18th World IMACS / MODSIM Congress, Cairns, Australia 13-17 July 2009
http://mssanz.org.au/modsim09

Plantation buffers for streams in agricultural catchments: developing the knowledge base for natural resource managers and farm-foresters

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Abstract: The use of buffers to protect streams in the agricultural landscape is a priority internationally for investing in water quality protection. However, the quantitative benefits of this practice are difficult to predict for a range of water quality parameters. It also has been generally unclear in Australia how codes of forest practice apply to situations where land managers want to use forest plantation trees in stream-side buffers for both environmental and commercial benefits.

We are conducting research to quantify the effects on water quality and stream flow of using plantation buffers on pastured farmland, and developing knowledge and guidelines that will influence policy and practice. A paired-catchment experiment of the plantation establishment phase has commenced, and other work will address the harvesting phase and farm-scale economics. A range of water quality parameters are being monitored, with hillslope nitrogen dynamics a particular focus for measurement and modelling.

In the establishment phase experiment, pre-establishment monitoring of water quality was followed by installation of the plantation buffer in August 2008. Early results indicate that soil disturbance close to the stream associated and with spot cultivation for tree seedlings has not adversely affected turbidity of stream water.

The HYDRUS model (including the CW2D nitrogen module) will be used for modelling hillslope nitrogen dynamics (mineralisation, nitrification, leaching, runoff, denitrification and uptake) as affected by buffer establishment. The buffer could particularly affect soil water status, denitrification and uptake, the combined effect of which could mitigate nitrogen delivery to the stream. By validating this approach in the experimental catchment, we expect to provide a modelling framework that can be applied to a diverse range of situations, e.g. designing buffer widths and management to achieve particular water quality nitrogen objectives in contrasting soil and climate conditions. Early results will be shown that indicate progress towards this objective.

By linking various aspects of the research we expect to influence streamside buffer adoption and management at several scales. At the national and state scales we are in the process of advising regulators on improvements to codes of forest practice and policy options that encourage adoption. At the regional scale we have started advising natural resource managers of the quantitative effects of streamside buffers on water outcomes. At the farm scale we will be developing guidelines for the practical aspects of buffer management and advising on the expected costs and benefits.

Keywords: *Water quality, hillslope modelling, nitrogen, turbidity, forest plantations*

1. INTRODUCTION

Australia's forest plantation estate has expanded rapidly during the past two decades (BRS, 2009), and most of the development has been large-scale on cleared farmland. Future plantation developments could involve a higher degree of integration with agriculture. This practice already occurs in some areas, and farmers commonly choose gullies for these developments (Reid and Burk 2002).

The use of buffers to protect streams in the agricultural landscape is a priority internationally for investing in water quality protection (Norris, 1993; Barling and Moore, 1994; Fennessy and Cronk, 1997; Lowrance et al., 2002; Robins, 2002). However, the quantitative benefits of this practice are difficult to predict for a range of water quality parameters. It also has been generally unclear in Australia how codes of forest practice apply to situations where land managers want to use plantations of commercial trees in stream-side buffers for both environmental and commercial benefits (Smethurst 2008). In a plantation cycle, most concerns about potential effects on water quality arise during establishment, harvesting, or tending operations that include major soil disturbance, or the application of fertilisers, herbicides or pesticides.

We are conducting research to quantify the effects on water quality and stream flow of using plantation buffers on pastured farmland, and developing knowledge and guidelines that will assist farmers, regulators and other natural resource managers. We are focusing on the establishment, harvesting and fertilising phases. A paired-catchment experiment of the plantation establishment phase has commenced, which includes fertiliser application. Other work will address the harvesting phase and farm-scale economics. A range of water quality parameters are being monitored, with hillslope nitrogen dynamics a particular focus for measurement and modelling. Here we provide an overview of the project, including some early results. The project is due for completion in June 2012.

2. METHODS

2.1 Plantation Buffer Establishment: Paired-Catchment Experiment

A paired-catchment experiment has commenced on two adjacent headwater catchments on a farm near Cygnet, Tasmania, in the Forsters Rivulet catchment (Fig. 1). The farmer's motivation was to use the buffers to provide a range of environment benefits (water quality, shelterbelts, habitat for native animals and plants, erosion prevention, aesthetics, and stock safety) and a future option for wood sales. Research will indicate the extent to which this practice affects water quality and stream flow under these conditions. The farm is a grazing property with only a small proportion of the total area retained as native forests. Cattle have free access to all streams, except those that have been buffered. The paired-catchments, which are in the same paddock and therefore have the same stock management (low intensity rotational grazing), are instrumented for flow, water quality, and weather. A buffer in one of the paired catchments was established in 2008 (Fig. 2) after a period of pre-buffering measurements; the other will remain un-buffered for comparison. To put the water quality of these streams in context with the larger Forsters Rivulet catchment, eight other points between these headwaters and the estuary c. 6 km downstream have been sampled at 3-4 week intervals since July 2007 when flowing, i.e. a spot-sampling program. Dominant land-uses in the catchment are extensive grazing and native forests. The intensively monitored catchments are 5 ha (control) and 11 ha (buffered) in area. Average annual rainfall 1991-2006 was 722 mm (range 501-975 mm). The catchments are in steep terrain. Soils are c. 3 m deep and derived from interlaid slope deposits of cretaceous syenite and permian mudstone.

Water quality parameters being monitored include turbidity, suspended solids, salinity, acidity, nutrients (nitrogen and phosphorus), oxygen, carbon and temperature. The nitrogen (N), phosphorus (P) and carbon (C) measurements in soil solids, soil water, and stream water are expected to contribute to a quantitative understanding of the sources, transformations and transport of these solutes in this and other catchments (see section 2.3).

2.2 Plantation Buffer Harvest: Water Quality Monitoring and International Experience

We have commenced studying the water quality of a tributary of the Pet River near Burnie, Tasmania, where a 20-year-old, stream-side *Eucalyptus nitens* plantation will be harvested in 2009. The catchment receives 1540 mm of mean annual rainfall. The soil is a well-structured clay-loam derived from basalt (Ferrosol). Surrounding land-use is dominantly grazing with some rotational cropping (primarily seed potatoes). Stream level, temperature, turbidity and conductivity are being monitored in a spot-sampling program.

We will also review best management practices for harvesting stream-side plantations in the US and NZ, where such practices occur more commonly than in Australia.

2.3 Riparian Nitrogen Buffering

In the paired-catchment experiment described in section 2.1 there is a focus on N dynamics and its interactions with C and P. Hydrology is being characterised by monitoring the weather, soil water status and stream flow, and assessing salient soil properties like hydraulic conductivity. Quantification of water and N dynamics is being integrated using the HYDRUS model (version 1.05) in a 2-dimensional, sloped, rectangular configuration, and an adaptation of a HYDRUS-compatible N module (CW2D) developed for constructed wetlands (Langergraber et al. 2005).

2.4 Plantation Buffers: Farm-Scale Guidelines and Economics

Later in the project, experience from the project, collaborating farmers, other practitioners, researchers and regulators will be brought together in guidelines for using plantations as stream-side buffers on farms. In addition, a study of farm-scale economics will provide an indication of the expected ranges of net financial costs and benefits of this practice.

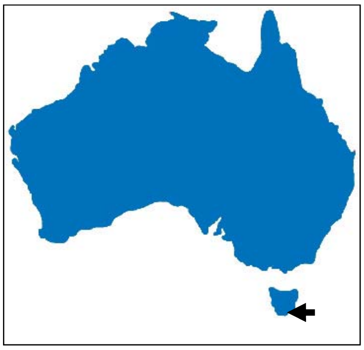

Fig. 1. The plantation buffer establishment experiment is located near Cygnet, Tasmania, Australia (indicated by the arrow).

Fig. 2. A view of the farm where streamside plantations are being established in a paired-catchment experiment. Shown in the foreground is the 2008-established buffer on a headwater stream of one of the paired catchments. The plantation buffer consists of *Acacia melanoxylon* (blackwood) planted in the saturated riparian zone, surrounded by several rows of *Eucalyptus globulus* (blue gum) or *E. nitens* (shining gum). In the middle ground is the 2008-established buffer.

3. RESULTS AND DISCUSSION

3.1 Plantation Buffer Establishment: Paired-Catchment Experiment

By comparing continuous pre- and post-establishment water quality patterns, we have so far detected no deterioration in water quality due to buffer establishment. For example, despite steep slopes, soil disturbance due to cultivation, and spot cultivation as close as 1 m from the saturated riparian zone, an increase in turbidity was not detected during rainfall events immediately subsequent to cultivation (Fig. 3). In both the treated and untreated catchments, turbidity during baseflow was less than 10 NTU compared to 20-30 NTU during rainfall events. This lack of an increased turbidity signal during the establishment phase is probably related to the retention of grass, and the creation of surface roughness by the scoop-and-mound spot cultivation method employed (Fig. 4). Sampling 25 mm into a storm in February 2009, which followed closely after 39 days of grazing, indicated that organic and slightly turbid water running off pastures was reaching the stream of the un-buffered catchment, while water in the weir of the buffered catchment remained clearer (Fig. 5) because runoff had been trapped in the buffer. Sampling after an unusually large storm (65 mm) in March 2009 indicated elevated turbidity in both weirs, which illustrates that buffer efficacy depends on many factors, including buffer design and rainfall pattern. On both these occasions in 2009, turbidity in the control (un-buffered) weir was 7-10 NTUs higher than in the buffered weir.

Spot samples of water quality indicate that the paired catchments (prior to buffer establishment) had similar water quality for most parameters compared to other similar, nearby headwater catchments. Total N data are shown in Fig. 6. Other parameters demonstrating similarity were inorganic N, total and inorganic P, turbidity, total suspended sediments, pH, dissolved oxygen, and temperature. However, electrical conductivity (salinity) was usually highest in the paired catchment that was to be buffered, which might be related to more syenite parent rock in that catchment.

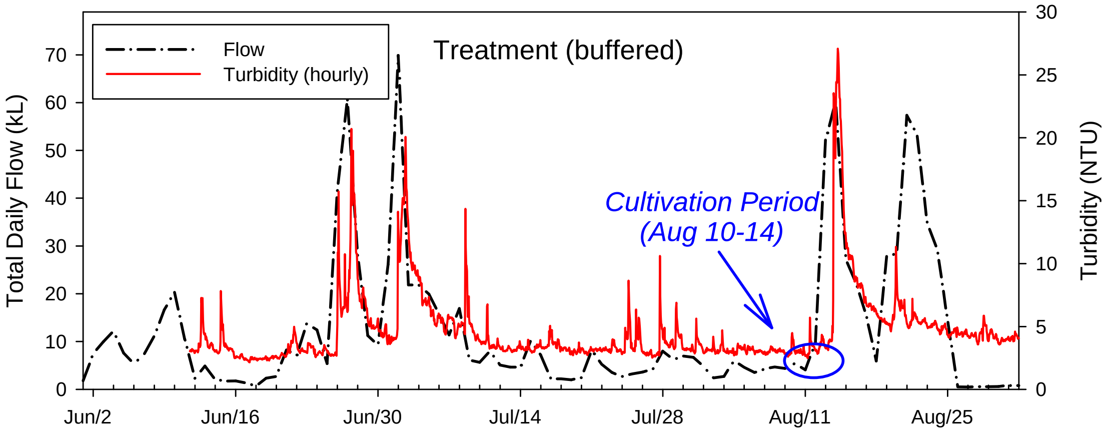

Fig. 3. Temporal patterns of flow and turbidity in the buffered catchment. Spot cultivation was carried out 10-14 August 2008 (indicated). The increase in turbidity with flow during rain events was similar before and immediately after cultivation, suggesting that soil disturbance had not increased stream sedimentation.

Fig. 4. This photo shows a transect across the buffer with spot cultivation by a scoop-and-mound method that increased surface roughness and retained about 50% grass coverage. Note that the saturated riparian zone (indicated by tussocks) was planted to blackwoods, but not cultivated. Eucalypt seedlings were planted on the mounds and white tree-guards were used to protect seedlings from wildlife browsing. The buffer was fenced to exclude stock.

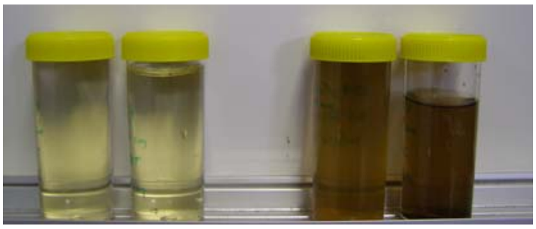

Fig. 5. Water samples taken from the paired-catchment experiment after grazing and 25 mm of rain. The relatively clear samples (left pair) were from the buffered catchment. The coloured and turbid samples (right pair) are from the un-buffered catchment. Within each pair, the left sample was taken from within the weir, and the right sample from the stream immediately above the weir.

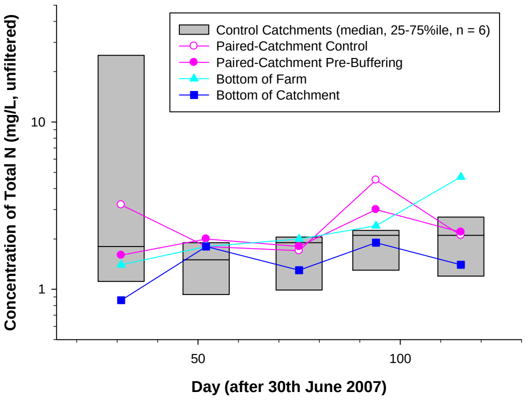

Fig. 6. Total N concentrations in steam water at several points in the Forsters Rivulet catchment. Results show that the samples from streams in headwater catchments of the paired-catchment experiment had similar total N concentrations to those elsewhere in the catchment. Paired catchments are intermittent, headwater streams. The bottom of farm sampling point is usually a permanent stream and c. 300 m below the paired catchments. The bottom of catchment sampling point is a permanent stream c. 6 km below the farm and just prior to the rivulet entering the estuary. The grey bars indicate the median and range of samples taken in six other headwater streams of the catchment that were similar in size and management to those in the paired catchments.

3.2 Plantation Buffer Harvest: Water Quality Monitoring and International Experience

The buffer to be harvested was originally planted for pulpwood production and therefore has not been pruned or thinned (Fig. 7). Never-the-less, some trees have reached a size suitable for veneer or sawlog production. The main stream being sampled flows approximately from south to north. During the period of the study, only the plantations on the eastern side of this main stream will be harvested in order that the remaining plantations on the western side can provide shelter for the new plantation from the predominantly westerly winds. Water will be monitored at points in the stream above and below the reach next to the planned harvest.

There are already examples elsewhere of plantations being established and harvested immediately adjacent to streams. As far as we are aware, no evidence exists and no concerns have been raised that this practice leads to negative impacts on steam water quality if conducted within recommended guidelines (Smethurst 2004, Reid 2008). During the next year, we plan to summarise these and other examples, including operational guidelines and regulatory requirements used internationally for stream-side forestry operations.

3.3 Riparian Nitrogen Buffering

The HYDRUS model was found to have limited use for simulating runoff as overland flow (Smethurst et al. 2009), but with the CW2D module it is expected to be useful for simulating below-ground N pools and fluxes, of which denitrification and plant uptake are the dominant stream-side buffer processes of interest. A hypothetical hillslope simulation incorporating these processes has already been constructed, and we are in the process of specifically adapting the scenario to our study catchments. This research is the first attempt to use the HYDRUS model to simulate hill-slope N dynamics, which, if successful, will offer the possibility of its application in a wide variety of landscapes for integrating climate, land management, landscape features and water quality outcomes.

Fig. 7. A view of the farm with the 20-year-old eucalypt (*Eucalyptus nitens*) plantation (right background) ready for harvesting. This end-view of the eucalypt plantation is the start of about 1 km of a stream-side buffer plantation. The right (eastern) side will be harvested first and a new plantation established before the left (western) side is considered for harvesting and replanting. In the foreground is a 6-year-old up-stream extension of the stream-side buffer using blackwoods (*Acacia melanoxylon*).

4. CONCLUSIONS

Early results indicate that

- cultivation of this stream-side buffer did not lead to increased sediment delivery to streams,
- the paired-catchments are representative of headwater catchments in other parts of the Forsters Rivulet catchment, except for higher stream water salinity in the buffered catchment, and
- it will probably be possible to simulate hillslope N dynamics using the HYDRUS-CW2D model.

The research described above is on-track to advance

- the science of integrating our understanding of water and contaminant transport from farmland, through plantation buffers and into streams, and
- the knowledge base on which famers and other practitioners can plan other plantation buffers.

By linking various aspects of the research we expect to influence streamside buffer adoption and management at several scales. At the national and state scales we are in the process of advising regulators on improvements to codes of forest practice and policy options that encourage adoption. At the regional scale we have started advising natural resource managers of the quantitative effects of streamside buffers on water outcomes, which will assist in prioritising investments in streamside buffering. At the farm scale we intend developing guidelines for the practical aspects of buffer management, and advising on the expected costs and benefits.

ACKNOWLEDGEMENTS

We greatly appreciate cooperation from farmers Chris and Giuliana White, Richard Boland and Rowan Reid. We also value advice or assistance from Dan Neary, Pat Lane, Sarah Munks, Peter McIntosh, Greg Holz, Dale Worledge, Tivi Theiveyanathan, Vijay Koul, Nico Marcar, John Gallant, and David Nash. Plantation establishment was assisted by Private Forests Tasmania. Bill Cotching is assisting with water quality monitoring in the Pet River catchment. The research is funded by CSIRO, the CRC for Forestry, and the Landscape Logic CERF hub. Comments by two anonymous reviewers on an earlier draft were appreciated.

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