systems would enhance a range of beneficial ecosystem services, including high water quality, flood mitigation, reduced nutrient and sediment loads, cooler water temperatures and sources of biota for re-colonisation.

The state of downstream waterways and their biological communities will be influenced by the processes occurring upstream. There would be significant benefits in prioritising the establishment of riparian areas when undertaking afforestation projects in the headwater catchments before progressing their implementation downstream. Restoration and enhancement of riparian headwater areas, and maximising connectivity to the remaining indigenous forest remnants, will also contribute to goals of improving water quality and biodiversity.

It would be advantageous to identify species suitable for planting in headwater riparian areas to aid the re-establishment of an indigenous vegetation cover as their site characteristics will differ from upslope areas and downstream riparian areas. However, some of these options are expensive, all will require some degree of pest and weed control, and the largely non-economic benefits in afforesting headwater riparian areas will need to be assessed against the costs (both in terms of dollars and the loss of potentially production land).

The next step may be advancing to a case study scenario and carrying out a more in-depth assessment and mapping of riparian areas, and the identification of suitable plant species and restoration options to achieve the management goals. Long-term landowner and community buy-in and managing expectations of what riparian restoration can achieve will be critical to the success of this project.

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