Assessing the feasibility and net costs of achieving water quality targets: A case study in the Burnett-Mary region, Queensland, Australia

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Abstract
This paper describes the construction of a bio-economic optimisation framework to evaluate the feasibility and net profit (or net costs) of achieving water quality targets in the Burnett-Mary region within the southern portion of the Great Barrier Reef (GBR), southern Queensland, Australia. Key outcomes from the study were that current sediment, nitrogen and phosphorus load reduction targets could be achieved whereas more ambitious ecologically relevant targets required significant additional investment and were not feasible based on the model if individual basins must meet the targets.

Key Words
bio-economic optimisation framework, decision support system (DSS)

Introduction
The Great Barrier Reef (GBR) Marine Park region hosts biodiversity values that are globally important. Increased loads of nitrogen, phosphorus and sediments from adjacent catchments as reported by Kroon et al. (2013) have led to detrimental changes in environmental conditions for GBR species and ecosystems. To meet environmental targets in the Burnett-Mary region in Queensland, Australia, and to help protect the condition of coastal and marine receiving waters, the development of a Water Quality Improvement Plan (WQIP) was commissioned. This region includes the southern-most portion of the World Heritage-listed GBR Marine Park and the Ramsar-listed Great Sandy Strait (Figure 1). The health of the coastal and inshore marine areas within the Burnett-Mary region is influenced by the quality and quantity of runoff from five river basins in which the major primary industries are grazing, sugarcane, horticulture, forestry and mining. The focus of the WQIP (Anonymous, 2015) was to improve water quality through the implementation of agricultural management practices based on the 'ABCD' water quality risk framework for the sugarcane and grazing industries (Anonymous, 2013a; Anonymous, 2013b): 'A' represents cutting edge unproven technologies; 'B' represents current best-management practices; 'C' is common current industry practice and; 'D' is below industry practice expectations.

To inform the WQIP, a bio-economic model was developed to assist the Burnett-Mary regional group evaluate the feasibility and costs of various land management options to achieve two sets of pollutant load reduction targets, namely (1) the Reef Plan Targets (RPTs) representing the currently agreed targets, and (2) the more ambitious Ecologically Relevant Targets (ERTs) reported by Brodie and Lewis (2014) designed to better protect the values of the GBR. This paper describes the construct and underpinning data used to develop the bio-economic model that explicitly considers the feasibility and net profits/costs of achieving water quality objectives.

Methods
The bio-economic model requires information regarding generation rates and load predictions for various land management actions, characterisation of representative farming systems and the estimation of the effectiveness and costs of alternative land management practices. Each data set is described below.

Estimation of generation rates and loads
The estimates of generation rates and loads were derived using a watershed simulation model and several field-scale farming system models. The watershed simulation results were collated from Source Catchments (2008-2009 version) modelling from the Paddock to Reef Integrated Monitoring, Modelling and Reporting program (Fentie et al., 2014). These results provided a prediction of generation rates and end-of-catchment loads for key constituents, specifically: dissolved inorganic nitrogen (DIN), dissolved organic nitrogen (DON), particulate nitrogen (PN), dissolved organic phosphorus (DOP), dissolved inorganic phosphorus

(DIP), particulate phosphorus (PP) and total suspended solids (TSS). Landscape attenuation coefficients were also derived based on 597 sub-catchment and regional baseline 2008-09 calibration results.

For grazing systems, the relative impact of various management practices on constituent generation rates for A, B, C and D classifications were based on field-scale GRASP (Whish, 2012) modelling. For sugarcane, the effectiveness associated with the transition from one land system classification (A, B, C or D) to another were based on the relative constituent losses derived from APSIM (McCown et al., 1995) and Howleaky (McClymont and Freebairn, 2007) field-scale modelling. Stream bank and gully remediation impacts were also incorporated into the bio-economic model. The effectiveness in load reductions associated with stream bank and gully remediation were based on Table 4 in Thorburn and Wilkinson (2013) and assumed to be 35% for TSS and 25% for both PN and PP with no impact of management on all other constituents.

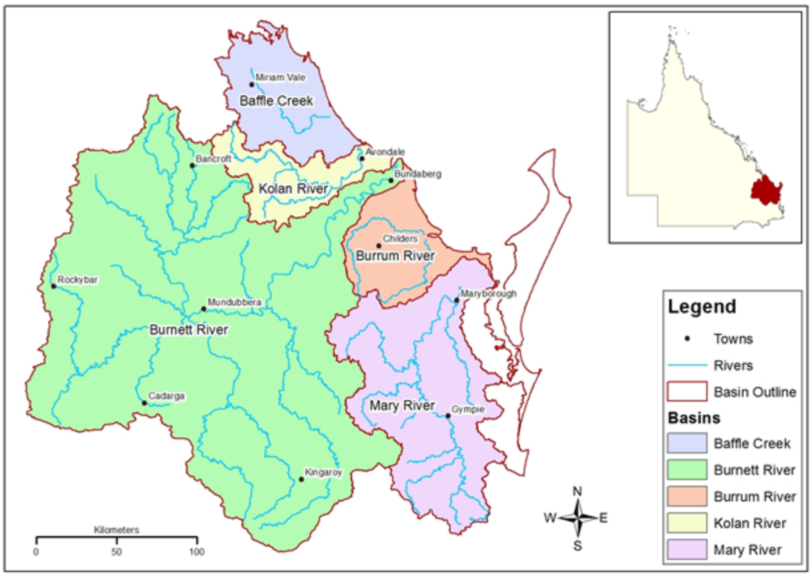

Figure 1. Location of the Burnett-Mary watershed in Queensland, Australia.

Cost of alternative management practices

The net profit of various grazing management systems as reported by Pannell et al. (2014) were shown to always be negative (a cost). The analysis included simple consideration of non-profit related barriers. In contrast, the net annual profits (or costs) associated with each sugarcane practice were based on the economic analysis by van Grieken et al. (2014) in which not all states incur a cost. Stream bank remediation costs ($/km annualised over 20 years) were assumed to be $3,887/km/year whereas gully remediation costs were assumed to be $3,582/km/year based on discussions with the relevant catchment management authority. Both up-front and maintenance costs were considered and a 6% discount rate (same discount rate as used for the sugarcane and grazing analysis) was assumed.

Bio-economic model

The bio-economic model sought to maximise total net benefits which were defined in terms of area within various management practice classifications for a given abatement target/s. The solution calculated the cost of transitions to an environmentally superior practice (e.g., C to B). That is, it assumed (1) no cost to remain in the current state and (2) no option to transition to a worse state (e.g., B to C). Other constraint assumptions that were applied included: (i) the distribution of small, medium and large farms maintained at current levels; (ii) the relative percentage of each land use within each sub-catchment is maintained at current levels and; (iii) the land use areas currently in A and B class practices were not permitted to be reduced. The bio-economic model components were solved using nonlinear programming with the CONOPT solver in the General Algebraic Modelling System (GAMS) (Brooke et al., 2008).

Water quality targets

Two sets of targets were selected by local stakeholders as a focus for the Burnett-Mary WQIP, namely the Reef Plan Targets (RPTs) and Ecologically Relevant Targets (ERTs). Each target was evaluated at both the regional and individual basin scale and the costs to achieve targets were assumed to be over a 20-year period. All targets were defined in terms of percentage reduction in anthropogenic loads (Table 1).

Results

Four scenarios based on meeting RPTs and ERTs were selected. The scenarios evaluated either meeting each individual constituent in each of the five basins (Baffle, Kolan, Burnett, Burrum and Mary) or only meeting the target across the whole region. The annual cost of attaining scenario targets are summarised in Table 1; also reported are the anthropogenic load reductions achieved for each scenario. If RPTs only have to be met on a whole of region basis, then huge savings can be made (see Scenario 2 Table 1 compared to Scenario 1). The net cost is estimated to be approximately $1.8 million/year compared with a net loss of approximately $6.5 million/year from Scenario 1. At a whole of region scale, ERTs pose at least an additional $14.6 million net loss/year on agriculture than RPTs. Meeting ERTs poses significant feasibility issues because particulate losses come mostly from grazing land uses, stream bank and gully erosion, all of which incur large costs. As illustrated in Table 1, achieving ERTs in the Mary catchment is not obtainable given the model constraints imposed (Scenario 3). Results suggest that DIP is the most limiting RPT constituent whereas DIN, PP and DIP are the most limiting ERT constituents depending on basin attributes and land uses; PN is the most limiting whole region ERT target to achieve.

In addition to the areas modified to meet RPTs, adoption of whole region ERTs requires an extra 44,406 ha to be transitioned into sugarcane A practice and an extra 112,465 ha to be transitioned into grazing A. Of those sub-catchments required to modify land use practice in order to meet whole region targets, 36% are more profitable under RPTs as opposed to only 10% under ERTs. Of all those affected sub-catchments that include sugarcane, 70% are profitable under RPTs in contrast to only 24% under ERTs.

Table 1. Anthropogenic load reduction achievements associated with four water quality target scenarios in the Burnett Mary region.

Scenario	Constituent	Target (% load reduction)	Load reduction (%achieved)					
			Whole Region	Baffle	Kolan	Burnett	Burrum	Mary
1 Meet RPTs in each basin	TSS	20		22	**20**	36	40	**20**
	DIN	50		53	73	91	85	75
	PN	20		135*	48	45	48	30
	PP	20		107*	34	35	40	29
	DIP	20		**20**	**20**	**20**	**20**	**20**
	NetProfit**		-$6.5M	-$1.4M	+$0.8M	-$4.5M	+$1.0M	-$2.4M
2 Whole region RPTs	TSS	20	**20**	15	24	20	37	19
	DIN	50	80	47	85	89	85	76
	PN	20	39	130*	53	41	48	30
	PP	20	36	99	39	31	40	31
	DIP	20	**20**	13	25	4	17	24
	NetProfit**		-$1.8M	-$0.8M	+$0.7M	+$1.0M	+$1.3M	-$4.0M
3 Meet all ERTs in each basin	TSS	20		51	32	51	40	Not feasible
	DIN	80		**80**	86	97	87	
	PN	50		158*	60	57	54	
	PP	50		141*	**50**	**50**	**50**	
	DIP	20		48	26	**20**	**20**	
	NetProfit**		(-$11.4M in only 4 basins)	-$4.3M	+$0.2M	-$7.6M	+$0.3M	
4 Whole region ERTs	TSS	20	32	61	37	35	42	27
	DIN	80	87	78	93	97	90	81
	PN	50	**50**	167*	72	54	66	38
	PP	50	50	150*	64	43	62	40
	DIP	20	21	45	27	5	14	20
	NetProfit**		-$16.4M	-$4.9M	-$1.2M	-$2.1M	-$1.3M	-$6.9M

*Values in excess of 100% reflect a total reduction in anthropogenic loads and reduced pre-development exports.
**Negative values indicate a net cost and positive values indicate a net profit.
Bold text identifies the most limiting constituent/s.

Conclusion

Bio-economic modelling is a powerful tool to assess the benefits and costs of meeting water quality targets. This application integrated economic data sets and field- to catchment-scale biophysical model results to enable the evaluation of the effectiveness of alternative land management options to meet abatement targets. Application of the model to the Burnett-Mary catchment identified that large and ongoing support will be needed for the grazing industry to achieve RPT sediment, particulate P and particulate N targets whereas ERTs cannot be met without substantial costs and are not feasible if individual basins must meet the targets.

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