Integrating Modelling And Field-Based Analysis For Improving Catchment-Scale Pollutant Management: An Application Of The Catchmods Model In The Moruya River Catchment

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EXTENDED ABSTRACT

Water quality decline is a significant environmental issue in Australia and many other countries. Much emphasis has been placed on nutrient management especially for phosphorus (P) and nitrogen (N) in an attempt to reduce their loss to water bodies. Identifying nutrient sources and their transport potential can assist catchment managers to recognise critical nutrient sources and to devise management interventions for their control.

High concentrations of ammonia and phosphate have been observed in the available water quality data for the Moruya River, indicating the potential risk of eutrophication (AMOG Consulting, 2003). Stream bank erosion has been identified as a major erosion problem for the Moruya Estuary and is a potentially significant source of nutrients. However, the impacts of stream bank erosion on sediment output and nutrient loss have not been well quantified and the costs of stream bank management have not been adequately assessed.

This study demonstrates the use of an integrated modelling and field sampling approach to improve identification of nutrient sources. The Catchment-scale Management Of Diffuse Sources model (CatchMODS) was used to estimate suspended sediment yields under a variety of management change scenarios in the Mogendoura Creek subcatchment of the Moruya River, NSW. Nutrient source strengths were determined from field and laboratory analysis of soil nutrient concentrations (total N and total P). Soil samples were collected from different land uses (dairying, beef grazing and forest) and from actively eroding areas (gullies and stream banks). By incorporating the nutrient field data and modelled sediment yields, the annual particulate nutrient inputs under each of the management change scenarios were estimated. Scenarios were investigated representing the current (business-as-usual) situation, the effects of afforestation and the effects of various channel erosion management measures.

Results show that stream bank erosion is the largest sediment and particulate nutrient input to the subcatchment. Currently, stream bank erosion is estimated to contribute over 2000 t/yr of suspended sediment yield, followed by gully erosion (336 t/yr) and hill slope erosion (2.3 t/yr). Stream bank, gully, and hill slope erosion contribute differently to nutrient loss. More than 85% of the N and P loss is estimated to come from stream bank erosion, mainly due to the high rate of suspended sediment delivery. Severe gullies contribute 12% of the N and P loss. The remainder of erosion types are estimated to contribute only 3% of total particulate nutrient loss.

Accordingly, management practices applied to riparian areas, employing either engineering or revegetation techniques, are thought to be the most effective and also the most economical way to reduce nutrient-associated water quality impacts. Land use change, such as converting pasture to forest, was found to have a very limited effect on reducing nutrient transfer. The opportunity cost of losing income from grazing, however, is high. Nevertheless, for catchments which have lower levels of erosion and more intensive land uses, such as dairying, the recommended management interventions may be quite different. The paper demonstrates the advantages of combining modelling and field work for improving water quality management.

1. INTRODUCTION

Water quality decline is a significant environmental issue in Australia and many other countries. Much emphasis has been placed on nutrient management especially in measures to control phosphorus (P) and nitrogen (N) loss to water bodies. A body of research has focused on the relationship between nutrient exports and suspended sediment yields (e.g. Nelson *et al.*, 1996; Mitchell *et al.*, 1997; Letcher *et al.*, 1999). These have shown considerable promise for management assessment and planning purposes.

Sediment and nutrient loads can be estimated using empirical data analysis, modelling techniques or a combination of the above (Croke & Jakeman, 2001). The combination of techniques, i.e. incorporating empirical data into models, affords substantial advantages. This paper aims to demonstrate an integrated modelling and field-based approach for improving catchment-scale pollutant management. A case study of the Mogendoura Creek subcatchment, Moruya River, on the south coast of NSW is used. The Catchment-scale Management Of Diffuse Sources model (CatchMODS) is used to predict sediment yield under different management scenarios (Newham *et al.*, 2004). Information from the CatchMODS model is incorporated with soil nutrient concentration data to improve assessment of techniques for reducing particulate nutrient loads from the catchment.

2. STUDY CATCHMENT

The 4280 ha Mogendoura Creek subcatchment is located in the lower part of the Moruya River catchment of the NSW south coast. Geologically, biotite granite dominates the central subcatchment, and the watershed of the subcatchment is dominated by Ordovician sedimentary rocks (NSWDM 1966).

The Mogendoura Creek subcatchment occupies only 3% of the Moruya River catchment but contains 10% of the total extent of stream bank erosion and over 70% of the severe gully erosion occurring in the catchment. A large proportion of the stream banks and gullies have little vegetation cover, indicating the possibly of high sediment contribution.

Forestry and cattle grazing are the two dominant land uses in the Mogendoura Creek subcatchment. A 160 ha dairy farm is situated near the headwater of the subcatchment. Only 1% of the total area of the subcatchment is cropped (Baginska *et al.* 2004).

3. FIELD SAMPLING AND ANALYSIS

A field soil survey was conducted in early November 2004 in forest, beef cattle grazing, and dairy effluent discharge sites. In addition, soil samples were collected from selected actively eroding areas along gullies and stream bank sites. All samples were collected at sites with the same underlying geology. The locations of these land use, erosion areas and sampling sites are shown in Figure 1.

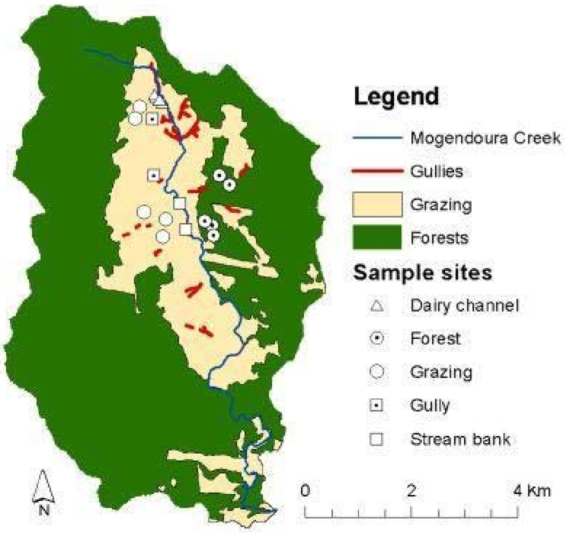

Figure 1: The distribution of land use, erosion areas and soil sampling sites in the Mogendoura Creek subcatchment.

Five forest surface soil samples were collected from accessible locations, using a soil auger to 10 cm depth. Replicate soil cores were collected separated by a few metres. A sample was amalgamated from three cores in order to collect a representative bulk sample. Five beef grazing soil samples and six dairy effluent channel samples were collected using the same technique as that used in the forest sampling. Two gully wall and two stream bank sites were selected. Each had little vegetation cover except for some scattered pasture plants.

After collection in the field, soil samples were air dried and then passed through a 2.0 mm sieve. Subsamples were placed in sealed glass vials and moved to the laboratory for total N and total P analysis. The determination of soil total N and P is based on the method (Johnston, 1995) developed jointly by the Department of Forestry, ANU and

CSIRO Division of Forest Products using a Technicon Auto Analyser Mark II.

4. MODELLING

4.1. Model framework

CatchMODS integrates several submodels to estimate streamflow, sediment yields and costs under different management scenarios (Newham *et al.*, 2004). CatchMODS has the advantage of modest data requirements and flexibility in its application. The model outputs are easy to interpret and thus can assist stakeholders to improve catchment management outcomes (Newham *et al.*, 2004). A description of the model framework is shown in Figure 2.

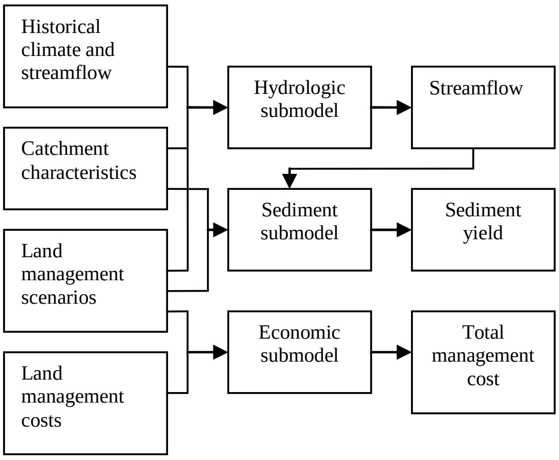

Figure 2: CatchMODS model framework

The hydrologic submodel is based on the IHACRES rainfall-runoff model (Identification of unit Hydrographs And Component flows from Rainfall, Evapotranspiration and Streamflow data) (Jakeman *et al.*, 1990; Jakeman and Hornberger, 1993). The model inputs are time series data for rainfall, temperature and streamflow, as well as catchment characteristics (Croke *et al.*, 2004). The outputs of the hydrologic submodel are daily stream flows along with estimates of several flow statistics including baseflow-associated stream flow (Newham *et al.*, 2003).

The sediment submodel is modified from the SedNet model (Prosser *et al.*, 2001). The sediment submodel calculates sediment inputs from each stream link and internal catchment area, and then combines them to compute deposition in the subcatchment and sediment yield at the subcatchment outlet. Three erosion processes contribute to the sediment inputs for each link: hill slope erosion, gully erosion and stream bank erosion. CatchMODS estimates suspended load to enable the effects of current land management to be accessed.

An important feature of the CatchMODS model is that it enables estimation of the costs of different management scenarios. The scenarios provide information on the areas of different land use and the managed lengths of gully or stream bank. The economic values of these land uses and the costs of gully or stream bank management changes are estimated by a simple cost-benefit analysis. By multiplying the areas or lengths by the land use values or management costs, the total costs or returns from different land management scenarios can be estimated.

4.2. Scenarios

The CatchMODS model for the Moruya River catchments was developed with wet and dry climates, based on time series data of rainfall and temperature from 1963 to 2002 (Ng, 2004). The differences between these two scenarios are relatively minor, thus the selection of rainfall sequences does not greatly change the relative sources of sediments (Ng, 2004). The dry climate scenario, which is more recent, is used for comparison of management scenarios.

Three management options are provided in CatchMODS: land use change, gully management and stream bank management (Newham *et al.*, 2004). As part of the land use change management option, different proportions of pasture, crop and forest land can be selected for individual subcatchments. In gully and stream bank management, different lengths of severe, moderate, minor gullies and stream bank erosion sites can be revegetated or stabilised using engineering approaches such as fencing, reducing bank height and bank steepness, and provision of protective structure such as logs, rocks or shingles.

Table 1: The data inputs of management scenarios

Scenario Number	Scenario descriptions	
0	80% forest, 19% pasture, 1% cropping, 0 m channel erosion control	
1	99% forest, 0% pasture	
2	Revegetate all minor gullies	*463m*
3	Revegetate all severe gullies	*4612m*
4	Revegetate all stream banks	*3612m*
5	Engineering all stream banks	*3612m*

The data inputs for management scenarios are listed in Table 1. Currently, 80% of the catchment is covered by forest, 19% by pasture and 1% cropping (Baginska *et al*, 2004). There is a total length of 3612 m of stream bank erosion, 4612 m of severe gully erosion, and 463 m of minor gully erosion in the Mogendoura Creek subcatchment (DIPNR, 1992). Scenario 0 represents current (business-as-usual) situation; Scenario 1 examines the effect of afforestation; and Scenarios 2 to 5 investigate the effects of channel erosion management.

The land use value and management costs are used to estimate the fixed and ongoing costs of changing land use proportions and erosion management. The costs used in the modelling have been determined from discussions with farmers in the Ben Chifley Dam catchment (Newham *et al.*, 2004) but are thought broadly applicable in the current application. The gross margins (profits) for each of the land uses are $100 / ha, $550 / ha and $1000 / ha for forest, grazing and cropping, respectively. The fixed costs for gully revegetation, stream bank revegetation, and stream bank engineering are $3,000, $2,500 and $20,000 per kilometre respectively. The ongoing costs for all these channel controls are $250/km per year.

4.3. Modelling and field work

Annual suspended sediment yields under different management scenarios were estimated from the CatchMODS model for hill slopes, severe gullies, moderate gullies, minor gullies and stream banks. The suspended sediment yield from hill slope areas was subdivided into those from forests and beef grazing areas using the area of land use and the USLE C factor, which is assumed as 0.04 for forest and 0.1 for beef grazing areas. Nutrient concentrations were measured from laboratory analysis for forest, beef grazing, gully and stream bank classes. The gully erosion nutrient concentration is a weighted average of the values from across all depths in the profile, likewise for the stream banks. The forest and grazing nutrient concentrations are averages of the values from the forest and grazing sites.

Annual total N and P particulate yields under different scenarios in the Mogendoura Creek subcatchment were then calculated by multiplying the annual suspended sediment yield by relative nutrient concentrations in the soils. Annual nutrient yields from forests and beef grazing areas were summed to represent those from hill slope overall. The method is summarized in Figure 3.

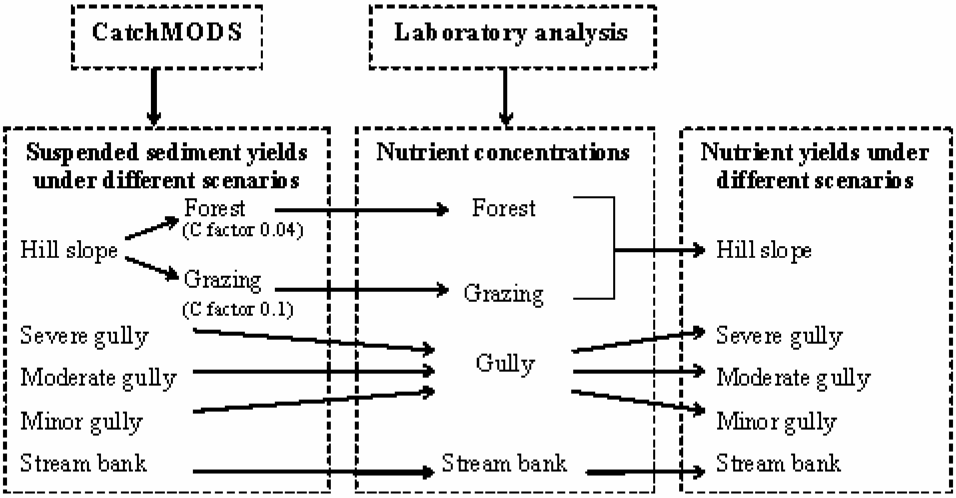

Figure 3: The method used to calculate nutrient yields under different management scenarios.

5. RESULTS

5.1. Sediment modelling results

The amount of sediment sourced from severe, moderate and minor gullies, and also that from stream bank and hill slope erosion was estimated by the model. Likewise, the annual sediment deposition to floodplain and the resulting annual suspended sediment yield was calculated.

The results indicate that currently, stream bank erosion contributes to over 85% of the total suspended sediment yield, followed by gully erosion (14%) and hill slope erosion (1%). Examination of the scenario runs indicate that the most significant reductions of total suspended sediment occur in Scenario 5 (Stream bank engineering) and Scenario 4 (Stream bank revegetation). Implementation of such works is estimated to reduce the total suspended sediment output by 86% and 64%, respectively. Scenario 2 (minor gully revegetation) has the least effect, with only 0.2% reduction in total suspended sediment yield.

Table 2 illustrates the contribution of individual scenarios to the change of sediment yield compared to the current situation (Scenario 0). Land use change (Scenario 1) is the only scenario to change sediment yields from hill slopes, however the amounts are very small. Gully and stream bank management, by means of revegetation and / or engineering, only change the sediment yield from that source. In general, engineering is more effective than a revegetation approach but is much more expensive.

5.2. Nutrient results

The mean N concentrations for forests and grazing sites were approximately 1.9 kg/t and 4.4 kg/t respectively. Soils from gullies and stream banks have lower N concentrations, with 1.0 kg/t in gullies and 1.1 kg/t in stream banks. The mean P concentrations are found 0.2 kg/t in forests, 0.7 kg/t in grazing, 0.39 kg/t in gullies and 0.43 kg/t in stream banks.

The results of nutrient exports under different management scenarios are illustrated in Table 2. Currently, approximately 2,600 kg of N and 1,000 kg of particulate P are estimated to be lost annually from the Mogendoura Creek subcatchment by means of gully, stream bank and hill slope erosion. More than 85% of the particulate N and P loss is estimated to come from stream bank erosion. Severe gullies contribute 12% of the N and P loss. The remainder are estimated to contribute only 3% of total particulate nutrient loss. The most significant reduction would result from engineering stream bank stabilisation, which could reduce the total N and P loss by 2246 kg/year and 878 kg/year respectively. The effect of revegetation of the stream banks would also be considerable. Managing minor gullies by stabilisation would be expected to have very limited effects on reducing overall nutrient losses.

Table 2: Comparison of sediment and nutrient yield, cost and first year total nutrient reduction per dollar across six scenarios.

Scenarios	Sediment yield (t/yr)					Nutrient yield (kg/yr)		Fixed costs ($)	Ongoing costs ($/yr)	Total Nutrient reduction per dollar (kg/1000$)
	Hill slope	Minor gully	Moderate gully	Severe gully	Stream banks	N	P			
0	2	6	19	311	2038	1010	2600	0	0	
1	1	6	19	311	1970	981	2526	0	366,000	0.3
2	2	1	19	311	2038	1008	2596	1,400	100	4.0
3	2	6	19	77	2038	919	2359	13,800	1,100	22.3
4	2	6	19	311	510	352	916	9,000	900	236.6
5	2	6	19	311	0	132	354	72,200	900	42.7

5.3. Economic modelling results

The fixed and ongoing costs for each scenario have been estimated in the economic submodel of CatchMODS (see Table 2). Converting all pastures to forests contains the highest costs with over $366,000 a year. However, the effect on reducing sediment yield for this scenario is very small. Therefore, it would not be an economical way to reduce sediment yield. Interestingly, the costs to revegetate the stream bank (Scenario 4) are lower than for revegetating the severe gullies (Scenario 3). However, the effects of stream bank revegetation on reducing sediment yield are 6 times higher than for severe gully revegetation. Engineering management (Scenario 5) can reduce sediment yields more than the revegetation approach (Scenario 4), but the costs of the former are significantly higher. In order to compare the efficiency of the money spent on management, the total nutrient reduction (compared to Scenario 0) per dollar spent for the first year is listed in Table 2. The data suggest that revegetating stream banks is the most economical management intervention. For $1000 spent on revegetating stream banks, the total nutrient can be reduced by more than 200 kg, compared to only 40 kg under an engineering approach.

6. DISCUSSION AND CONCLUSIONS

6.1. Sediment yield

Suspended sediment sources and yields for the Mogendoura Creek subcatchment were estimated using the CatchMODS model. Under current conditions, hill slope, gully and stream bank sources were estimated at 2 t/year, 336 t/year and 2038 t/year, respectively. Stream bank erosion is the dominant contributor of sediment export in the subcatchment, accounting for nearly 86% of the total suspended sediment yield. Hill slope erosion, however, contributes only 0.1% of the total suspended sediment yield. Considering only sediment sources indicates that stream bank control should be emphasised in land management practices in order to reduce sediment yield.

6.2. Best management practices

In addition to biophysical modelling, cost benefit approaches to nutrient management are also needed. The results of this research imply that best management practices can be targeted to critical areas of the subcatchment that contribute most of the sediment or nutrient transfer. Because there is a similar pattern of sediment yield and nutrient concentration across hill slope, gully and stream banks, integrated management approaches that directly address both sediment and nutrient can be achieved. From the results presented in this research, it can be seen that management practices applied to stream banks (either engineering or revegetation) are the most effective way to reduce sediment and nutrient yields. The engineering approach is more expensive than revegetation alone, but it would provide more effective protection to gullies and stream banks. However, the most economically effective intervention is stream bank revegetation.

6.3. Nutrient and sediment correlation

The nutrient concentrations of soils from hill slope (forest and grazing) are higher than that found in gullies and stream banks. This is especially true for N. The mean N concentrations of forests and grazing site soils are twice to four times as much as that in gullies and stream banks. However, if taking in account the amount of sediments derived from these erosion sites, the annual nutrient yield from hill slope is minor compared to gullies and stream banks. This is because of the high proportions of gully and stream bank erosions in the Mogendoura Creek subcatchment. The area of studied subcatchment is only 3% of the Moruya-Deua River catchment. However, it contains 72% of the severe gullies and 10% of the stream banks in the catchment. In other subcatchments with higher proportion of hill slope erosion, the types of recommended management may be quite different. This illustrates the need for the site-specific integration of modelling and field-based analysis techniques.

6.4. Limitations

The difference between soil nutrient concentration and water nutrient concentration cannot be ignored. Most runoff contains fine particles which have high N and P compared to soil nutrient concentrations (Hunter & Rayment, 1991). Moss *et al.* (1992) used 1.5 times enrichment ratio for both N and P in 20 coastal catchments in Queensland. An enrichment ratio of 1.6 for P and 0.8 for N were suggested for the Richmond River subcatchment in NSW (Letcher *et al.*, 1999). The enrichment ratio for P ranges broadly from 1.5 to 8.9 (Sharpley & Menzel, 1987). Therefore, to more accurately calculate the nutrient export rate, a nutrient enrichment ratio is required, derived by comparing sediment bound nutrients in waterways with soil nutrient concentrations. The concentration of nutrients in water bodies involves the concentration and release rate of nutrients in soil. To more accurately describe soil nutrient loss to runoff water, the nutrient solubility and release kinetics in the soils should be further investigated (McDowell & Sharpley, 2003).

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