The economics of riparian plantings for carbon and water quality benefit in the Mount Lofty Ranges

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Executive summary

This report is one of a series of reports prepared for the Goyder Institute *Assessing South Australian carbon offset supply and policy for co-beneficial outcomes* project. The project seeks to provide improved understanding of the biophysical and economic potential for carbon sequestration through land use change to carbon plantings across South Australia's intensive agricultural lands.

This report presents a case study assessing potential for carbon plantings in gullies and creek lines in the Mount Lofty Ranges, Happy Valley Reservoir water supply catchment, where there is high potential to produce both significant carbon sequestration and water quality benefits. Evaluating potential for revegetation of currently cleared riparian areas in the catchment to improve water quality and reduce water treatment cost involved: a) estimating phosphorus load reductions resulting from varying streambank vegetation buffer lengths and widths; and b) estimating the resulting impact on phosphorus levels in Happy Valley Reservoir; and c) the reduction in the frequency of algal growth treatments and costs resulting from reduced phosphorus concentrations.

Water quality analysis was complemented with an assessment of the carbon price at which costs of riparian revegetation would be covered by carbon sequestration payments in carbon credit incentive schemes such as the Commonwealth Emissions Reduction Fund (ERF). Two methods for estimating carbon sequestration were considered. The first method used was the official ERF methods that relies on the carbon accounting software Full Carbon Accounting Model (FullCAM). This is the current officially sanctioned method use in estimating credit values in the ERF that is most relevant for the case study. The second carbon supply estimation method relied on data developed by the South Australian Department for Environment and Water (DEW) as a part of the report *Carbon Sequestration from Revegetation: South Australian Agricultural Regions* (Hobbs *et al.* 2013). This method is not officially sanctioned as an ERF method but is more indicative of actual expected carbon yields than the relatively conservative FullCAM measure.

Evaluation based on ERF FullCAM carbon accounting considering full costs (including establishment, maintenance and forgone agricultural production costs) found that high carbon prices (\$75/t CO^2 e) are required to make buffering economically viable for at least 17% of the total stream length that could potentially be buffered. Further, a price of \$125/t CO^2 e would be required for carbon payments to cover costs of buffering on 100% of stream length potentially available for buffering with this form of carbon and cost accounting. Stated differently, carbon credits at \$14/t CO^2 e would only cover about 19% of full establishment plus opportunity cost for the most economical 17% of buffering opportunity.

Estimates of economically viable supply without considering opportunity costs may be appropriate for the many amenity and lifestyles properties in the catchment. The first significant increments of economically viable buffering (15% of all potential stream length that could be buffered) are estimated to be available at considerably lower carbon prices (\$33/t CO^2 e) under these assumptions and 88% of potential buffer area becomes economically viable at \$50/t CO^2 e. Another way to express these results is that carbon credits at \$14/t CO^2 e would only cover about 47% of full establishment costs for the most economical 15% of buffering opportunity.

Carbon prices at which carbon payments offset costs of establishing buffer strips are much lower with the Hobbs *et al.* (2013) estimates of carbon sequestration. For example, with consideration of all costs relevant to production-oriented landholders, 69% of potential buffer area is estimated to be economically viable at a carbon price of \$26/t CO^2e. Without accounting for opportunity cost, 74% of eligible area becomes economically viable at a carbon price of \$12/t CO^2 e.

The results from water quality and treatment cost assessment suggest very high potential treatment cost savings from implementation of buffer strips. For a scenario with buffering of 50% of eligible land on degraded streambanks in the watershed and with ERF FullCAM carbon accounting, potential savings from implementing 10 m buffers were estimated at $200,000/year. The estimated value of water quality benefit is equal to 176% of establishment cost and 95% of establishment plus opportunity cost for the 152 hectares of buffers involved in this scenario over 20 years with 5% discounting. Most 10 metre buffer width scenarios were estimated to produce net economic benefits when both carbon credit value and water quality benefits were considered. The conclusion holds for the ERF FullCAM carbon method with opportunity costs ($0.5M net benefit); for the ERF FullCAM carbon method without opportunity costs ($1.8M net benefit); and for the not currently ERF eligible method (Hobbs *et al.* 2013) with opportunity costs ($2M net benefit).

Twenty metre wide buffers involve double the area (304 Ha for the 50% buffering scenario) and establishment costs and carbon credit values compared to 10 m buffers. However, estimated water quality benefit (avoided treatment cost) increases by just 9% from $200,000 to $218,000. This small increment is a result of diminishing marginal impact of wider buffers. Water quality benefit value only covers about half of establishment and opportunity cost for the FullCAM method for this scenario. A negative net benefit is estimated for FullCAM method with opportunity costs (-$1.6M); but positive net benefit for ERF FullCAM carbon method without opportunity costs ($0.9M net benefit); and for the not currently ERF eligible method (Hobbs *et al.* 2013) with opportunity costs ($1.3M net benefit). Whilst buffer width was found to be the single most influential factor determining potential for net benefit, other factors also impact estimated value of net benefit and should be further explored in future more detailed uncertainty analysis.

1 Introduction

1.1 Overview

This report is one of a series of reports prepared for the Goyder Institute for Water Research project *Assessing South Australian carbon offset supply and policy for co-beneficial outcomes*. The project seeks to provide improved understanding of the biophysical and economic potential for carbon sequestration through land use change to carbon plantings across South Australia's intensive agricultural lands.

The focus this report is a case study that assessed potential for carbon plantings in gullies and creek lines in a Mount Lofty Ranges water supply catchment with potential to produce carbon sequestration and water quality benefits. Both potential carbon sequestration and potential avoided water treatment benefits were valued in physical unit (tonnes of carbon dioxide equivalent, reduced treatment inputs) and in dollar terms.

1.2 Water quality management

Providing safe drinking water requires a water utility to treat the water to adequate health standards. Deteriorated water quality from water supply catchments can often result in the need for added, expensive treatment at a treatment plant. Natural or revegetated (riparian) buffer strips can reduce and naturally treat runoff from agricultural areas.

The Mount Lofty Ranges (MLR) are an important part of South Australia's drinking water network. The catchments in the MLR are generally open to human activity and contain a variety of land uses including urban areas, diverse agricultural enterprises, and industry. As a consequence, reservoirs in the MLR can be subject to high sediment and nutrient loadings. Excessive nutrient loadings into these reservoirs can promote the growth of freshwater blue-green algae (cyanobacteria), which has the potential to produce harmful cyanotoxins and release unpleasant taste and odour compounds. While SA Water, which manages water services for South Australia, has a number of strategies to mitigate these problems, they can be expensive with environmental and safety consequences.

Preventative measures to reduce pollution loads at the source can often be a cost effective way to meeting drink water quality standards compared to treatment of water once it has already been polluted (Connor, 2008). Vegetation buffer strips are one commonly applied pollution source control strategy. A number of international and local studies demonstrate the potential for valuable water supply co-benefits (improved water quality) from increased vegetation plantings along riparian creek lines and gullies. Such plantings can significantly prevent erosion (Barling and Moore 1994; Cooper 1990; McKergow *et al.* 2003), reduce sediment and nutrient loading (Dosskey *et al.* 2002; Sunohara *et al.* 2012) and improve water quality (Dosskey *et al.* 2010; Gharabaghi *et al.* 2002; Mankin *et al.* 2007), while simultaneously reducing water treatment costs required to reach drinking water quality standards.

Whilst it is generally understood that riparian plantings can reduce sediment and nutrient loads and thus have potential to reduce need for expensive water treatment, the hypothesis that riparian plantings may provide significant avoided treatment cost has not been tested previously for Happy Valley Reservoir in the MLR. The reservoir regularly experiences problematic cyanobacterial growth and requires higher treatment costs compared to other SA Water reservoirs such as Myponga, where catchment works (including riparian revegetation for sediment retention) have been widely implemented and the reservoir depth and source water mixing leads to a lower need for cyanobacterial management. The potential to reduce the frequency of expensive treatment to avoid cyanobacterial growth associated with the Happy Valley Reservoir could lead to significant cost savings.

Another reason for focus on gullies and riparian areas in the MLR is that some of South Australia's highest per hectare carbon yields estimated using the Commonwealth Emissions Reduction Fund (ERF) FullCAM method occur in the MLR. However, the carbon yields estimated with this ERF method produce conservative and low spatial resolution estimates of actual carbon yields from reforesting in part of the MLR. Actual values may be larger because ERF estimates may not fully account for fine variation in local gully conditions, where significant runoff from up gradient significantly increases effective rainfall and carbon yields compared to area averages that don't account for topography in the relevant ERF method (Hobbs *et al.* 2013). To the extent that higher carbon yields in these settings can be verified so as to be eligible for ERF payments, the price of carbon required to justify plantings in this setting may be significantly less than have been previously modelled with ERF default carbon sequestration data, for example in the *Assessing South Australian Carbon Offset Supply and Cost* (Regan *et al.* 2019a) report.

1.3 Study objectives

The objectives of this study were to:

- assess revegetation potential of currently cleared riparian areas within the Happy Valley Reservoir catchment with consideration of varying the proportion of eligible stream bank covered, and the widths of buffer strips;
- assess the carbon price at which costs involved would be covered by payments for carbon sequestered for two case: 1) consideration of full cost including cost of forgone agricultural production on reforested area, an appropriate assumption for production-oriented farm property owners and 2) consideration of only establishment and maintenance cost, an appropriate assumption for lifestyle/amenity-oriented property owners;
- estimate sediment and phosphorus load reductions resulting from varying streambank vegetation buffer lengths, and the resulting impact on phosphorus levels in Happy Valley Reservoir; and
- estimate the reduction in the frequency of algal growth treatments resulting from reduced phosphorus concentrations and the associated avoided water quality treatment cost.

2 Case study background

2.1 Water quality issues in Mt Lofty Ranges Reservoirs

The relatively high nutrient load to SA Water's reservoirs in the MLR watershed promotes and supports the growth of freshwater blue-green algae (cyanobacteria), particularly over warmer periods. Cyanobacteria have the potential to produce harmful cyanotoxins, or release taste and odour (T&O) compounds such as MIB (2-Methylisoborneol) and geosmin (trans-1, 10-dimethyl-trans-9-decalol). SA Water's current management strategies for cyanobacteria blooms include near real-time monitoring of algal abundance and stratification in the reservoirs; optimising the management of multiple offtake levels positioned at different reservoir depths at the primary Water Treatment Plant (WTP) inlet locations; operation of in-reservoir aerators; application of copper sulphate as an algaecide; increased monitoring and changes in WTP operations. Enhanced WTP processes, including the application of Powdered Activated Carbon (PAC), are required to remove cyanobacteria-derived T&O compounds. An improvement of water quality (especially the reduction of nutrients, phosphorus in particular entering reservoirs through on-ground catchment management works has the potential to reduce algal blooms and, ultimately, public water treatment costs.

2.2 Case study area: Happy Valley Reservoir catchment

The Happy Valley Reservoir is supplied by a pipeline from Clarendon Weir (in the township of Clarendon). The weir pool receives water from the lower Onkaparinga River catchment, and water released from Mount Bold Reservoir, which receives water from the River Murray via a pipeline and the upper Onkaparinga River catchment. The total size of the catchment above Clarendon Weir is 380 km^2 (see Figure 1). The reservoir capacity is 12.7 GL. The catchment is open to human activities and consists of mixed land uses including grazing beef cattle, sheep, horses, residential, irrigated perennial cropping and annual horticulture. Cyanobacterial blooms in Happy Valley Reservoir are currently mitigated using copper sulphate treatment. Due to the shallow depth of Happy Valley Reservoir and the high network supply demand, there is much less flexibility within the system to manage algal blooms compared to other water supply reservoirs such as Myponga. For example, the 'natural limitation' strategy cannot be applied to Happy Valley Reservoir, primarily due to the lack of multiple offtakes (to avoid intake of algae) and its shallow depth. The current operational mitigation strategy of copper sulphate dosing at Happy Valley Reservoir costs SA Water around $1.3 million per year, requires substantial environmental and safety-related management, and is not always 100% effective at preventing detectable levels of T&O compounds.

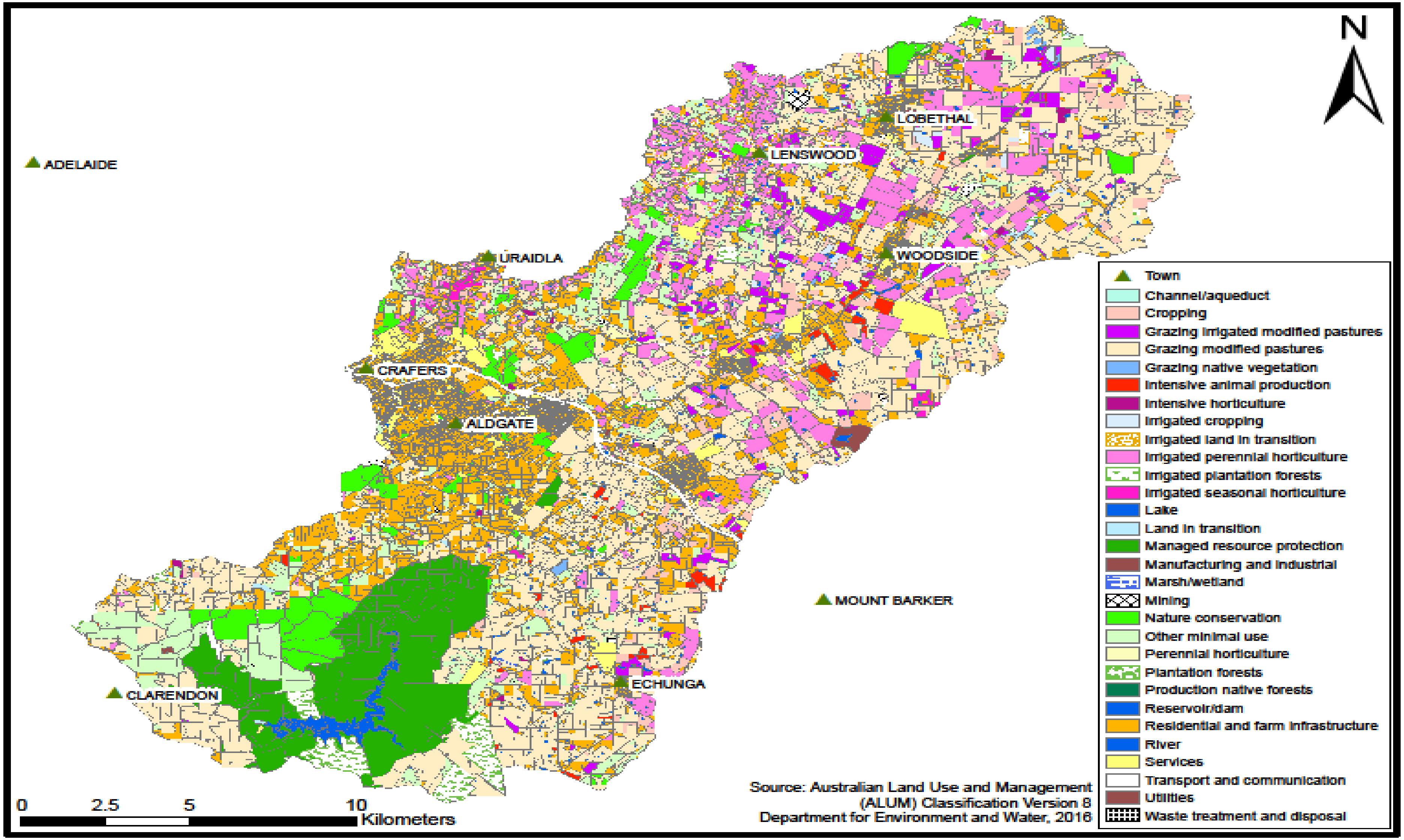


Figure 1: Land use in the upper Onkaparinga catchment.

2.3 Previous riparian works in MLR

The more pristinea water supply catchment is, the less likely it is for its water bodies to experience algal blooms. In addition to solar radiation inputs, light, temperature stratification along a vertical depth gradient, nutrients play a significant role in algal bloom occurrence. The reduction of phosphorus in particular is often considered an essential component as part of a mitigation strategy. Over the last decades, the South Australian Catchment Management Boards, Natural Resources Management Boards, the South Australian EPA and SA Water have collectively supported the improvement of riparian erosion zones, to ultimately reduce the ingress of nutrients and pathogens into water courses. These riparian buffer strips, sometimes in combination of reducing the stream bank slope, have been shown to significantly reduce phosphorus loads into rehabilitated creeks, a finding which was further supported by modelling results as well as monitoring data (e.g. in the Myponga catchment (Ying *et al.* 2011)).

2.4 High carbon yield potential from plantings in Mount Lofty Ranges gullies and stream corridors

There is mounting evidence that the production of biomass of carbon plantings can differ depending on the local conditions (Hobbs *et al.* 2016), which may or may not be adequately incorporated into the currently accepted models used for assessing sequestered carbon (e.g. FullCAM model). Furthermore, the production of carbon biomass in gullies and along creek lines may be especially favourable from a pure carbon production point of view. If this is the case, the price of carbon required to justify plantings in this setting maybe significantly less than have been previously modelled with ERF default methods. The combination of carbon plantings that are viable at prices closer to current ERF prices and potentially valuable water quality co-benefits make carbon plantings along creek lines and/or in gullies in catchments feeding water supply a potentially attractive proposition with high potential to generate benefits with economic value in excess of cost of implementation.

3 Methods

3.1 Water quality modelling

An assessment of the relationships between a) the proportion of stream length with tree planting buffer strips and phosphorus load reductions (; and b) the relationship between phosphorus concentrations in Happy Valley Reservoir and algal treatment frequency was undertaken. SA Water provided information to calculate current costs of algal treatment and how they could be lowered with reduced phosphorus concentrations.

The relationship between tree planting buffer strips and phosphorus loads was established by plotting results from a selected subset of 21 previous peer reviewed studies that measured percentage phosphorus phosphorus load reductions resulting from buffer strip installations (see table in Appendix A). To account for the greater effectiveness of wider buffers, width of buffer strip in trials reported in the studies were plotted on the x-axis and percent reductions and total phosphorus runoff reductions reported were plotted on the y-axis. This provided the basis for a statistical analysis regressing percent phosphorus load reduction on buffer strip width. A logarithm functional form was found to best fit the diminishing marginal phosphorus load reductions associated with increased buffer width. The result of this regression is shown in Figure 2.

In a sense this represents a conservative estimate because the data underlying it includes primarily studies that evaluated grass buffer strips, whereas those that considered tree buffer strips generally found even greater effectiveness. We included all studies for greater sample size and to ensure conservative as opposed to optimistic results.

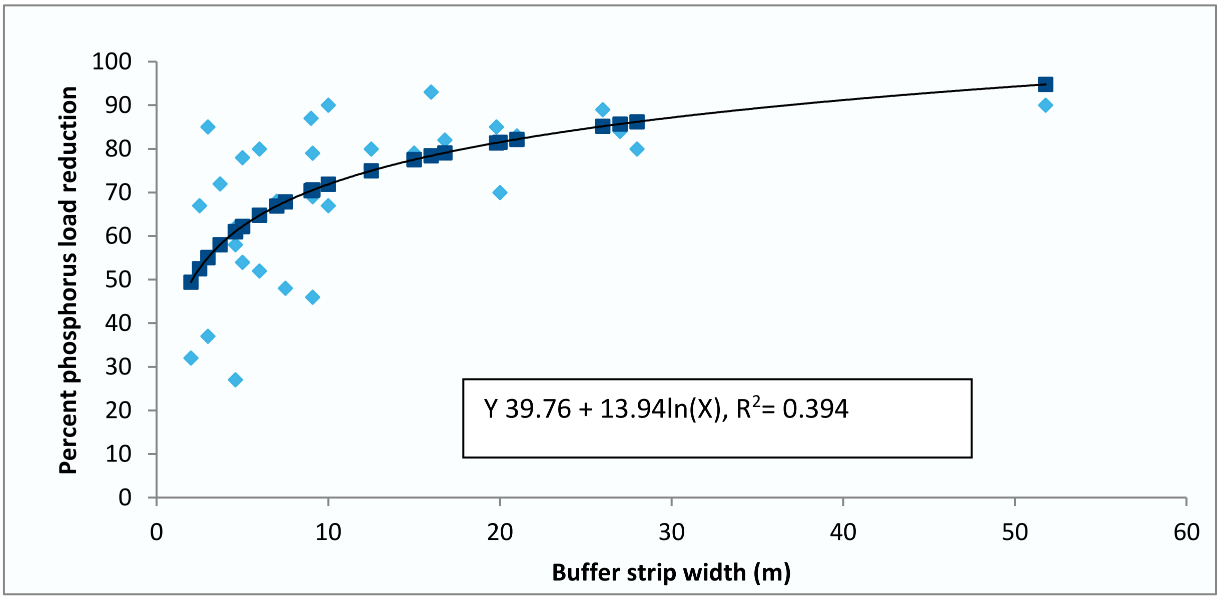


Figure 2: Regression relationship between buffer strip width and percent phosphorus load reduction (diamonds represent data points and squares represent regression point predictions).

Table 1 shows percentage phosphorus load reductions predicted with this relationship for buffer strip widths from 10 m to 40 m. Results show that for each 1% increase in buffered stream length a 0.719% reduction in total phosphorus load to the adjacent stream could be expected for 10 m buffer strips and 0.912% reduction could be expected for 40 m buffer strips.

Table 1: Percent reduction in phosphorus load for varying widths of buffer.

Buffer width (m)	10	20	30	40
% phosphorus load reduction	71.9%	81.5%	87.2%	91.2%

Because the mix of water sources providing inflows to the Happy Valley reservoir would be negligibly influenced by the establishment of buffers, it is reasonable to assume that each one percent reduction in total phosphorus load flowing into the reservoir leads to a one percent reduction in reservoir phosphorus concentration from the base case (*bc*) average of 0.086 mg/L. It is further assumed that even with zero loading from land that can be buffered, some minimal concentration of phosphorus (*mc*) would be present at an assumed level of 0.010 mg/L. Average reservoir phosphorus concentration *c* was estimated as a function of the proportion of area with potential for buffering that is buffered can be written as:

$$c = mc + (1 - \%b * pr_w) * (bc - mc) \qquad (1)$$

where *%b* is the percentage of possible stream length for buffering that is buffered; pr_w is the percentage reduction in phosphorus loading expected for buffered as opposed to unbuffered stream segments; the subscript *w* indicates that this value varies with buffer width; the values for this coefficient for the four buffer widths considered are that values shown in Table 1.

The extent to which lower phosphorus concentrations in the reservoir allow reduced frequency of chemical treatment for algal blooms was inferred from SA Water monitoring data on frequency of treatment and observed concentration of phosphorus in the reservoir over the period 1997 to 2017.

To estimate a relationship between concentration and treatment frequency average concentration in each quarter was categorised as 0 to 0.6 mg/L or >0.6 mg/L. The mean number of copper sulphate doses in quarters with above and below the 0.06 mg/L concentration threshold were then compared for statistical difference and presented as mean as well as upper and lower 95% confidence level difference estimates. The basis for statistical comparison was the Wald confidence interval, a model that is appropriate given the discrete count nature of the dependent variable (doses per quarter) (Agresti and Coull, 1998).

Cost reduction from reduced requirement to treat from the base level of $1.3 million per year was considered. However, only approximately $700,000 of the annual costs are likely to vary significantly with reduced frequency of treatment. These are the costs of treatment chemicals and their application to the reservoirs. The remaining $600,000 cost is primarily for sludge removal and disposal, an element of cost that only marginally varies with frequency of treatment. We chose to treat this as invariant to dosing frequency as a conservative assumption.

3.2 Carbon supply

Cumulative and annual carbon supply was calculated across the study area using two different methods. The first method used was the official ERF methods that relies on the carbon accounting software Full Carbon Accounting Model (FullCAM) (DEE 2016). FullCAM is designed to model carbon sequestration across Australia for a range of species that adhere to ERF project mechanisms and estimate carbon yields that are eligible to earn Australian Carbon Credit Units (ACCUs).

We used the carbon supply estimates detailed in the *Technical Estimation of Carbon Supply Data and Methodology* report (Settre *et al.* 2019), and that formed the basis for the report *Assessing South Australian Carbon Offset Supply and Cost* (Regan *et al.* 2019a). These estimates were developed on a 10 km grid across South Australia, including the MLR, and provided cumulative carbon sequestration over 100 years (Figure 3). The original carbon supply modelling (Settre *et al.* 2019) estimated carbon sequestration for a range of ERF eligible methodologies including environmental plantings, plantation forestry and human induced regeneration. For this study we only considered environmental planting as it more closely aligned with other MLR considerations such as the improved biodiversity. This resulted in carbon supply estimates calculated in tonnes of CO_2e per hectare annually and cumulative over a 100 year time series for each 10 km grid cell falling within the Happy Valley catchment.

The second carbon supply estimation method relied on data developed by Hobbs *et al.* (2013) as a part of the *Carbon Sequestration from Revegetation: South Australian Agricultural Regions* project . This report provides techniques and models to assess carbon stocks and sequestration rates across South Australia with the specific aim of improving the reliability of Australian carbon accounting methodologies. It used extensive data sources including previous revegetation efforts, the Department for Environment and Water's herbarium records and biological databases and a series of destructive and non-destructive surveys across the state to build a database covering plant density, tree/shrub proportions, revegetation age, remnant average height and climate and soil information. This information was in turn used to build a series of regression models for South Australia to predict revegetation and carbon sequestration potential. For a full description see Hobbs *et al.* (2013).

Biomass sequestration raster layers developed by Hobbs et al (2013) were provided for analysis in this study. Raster layers were provided as tonnes of biomass per hectare at 100 m spatial resolution across three time steps: 25 years from planting, 45 years from planting and 65 years from planting (Figure 3).

In order to create a 100 year dataset of CO_2e estimates comparable to the ERF data, a series of pre-processing steps were undertaken:

- Conversion factors were applied to the biomass sequestration estimates to convert them to tonnes of carbon per hectare (0.496) and then to tonnes of CO_2e per hectare (3.67).
- Data values for each layer were capped at the 99^{th} percentile to remove very high values across the study site and ensure conservative carbon supply estimates (Figure 4).
- A 100 year time series was created by dividing the supply in each time step by the number of intervening years. Supply beyond 65 years was assumed to be negligible.

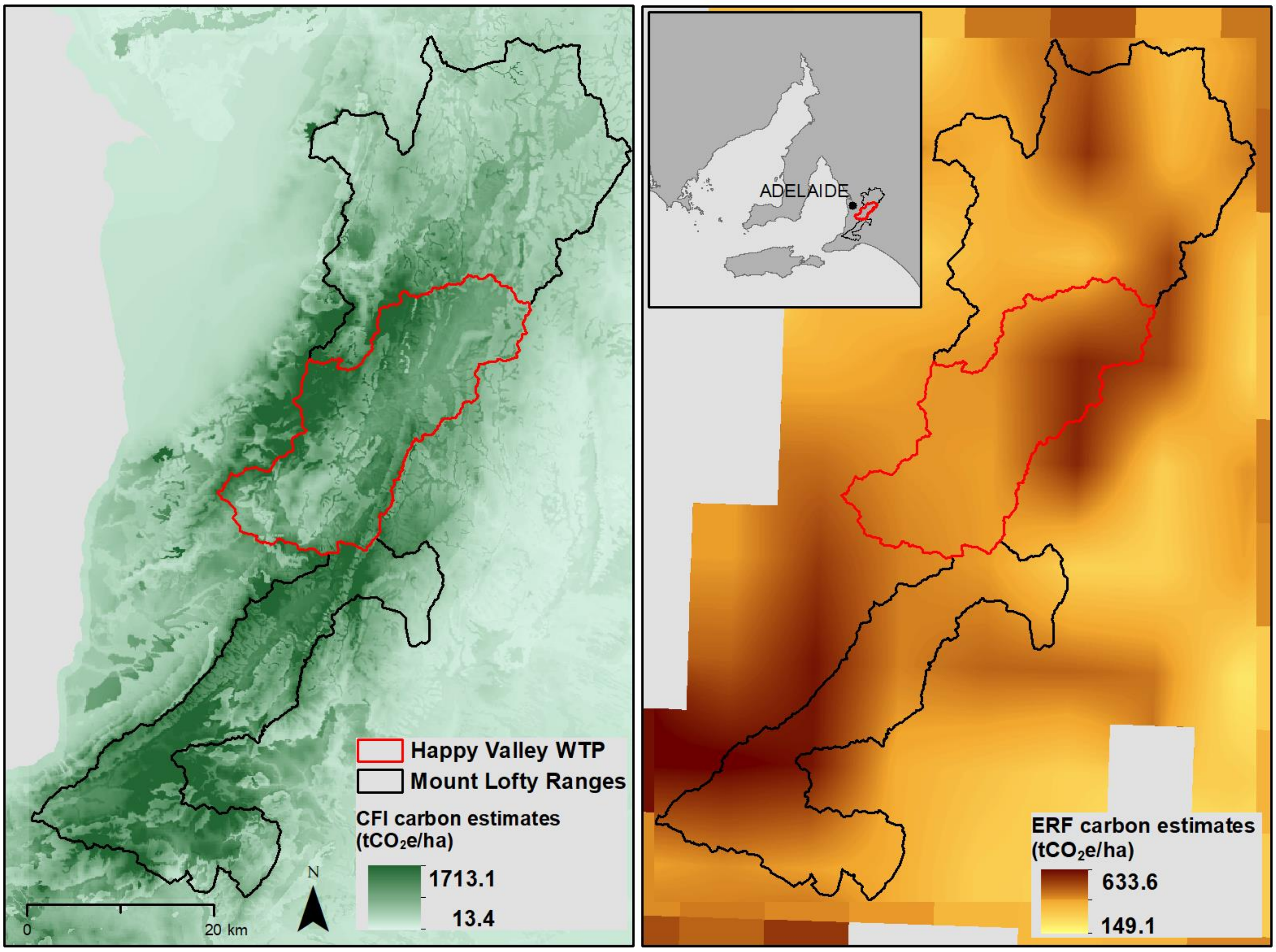


Figure 3: Spatial distribution of Hobbs *et al.* (2013) and the ERF FullCAM carbon supply estimates.

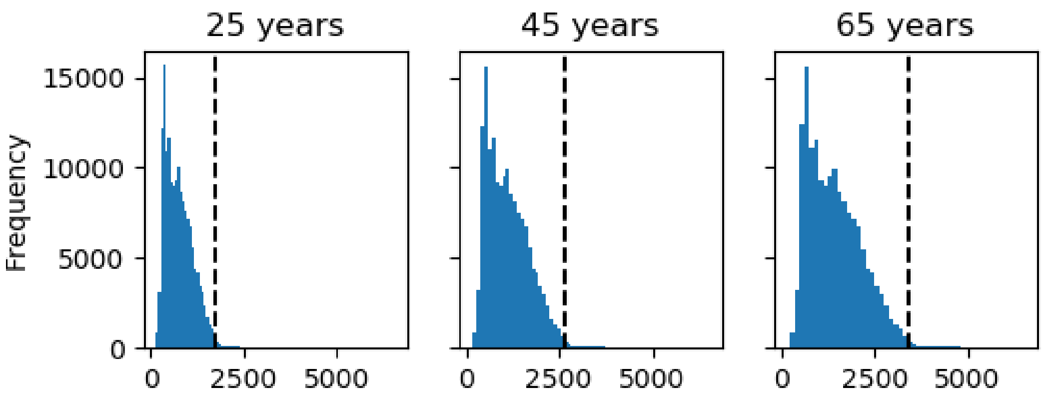


Figure 4: Histogram showing distribution of CO_2e sequestration estimates across locations in the Happy Valley catchment with the Hobbs *et al.* (2013) CFI model. Dashed line shows the 99th percentile.

3.3 Carbon supply economics

Understanding project implementation cost required estimates of the economic viability of buffer strips from the perspective of a landholder. In this case most eligible areas are cleared agricultural land where two costs are relevant: the costs of forest establishment and the opportunity costs from forgone agriculture such as grazing that would no longer be possible. We also considered a scenario where no opportunity costs associated with foregone agricultural production is considered. This is consistent with the way that many lifestyle and amenity property owners who are found in the study area derive and expect little if any agricultural return from their property.

The potential additional income returns from payments for carbon offsets depends on the rules and methods governing the carbon credit payment scheme that credits are sold into. For this analysis we considered the most viable relevant credit payment scheme to be ERF Environmental Planting method. The ERF program builds some degree of conservativism into relevant rules to ensure reasonable probability of truly additional carbon. In the case of the ERF FullCAM Environmental planting method conservativism is included in two ways: 1) a 25 year crediting and a 100 year permanency requirement; and 2) relatively conservative default levels of carbon credit for land use change to environmental planting relative to expected amounts.

For this report the carbon supply economics were calculated across the study site for the two carbon supply methods applied using the economic methods and data outlined in Regan *et al.* (2019b). This method considers the economic returns to carbon sequestration net of the opportunity costs to forgone agriculture (calculated as profit at full equity (PFE)) and establishment and maintenance costs for the carbon plantations themselves.

To deal with the long investment horizon (100 years), net present value methods were applied which involves discounting all future costs and returns: the formulas applied are describe in Regan *et al.* (2019b). To account for the 100 year permanence and 25 year crediting period consistently with the ERF method, only carbon values for the first 25 years are counted but the land use change is required to stay in place and opportunity cost is charged for the entire 100 years. This results in about 25% higher cost per CO^2e than results when 100 years of carbon credit value are considered.

3.4 Spatial analysis

The amount of carbon supply for each carbon modelling method was calculated for buffer distances from streams within the study area of 10 m, 20 m, 30 m and 40 m applied to both sides of stream centreline shapefiles provided by SA Water using ArcGIS 10.5.1 (ESRI 2017) (Figure 5).

Areas within the buffer strips that were not eligible for carbon planting were masked and precluded from further analysis (Figure 5). The masked areas were identified using land use, land cover and forest cover datasets:

- Land cover was defined using the South Australian Land Cover Layers (Willoughby *et al.* 201). Areas classified as ‘Grazing modified pastures’ and ‘Grazing irrigated modified pastures’ were included for further analysis. All other areas were precluded from further analysis.
- Land use was defined using the Australian Land Use and Management Classification (ABARES 2016). Only areas classified as dryland agriculture was included for further analysis, all other areas were precluded.
- Forest cover was defined using the National Carbon Accounting System (NCAS) National forest and sparse woody vegetation data (DEE 2017, Furby 2002). This dataset consists of three classes, forest, non-forest and sparse vegetation. Areas that were classified as non-forest and sparse vegetation were included in the analysis. All forest areas were precluded.

Carbon physical supply and carbon economic supply analysis was carried out on all non-masked areas within the stream buffer zones as described above. All spatial analysis was carried out at 10 m spatial resolution using Python 3.4 (Python Core Team 2014) and the Xarray module.

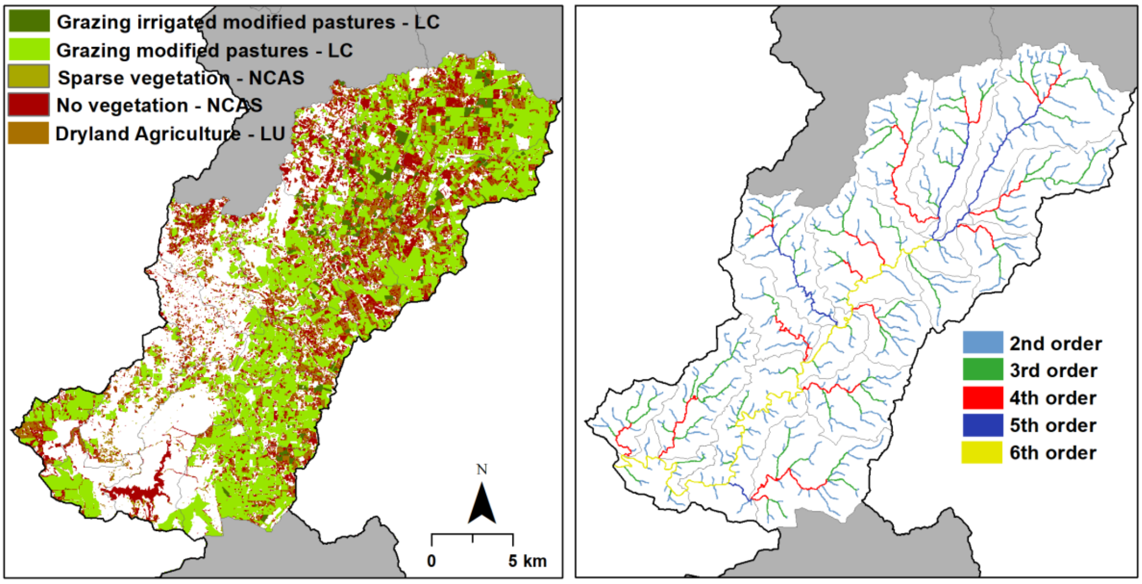


Figure 5: The Happy Valley drinking water catchment showing land use, land cover and forest cover masks and 40 m buffer of stream orders.

4 Results

4.1 Economically viable buffer area and carbon offset supply

Table 2 shows the percentages of eligible stream bank length for which carbon credit economic returns were estimated to be sufficient to cover costs involved and the corresponding hectare areas for differing widths of buffer strip. The results are shown for both methods of carbon sequestration estimation considered and with and without accounting for opportunity cost.

Significant differences in economic viability of covering costs of buffer strips with the carbon credit value they can generate are evident depending on the method of carbon sequestration estimation, carbon price and the set of costs considered.

In the case of the results based on ERF FullCAM carbon accounting, considering full cost (including establishment, maintenance and forgone agricultural production costs), high carbon prices are required for stream buffering to be economically viable. The most economical portion of the stream length that could potentially be buffered, approximately 17% of the total, would cost \$75/t CO^2 e. A price of \$125/t CO^2 e would be required for carbon payments to cover costs of buffering on 100% of stream length potentially available for buffering with this form of carbon and cost accounting.

Estimates of economically viable supply without considering opportunity costs may be appropriate for the many amenity and lifestyles properties in the catchment. The first significant increments of economically viable buffering (15% of all potential stream length that could be buffered) are estimated to be available at considerably lower carbon prices (\$32/t CO^2 e) under these assumptions and 88% of potential buffer area becomes economically viable at \$50/t CO^2 e.

Carbon prices at which carbon payments offset costs of establishing buffer strips are much lower with the Hobbs *et al.* (2013) estimates of carbon sequestration. For example, with consideration of all costs relevant to production-oriented landholders, 69% of potential buffer area is estimated to be economically viable at a carbon price of \$26/t CO^2e. Without accounting for opportunity cost, 74% of eligible area becomes economically viable at a carbon price of \$12/t CO^2 e.

The reason that buffer strip establishment is so much more economically viable with the Hobbs *et al.* (2013) method in comparison to the ERF method of carbon accounting is that much greater levels of carbon sequestration are estimated with that method. This is evident in Figure 6 which shows that much greater estimated carbon supply is possible with the Hobbs *et al.* (2013) method for all orders of streams considered in the study. Furthermore, much greater carbon supply results in much greater returns from carbon payments at any given carbon price. This is why the carbon supply curves for the Hobbs *et al.* (2013) are well below and to the right of the ERF supply curves in all cases (Figure 6). Supply curves moving downward in Figure 6 show that supply of carbon increases in direct proportion to buffer strip width, because area in carbon plantings increases in direct proportion to buffer strip width as shown in

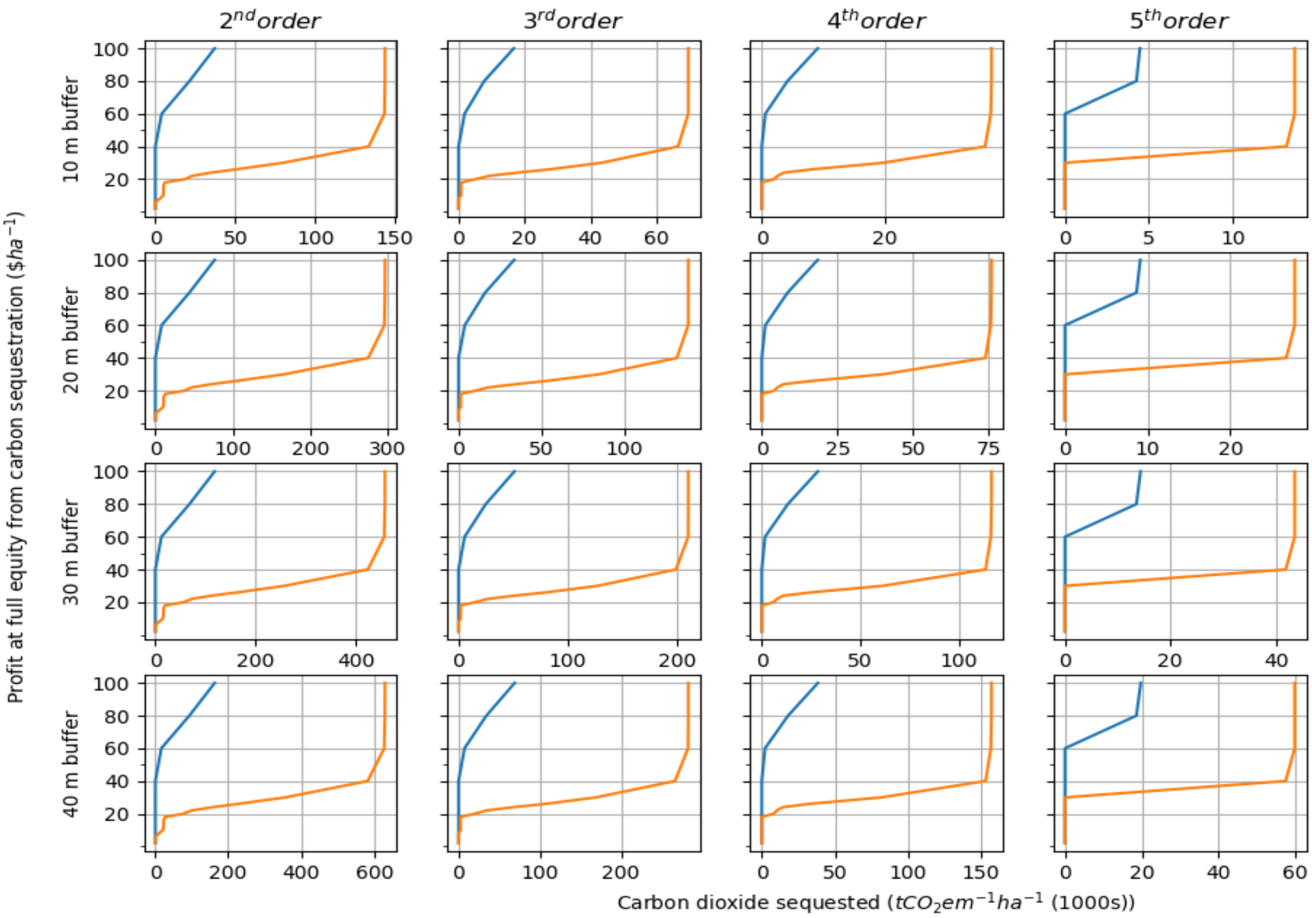


Figure 6: Economically viable carbon abatement at different carbon price points for different stream orders and buffer widths for two carbon sequestration estimation methods (ERF = ERF FullCAM environmental planting method; CFI = Hobbs *et al.* (2013), non-ERF direct measurement) in the Happy Valley catchment.

Table 3 and Table 4.

Table 2: Percent of eligible stream buffer and hectare that would be economically viable at a range of carbon prices.

Hobbs *et al.* (2013) Non-ERF method assuming full cost									
Carbon price ($/t CO2 e)	14	16	18	20	22	24	26	30	40
% eligible stream length buffered	2	10	15	27	41	55	69	92	99
Total area in buffers for 10 m strips (hectares)	4	15	23	41	62	84	105	140	151
Total area in buffers for 20 m strips (hectares)	7	30	46	83	125	169	210	279	302
Total area in buffers for 30 m strips (hectares)	11	45	69	124	187	253	315	419	453
Total area in buffers for 40 m strips (hectares)	15	60	92	165	250	338	421	558	604
Hobbs *et al.* (2013) Non-ERF method assuming establishment and maintenance cost only (no opportunity cost)									
Carbon price ($/t CO2 e)	6	8	10	12	14	16	18	20	
% eligible stream length buffered	1	13	41	74	92	98	99	99	
Total area in buffers for 10 m strips (hectares)	1	20	62	113	140	149	151	152	
Total area in buffers for 20 m strips (hectares)	3	40	125	226	280	297	302	303	
Total area in buffers for 30 m strips (hectares)	4	59	187	339	419	446	453	455	
Total area in buffers for 40 m strips (hectares)	5	79	250	452	559	595	604	606	
ERF FullCAM method assuming full cost									
Carbon price ($/t CO^2 e)	50	75	100	125					
% eligible stream length buffered	0	17	72	100					
Total area in buffers for 10 m strips (hectares)	0	26	110	152					
Total area in buffers for 20 m strips (hectares)	0	51	220	305					
Total area in buffers for 30 m strips (hectares)	0	77	330	457					
Total area in buffers for 40 m strips (hectares)	0	102	441	609					
ERF FullCAM method assuming establishment and maintenance cost only (no opportunity cost)									
Carbon price ($/t CO^2 e)	30	32	38	50	75				
% eligible stream length buffered	0	15	37	88	100				
Total area in buffers for 10 m strips (hectares)	0	24	56	134	152				
Total area in buffers for 20 m strips (hectares)	0	47	111	267	305				
Total area in buffers for 30 m strips (hectares)	0	71	167	401	457				
Total area in buffers for 40 m strips (hectares)	0	94	223	535	609				

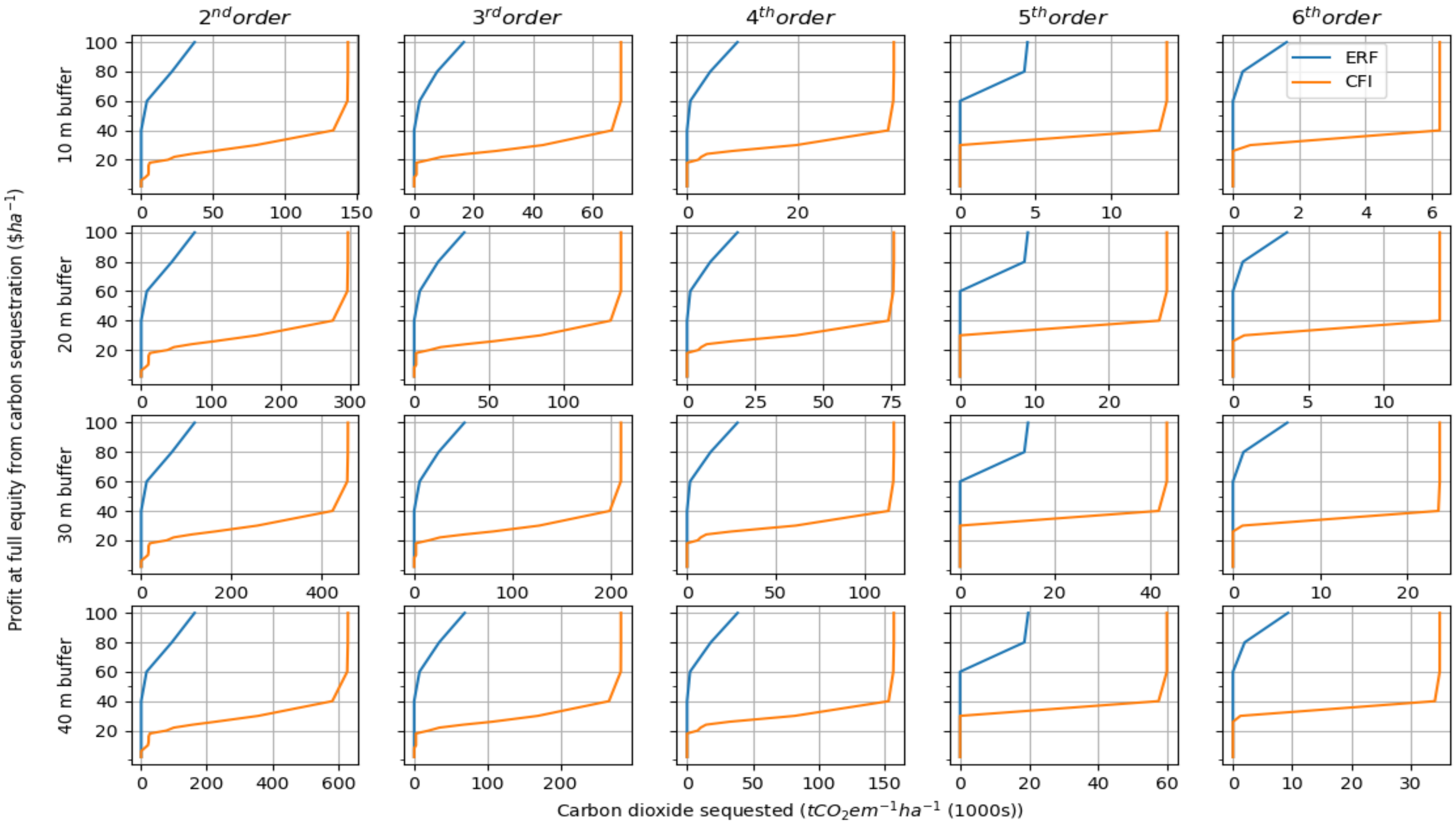


Figure 6: Economically viable carbon abatement at different carbon price points for different stream orders and buffer widths for two carbon sequestration estimation methods (ERF = ERF FullCAM environmental planting method; CFI = Hobbs *et al.* (2013), non-ERF direct measurement) in the Happy Valley catchment.

Table 3: Tonnes CO^2e from economically viable stream buffers at a range of carbon prices with Hobbs (2013) Non-ERF method.

Hobbs *et al.* (2013) Non-ERF method assuming full cost									
% eligible stream length buffered	2%	10%	15%	27%	41%	55%	69%	92%	99%
Total 100 year CO^2e - 10m buffer strips(~~(~~10^3t)	6.6	27	41.6	74.4	112.4	151.8	187.9	248.2	268.6
Total 100 year CO^2e - 20m buffer strips (10^3t)	13.2	54	83.1	148.9	224.8	303.7	375.7	496.4	537.2
Total 100 year CO^2e - 30m buffer strips (10^3t)	19.8	81	124.7	223.3	337.3	455.5	563.6	744.5	805.8
Total 100 year CO^2e - 40m buffer strips (10^3t)	26.4	108	166.2	297.8	449.7	607.3	751.5	992.7	1074.4

Hobbs *et al.* (2013) Non-ERF method assuming establishment and maintenance cost only (no opportunity cost)									
Carbon price (\$/t CO^2 e)	6	8	10	12	14	16	18	20	22
% eligible stream length buffered	2	10	15	27	41	55	69	92	99
Total 100 year CO^2e - 10m buffer strips (10^3t)	2.3	35.6	112.4	201.3	248.4	264.3	268.5	269.3	270.5
Total 100 year CO^2e - 20m buffer strips (10^3t)	4.6	71.1	224.8	402.7	496.8	528.6	537.0	538.7	541.0
Total 100 year CO^2e - 30m buffer strips (10^3t)	7.0	106.7	337.2	604.0	745.2	792.9	805.5	808.0	811.5
Total 100 year CO^2e - 40m buffer strips (10^3t)	9.3	142.2	449.6	805.4	993.6	1057.2	1074.0	1077.4	1082.0

Table 4: Tonnes CO2e from economically viable stream buffers at a range of carbon prices with ERF FullCAM method.

Assuming full cost					
Carbon price (\$/t CO^2 e)	50	75	100	125	
% eligible stream length buffered	0	17	72	100	
Total 100 year CO^2e - 10m buffer strips (10^3t)	0.0	11.2	48.5	66.9	
Total 100 year CO^2e - 20m buffer strips (10^3t)	0.0	22.4	97.0	133.8	
Total 100 year CO^2e - 30m buffer strips (10^3t)	0.0	33.5	145.6	200.7	
Total 100 year CO^2e - 40m buffer strips (10^3t)	0.0	44.7	194.1	267.6	
Assuming establishment and maintenance cost only (no opportunity cost)					
Carbon price (\$/t CO^2 e)	30	33	38	50	75
% eligible stream length buffered	0	15	37	88	100
Total 100 year CO^2e - 10m buffer strips (10^3t)	0.0	10.3	24.8	58.8	66.9
Total 100 year CO^2e - 20m buffer strips (10^3t)	0.0	20.6	49.5	117.5	133.8
Total 100 year CO^2e - 30m buffer strips (10^3t)	0.0	30.9	74.3	176.3	200.7
Total 100 year CO^2e - 40m buffer strips (10^3t)	0.0	41.2	99.0	235.1	267.6

4.2 Water treatment cost savings and net benefit

As described in the methods section of this report, proportion of catchment stream length covered with forest buffer strips was related to percentage phosphorus load reduction. This was further related to changes in reservoir phosphorus concentration and resulting potential to decrease algal growth treatment and the cost saving that could be expected to follow was calculated. The analysis revealed that a reduction in concentration lead to an almost directly proportionate reduction in the need for treatment. For example, it is estimated that reducing concentration of inflow with buffers from the current mean level of 0.086 mg/l to half that concentration could on average be expected to approximately half (reduce by 51%) the mean number of required algal bloom treatment doses. This finding was used as basis to assume that each percentage point reduction in reservoir phosphorus concentration would lead to a directly proportionate reduction in the number of doses.

The results suggest very high potential treatment cost savings for buffering from the baseline level of $700,000/year in costs that vary with concentration. For a scenario with buffering of 50% of eligible degraded streambank in the watershed, potential savings from 10 m buffers were estimated at $200,000/year. Furthermore, the estimated value of water quality benefit over 20 years with 5% discounting is equal to 176% of establishment and 95% of establishment plus opportunity costs for the 152 hectares of buffers involved in this scenario (Figure 7).

Twenty metre as opposed to 10 metre buffers, involve double the area and costs and credit values both double. Estimated water quality (avoided treatment cost) benefit increases by just 9% from $200,000 to $218,000. This small increment is a result of diminishing marginal impact of wider buffers. Water quality benefit value only covers about half of establishment and opportunity cost for the FullCAM method for this scenario (Figure 7).

Cost, water quality benefit, carbon credit value and net benefit estimates are shown in comparison in Figure 7. The 10 metre buffer on 50% of eligible riparian area scenario is estimated to produce net economic benefits when both of carbon credit value and water quality benefits are considered. The conclusion holds for the ERF FullCAM carbon method with opportunity costs ($0.5M net benefit); for the ERF FullCAM carbon method without opportunity costs ($1.8M net benefit); and for the not currently ERF eligible method (Hobbs *et al.* 2013) with opportunity costs ($2M net benefit).

The 20 metre buffer on 50% of eligible riparian area scenario is estimated to produce a negative net benefit for the FullCAM method with opportunity costs (-$1.6M); but a positive net benefit for the ERF FullCAM carbon method without opportunity costs ($0.9M net benefit); and for the not currently ERF eligible method (Hobbs *et al.* 2013) with opportunity costs ($1.3M net benefit). Buffer width was found to be the single most influential factor determining potential for net benefit, other assumptions also impact estimated value of net benefit and should be further explored in future more detailed uncertainty analysis (Figure 7).

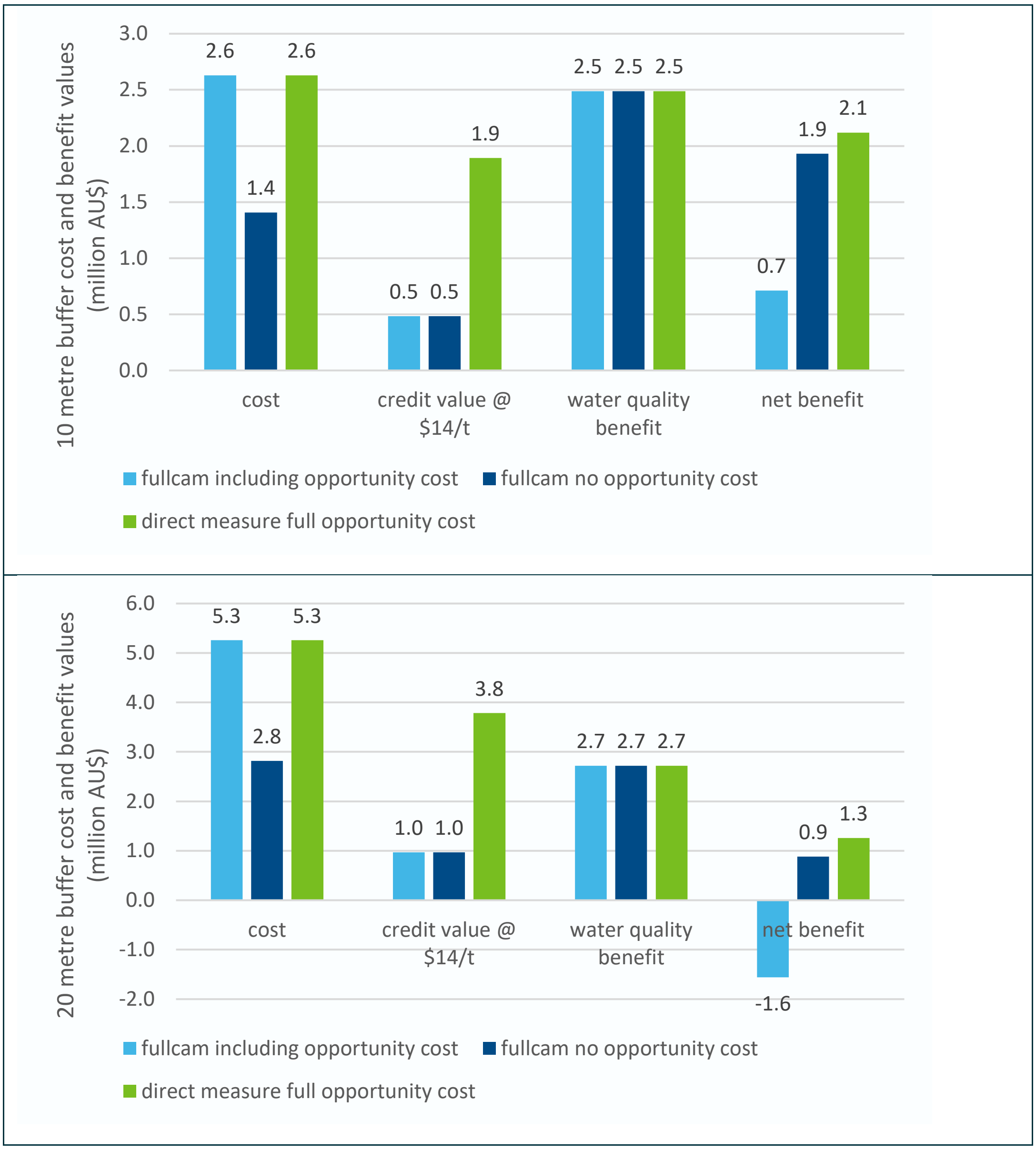


Figure 7: Economic buffer implementation cost, carbon credit value, avoided water treatment cost and net benefit for 10 and 20 metre buffers along 50% of eligible riparian areas (y-axis = $m net present value).

4.3 Uncertainty in water quality and net benefit estimates

As for any ecosystem service economic valuation, uncertainty arises from a number of issues such as: incomplete information about relevant processes and pathways; limits to ability to measure relevant environmental processes; difficulty to control for and measure confounding determinants of complex environmental outcomes; uncertainties around management measures of interest; and uncertainty in non-market and future market valuation estimates. Whilst buffer width, carbon accounting method, and inclusion versus exclusion of opportunity cost were found to be the most influential factors determining potential for net benefit, other assumptions also impact estimated value of net benefit and should be further explored in future more detailed uncertainty analysis.

5 Summary and conclusions

The results of this study demonstrate that planting trees along gullies and streamlines in MLR water supply catchments have significant potential to generate high volumes per hectare of carbon sequestration. However, with the standard method for selling credits into the ERF (FullCAM), the expected returns from carbon credits that would result are unlikely to cover expected costs. Evaluation more specifically suited to the MLR found that actual potential for carbon sequestration in MLR gullies and streamlines may be much greater than the conservative and low spatial resolution FullCAM estimates (Hobbs *et al.* 2013). This study applied carbon estimates using the Hobbs *et al.* (2013) method to assess potential to offset buffer strip forest implementation costs with the value of carbon credits that could be expected to result. We found that if this method could be implemented as a basis for generating carbon credits, a there would be very high potential to offset cost of implementing tree buffers along MLR watershed gullies at recently prevailing ERF carbon credit prices.

This study also investigated potential for water pollution source control with forest buffer strips. Focus was on the Happy Valley water supply catchment because the reservoir is particularly vulnerable to algal growth, which requires expensive and environmentally problematic treatment to ensure safe and palatable drinking water. The requirement to treat algal growth increases with higher concentrations of phosphorus. A large body of previous studies and experience in nearby MLR catchments demonstrates that buffer strips can significantly reduce phosphorus loads flowing into streams. This study estimated potential reductions in phosphorus loads, reservoir phosphorus concentrations, frequency of required treatment and treatment cost savings that could be expected to result from implementation of buffers over significant amounts of presently degraded riparian land along streams and gullies feeding into the Happy Valley reservoir catchment. The results from this assessment suggested very high potential treatment cost savings from implementation of buffer strips on significant amounts of degraded streambank in the watershed. For example, potential savings from implementing 10 m buffers on 50 % of eligible streambank length were estimated at over $200,000/year. Net benefit, including water quality plus carbon benefits, was estimated to be positive for all carbon method and opportunity cost assumptions for 10 m buffers. For 20 m buffers, net benefit was estimated to be positive for two out of three carbon method and opportunity cost scenarios considered. This includes a positive net benefit for the currently feasible ERF FullCAM environmental planting method when opportunity cost for agricultural production isn't a relevant cost.

Whilst there are a number of caveats and limitation to this analysis, it does suggest that there is significant potential for forest buffer strip plantings along MLR streambanks to generate significant carbon value and avoided water treatment cost savings. To the extent that the Hobbs *et al.* (2013) method can actually be implemented, the carbon credit payments that such buffer strip plantings could generate would possibly be sufficient to cover costs involved. Though, this approach may be possible even under current ERF rules, it would require expensive monitoring of actual tree growth which would involve additional costs that are not estimated or considered in results presented here.

Estimated potential water treatment cost saving from stream buffer tree plantings here may also be sufficient to justify some buffer strip planting subsidisation in a way that can still generate net savings. Such subsidisation may be necessary to convince local land holders to implement such plantings if ERF FullCAM carbon accounting is the method applied. This is because the ERF FullCAM method would produce considerably fewer carbon credits and a value of carbon credit payments significantly less than costs of implementing plantings. Additionally, with either carbon planting method, there are number of costs involved with administering carbon credit transactions and property agreements that haven't been estimated for this study. Despite these caveats, the proposition of riparian tree plantings for carbon and water treatment cost saving benefits appears to have high potential and warrant further and more detailed investigation.

Finally, actual implementation would require considering the potential for water yield loss due to additional plantings in the catchments. The Western Mount Lofty Water Allocation Plan (AMLR NRM 2013) stipulates the need for a water allocation permit to be sought if 'plantations' are considered. Whilst the impact on water yield by carbon plantings can be assessed using the prescribed formula in the Western Mount Lofty Water Allocation Plan, policy advice would need to be sought prior to implementing larger scale carbon plantings in the MLR watershed.

References

Agresti, A., Coull, B.A., 1998. Approximate is better than “exact” for interval estimation of binomial proportions. *The American Statistician* 52, 119-126.

ABARES (2016) *The Australian Land Use and Management Classification Version 8*, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra, Australia.

AMLR NRM, Adelaide and Mount Lofty Ranges Natural Resources Management Board (2013) *Western Mount Lofty Ranges Water Allocation Plan*, Government of South Australia.

Barling, R.D. and Moore, I.D. (1994) Role of buffer strips in management of waterway pollution: A review. *Environmental Management* 18(4), 543-558.

Connor, J. (2008) The economics of time delayed salinity impact management in the River Murray. *Water Resources Researc*h 44(3).

Cooper, A.B. (1990) Nitrate depletion in the riparian zone and stream channel of a small headwater catchment. *Hydrobiologia* 202(1), 13-26.

Department of the Environment and Energy (2016) *Full Carbon Accounting Model (FullCAM)* V4.1.6.19417, Available at http://www.environment.gov.au/climate-change/climate-science-data/greenhouse-gas-measurement/land-sector. Australian Government.

Department of the Environment and Energy (2017) *National forest and sparse woody vegetation data. Version 1.0*, Commonwealth of Australia, Canberra, Australia.

Dosskey, M.G., Helmers, M.J., Eisenhauer, D.E., Franti, T.G. and Hoagland, K.D. (2002) Assessment of concentrated flow through riparian buffers. *Journal Of Soil And Water Conservation* 57(6), 336-343.

Dosskey, M.G., Vidon, P., Gurwick, N.P., Allan, C.J., Duval, T.P. and Lowrance, R. (2010) The Role of Riparian Vegetation in Protecting and Improving Chemical Water Quality in Streams1. *JAWRA Journal of the American Water Resources Association* 46(2), 261-277.

ESRI (2017) *ArcGIS Desktop 10.5.1,* Environmental Systems Research Institute, Redlands, California Available.

Furby, S. (2002) *Land Cover Change: Specification for Remote Sensing Analysis.* National Carbon Accounting System Technical Report No. 9, Australian Greenhouse office.

Gharabaghi, B., Rudra, R.P., Whiteley, H.R. and Dickingson, W.T. (2002) *Best modelling practices for urban water systems.* Monogrph 10. James, W. (ed), pp. 289-302.

Hobbs, T.J., Neumann, C.R., Meyer, W.S., Moon, T. and Bryan, B.A. (2016) Models of reforestation productivity and carbon sequestration for land use and climate change adaptation planning in South Australia. *Journal Of Environmental Management* 181, 279-288.

Hobbs, T.J., Neumann, C.R., Tucker, M. and Ryan, K.T. (2013) *Carbon Sequestration from Revegetation: South Australian Agricultural Regionss, DEWNR Technical Report 2013/14*, Government of South Australia, through Department of Environment, Water and Natural Resources., Adelaide, South Australia.

Mankin, K.R., Ngandu, D.M., Barden, C.J., Hutchinson, S.L. and Geyer, W.A. (2007) Grass-Shrub Riparian Buffer Removal of Sediment, Phosphorus, and Nitrogen From Simulated Runoff1. *JAWRA Journal of the American Water Resources Association* 43(5), 1108-1116.

McKergow, L.A., Weaver, D.M., Prosser, I.P., Grayson, R.B. and Reed, A.E.G. (2003) Before and after riparian management: sediment and nutrient exports from a small agricultural catchment, Western Australia. *Journal Of Hydrology* 270(3), 253-272.

Python Software Foundation (2014) *Python Language Reference*, version 3.4, Available at www.python.org.

Regan, C., Connor, J., Settre, C., Summers, D.M. and Cavagnaro, T. (2019) *Assessing South Australian Carbon Offset Supply and Cost.* Goyder Institute for Water Research Technical Report Series 19/03, Adelaide, South Australia.

Regan, C., and Connor, J. (2019) Economic methods for assessing carbon supply costs. *Goyder Institute for Water Research Technical Report Series 19/05, Adelaide, South Australia.*

Settre, C., Cavagnaro, T. and Regan, C. (2019) *Technical estimation of carbon supply data and methodology report*. Goyder Institute for Water Research Technical Report Series 19/04, Adelaide, South Australia.

Sunohara, M.D., Topp, E., Wilkes, G., Gottschall, N., Neumann, N., Ruecker, N., Jones, T.H., Edge, T.A., Marti, R. and Lapen*, D.R. (2012) Impact of Riparian Zone Protection from Cattle on Nutrient, Bacteria, F-coliphage, Cryptosporidium, and Giardia Loading of an Intermittent Stream. *Journal Of Environmental Quality* 41(4), 1301-1314.

Department for Environment and Water (2019) *South Australian land cover layers: an intoroduction and summary statistics*, Department for Environment and Water, Adelaide, South Australia, Available.

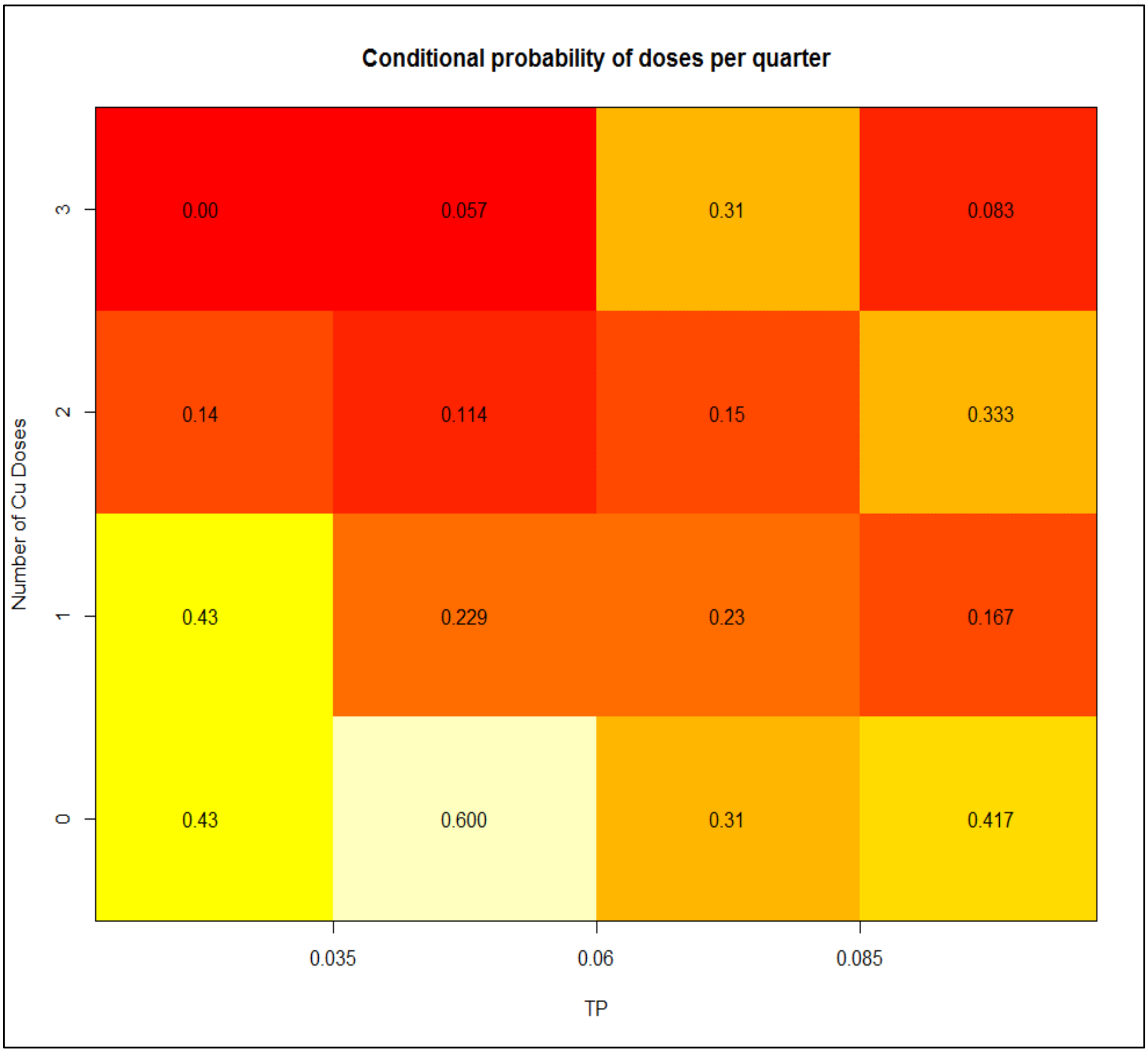
Ying, H., Thomas, S., Fleming, N. and Bradford, G. (2011) *Implementing the Riparian Particulate Model to assess the impact of watercourse project in the Myponga River Catchment*, Perth, Western Australia.

Appendix A

Table A-1: Summary of literature review: Effects of riparian buffers on sediment and nutrient removal from water bodies.

Author	Width (m)	Slope (%)	Efficiency – SS (%)	Efficiency – TP (%)	Efficiency – FRP (%)	Efficiency – TN (%)	Soil type	Composition
Abu-Zreig et al (2003)	2 5 10 15	2.3 - 5	-	32 54 67 79	-	-	Silt loam	Grass
Al-wadaey et al (2012)	3.7	5.5	67 - 84	68 - 76	66 - 73	-	Silt loam	Grass
Borin et al (2005)	6	3	93	80	78	72	Loam	Fescue, shrubs and trees
Blanco-Canqui et al (2004)	0.7 4 8	4.9		53 84 99			Silt loam	Fescue grass Switchgrass
Dillaha et al (1988)	4.6 9.1	5 - 16	81 91	58 69	-	-	Loam	Grass
Dillaha et al (1989)	4.6 9.1	5 - 16	70 84	61 79	-	54 73	Loam	Grass
Duchemin & Madjoub (2004)	3 9	2	87 90	85 87	41 57	85 96 (NO3)	Sandy loam	Grass
Kronvang et al (2000)	0.5 29			32 100				
Lee et al (1999)	3 6	3	66 77	37 52	34 43	28 46	Fine loam	Grass
Lee et al (2000)	7.1 16.3	5 8	-	72 93	-	-	Silty clay loam	Grass-woody
Lim et al (1998)	6.1 12.2 18.3	3		76.1 90.1 93.6			Silt loam	
Lowrance et al (2001)	4.6 16.8 19.8 51.8			62 82 85 90			Loamy sand	Mature hardwood Mature hardwood, mature pines Mature hardwood, mature pines, perennial grass Mature hardwood, mature pines, perennial grass
Lowrance & Sheridan (2005)	2.5	8	-	67	-	-	Loamy sand	Grass
Magette et al (1989)	4.6 9.1	-	66	18 46	-	0	Sandy loam	Grass
Mander et al (1997)	20 28			70 80				
Schmitt et al (1999)	7.5 15	6 7	63 93	48 79	19 50	-	Clay-loam	Grass or shrubs or sorghum
Schwer & Claursen (1989)	26	2	95	89	92	92		Grass
Smith (1989)	11.5	-	87	80	55	85	-	Grass
Syversen (2005)	5 10	-	-	78 90	-	-	-	Grass
Young et al (1980)	21 27	4	67 79	83 84	-	84	-	Grass

Figure A-2: Conditional probability of chemical doses per quarter (Source: SA Water).



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