Testing and Application of the Riparian Particulate Model

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Keywords: *Riparian Particulate Model (RPM); Riparian buffers; Water quality modelling; Model simulation*

ABSTRACT

The Riparian Particulate Model (RPM) (Newham *et al.* 2005) is a simple conceptual model of particulate trapping in riparian buffer zones. The model represents the processes of settling, infiltration and adsorption which are thought to control particulate trapping. The model is intended for use by catchment managers and researchers to quantify the effectiveness of riparian buffers at site and catchment scales. Application of the model enables assessment of the likely effects of riparian buffer establishment and assists in the prioritisation of investment. The RPM operates at a daily time interval. It is sensitive to the effects of consecutive pollutant loading events and variations in a range of buffer characteristics e.g. vegetation type, buffer slope and size.

This paper reports on testing and application of the RPM. Two experimental studies are simulated for comparison against observed experimental results. Two management-orientated applications are then presented to illustrate potential uses of the RPM. Testing of the model was conducted via comparison of the outputs of the RPM against the experimental studies of Abu-Zreig *et al.* (2001) and Abu-Zreig *et al.* (2004). It was observed in the first comparison that the model consistently underestimated particulate trapping. The nature of the study indicated additional storage capacity may be available for fine particulates, possibly via settling on the surface of the buffer. Further research is suggested to quantify these possible effects. The second comparison (against the study of Abu-Zreig *et al.* (2004)) simulated both coarse and fine particulate trapping mechanisms. This comparison showed much closer agreement between observed and modelled particulate trapping (R^2=0.73). It demonstrated that when adequate information was available to parameterise the RPM, reasonable confidence in outputs could be expected.

The first application of the RPM illustrates the hillslope-scale use of the model. The potential effectiveness of riparian buffer establishment is simulated using input data from an intensively monitored hillslope (MVTB4) of the Wheel Creek subcatchment in the Burdekin River catchment of north Queensland. Results from the simulation show high trapping efficiency for coarse particulates and medium to good trapping for fine particulates. The application demonstrated how the RPM can be used to generate information for the planning of riparian buffer establishment.

The second application is a catchment-scale simulation of riparian buffer effectiveness in the 347 km^2 Pine Rivers subcatchment of southeast Queensland. The application demonstrated that while riparian buffers could be potentially very useful control measures, practical constraints on their establishment can limit their effectiveness as a tool for pollutant trapping at catchment scales. The simulated particulate trapping efficiency of an individual buffer was approximately 75% but constraints on the placement of riparian buffers reduced the maximum potential effectiveness for the catchment to only 4% and hence it is suggested that alternative means of pollutant reduction be investigated.

Further development of the RPM is most constrained by the availability of experimental and field-based data for comparison of model performance and to identify components of the RPM that require further research effort. Testing has identified that additional storage capacity for fine particulates may be available and quantification of this effect is suggested. Other priority research areas include investigation into the reduction in trapping potential due to the damage of vegetation during high flows.

1. INTRODUCTION

Management organisations worldwide are encouraging the establishment of riparian buffers to mitigate the effects of terrestrially-sourced surface-water pollutants. The rationale for the establishment of riparian buffers is often based on experimental evidence demonstrating the success of riparian buffers at trapping pollutants across a range of sites and buffer types. However, several studies have identified the failure of riparian buffers in non-experimental applications. Dosskey *et al.* (2002), for example, describes reduced pollutant removal capacity due to concentrated surface flows. Dillaha *et al.* (1989) describe significant reductions in pollutant removal by riparian buffers owing to the accumulation of pollutants (especially sediment) and the release of soluble nutrients, from trapped particulates. The catchment-scale study of McKergow *et al.* (2003) adds further to these concerns.

Knowledge of the expected pollutant trapping efficacy resulting from the establishment of riparian buffers is necessary for the effective design and planning of riparian buffers. Few, if any, simple and easy to use models are available to enable routine assessment of the effectiveness of riparian buffers for pollutant trapping. This is particularly the case for application in data-poor situations, including in developing countries and in the extensive agricultural areas of Australia.

The Riparian Particulate Model (RPM) was designed to address this deficiency. In this paper we briefly describe the RPM. We then present results from testing against published experimental studies. The application of the model is then demonstrated in two case studies. The first is the hillslope-scale application of the model in a tropical Queensland catchment. A range of simulations of the model are presented and from this information design criteria for the establishment of riparian buffers are suggested. The second simulation is the application of the model to assess the likely effectiveness of riparian buffer establishment at catchment scales.

1.1. Riparian Particulate Model

The RPM is a conceptual model of particulate trapping in riparian buffers. Its intended use is to quantify the trapping capacity of grassed riparian buffers through processes of settling, infiltration and adhesion (Newham *et al.* 2005). The model is generally applied at a daily timestep and has modest and generally widely available input requirements.

The ability of a riparian buffer strip to trap particulates depends on the quantity of material it can store. The RPM is conceptualised to consist of two storages, one for coarse material and one for fine material (Newham *et al.* 2005). The storages collect all particulate material entering the riparian buffer strip until they are full, at which point material begins to pass through.

The capacity of the coarse storage depends on its volume and the density of material that can be packed in it. Coarse material is assumed to be trapped via settling in the vegetated region as well as in the 'backwater wedge' – the area upslope of the riparian buffer strip. The volume of this region depends on the length and width of the riparian buffer strip, the effective height to which particulates may accumulate, and the ground slope. The effective maximum vegetation height is the maximum thickness of a layer of coarse sediment evenly covering the surface of the riparian buffer strip.

Trapping of fine particles can occur via infiltration into a fixed volume corresponding to soil macropores. It is important to note that fine sediment is trapped by infiltration only, and coarse sediment by settling only. The fine particle storage is equivalent to the infiltration volume of the soil volume of the riparian buffer strip. Figure 1 shows the storages of the RPM.

In its hillslope-scale application, the RPM is implemented in the Interactive Component Modelling System (ICMS) (Reed *et al.* 1999). Model users are able to use observed or externally generated data as input to the model. For catchment-scale applications, the RPM is implemented as part of the E2 model (see www.toolkit.net.au for details of E2). Model users are able to apply the RPM to assess the likely effectiveness of riparian buffer strips and identify where in catchments to invest in establishing and protecting riparian buffers. A full description of the RPM and its catchment-scale implementation in E2 can be found in Newham *et al.* (2005).

2. MODEL TESTING

The accuracy of the RPM has been assessed by simulating the performance of experimental riparian buffers as described in the two experimental studies of Abu-Zreig *et al.* (2001) and Abu-Zreig *et al.* (2004). In both studies, a range of riparian buffer strips were subjected to a simulated runoff consisting of a mix of sediment and clear water. Various sizes and slopes were tested, as were a range of vegetation types.

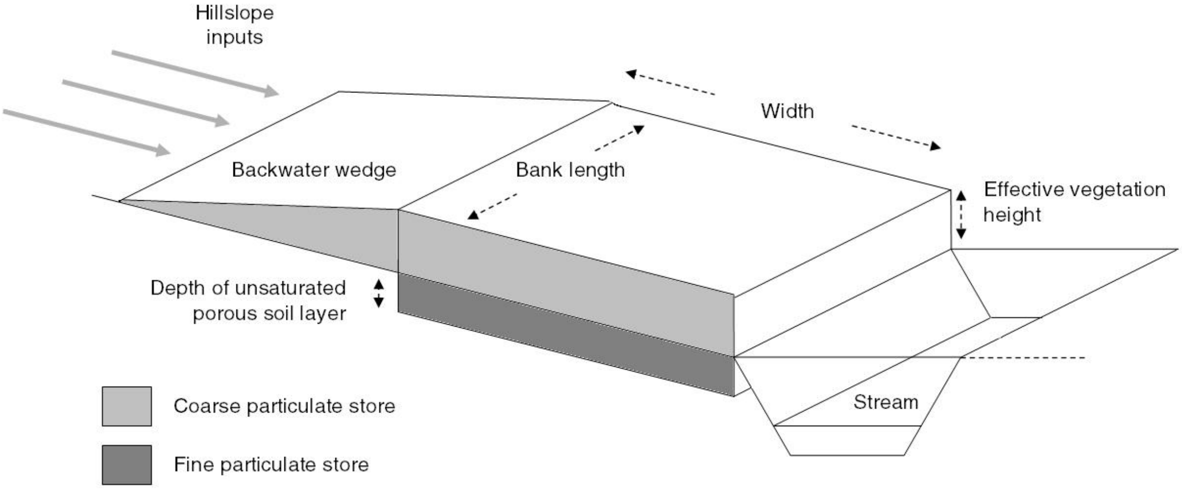


Figure 1. Coarse and fine particulate storages of the RPM.

The model testing focused on hillslope-scale applications of the model. This is thought appropriate given: (i) the relatively simple designs of the experimental studies; and (ii) the performance of the buffer is isolated from possible confounding factors that would influence catchment-scale applications e.g. the need to accurately estimate in-channel sediment sources. For simplicity, the adhesion trapping mechanism was excluded from the testing of both studies as its trapping effect is typically very small relative to infiltration.

The tests conducted involve fixed and variable parameters relating either directly or indirectly to the parameters of the RPM. The riparian buffer strip slope, width and length, as well as the water supplied (flow) and inflow sediment defined in the published papers correspond directly to RPM inputs. The other soil and vegetation characteristics required by the model were defined only in descriptive terms in the published papers. Model parameters were estimated so as to match as closely as possible these descriptions.

2.1. Comparison with Abu-Zreig *et al.* (2001)

Tests conducted by Abu-Zreig *et al.* (2001) subjected 20 constructed riparian buffer strips to simulated flow conditions to determine their particulate trapping efficiency. In each case, the sediment introduced to the riparian buffer strip was silt-sized with a mean diameter of approximately 10 µm. No coarse sediment was introduced. In attempting to replicate these tests using the RPM, it is important to note that given the absence of coarse particles, only the infiltration submodel was used to simulate trapping. Furthermore, the modelled infiltration process is independent of the presence or nature of vegetation, and depends only on the soil macroporosity and depth[†]. These two parameters are used by the RPM to define the size of the fixed storage space corresponding to the potential of the buffer to capture fine particulates.

Our approach was to define a fixed storage volume equal to the size of Abu's infiltration volume, represented below as v (L). Two of the three model parameters, width: w (m) and length: l (m) that describe the fine storage volume were specified in the published papers. For testing purposes only, we assumed that the soil had a 100% porosity. The third parameter, soil depth, d (m) was then calculated as follows:

$$d = v / 1000wl \qquad (1)$$

[†] Vegetation type may affect macroporosity but an explicit relationship is not built into the RPM.

Figure 2(a) shows the performance of the model (observed versus modelled results). It can be seen that the RPM underestimated the trapping efficiency observed by Abu-Zreig *et al.* (2001) in virtually all cases. The worst performance occurs at low-medium trapping. The underestimation of the RPM relative to Abu-Zreig *et al.* (2001) may point to additional trapping capacity in the buffer but which is not currently simulated in the RPM. Further experimental investigations are required to identify the type and capacity of any additional storage. Potential storages include: (i) the flocculation and settling of fine particulates on the surface of the buffer and in the backwater wedge; and (ii) infiltration of fine particulates in the backwater wedge.

2.2. Comparison with Abu-Zreig *et al.* (2004)

Later experimental work conducted by Abu-Zreig et al. (2004) was conducted in a field with a soil profile comprising 38% sand-, 54% silt- and 8% clay-sized particles. It was assumed that one quarter of the silt-sized particles had a diameter greater than 50 µm (the threshold used in the RPM to differentiate between coarse and fine particulates) and hence the RPM was tested with a sediment input with a proportion of fine particles of 0.485.

Soil depth was estimated using the method described in Section 2.1. In this case, however, v was calculated from values of buffer water retention percentage (r) and water supplied (Q) specified in the published paper according to the following relation before being substituted into equation (1).

$$v = Q(r/100) \qquad (2)$$

For this simulation, coarse particles were introduced and hence the values of vegetation-related parameters became important. The RPM's maximum effective vegetation height parameter ($h_{\max}$) determines the storage capacity of the vegetation, and thus impacts on the efficiency with which the buffer captures coarse particulates. It can be thought of as the maximum depth of coarse particulates that can be trapped via settling. The two variables given by Abu-Zreig *et al.* (2004) are vegetation type and mean vegetation coverage (%). The experimental results described in the study suggest that the type of vegetation had little effect on the trapping efficiency of the buffer except where there was no vegetation present. There is a trend in the experimental results to suggest that an increase in mean vegetation coverage corresponds to an increase in trapping efficiency. In accordance with these tendencies, it was decided that a linear relationship between the experimental parameter mean vegetation coverage (c) and the model parameter ($h_{\max}$) should exist.

Given the nature of the storage capacity concept central to the model, the following calculation was used to determine appropriate values of ($h_{\max}$) for each model simulation of an experimental equivalent:

$$h_{\max} = h_{local}(c/100) \qquad (3)$$

where h_{local} is the average effective vegetation height representing the height to which a layer of coarse particles can increase before coarse particulate trapping stops (note that $h_{local} = h_{\max}$ if $c = 100\%$). Fixing the bulk density of coarse sediment at 1.5 t/m^3, various reasonable values for h_{local} were applied to the model. All such values resulted in a large potential storage potential for coarse sediment resulting in a trapping efficiency of 1. Indeed, for all values of h_{local} above 0.00002m (0.02mm), this was the case. An arbitrary value of h_{local} = 0.1mm was chosen above this threshold.

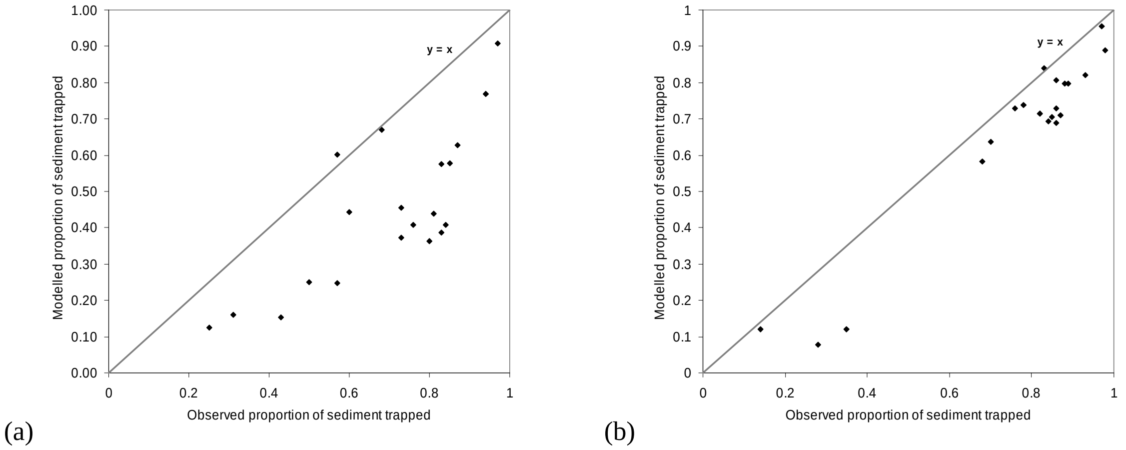
Employing both of its submodels, the RPM more closely simulated the results observed by Abu-Zreig *et al.* (2004) (R^2=0.73). Results can be seen in Figure 2(b).

3. WHEEL CREEK SUBCATCHMENT APPLICATION

The application of the RPM in the Wheel Creek subcatchment is intended to demonstrate the use of the model for assessing the likely effectiveness of riparian buffer establishment at hillslope scales.

3.1. Location and management issues

The Wheel Creek subcatchment is part of the Burdekin River catchment of north Queensland. The Burdekin River catchment is a large contributor of sediment and nutrient loadings to the Great Barrier Reef lagoon. Research and management organisations are actively investigating options, including riparian buffer establishment, for the control of sediment and nutrient pollution e.g. Roth *et al.* (2003).



(a)

(b)

Figure 2. Model performance against experimental studies and represented as modelled versus observed particulate trapping: (a) Abu-Zreig *et al.* (2001), $R^2 = -1.03$; (b) Abu-Zreig *et al.* (2004), $R^2 = 0.73$.

Annual average rainfall in the Wheel Creek subcatchment is approximately 660mm. Rainfall, while summer dominated, is highly variable both temporally and spatially. A correspondingly high level of variability is observed in surface flow events.

3.2. Simulations

Since early-2001, surface flow and sediment exports from the Wheel Creek subcatchment have been intensively monitored at four sites by CSIRO researchers (see Post *et al.* (2005) and Roth *et al.* (2003) for further details). Data from these surface flow events (16 in total until the beginning of 2005) are used as input to the RPM. Results are presented here for MVTB4 site which has the highest sediment yields among the four sites.

The model was applied at a daily timestep using the parameter values shown in Table 1. A riparian zone of 40m (20m on both sides of the channel) is used as a base for simulations for the 0.13 ha study site. An initial riparian zone width of 10m was used in the simulations. Again, for simplicity, the adhesion component of the model is not used. Model outputs (expressed as trapping efficiency) under a range of scenarios, are reported in the following section.

3.3. Results and discussion

Using the parameter values of Table 1, the modelled sediment trapping was 76% with simulated trapping of 100% and 70% for coarse and fine particulates, respectively. The trapping of all coarse sediment indicates a high storage capacity even for relatively small buffers.

Table 1. Parameter values used in the Wheel Creek application.

Parameter	Value	Units
Proportion of fine sediment	0.8	-
Vegetation growth rate	0.001	m/day
Maximum effective vegetation height	0.005	m
Lower damage flow threshold	0.5	ML/m
Upper damage flow threshold	3.0	ML/m
Bulk density of deposited coarse sediment	1.5	t/m3
Soil macroporosity	0.3	-
Soil depth	0.2	m
Slope	5	degrees

Figure 3 shows simulated trapping efficiencies for fine sediment for a range of values of soil depth. It can be seen that a threshold exists at a soil depth of approximately 0.15m beyond which the rate of additional trapping declines. Similar plots and look-up tables can potentially be generated for other buffer characteristics for the planning for establishing riparian buffers.

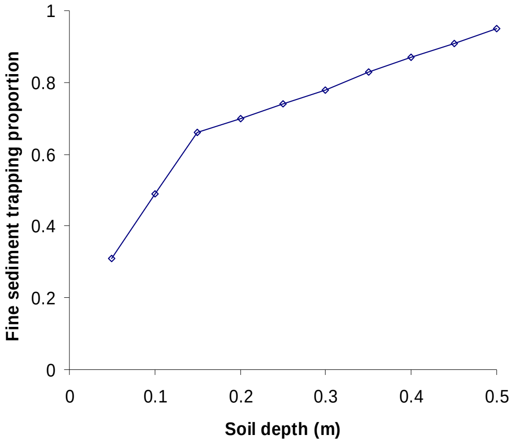


Figure 3. Simulated fine sediment trapping efficiency versus soil depth.

4. PINE RIVERS CATCHMENT APPLICATION

The Pine Rivers application demonstrates the use of the RPM to estimate the effects of riparian buffer establishment at catchment scales.

4.1. Location and management issues

The Pine Rivers catchment is located to the north east of the city of Brisbane. The northern branch (North Pine River), flows into Lake Samsonvale, a major water storage in the South East Queensland region. The management of water quality within this storage is critical to ensure the supply of potable water for the greater Brisbane area. Most of the North Pine River catchment is rural in nature, with smaller settlements having some urban and peri-urban development. Grazing occurs in parts of the catchment along with other agricultural activities such as horticulture and dairying. Little riparian vegetation remains, particularly in the eastern parts and lower reaches of the catchment.

4.2. Simulations

In the catchment-scale application of the RPM, inputs from the E2 model are required for the generation of time series of overland flow and particulate inputs. The RPM acts to filter particulates from surface flows prior to their entry into streams. The primary output from the model is a daily time series of particulates flowing into streams and an estimate of overall riparian buffer performance. While it was intended to use an integrated version of the RPM within the E2 model, it was found that a stand alone version was more flexible and easier to implement when riparian buffers were being considered for application in only small numbers of catchments.

Two scenarios were tested. The first entailed the application of riparian buffers in all grazing, agricultural and rural residential lands in the catchment. A second scenario evaluated those areas where application of riparian buffers was most practical.

4.3. Results and discussion

The standalone RPM module was used to give results for a standard length and width riparian buffer using locally specific climate and catchment data for parameterisation. These results were then used as the basis to implement reductions in Event Mean Concentrations from all land uses where the riparian buffer applied. This translated to a 75% reduction in TSS; and a 20% reduction in TP.

It is important to note that the above reductions imply that all runoff predicted by E2 travelled through the stream buffer; in other words this is the maximum achievable reduction pollutant loading possible via this mechanism. For this reason, the second scenario examined the extent of ‘practical application’ of the buffer as discussed above. When completed, this yielded reductions of only 4% for both TSS and TP.

These results demonstrated that previous assumptions of the implementation of riparian buffers as a fix-all for pollutant export in a catchment can be severely hampered by the constrained spatial extent of buffer application. This was particularly the case in the North Pine catchment. In determining the efficacy of riparian buffers, it was critical that the extent of potential application was determined. This was completed through examination of several catchment attributes, such as topography (buffers are most practically applied in 2-5% slopes) and land use (buffers are most likely to be effective in grazing lands). Once these attributes were combined with identification of stream orders, understanding of the constraints in implementation of a catchment-wide riparian buffer program were highlighted. This indicated that the catchment attributes dictated the extent of buffer application and hence the overall effectiveness of the application of buffers. This and use of the RPM showed that unless very high levels of buffer implementation occured (where the catchment attributes were conducive to buffer application), other changes such as urban stormwater quality management were potentially more effective measures for pollutant control.

5. SUMMARY

There is a pressing need for simple and easy to use models to enable assessment of the effectiveness of riparian buffers for pollutant trapping. The RPM was developed to address this knowledge gap for particulate trapping. The RPM captures important features of riparian buffer performance and enables investigation of the anticipated effects of changes to a range of buffer characteristics e.g. width, slope, vegetation type and placement. The RPM is applicable for use at hillslope or catchment scales.

The testing of the RPM is a challenging task due to the difficulty in obtaining experimental data that is sufficiently well described to enable correct parameterisation of the model. The performance of the RPM was assessed here relative to two experimental studies. It was found that the RPM matched observed trapping efficiencies well when its parameter values were well known.

Applications of the RPM at hillslope and catchment scales have also been demonstrated. The hillslope-scale application showed the potential for the model to simulate the likely effects on pollutant trapping of changes in common buffer characteristics. The catchment-scale application demonstrated the use of the RPM within a broader modelling context. It was possible, in the catchment-scale application, to compare the effectiveness of riparian buffer establishment against other potential pollutant control measures.

Further development and testing of the RPM is required to improve confidence in model outputs. Those intending to use the RPM for management purposes should, where possible, implement monitoring programs to ensure correct parameterisation of the model. Further testing is needed at catchment scales. Testing of the performance of parts of the model that have not been thoroughly assessed, e.g. the reduction in trapping potential due to the damage of vegetation by high flows, is also needed.

6. ACKNOWLEDGEMENTS

The RPM was developed as part of a Land & Water Australia-funded project (CLW55). The collection of data for the Wheel Creek application was funded by Meat & Livestock Australia and CSIRO Land and Water. John Ramsay graciously provided access to Meadowvale Station to enable the data collection to proceed. The Pine Rivers catchment application was undertaken by WBM Oceanics on behalf of SEQWater. The authors are grateful for the assistance of each of these organisations and also to the many people involved in those projects.

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