Reducing nutrient discharge from agriculture through the implementation of BMPs – how far can we go?

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ABSTRACT
Algal blooms in south west Western Australia are a symptomatic response to excess nutrient input. Whilst a range of Best Management Practices (BMPs) are available to address the causes of nutrient pollution, most investment has been directed towards symptoms. In order to treat nutrient pollution causes effectively it is important to evaluate possible nutrient reductions and costs, and to determine whether accrued benefits can influence BMP adoption. Models were developed for catchments near Albany (south coast of Western Australia), and for the Peel-Harvey catchment (70 km south of Perth) to estimate costs and benefits of implementing conventional BMPs in scenarios representing the current nutrient reduction effort, the maximum feasible and the most cost effective suite of BMPs. For catchments without ready access to Alkaloam™ (a nutrient-retentive soil amendment), model estimates indicate that current nutrient reductions are around 10%, with a further 20-30% possible. Those with access to Alkaloam™ could reduce phosphorus by a further 25%. Over a 10 year period, the net cost of BMPs was budget positive, resulting in a net benefit to land managers. Economic barriers to the adoption of these BMPs appear limited and bring the current low adoption levels into question. The maximum possible reductions using available BMPs may not be sufficient to arrest water quality decline and to achieve water quality targets.

KEYWORDS
Best management practices; cost-effectiveness; nutrient management; modelling

INTRODUCTION
Agricultural development in south-west of Western Australia (WA) over the latter half of the 20th century has contributed to increased nutrient export to waterways (Hodgkin and Hamilton, 1993). Previous research has identified nutrient sources and delivery processes (Heathwaite, 1997; Weaver and Reed, 1998), and the nutrient attenuation efficiency of actions such as vegetated stream buffers (McKergow *et al*., 2002). Until recently, assessments of the costs and catchment-wide nutrient reductions arising from the implementation of management actions had received little attention (Weaver *et al*., 2003).

The increased need for community groups and government to respond to degradation issues, sometimes through ad-hoc funding or programs has heightened the importance of evaluating the cost effectiveness of improved management so that limited resources can be better targeted. Resource requirements and likely timeframes to meet water quality targets are also needed to fine-tune farmer extension programs and pollution control activities. Catchment-scale evaluation of implementation scenarios offers short term insights not possible through long term on-ground implementation and performance monitoring.

Evaluation of alternative Best Management Practice (BMP) adoption strategies is an important component of an adaptive management approach (Iles, 1996; Walters, 1986) where strategies are refined over time through focussed experimentation and feed-back monitoring.

Modelling approaches such as compartment flux models, process based models such as CREAMS, AGNPS and ANSWERS have been used to estimate nutrient load reductions from BMP implementation. Geographical Information Systems have been employed to estimate catchment nutrient loss (Heidtke and Auer, 1993). Decision Support Systems and Expert Systems offer alternative approaches in identifying possible causes of nutrient pollution, and may be used to recommend management practices for critical source areas (Djodjic, 2002).

Many of these modelling approaches can be complicated, and their widespread use may be restricted by computational complexities and the time required to develop data, particularly in landscapes that are spatially and temporally heterogeneous. Further, few of the models provide information to guide management investment, except WINCMSS (Young *et al.*, 1995) which enables assessment of costs and nutrient exports from land management and planning decisions, and land use change. Despite its relative simplicity, WINCMSS provides a useful basis to evaluate the costs and benefits of scenarios that can result in reduced nutrient loads, an approach suggested elsewhere (Heidtke and Auer, 1993). The output can assist managers to be more targeted when investing limited resources in management actions.

This paper describes an adaptation of the approach of Young *et al.* (1995) to evaluate the costs and benefits of adopting different levels of BMPs in the Peel-Harvey catchment and compares the outcomes to the application of similar models for catchments studied on the south coast of WA (Weaver *et al.*, 2003). Fundamentally the approach provides indicative or relative information to guide decisions on nutrient management and does not aim to definitively quantify nutrients produced from certain areas or land uses.

MATERIALS AND METHODS

Previous Work

Case studies (Weaver *et al.*, 2003) evaluated the costs and benefits of adopting different levels of BMPs for catchments on the south coast of Western Australia (WA) (Oyster Harbour, Wilson Inlet, Torbay Inlet and Princess Royal Harbour [PRH]) (Figure 1, Table 1) and included the development of a digital elevation model to derive catchment and landscape characteristics influencing nutrient transport. Soil survey data (Weaver and Reed, 1998) was used to modify control over P export via different transport pathways (Heathwaite, 1997) and was combined with land slope, land use (National Land and Water Resources Audit, 2001) nutrient generation rates (Young *et al.*, 1996; Young *et al.*, 1997; Vanderholm, 1984) to estimate P and N loss at source. Nutrient generation was modified using assimilation functions (Simmons and Cheng, 1985; Davis *et al.*, 1996) based on the Bransby-Williams formula to determine nutrient exports. The cost and nutrient reduction benefits of six conventional management actions (vegetated stream buffers [VSB], perennial pasture, minimum tillage, effective fertiliser use, stock control/water management and effluent management) were then evaluated for different combinations and levels of implementation.

Current Work

The model described by Weaver *et al.* (2003) was adapted to examine nutrient management scenarios for the Peel-Harvey catchment (Figure 1). The adaptation considered different BMPs, particularly Alkaloam™ (nutrient retentive soil amendment) in the Peel Harvey catchment, and the use of landuse specific nutrient balance data (Neville *et al.*, [submitted]) in conjunction with landscape characteristics to estimate nutrient generation rates.

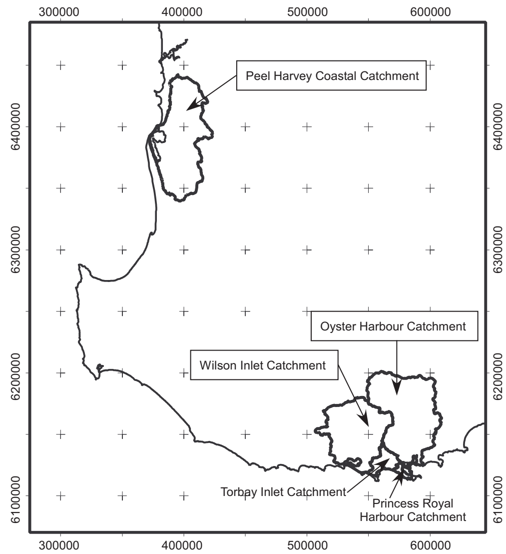

Figure 1. Location of study catchments

Table 1. Comparison of study catchments, areas, landuse composition (%) and for the Peel-Harvey catchment phosphorus (P) load and mean P export rate

Landuse	Oyster Harbour (%)	Wilson Inlet (%)	Torbay Inlet (%)	PRH (%)	Peel-Harvey Catchment (%)	Peel-Harvey Catchment (% P Load)	Peel-Harvey Catchment Mean export rate (kg ha^{-1})
Remnant Vegetation	28	51	34	74	25	<1	0.01
Grazing	56	33	53	10			
Cattle for Beef					42	51	2.6
Cattle for Dairy					8	16	4.4
Mixed Grazing					4	3	1.9
Feedlots					1	5	11.5
Mining					3	<1	0.3
Horses					3	4	2.6
Cropping	2	<1	<1	<1	<1	<1	0.3
Horticulture	1	<1	4	<1	2	5	4.3
Plantation	11	15	5	2	1	<1	0.5
Urban					3	5	3.3
Sewered Urban	<1	<1	<1	3			
Unsewered urban	<1	<1	<1	2			
Peri Urban	<1	<1	2	7	5	4	1.8
Piggery					<1	6	33
Other – poultry, processing					<1	<1	4.0
Total Area (km^2)	**2989**	**2258**	**320**	**81**	**2556**		

The nutrient export model used is an adaptation of the P indicators approach of Heathwaite *et al.* (2003) which combines source factors (nutrient inputs and soil mineralisation), transfer factors (effective rainfall and erosion risk), and delivery factors (land drainage or hydrological connectivity). Nutrient assimilation is then applied and considers both assimilation *within* each sub-catchment where nutrients are generated, as well as subsequent assimilation as nutrients *pass through* downstream catchments and other significant hydrological features.

Source factors were represented by P production loss data sourced from farm gate nutrient balances for agricultural land uses (Neville *et al.* [submitted]), or derived from published work for urban land uses (Gerritse *et al.*, 1990; Kelsey and Zammit, 2003). Transfer and delivery factors were represented by an existing framework for P loss risk for Western Australian soils (van Gool *et al.*

2001). This P loss risk weights the ability of soils to store, transfer, and deliver P based on soil and landform qualities. The model output was compared for a series of sub-catchments that had been monitored over a number of years.

Best Management Practices

Some BMPs (Table 2) have been field tested to determine potential nutrient reductions and costs of implementation. These BMPs vary in effectiveness for different locations and conditions. For example VSB have been reported to reduce nutrient loss by up to 90% (Line *et al*., 2000), however research on the south coast of WA showed moderate N reductions, and little P reduction due to specific nutrient transport pathways in that region (McKergow *et al*., 2002). Research in the Peel-Harvey showed P reductions of 30-60% that were difficult to attribute to the use of VSB due to experimental anomalies (Cronin, 1998). Therefore a number of actions were evaluated across a range, but where possible locally derived data on costs and effectiveness was used to evaluate BMPs.

Alkaloam™ is an alkaline residue from bauxite processing and has significant P retention properties whilst providing production benefits (Summers *et al*., 1996). The capacity of Alkaloam™ to reduce P loss ranges between 30 and 60% depending on application rate and is expected to require replacement about every 10 years.

Perennial pastures appear to offer an opportunity to reduce nutrient loss whilst increasing farm productivity through high water use, deeper rooting systems (White, 2003) and lower nutrient requirements (Knight, 1990). Previous research has compared perennial systems and their attendant nutrient losses (Ridley *et al*., 2003), however no research has compared nutrient losses from annual and perennial pasture based systems. Productivity returns are more certain, but nutrient export reductions of around 20-30% are expected.

Effective fertiliser use considers the lowest and the most effective use of nutrients in farming. It includes soil and tissue testing to determine nutrient requirements, nutrient specific deficiencies, and selection of the most appropriate fertiliser, rates, timing and locations (eg exclusion of firebreaks, use of fertiliser buffers). Surveys indicate that fertiliser applications are made independently of soil test results (Weaver and Reed, 1998) and many farms could forgo a fertiliser application for at least one year. Given the dependence on P based fertilisers in these catchments, full adoption P reductions of around 5-10% are possible.

Expected P and N reduction, capital costs of individual BMPs and a net cost or benefit per year is shown in Table 2. Capital costs and expected on-going or maintenance costs were combined with expected productivity benefits, to estimate net on-going costs or benefits. This is important where high capital costs are offset over time with benefit from productivity increases. Nutrient reductions, costs and benefits (productivity returns), costs per kg, and net costs or benefits (implementation and on-going [maintenance] costs minus productivity returns averaged over 10 years) were derived. Reductions and costs were compared to a base level of no management and were assessed in the context of the asset being protected from nutrient inflows (eg inlets, estuaries, harbours) rather than the farm gate. Other external costs and benefits (such as amenity or ecosystem services) were not accounted for.

Nutrient (P) reductions and costs for the Peel-Harvey catchment were evaluated for individual actions at 100% adoption, and current levels. Previous work (Weaver *et al*., 2003) combined individual BMPs into scenarios to test outcomes such as the current nutrient reduction effort (status quo), highest possible nutrient reduction and the most cost effective nutrient reduction.

Table 2. Percentage P and N reductions, Capital and Net costs or (benefits) for different BMPs.

BMP	% reduction		Capital Cost of BMP implementation	‡Net Cost or (Benefit) yr^{-1}
	N	P		
†1st order Vegetated Stream Buffers	40	5	$6,110 km^{-1}	$475 km^{-1}
†2nd order Vegetated Stream Buffers	40	5	$5,030 km^{-1}	$225 km^{-1}
†3rd order+ Vegetated Stream Buffers	40	5	$3,975 km^{-1}	$175 km^{-1}
Perennials pastures	20	20-30	$135 ha^{-1}	($60) ha^{-1}
Minimum tillage	5	10	$265 ha^{-1}	($3) ha^{-1}
Effective fertiliser use	5	5-10	$10.00 ha^{-1}	($9.40) ha^{-1}
†1st order stock control, water management	10	5	$750 km^{-1}	$50 km^{-1}
†2nd order stock control, water management	10	5	$1250 km^{-1}	$50 km^{-1}
†3rd order+ order stock control, water management	10	5	$2000 km^{-1}	$50 km^{-1}
Dairy effluent management	75	75	$75 $source^{-1}$	($3) $source^{-1}$
Piggery effluent management	75	75	$100 $source^{-1}$	($3) $source^{-1}$
Alkaloam soil amendment (5-20 tonnes ha^{-1})	ND	30-60	$70-$280 ha^{-1}	($40) ha^{-1}

† VSB and stock control water management were assessed on Strahler stream order, and combined for the Peel-Harvey catchment. Because of variations in reported effectiveness this action was tested over the range of 7.5 to 30% for P
‡Benefits are shown in parenthesis. Net benefits or costs are an annual value excluding capital costs
ND – not determined

RESULTS AND DISCUSSION

Notwithstanding limitations, these simple lumped-models appear to provide useful information to guide decisions on nutrient management (Heidtke and Auer, 1993). Figure 2 shows a good correlation between estimated and monitored loads. Deviations between estimated and monitored loads may be due to assimilation and monitoring errors or to other factors not included in the model. The model was not intended to replace monitoring, nor to derive accurate nutrient load estimates, rather it was to provide “relative and indicative” costs and benefits of implementing BMPs in the Peel-Harvey catchment. Figure 2 suggests that the model can achieve these aims.

For diffuse-source dominated catchments on the south coast of WA, cost effective scenarios provide nutrient reductions of 20-30% above existing efforts and provide financial benefits to land managers (Table 4) in excess of capital and on-going BMP costs. Full implementation of those actions identified in Table 3 for the Peel Harvey catchment delivered nutrient reductions of 47-59% whilst returning \$3.5M yr^{-1} to the rural community.

This is significant given that the maximum possible scenarios evaluated for south coast catchments did not apply full implementation of actions (Weaver *et al*., 2003). For example, perennial pastures, effective fertiliser use and VSB could have increased by a further 35%. Whilst this would lead to greater P reductions, it is unlikely to improve cost effectiveness because economic gains made through perennial pastures and effective fertiliser use would have been offset by costs of implementing VSB (Table 3). Based on the south coast data (Table 4) targeting of actions in locations where they are the most cost effective for the Peel-Harvey catchment should see P reductions remain at levels similar to full implementation with further economic gains. The major difference between the Peel-Harvey catchment and the catchments on the south coast of WA is the availability of Alkaloam™. It is this BMP that would allow significant environmental improvement in a cost effective manner.

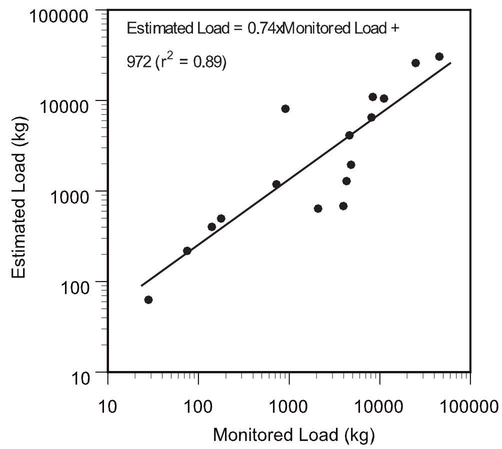

Figure 2. Estimated P loads compared to monitored loads for Peel-Harvey sub catchments

Table 3. Percentage P reductions, cost effectiveness ($ kg^{-1}), Capital and Net on-going costs or (benefits) for fully implemented BMPs and current BMP adoption in the Peel-Harvey catchment.

BMP	P reduction (%)	$ kg^{-1}	Capital Cost ($M)	Net cost yr^{-1} ($M)		**Current Adoption (%)
†Alkaloam™ @ 5T/ha	24	($191)	$8.8	($3.3)	*	-
†Alkaloam™ @ 10T/ha	40	($53)	$17.7	($1.5)		-
†Alkaloam™ @ 20T/ha	48	$59	$35.4	$2.0		<1
Fertiliser Management	3.7	($510)	$1.6	($1.3)	*	5-10
Perennial Pastures	14 - 22	($691 -$460)	$20.8	($7.2)	*	12.5
‡Vegetated Stream Buffers	7.3 - 29	$15,958 - $3,989	$50.8	$8.2	*	5, 1st order; 10, 2nd order; 50, 3rd order+

* actions chosen for full implementation, ** based on Lavell *et al* (submitted) and Weaver *et al*., (2003)
† applied only to soils with low P sorption
‡ costs and BMP effect could reduce by up to 25% depending on coincidence of remnant vegetation with VSB

For diffuse-source dominated catchments on the south coast of WA it would appear that P reductions greater than 20-30% above existing efforts are not feasible with current land uses and management actions. However, the financial benefits to land managers may provide capacity for management at higher levels and provide impetus to agricultural extension efforts. These findings contrast with other reports (D'Arcy and Frost, 2001) suggesting that diffuse control measures are unlikely to return financial benefits to farmers, and may require incentives to encourage implementation. While incentives may improve uptake, good nutrient management is of financial interest to farmers and may lead to other benefits in the form of maintenance of ecosystem services (Daily, 1997).

The largest potential nutrient reductions are in the point-source dominated Princess Royal Harbour (Table 4), but without similar financial benefit. This was enabled through industry closure and sewerage treatment, and demonstrates community financial support to avoid on-going environmental damage. The three south coast diffuse-dominated catchments had similar levels of reduction, and associated cost and benefits. This was true for both existing efforts (the Status Quo scenario) and the other scenarios evaluated (Table 4). The limited capacity of VSB to reduce P loss contrasted with many other studies and was related to the soils and nutrient transport pathways and forms present in the study catchments (McKergow *et al*., 2002).

Alkaloam™, perennial pastures and effective fertiliser use were the most cost-effective of the broadscale landuse measures (Table 3). The highest nutrient reductions relative to costs were probably to be found in animal effluent management (Weaver *et al.*, 2003), however effluent from dairy sheds only represents 20% of the dairy farm P load hence broadscale management measures are required to reduce 80% of the P from these enterprises.

Table 4. Percentage reductions of P, cost effectiveness ($ kg^{-1}) and Capital and Net on-going costs or (benefits) for different scenarios in different catchments

Scenario		Catchment				
		Oyster Harbour	Wilson Inlet	Torbay Inlet	Princess Royal Harbour	Peel-Harvey
Status Quo	P reduction (%)	7	9	7	40	†4-9
	$ kg^{-1}	(85)	(59)	(269)	7300	15
	Capital Cost ($M)	4.3	4.4	1.6	15est	10.5
	Net cost yr^{-1} ($M)	(0.14)	(0.07)	(0.1)	-	0.03
Maximum Possible	P reduction (%)	30	29	40	80	47-59
	$ kg^{-1}	31	204	(4)	200	(114)
	Capital Cost ($M)	20.5	15.1	2.3	2.3	82
	Net cost yr^{-1} ($M)	0.18	0.48	(<0.01)	0.41	(3.5)
Most Cost Effective	P reduction (%)	27	29	38	80	-
	$ kg^{-1}	(217)	(77)	(139)	52	-
	Capital Cost ($M)	13.1	7.0	1.5	0.8	-
	Net cost yr^{-1} ($M)	(1.08)	(0.20)	(0.26)	0.11	-

† This comprises 1-2% from perennial pastures, <1% from fertilizer management and up to 6% from VSB

Despite the P reductions estimated here, the question remains are these reductions enough to reverse declining environmental quality in estuaries? A recent review of south-western estuaries of WA suggests that reductions of up to 70% may be required to meet external loading targets, however even greater reductions may be required to also run down internal loadings from accumulated nutrients (Deeley, 2001). This indicates that to achieve further reductions we must look to greater changes in agricultural systems than those investigated here, and also extend recognition of the problems and alternative solutions beyond land managers and into the broader community. Options to consider include a different sort of financial incentive package such as differential ratings and even a broad-scale change to more nutrient-benign land uses. The expanding plantation timber industry in the area is one such land use example for these fragile catchments.

CONCLUSIONS

For diffuse source catchments without access to Alkaloam™, P reductions of 20-30% above current levels appear possible. Alkaloam™ can improve these reductions by around 25% whilst providing further positive economic outcomes. Economic barriers to the adoption of these BMPs appears limited and brings the current low adoption levels into question. The maximum possible reductions using available BMPs may not be sufficient to arrest water quality decline.

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