Bioeconomic modelling scenarios and results report

Milestone 3 – Burnett Mary Water Quality Improvement Plan

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Introduction

This report presents the results from the application of a purpose built bioeconomic model to a range of scenarios for water quality targets in the Burnett-Mary region. This model, along with the Investment Framework for Environmental Resources (INFFER), will be used to assess the costs and benefits of achieving a range of water quality targets related to protecting key assets associated with the Great Barrier Reef. The concept of bioeconomic modelling is outlined in Appendix 1.

Milestone Report 2 'Bioeconomic modelling methods development report' provides an initial overview of the approach taken to developing the model, including the underpinning principles, the participatory approach to integration of local information (e.g. cane and grazing economics) and the model construct itself.

A companion report to this Milestone 3 report 'Construction of a bioeconomic model to assess net benefits of achieving water quality targets in the Burnett-Mary region' (Beverly et al. May 2014) outlines the model conceptualisation in detail.

Two sets of targets – Reef Plan and Ecologically Relevant

Two different sets of targets are reported here (we have assessed many more). These are referred to as Reef Plan Targets (RPTs) and Ecologically Relevant Targets (ERTs). Initial scenarios focused on RPTs, and then recently, the more ambitious ERTs have also been included.

At least one detailed INFFER analysis Project Assessment (PAF) will be undertaken. Results from the bioeconomic model and discussions with Burnett Mary have informed the decision of which targets scenario should be analysed. At this stage we are using the 'base case' INFFER assessment as the whole of region ERT for the PAF. Benefits and costs of additional scenarios and sensitivity of Benefit:Cost Ratio (BCR) parameters will be undertaken using the BCR calculator.

Reef Plan Targets

Brodie and Lewis have developed RPTs at the individual basin scale, based on a mixed 2009 and 2013 target set (see TropWATER Report 14/11, March 2014 for an explanation of the methods). RPTs are outlined in Table 1.

They used targets (for 2018) of a 20% overall reduction in anthropogenic suspended sediment load; a 20% (based on Reef Plan 2013 target) and 50% (based on Reef Plan 2009) reduction in anthropogenic loads of particulate nitrogen (PN) and particulate phosphorus (PP); 50% (based on Reef Plan 2013) reduction in anthropogenic loads of dissolved inorganic nitrogen (DIN); 50% (based on 'interpreted' Reef Plan 2009) reduction in anthropogenic loads of dissolved inorganic phosphorus (DIP) and 50% (Reef Plan 2009) and 60% (Reef Plan 2013) reductions of loads of PSII herbicides (i.e. the 2009 target and the 2013 target respectively). The PSII herbicides considered are hexazinone, ametryn, atrazine, diuron and tebuthiuron.

Note that the targets are calculated as the decrease from anthropogenic (not total load). The targets outlined in Table 1 are copied directly from Brodie and Lewis, TropWater Report 14/11 March 2014. We have used the principles from Brodie and Lewis (namely pre-development load minus total load = anthropogenic load) to calculate the anthropogenic load reductions required from Source Catchments (the model used by the Queensland government as the basis for informing ReefPlan).

Table 1: Reef Plan targets broken down at individual basin level for the Burnett Mary catchment.

Basin Name	Pre-Development	Total (08/09)	Anthropogenic load	Target reduction	Target	% decrease of anthropogenic load
TSS loads (kt.y^{-1}) – 20% reduction target						
Baffle Creek	20	56	36	7.2	49	20%
Kolan River	2	12	9	1.9	10	20%
Burnett River	3	20	17	3.4	17	20%
Burrum River	7	25	18	3.6	21	20%
Mary River	61	362	301	60.3	302	20%
DIN loads (t.y^{-1}) - 50% reduction target						
Baffle Creek	12	31	19	9.5	21	50%
Kolan River	2	22	19	9.7	12	50%
Burnett River	31	121	90	45.1	76	50%
Burrum River	17	119	102	50.9	68	50%
Mary River	60	271	211	105.6	165	50%
PN loads (t.y^{-1}) - 20% reduction target						
Baffle Creek	63	96	33	6.7	90	20%
Kolan River	8	31	23	4.5	26	20%
Burnett River	19	97	78	15.6	81	20%

Burrum River	27	80	53	10.6	69	20%
Mary River	210	697	487	97.4	600	20%
PN loads (t.y^{-1}) - 50% reduction target						
Baffle Creek	63	96	33	16.7	80	50%
Kolan River	8	31	23	11.4	19	50%
Burnett River	19	97	78	39.1	58	50%
Burrum River	27	80	53	26.5	53	50%
Mary River	210	697	487	243.6	454	50%
DIP loads (t.y^{-1}) - 50% reduction target						
Baffle Creek	3	7	4	2.0	5	50%
Kolan River	1	3	2	1.2	2	50%
Burnett River	10	14	4	2.1	12	50%
Burrum River	5	10	5	2.7	7	50%
Mary River	16	41	25	12.4	28	50%
PP loads for the GBR basins (t.y^{-1}) - 20% reduction target						
Baffle Creek	25	39	14	2.8	36	20%
Kolan River	3	10	7	1.4	8	20%
Burnett River	8	38	30	6.0	32	20%
Burrum River	8	23	15	3.0	20	20%
Mary River	73	225	152	30.4	195	20%
PP loads for the GBR basins (t.y^{-1}) - 50% reduction target						
Baffle Creek	25	39	14	7.1	32	50%
Kolan River	3	10	7	3.4	6	50%
Burnett River	8	38	30	15.0	23	50%
Burrum River	8	23	15	7.5	16	50%
Mary River	73	225	152	76.1	149	50%
PSII loads (kg.y^{-1}) - 60% reduction target						
Baffle Creek	0	24	24	14.3	10	60%
Kolan River	0	267	267	160.2	107	60%
Burnett River	0	279	279	167.6	112	60%
Burrum River	0	530	530	317.8	212	60%
Mary River	0	456	456	273.9	183	60%

Ecologically Relevant Targets

Ecologically Relevant Targets (ERTs) have also been developed for a similar range of constituents to those for RPTs, but with a longer time horizon (2030), and generally with larger required reductions in anthropogenic loads. In contrast to RPTs, the development of ERTs acknowledges the lag time between reducing pollutant loads and a subsequent ecological response of significant assets affected by water quality.

The Ecologically Relevant Targets that have been considered in this report are (based on reductions in anthropogenic load from the 2008-09 baseline): 20% overall reduction in suspended sediment load; a 50% reduction in particulate nitrogen (PN) and particulate phosphorus (PP); 80% reduction in dissolved inorganic nitrogen (DIN); 50% reduction in anthropogenic loads of dissolved inorganic phosphorus (DIP) and 60% reduction of loads of PSII herbicides. It should be noted that a 50% reduction in DIP proved to be infeasible and this constituent was limited to a 20% reduction in the tested scenarios.

Land Use overview

The major land uses in the Burnett-Mary region provide a useful context for consideration of the preliminary results of the bioeconomic model. Table 2 sets out the area of each land use by basin, and across the region, while Table 3 represents these data on a proportional basis.

Table 2: Land use by area (ha) in the Burnett Mary catchment (based on QLUMP data used in SourceCatchments).

Land Use (ha)	Basin					
	Baffle	Kolan	Burnett	Burrum	Mary	All basins
Sugar Cane[A]	842 *556*	14,940 *9,870*	19,852 *13,116*	31,727 *20,961*	19,047 *12584*	86,408 *57,087*
Grazing	271,460	203,501	2,550,451	128,790	472,326	3,626,528
Conservation	75,396	26,473	131,552	72,084	166,165	471,670
Forestry	28,084	26,473	404,490	76,506	192,623	728,176
Dryland Cropping	132	157	81124	399	197	82,009
Irrigated Cropping	489	714	40,875	587	3,885	46,550
Horticulture	1,559	3,220	10,223	6,576	7,972	29,550
Urban	7,197	9,757	36,881	15,594	53,926	123,355
Water	17,603	9,879	19,093	9,380	11,541	67,496
Other	780	344	9,256	3,395	6,292	20,067
Total	403,543	295,470	3,303,802	345,039	933,976	5,281,830

[A] – The area reported for sugar cane, based on QLUMP, is an overestimate when compared with actual mill and ABS data. This data suggests that the effective economic area of sugar cane production is approximately 57087 ha, which includes the area planted to cane plus an allowance of 20% for fallow. To account for this discrepancy a scaling factor has been used in the bioeconomic model to restrict the cane area to 57087ha in terms of assessment of net benefits. Scaled figures are shown in italics.

Table 3: Land use as a % of overall area in the Burnett Mary catchment (based on QLUMP data)

Land Use	Basin					
	Baffle	Kolan	Burnett	Burrum	Mary	All basins
Sugar Cane	0.21	5.06	0.60	9.20	2.04	1.64
Grazing	67.27	68.87	77.20	37.33	50.57	68.66
Conservation	18.68	8.96	3.98	20.89	17.79	8.93
Forestry	6.96	8.96	12.24	22.17	20.62	13.79
Dryland Cropping	0.03	0.05	2.46	0.12	0.02	1.55
Irrigated Cropping	0.12	0.24	1.24	0.17	0.42	0.88
Horticulture	0.39	1.09	0.31	1.91	0.85	0.56
Urban	1.78	3.30	1.12	4.52	5.77	2.34
Water	4.36	3.34	0.58	2.72	1.24	0.38
Other	0.19	0.12	0.28	0.98	0.67	0.38
Total	100	100	100	100	100	100

The bioeconomic model only covers land uses of grazing and cane because these are both major industries of importance for ReefPlan and also because these are the only industries we have developed economic analysis for. For completeness in future work, and in view of the significant potential for load generation, land uses of horticulture, cropping (both dryland and irrigated) as well as urban land uses should be considered in terms of the costs and potential for load reductions.

Of the industries covered in the bioeconomic modelling, grazing occupies by far the largest area, especially in the largest Burnett and Mary catchments (Table 2). Cane occupies the largest land area in the Burrum catchment (31,727 ha, non-scaled area as per Table 2), similar areas in the Burnett (19,852) and Mary (19,047), followed by the Kolan (14,940), with very little area under cane in the Baffle catchment (842 ha, Table 2).

An analysis of data for pollutant loads associated with the reported land uses indicates that significant contributions are associated with sugar cane, grazing and streambank erosion. Table 4 (below) provides a summary of these data.

Table 4: % of total pollutant loads associated with sugar cane, grazing and streambank processes.

Basin		**As a % of total basin load**					
		TSS	DIN	PN	DIP	PP	PSII
Baffle	Cane	0.4	24.9	1.5	2.3	0.8	80.7
	Grazing	74.0	55.9	68.0	66.0	75.2	4.7
	Streams	16.3	0.0	6.9	0.0	6.0	0.0
	Cane+grazing+streams	90.7	80.8	76.4	68.4	82.1	85.4
Kolan	Cane	19.1	84.8	38.2	32.0	27.3	98.7
	Grazing	56.5	6.5	32.7	20.3	43.4	0.1
	Streams	9.9	0.0	3.5	0.0	3.5	0.0
	Cane+grazing+streams	85.5	91.3	74.4	52.3	74.1	98.9
Burnett	Cane	16.8	72.6	20.3	2.4	13.5	95.9
	Grazing	33.1	4.3	42.9	20.2	50.1	0.4
	Streams	37.1	20.6	18.2	58.6	19.2	0.0
	Cane+grazing+streams	87.1	97.5	81.5	81.1	82.8	96.3
Burrum	Cane	24.3	79.3	37.0	21.1	35.1	98.8
	Grazing	21.9	5.3	8.6	17.0	10.5	0.2
	Streams	20.6	7.2	6.0	21.1	2.8	0.0
	Cane+grazing+streams	66.8	91.8	51.7	59.2	48.4	99.0
Mary	Cane	1.5	58.2	4.7	4.5	2.8	95.3
	Grazing	20.9	15.3	24.1	31.7	30.6	1.0
	Streams	66.8	8.7	37.6	13.9	35.2	0.0
	Cane+grazing+streams	89.3	82.2	66.4	50.1	68.6	96.4

Scenarios examined

The bioeconomic model is capable of generating results for a range of scenarios and for particular constituents. In this report we focus on four scenarios deemed of most interest to help decision-making regarding which is best to use for the INFFER PAF analysis and the WQIP itself:

- Scenario 1, all RPTs met on an individual Basin basis, with the exception of DIP where the target was 20% (50% DIP was infeasible)
- Scenario 2, all RPTs met on a whole of catchment basis, with the exception of DIP where the target was 20% (50% DIP was infeasible)

- Scenario 3, all ERTs met on an individual Basin basis, 80% DIN, 50% PN, 50% PP, 60% PSII, DIP 20% (50% DIP was infeasible)
- Scenario 4, all ERTs met on a whole of catchment basis, 80% DIN, 50% PN, 50% PP, 60% PSII, DIP 20% (50% DIP was infeasible)

The four scenarios assume that the targets will be achieved through actions in cane and grazing. This means that these industries bear the majority of the burden, whereas in reality other industries also contribute. It is possible to run additional scenarios where the cane and grazing industries only have to meet their proportional load contribution; for example if the load target for a constituent is 20%, that target will be achieved by reducing the respective loads from each landuse category by 20%. These scenarios have not yet been run. We have some concerns about how such analyses will be interpreted; there is risk that achievement of the overall targets might lose focus.

Results – costs/profits associated with achieving targets

DIP was found to be the major constraint in achieving targets (and interesting and new result in itself), which is why the four scenarios reported here are set to meet all targets with the exception of DIP which was set to 20%.

Scenario 1 indicates that if the RPTs have to be met in individual basins then targets are predicted to be achieved at a modest profit in the Kolan and Burrum basins (Table 5). This occurs because of their lesser size compared with the Burnett and Mary and the importance of sugarcane as a proportion of land use. Net costs are predicted in the Baffle, Burnett and Mary basins because of the need to include grazing in achieving targets, which always incurs a net loss.

If RPTs do not have to be met for each individual basin, instead being able to be met on a whole of region basis, then huge savings can be made (see Scenario 2, Table 5), the net cost being approximately $2.98 million/year compared with a net loss of approximately $7.89 million/year from Scenario 1.

If the more ambitious ERTs are required to protect the GBR then this poses additional costs and feasibility issues. If the contributions from streambank erosion and costs associated with achieving targets in the grazing industry are within the ballpark of reality, then catchments like the Mary present an enormous challenge; the costs and lack of feasibility in grazing dominated catchments are immense. Along with what we suspect could be possible over-optimism in terms of effectiveness of cane management practices, very difficult trade-off decisions about the importance of protecting natural assets (for example seagrass and dugongs) compared with the local beef industry are required if environmental values are to be protected (assuming meeting targets equates to protecting environmental values). The alternatives might include land retirement from grazing (it might be cheaper to pay for land stewardship rather than production) or write the environment off. Note also that we have only assumed stream remediation costs are fencing, off-stream watering and stock exclusion – if (as is likely) more expensive engineering options have to be used then stream remediation costs will be much higher.

Achieving the more ambitious ERTs from cane and grazing on an individual basin level (Scenario 3) is both costly and problematic. ERTs cannot be achieved in the Mary catchment and incur a $7.76 million/year loss in the Burnett catchment (Table 5). We also suspect that the predictions of profitability in the Kolan and Burrum catchments could be an artefact associated with the Mary infeasibility problem; it doesn't make intuitive sense compared with the large net losses sustained in these two catchments for the whole of catchments ERTs (see Table 6 individual catchment costs for scenario 4 compared with scenario 3). If ERTs are allowed to be achieved on a whole of basin level, it is feasible, but at a net estimated cost of $16.45 million/year.

Table 5: Costs/Profits of attaining scenario targets for each basin in the Burnett-Mary region.

Scenario	Annual Cost/Profit ($ million/year)				
	Baffle	Kolan	Burnett	Burrum	Mary
1. Meet RPTs (20% DIP*) – individual basins	-1,411,930	558,328	-4,774,090	497,837	-2,764,290
2. Whole catchment RPTs (20% DIP*)	-2,978,590				
3. Meet all ERTs (*20% DIP)	-4,296,060	188,568	-7,762,090	242,976	infeasible
4. Whole catchment ERTs (*20% DIP)	-16,448,000				

* DIP constrained to 20%.

In seeking to meet the least-cost solution in meeting targets, depending upon the land uses and practices selected, over-achievement of some constituents is possible. Table 6 shows the predicted target achievements for each scenario. Allowing targets to be met on a whole of catchment level (Scenario 2 compared to 1, or Scenario 3 compared to 4) is much more efficient than if targets have to be met on an individual basin level. Catchments where the relative proportion of cane land use is high can be selected (Kolan, Burrum, Burnett) before needing to move to basins that are more expensive. The Mary catchment in particular poses large problems, because large amounts of sediment come from streambanks and grazing, and the costs of remediation are extremely high.

Another important point from Table 6 is that the bioeconomic model can seek the optimal solution in terms of multiple constituents that are not readily picked up by 'eyeballing'. This is illustrated by DIP as commonly the most limiting constituent. For example, where RPTs are met on a whole of catchment basis (Scenario 2, Table 6) DIP targets vary from 4-25% in individual basins compared with where DIP targets have to be met to at least 20% for Scenario 1. Different combinations of constituent targets are achieved in different basins depending upon how constrained the model is.

Table 6: Achievement of individual constituent targets associated with four scenarios in the Burnett-Mary region.

Scenario	Net profit/Cost ($million/yr	Load reductions (% achieved)				
	Whole catchment	Baffle	Kolan	Burnett	Burrum	Mary
1. Meet RPTs (20% DIP*) – individual basins	-7,894,145	TSS – 21.8, DIN – 55.4 PN – 135.7, PP – 107.4, DIP – 20, PSII – 60 -1,411,930	TSS – 23.5, DIN – 86.9 PN – 54.9 PP – 40.4 DIP – 24.9 PSII –60 558,328	TSS – 36.2 DIN – 93.0 PN – 46.3, PP – 36.1, DIP – 20, PSII –60 -4,774,090	TSS – 39.5, DIN – 87.4 PN – 51.7, PP – 43.8, DIP – 20, PSII –60 497,837	TSS – 20, DIN – 76.9 PN – 30.1, PP – 29.6, DIP – 20, PSII –60 -2,764,290
2. Whole catchment RPTs (20% DIP*)	TSS – 20 DIN – 83 PN – 40 PP – 37 DIP – 20 PSII – 60 -2,978,590	TSS – 15 DIN – 48 PN – 130 PP – 99 DIP – 13 PSII – 49 -820,121	TSS – 24 DIN – 87 PN – 55 PP – 41 DIP – 25 PSII – 62 506,044	TSS – 20 DIN – 90 PN – 42 PP – 31 DIP – 4 PSII – 54 883,681	TSS – 37 DIN – 86 PN – 50 PP – 42 DIP – 17 PSII – 57 1,051,665	TSS – 19 DIN – 80 PN – 31 PP – 32 DIP – 24 PSII – 66 -4,599,860
3. Meet all ERTs (*20% DIP) individual basin	(net of individual basins is -11,626,606 in 4 basins, infeasible in Mary)	TSS –51 DIN – 80 PN – 158 PP – 141 DIP – 48 PSII –71 -4,296,060	TSS – 31 DIN – 87 PN – 61 PP – 50 DIP – 26 PSII – 60 188,568[A]	TSS –51 DIN – 97 PN –57 PP –50 DIP – 20 PSII –75 -7,762,090	TSS – 40 DIN – 87 PN – 55 PP – 50 DIP – 20 PSII – 60 242,976[A]	infeasible
4. Whole catchment ERTs (*20% DIP)	TSS – 32 DIN – 87 PN – 50 PP – 50 DIP – 21 PSII – 79 -16,448,000	TSS – 61 DIN – 78 PN – 166 PP – 150 DIP – 45 PSII – 71 -4,857,770	TSS – 37 DIN – 93 PN – 72 PP – 64 DIP – 27 PSII – 82 -1,186,370	TSS – 35 DIN – 97 PN – 54 PP – 43 DIP – 5 PSII – 81 -2,130,980	TSS – 42 DIN – 90 PN – 66 PP – 62 DIP – 14 PSII – 78 -1,336,160	TSS – 27 DIN – 81 PN – 38 PP – 40 DIP – 20 PSII – 80 -6,936,750

[A] Achieving a profit in the Kolan and Burrum catchments for ERTs appears problematic. We suspect this result is an artefact and associated with the infeasibility of solution for the Mary catchment. We suggest the scenario 3 results should not be used.

Results - land management practice changes associated with achieving ReefPlan targets (RPTs) and Ecologically Relevant targets (ERTs)

Tables 7a-11 provides a summary of the practice change transitions for respective practices in sugar cane and grazing, together with gully and streambank remediation where applicable, for Scenarios 1 to 4.

Note that we think that the cost and therefore transitions in the Burrum and Kolan catchments for Scenario 3 (ERTS on an individual basin basis) might be unreliable as a result of the infeasibility of solution in the Mary catchment.

Tables 7a-b: Practice change transitions in the Baffle Basin

Table 7a: RPTs (20% DIP) in the Baffle catchment optimised on an individual basin basis (Scenario 1 standard font) or whole of catchment basis *(Scenario 2 italicised font)*

	A (ha)	B (ha)	C (ha)	D (ha)	Total (ha)
Cane - original	0	61	331	164	556
Cane - new	325 *143*	231 *413*	0 *0*	0 *0*	556
Cane area change	325 *143*	231 *352*	-331 *-331*	-164 *-164*	
Grazing - original	42536	140032	67389	21503	271460
Grazing new	61998 *49690*	161864 *162405*	26093 *37860*	21503 *21503*	271460
Grazing area change	19462 *7154*	21832 *22373*	-41296 *-29529*	0 *0*	
Gullies fenced*(km)	0 of 324 km *0 of 324 km*				
Streams fenced*(km)	0 of 322 km *0 of 324 km*				

Greater transitions are made in both cane and grazing to B practice when targets can be achieved on a whole of basin basis for RPTs. Constraining the model to achieving targets on an individual basin requires increased A practice transitions in both grazing and cane. Due to the limited cane area in the Baffle catchment net losses are incurred for RPTs.

Table 7b: ERTs (20% DIP) in the Baffle catchment optimised on an individual basin basis (Scenario 3 standard font) or whole of catchment basis *(Scenario 4 italicised font)*

	A (ha)	B (ha)	C (ha)	D (ha)	Total (ha)
Cane - original	0	61	331	164	556
Cane - new	556 *556*	0 *0*	0 *0*	0 *0*	556
Cane area change	556 *556*	-61 *-61*	-331 *-331*	-164 *-164*	
Grazing - original	42536	140032	67389	21503	271460
Grazing new	159697 *141917*	90229 *107106*	7710 *13105*	13823 *9332*	271460
Grazing area change	117161 *99381*	-49803 *-32926*	-59679 *-54284*	-7680 *-12171*	
Gullies fenced*(km)	0 of 324 km *24 of 324 km*				
Streams fenced*(km)	0 of 322 km *127 of 322 km*				

Achieving the more ambitious ERTs requires all cane to transition to A practice under both Scenarios 3 and 4. Substantial shifts in the grazing industry are needed into A practice, particularly for individual basin Scenario 3. A small amount of gully and stream fencing is also predicted under the whole Basin scenario.

Tables 8a-b: Practice change transitions in the Burnett Basin

Table 8a: RPTs (20% DIP) in the Burnett catchment optimised on an individual basin basis (Scenario 1 standard font) or whole of catchment basis *(Scenario 2 italicised font)*

	A (ha)	B (ha)	C (ha)	D (ha)	Total (ha)
Cane - original	0	1439	7814	3863	13116
Cane - new	1560 *696*	11556 *12419*	0 *0*	0 *0*	13116
Cane – area change	1560 *696*	10117 *10980*	-7814 *-7814*	-3863 *-3863*	
Grazing - original	399638	1315641	633136	202036	2550451
Grazing new	524980 *400292*	1280405 *1315301*	554660 *632821*	190405 *202036*	2550451
Grazing – area change	125342 *654*	-35236 *-340*	-78476 *-315*	-11631 *0*	
Gullies fenced*(km)	0 of 6090 km *0 of 6090 km*				
Streams fenced*(km)	0 of 4006 km *0 of 4006 km*				

ReefPlan Targets are predicted to be met in the Burnett Basin by moving all of cane out of C and D practices to A and B practice both for targets achieved at whole of catchment or individual basin level. In addition a large area (125342 ha) of grazing land is transitioned from B, C and D class practices to A class where targets need to be achieved on an individual basin level, which explains the $4.77M net loss in profit (Table 5).

More movement into the most profitable B class cane practices can occur for whole catchment targets in the Burnett (Scenario 2 compared to Scenario 1) and much less movement is required in grazing overall, which explains why whole of Burnett RPTs can be achieved at a net profit of $883K compared with the $4.77M net loss where individual basin targets must be met.

Table 8b: ERTs (20% DIP) in the Burnett catchment optimised on an individual basin basis (Scenario 3 standard font) or whole of catchment basis *(Scenario 4 italicised font)*

	A (ha)	B (ha)	C (ha)	D (ha)	Total (ha)
Cane - original	0	1439	7814	3863	13116
Cane - new	8293 *10910*	4822 *2205*	0 *0*	0 *0*	13116
Cane area change	8293 *10910*	3383 *766*	-7814 *-7814*	-3863 *-3863*	
Grazing - original	399638	1315641	633136	202036	2550451
Grazing new	557212 *409519*	1275964 *1317639*	524427 *621399*	192848 *201893*	2550451
Grazing area change	157574 *9881*	-39677 *1998*	-108709 *-11737*	-9188 *-143*	
Gullies fenced*(km)	1 of 4006 km *0 of 4006 km*				
Streams fenced*(km)	162 of 6090 km *181 of 6090 km*				

To meet the ambitious ERTs in the Burnett Basin (Table 8b, Scenario 3) on an individual basin requires almost 63% of the cane land to move to A practice, with the remainder in B practice. Large transitions are also required in the grazing industry with much more land moving into A practice (157,574 ha) in Scenario 3 than scenario 4 (9,881 ha). For Scenario 4 (whole of basin ERTs) even larger transitions occur into A cane practice (10,910 ha, 83% cane area), but much less grazing transition is required overall, which explains the smaller net loss $2.1M than under the ERT whole catchment Scenario compared with a net loss in the Burnett Basin of $7.8M if ERTs are to be met at the individual basin scale. A small amount of stream fencing is also predicted in both scenarios.

Tables 9a-b: Practice change transitions in the Kolan Basin

Table 9a: RPTs (20% DIP) in the Kolan catchment optimised on an individual basin basis (Scenario 1 standard font) or whole of catchment basis *(Scenario 2 italicised font)*

	A (ha)	B (ha)	C (ha)	D (ha)	Total (ha)
Cane - original	0	1083	5880	2907	9870
Cane - new	1183 *1405*	8687 *8465*	0 *0*	0 *0*	9870
Cane – area change	2283 *1405*	7,604 *7,382*	-5880 *-5880*	-2907 *-2907*	
Grazing - original	31887	104975	50518	16120	203501
Grazing new	31887 *31927*	104975 *105044*	50518 *50409*	16120 *16120*	203501
Grazing – area change	0 *40*	0 *69*	0 *-109*	0 0	
Gullies fenced*(km)	0 of 350 km *0 of 350 km*				
Streams fenced*(km)	0 of 340 km *0 of 340 km*				

In the Kolan Basin both ReefPlan targets (Table 9a) and ERTs (Table 9b) can be achieved at a small net profit. Targets solved on an individual basis RPTs can be met by moving all cane into A and B practice with no transitions in grazing. The whole of basin targets involve a very small amount of grazing transition.

Table 9b: ERTs (20% DIP) in the Kolan catchment optimised on an individual basin basis (Scenario 3 standard font) or whole of catchment basis *(Scenario 4 italicised font)*

	A (ha)	B (ha)	C (ha)	D (ha)	Total (ha)
Cane - original	0	1083	5880	2907	9870
Cane - new	2226 *7902*	7644 *1968*	0 *0*	0 *0*	9870
Cane area change	2226 *7902*	6561 *885*	-5880 *-5880*	-2907 *-2907*	
Grazing - original	31887	104975	50518	16120	203501
Grazing new	37267 *44968*	104300 *100415*	46261 *42478*	15672 *15640*	203501
Grazing area change	5380 *13081*	-675 *-4560*	-4257 *-8040*	-448 *-480*	
Gullies fenced*(km)	0 of 350 km *0 of 350 km*				
Streams fenced*(km)	0 of 340 km *0 of 340 km*				

The ERTs on an individual basin basis require movement of cane into A practice (2226 ha) as well as a modest shift in grazing (additional 5380ha) to move into A practices – note we suspect the Scenario 3 results are unreliable as part of the infeasibility issue in the Mary catchment. The whole of catchment targets selects larger transitions to A practice in both cane (7,902 ha) and grazing (13,081 ha).

Tables 10a-b: Practice change transitions in the Burrum Basin

Table 10a: RPTs (20% DIP) in the Burrum catchment optimised on an individual basin basis (Scenario 1 standard font) or whole of catchment basis *(Scenario 2 italicised font)*

	A (ha)	B (ha)	C (ha)	D (ha)	Total (ha)
Cane - original	63	2289	12490	6117	20961
Cane - new	3094 *2782*	17867 *19135*	0 *0*	0 *0*	20961
Cane – area change	3031 *2721*	15578 *16846*	-12490 *-12490*	-6117 *-6117*	
Grazing - original	20180	66435	31971	10202	128789
Grazing new	38092 *26938*	60698 *66169*	20070 *25708*	9928 *9974*	128789
Grazing – area change	17912 *6758*	-5737 *-266*	-11901 *-6263*	-274 *-228*	
Gullies fenced*(km)	0 of 130 km *0 of 130 km*				
Streams fenced*(km)	0 of 378 km *0 of 378 km*				

The Burrum Basin has the highest cane area (20,961 ha). The Individual basin ReefPlan target scenario require cane transition from C and D to a majority of B and some A practices (Table 10a) with modest additional transitions in the grazing industry from all practices into A class management (17,912 ha). Despite this, because of the profitability of moving to B class practices in cane, net profit of $497K is predicted (Table 5). Higher net profit ($ 1.1M/year) can be achieved for Scenario 2, due in large part because smaller practice shifts to A in both grazing and cane being required.

Table 10b: ERTs (20% DIP) in the Burrum catchment optimised on an individual basin basis (Scenario 3 standard font) or whole of catchment basis *(Scenario 4 italicised font)*

	A (ha)	B (ha)	C (ha)	D (ha)	Total (ha)
Cane - original	63	2289	12490	6117	20961
Cane - new	4497 *14451*	16464 *6510*	0 0	0 0	20961
Cane area change	4434 *9954*	14175 *4221*	-12490 *-12490*	-6117 *-6117*	
Grazing - original	20180	66435	31971	10202	128789
Grazing new	35875 *22424*	64052 *65272*	19766 *30891*	9096 *10202*	128789
Grazing area change	15695 *2244*	-2383 *-1163*	-12205 *-1080*	-1106 *0*	
Gullies fenced*(km)	0 of 130 km, *2 of 130 km*				
Streams fenced*(km)	0 of 378 km, *68 of 378 km*				

For the more ambitious ERTs larger transitions to A practices in cane are predicted than under the individual basin targets scenario – it is possible Scenario 3 is incorrect due to being a possible artefact of infeasibility in the Mary (Table 10b). For Scenario 4, modest (2,244) change to A practices in grazing are required and a small amount of stream and gully work is also predicted.

Tables 11a-b: Practice change transitions in the Mary Basin

Table 11a: RPTs (20% DIP) in the Mary catchment optimised on an individual basin basis (Scenario 1 standard font) or whole of catchment basis *(Scenario 2 italicised font)*

	A (ha)	B (ha)	C (ha)	D (ha)	Total (ha)
Cane - original	1551	1115	7567	2352	12584
Cane - new	4177 *6019*	8406 *6565*	0 *0*	0 *0*	12584
Cane – area change	2626 *4468*	7291 *5450*	-7567 *-7657*	-2352 *-2352*	
Grazing – original	74010	243648	117252	37416	472326
Grazing new	163276 *190753*	209159 *209003*	70450 *48012*	29440 *24559*	472326
Grazing – area change	89266 *116743*	-34489 *-34645*	-46802 *-69240*	-7976 *-12857*	
Gullies fenced*(km)	0 of 747 km, *0 of 747 km*				
Streams fenced*(km)	30 of 1250 km, *16 of 1250 km*				

More change to A practices in both cane and grazing is possible under the whole of basin RPTs (Scenario 2) than when targets need to be achieved on an individual basin level (Scenario 1). Although substantial net cost occur in both scenarios, the net losses are much lower in Scenario 2 and 1 (Net loss of $2.76M/year compared to $4.60M/year).

Table 11b: ERTs (20% DIP) in the Mary catchment optimised on a whole of catchment basis *(Scenario 4 italicised font).* It is infeasible to meet Mary catchment targets on an individual catchment basis.

	A (ha)	B (ha)	C (ha)	D (ha)	Total (ha)
Cane - original	1551	1115	7567	2352	12584
Cane - new	Infeasible *12200*	Infeasible *383*	Infeasible *0*	Infeasible *0*	12584
Cane – area change	N/A *10649*	N/A *-732*	N/A *-7567*	N/A *-2352*	N/A
Grazing - original	74010	243648	117252	37416	472326
Grazing new	Infeasible *193238*	Infeasible *195258*	Infeasible *58373*	Infeasible *25456*	472326
Grazing – area change	N/A *119228*	N/A *-48390*	N/A *-58879*	N/A *-11960*	N/A
Gullies fenced*(km)	*0 of 747 km*				
Streams	*384 of 1250 km*				

fenced*(km)	

Large and expensive land management practice changes are required in the Mary catchment to achieve ERTs optimised over the whole of basin scale (net loss $6.94M/year). Almost all cane has to move to A practice, in addition to large areas of grazing also needing to move to A practice.

Conclusions

This is the first time such a comprehensive and integrated bioeconomic model has been constructed for GBR using available biophysical and economic modelling. While we have some concerns about the construct and inputs of the model (outlined in Appendix 2), it has been favourably reviewed by Graeme Doole, University of Waikato an expert in bioeconomic modelling using GAMS (Attached as Appendix 3). Overall while a model is only ever as good as its assumptions and inputs, it has been a very worthwhile process and has provided insights and a stronger basis on the feasibility of achieving multiple constituent targets than possible previously. If the estimates of practice efficiency and net profitability of practice change are within the ballpark of reality, then the implications for the GBR are large. Some of the main messages are:

- Large and on-going support will be needed for the grazing industry to achieve sediment and particulate P and N targets
- If cane efficiencies and profitability estimates are close to reality then, depending upon the ambitiousness of targets, cane transition to B practice is profitable.
- ERTs cannot be met without substantial costs (estimated to be a net loss of $16.45 million/year as a least-cost solution involving very heavy targeting, which will cause perceived 'equity' issues amongst industries.
- Such 'equity' comes at a large cost (compare the cost of $7.89 million if RPTs are met more 'equitably' on an individual catchment basis, compared with on a whole of basin basis where the next cost is less than $2.98 million). Taxpayer equity would seem to be important too…
- The Mary catchment in particular poses major challenges due to the large contribution from streambanks and grazing for particulates and sediment

APPENDIX 1: BIOECONOMIC MODELLING, INFFER and GREAT BARRIER REEF WATER QUALITY

Geoff Park and Anna Roberts

This document presents a brief introduction to the discipline of bioeconomic modelling, its application to problems in natural resource management, and its relevance to the development of Water Quality Improvement Plans for the Great Barrier Reef.

Introduction to bioeconomic modelling

The term 'bioeconomic modelling' is typically used by economists to describe models that have both economic and biophysical components. A recent paper [Kragt, 2012], provides an excellent overview. We have used this paper as the basis for the following introductory section and included the references for readers who wish to explore the topic in more detail.

Bioeconomic models can be a valuable decision support tool to support integrated environmental assessments and decision-making processes. Ideally, a bioeconomic model will adequately reflect the trade-offs between natural (biophysical and ecological) processes and socioeconomic systems, to help evaluate how management actions affect different policy objectives [van den Bergh et al. 2001].

Bioeconomic models are extensions of traditional mono-disciplinary economic models, which typically aim to quantify human uses of ecosystems for production and consumption activities [Braat and van Lierop 1987]. The representation of environmental processes in these models
Is often fairly narrow and static; the extent to which the system is simplified (both the biophysical and economic components) is important to recognise. Like all models, the usefulness of a bioeconomic model in decision making will depend upon the confidence of both the underpinning biological and economic components to represent the system of interest.

Bioeconomic models have been used in forestry, to determine the optimal level of resource extraction to maximise profits, in fisheries, to estimate maximum sustainable yields at which steady state levels of fish stocks and profits can be maintained, and in agricultural systems to predict the impacts of changes in environmental resources (e.g. soil quality or water quantity) on agricultural production.

Bioeconomic modelling of agricultural systems can be characterised by three different approaches [Weersink et al. 2002]: (i) accounting, (ii) regression, and (iii) mathematical programming.

- Accounting models are simple descriptive book-keeping systems of agricultural production system [Bouman et al. 1999, 1998]. Examples include simple gross margin analyses [e.g. Firth 2001].
- Regression models use statistical estimates of site-, or region-specific agro-economic production functions based on observed relationships between prices, farm inputs, policies, and physical characteristics of the land.
- Agro-economic mathematic programming models can optimise or simulate the 'optimal' demand for environmental inputs that would maximise farm profits, subject to input

and/or output prices, available capital or labour, and prevailing environmental conditions [e.g. climate or land availability; Hazell and Norton 1986]. Optimisation models such as MIDAS [Kingwell and Pannell 1987, Morrison et al.1986, Pannell 1996] have the advantage of allowing a detailed specification of farm management activities and restrictions simultaneously, including technologies, multiple crop rotations, livestock management, and different soil types [e.g. Monjardino et al. 2010, Moxey et al. 1995]. The analytical focus of agro-economic optimisation models is typically that of profit maximisation or cost minimisation, with environmental parameters exogenous to the model. Few examples account for environmental pollution impacts on and from agriculture [exceptions include Kopke et al. 2008, Oglethorpe and Sanderson 1999].

An important caveat on bioeconomic modelling as a decision support tool is that environmental systems produce benefits beyond those that are usually accounted for in the models described above. Bioeconomic models tend to focus on productive (marketable) environmental goods and services, but typically don't incorporate intangible ecosystem goods and services. The importance of such intangibles in the decision making problem needs to be considered in assessing their usefulness.

Bioeconomic modelling and INFFER

Bioeconomic modelling can be used as a stand-alone tool as well as an input to more fully integrated assessment processes such as INFFER (Investment Framework for environmental Resources, Pannell et al. 2011, Roberts et al. 2012, www.inffer.com.au). INFFER is a framework that allows users to prioritise among competing projects on the basis of the benefits and costs of each project.

INFFER uses the principles of benefit: cost analysis to undertake integrated assessments of projects that aim to achieve environmental outcomes. The framework can use whatever information is available including formal economic, social and biophysical studies as well as expert judgment. Bioeconomic modelling analysis can inform the cost component of INFFER, particularly the costs associated with management practice changes on private land to achieve environmental targets.

Detailed information on INFFER is available at www.inffer.com.au

Corner Inlet case study

The Corner Inlet Ramsar Site is the most southerly marine embayment and tidal mudflat system of mainland Australia. It supports outstanding environmental values that have been recognised through its listing as a wetland of international importance under the Ramsar Convention.

The condition and extent of important habitat including seagrass meadows, sandflats, mangroves and saltmarsh are threatened by nutrient and sediment pollution resulting mostly from catchment land uses. The Corner Inlet WQIP has been developed to significantly improve the quality of water entering the Corner Inlet Ramsar Site in order to protect its unique and significant values. Achieving this aim requires a measurable reduction in the level of nutrients and suspended sediment loads from surrounding catchments.

Development of a bioeconomic optimisation model using a mathematical programming approach (Brooke et al. 2008), and an INFFER analysis were integral to the Corner Inlet WQIP. *An essential component of INFFER was to assess the technical feasibility of achieving set nutrient load reduction* *targets. This required the estimation of the effectiveness of available land management options in reducing catchment nutrient loads. The development of a bioeconomic model made the task of assessing costs to achieve nutrient reduction targets much more transparent.* Rapid and iterative assessment of scenarios from the bioeconomic model also enabled adaptation of initially aspirational targets to more realistic levels. Targets eventually settled on were as high as possible (to try and protect the environmental values of Corner Inlet) whilst balancing the needs to maintain productive agriculture.

A summary of the bioeconomic modelling approach is outlined below, with more details provided in Beverly et al. (2013):

1. The biophysical basis was developed through adaptation of the previously calibrated catchment model called E2 (precursor to SourceCatchments), including updated mapped land use data on dairy and beef systems and gully risk mapping based on aerial photos and survey data which was correlated to streambank and gully erosion estimates from nearby catchments. The revised E2 modelling provided subcatchment load estimates of TN, TP and TSS from each of 67 subcatchments.
2. Construction of representative farming systems. Land-uses of dairy (four levels of intensity), beef and revegetation were considered using knowledge of local extension staff and relevant research and previous information from a range of sources.
3. Estimation of the percentage effectiveness of alternative management practices. In the absence of locally relevant field and published information and paddock scale modelling, workshops of local extension experts were held to identify so-called 'best management practices' (BMPs) for reducing nutrient and sediment losses on typical beef and dairy farms for both paddock management practices and also currently funded CMA activities such as waterway and gully fencing. For each practice, local experts were first asked to specify current practice, and then to identify the relevant BMP before considering the percentage effectiveness of the BMP relative to current practice. Some BMPs were relevant to either beef or dairy and some were relevant to both. Some BMPs applied to the whole farm, whereas others only applied to part of the farm. In each case experts were asked to think about the effectiveness of the practice and assign an indicative farm proportion to which the practice was relevant.
4. Estimation of the costs of implementing management practices. The annual net private benefit (+) or cost (-) of implementing each BMP on each representative dairy or beef farm was calculated relative to a baseline, this being the annual 'operating profit' for each system. The operating profit was calculated as gross income minus costs (including variable costs and fixed costs or overheads).
5. The bioeconomic model was programmed using the General Algebraic Modelling System (GAMS, Brooke et al. 2008). The optimisation model maximises total net benefits expressed as the difference between producer profit and regulatory costs for a given nutrient target. This cost-effectiveness approach, where emissions goals are sought at least cost (e.g. Doole, 2012; Doole and Pannell, 2012) avoids the difficulty and cost of assessing the benefits associated with improved water quality. Further details are outlined by Beverly et al. (2013). In summary, to achieve the targets set for a particular scenario the bioeconomic model could select between management practices (best-management or traditional activities) and land use (four levels of dairy intensity, beef or retirement of land).
6. Development of scenarios to assess changes in profit and land management implications associated with achieving sediment and nutrient reduction targets. Following the initial

aspirational and revised target setting with the Technical Panel, CMA *staff and modellers worked through over 20 scenarios to assess implications on profit, land use and management changes required to achieve targets.* The first scenarios were focussed on achieving targets at least-cost (allowing land use change options if these were more cost-effective than relying only on management practices). Following discussions regarding the economic and political acceptability of some of the management implications, additional scenarios were tested. Scenarios included no land change allowed, only allowing some BMPs to be considered, or focussing on particular catchments.

For the Corner Inlet study the biological component of the bioeconomic model was coarse and simplified due limited understanding of causal links between constituent loads (Nitrogen, Phosphorus and Suspended Sediment) and key asset values, especially seagrass. For example, a linear relationship between reductions in constituent loads and the improvements in condition and extent of seagrass was assumed.

Overall the bioeconomic model proved to be a very valuable tool in its own right as well as to inform the INFFER analysis. The WQIP targets ultimately agreed to strike a balance between the nutrient load reductions which could be realistically be achieved, albeit with a need for substantially increased funding, and which would maintain agricultural industries within the region. It also provides the basis for a longer term discussion about agricultural and environmental trade-off decisions which may be required to better protect Corner Inlet.

Bioeconomic modelling and water quality for the Great Barrier Reef

Water Quality Improvement Plans (WQIPs) are being developed for individual river basins on the Great Barrier Reef (GBR) catchment associated with the GBR Water Quality Protection Plan. Within each WQIP, marine ecosystem targets are linked to end-of-river pollutant (suspended sediments, nutrients and pesticides) load targets and to farm level management practice targets.

Bioeconomic modelling will form an important component of the Burnett-Mary WQIP. The approach will be similar in concept to that used in Corner Inlet, albeit with much more biophysical information available from both Paddock to Reef paddock-scale and catchment scale modelling. Source Catchments to be used as the basis of pre-BMP loads (2008-9) in the 597 subcatchments in Burnett-Mary and Paddock to Reef modelling will be used as the basis for informing the load reduction associated with ABDC management practices. Both sugarcane and grazing will be considered due to both the importance of these industries and the available knowledge base. Workshops with each of the cane and grazing industries have been held along with follow up with local industry representatives, extension staff and economists to assess benefit and cost implications associated with management practice changes.

A substantial improvement in the Burnett-Mary WQIP over Corner Inlet is that the targets will be set on an ecologically relevant basis (see Brodie, 2009). Targets will be developed for each of the five river basins (Burnett, Mary, Baffle, Burrum and Kolan) for sediment, dissolved nitrogen and pesticides The ecologically relevant targets able to be utilized in the bioeconomic model will be defined as load reductions at the end of nominated river basins, on the basis of known thresholds for maintaining values of the Great Barrier Reef and related assets outside the GBR. Concentration targets, known to be important for pesticides will not be able to be tested within the bioeconomic model. An iterative testing process will be used to assess the costs of attaining different levels of load reductions before agreement is reached on the selected targets on which the WQIP will be based and on which a subsequent INFFER analysis will be conducted.

Overall, the bioeconomic model is expected to provide some ‘ball-park’ figures for realistic costs associated with achieving nutrient load reduction targets, albeit with caveats both in terms of simplification of biophysical elements (such as being limited to long-term average annual loads from Source, over-simplification of soil heterogeneity, reliance on simple rules for scaling between paddock and catchment loads, limited information on stream and gully lengths and effectiveness estimates) and economic elements (representation of only three farm sizes for each of cane and grazing, single discount rate and time period of analysis). The bioeconomic model can be considered as a strong initial basis for integration of the available biophysical and economic work conducted to date to test the feasibility and costs to landholders associated with different levels of load reduction.

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APPENDIX 2: CHALLENGES ASSOCIATED WITH THE BIOECONOMIC MODEL

This is the first time such a comprehensive and integrated bioeconomic model has been constructed for GBR using available biophysical and economic modelling. There have been two sets of challenges associated with its development and interpretation of the outputs. Below we outline some concerns we encountered. We have qualitatively ranked the potential for errors (high, moderate, low) based on our iterative development and testing of the model and 'gut feel'.

Challenges with the model construct

These are issues about the construct of the bioeconomic model itself have potential for errors in outputs. Below we have identified what we see as major sources of uncertainty leading to error.

Land use/constituent and process representation In Source Catchments: Within the GBR Source Catchments design, the generation concept of pollutants is different for each land use. Pollutants and process representation is shown in Figure 1. Where possible the processes behind pollutant generation (hillslope, gully etc) are identified to allow reporting of generated loads to be categorised into these land use and process groups. The clearly defined processes of 'hillsope' and 'gully' are accompanied by less deterministic process categories of 'Diffuse Dissolved' and 'Point Source' when the pollutant generation process is less tangible or not technically assignable to a specific land use. A process category of 'Undefined' is applied to all land use generated pollutant loads that have no clear process definition (ie typically used to define the generation of pollutant loads where a simple, static concentration x runoff volume relationship has been used). The final process category employed by the GBR Source Catchments design is 'Streambank', with pollutants generated from the actions of streambank erosion not assignable to any specific land use in the current structure. When GBR Source Catchments are summarised for distribution to third parties, the aggregation process gives the appearance that every land use has had the contribution of every generation process. The categories are somewhat artificial. For example gullies are considered within cane and grazing land uses. While gully volumes have been calculated from spatially variable density estimates within a cross-sectional area estimate, how representative the gully representation is not clear. Likewise how the diffuse dissolved component and undefined categories relate to catchment processes is not very clear; the generated pollutant load may have come to SourceCatchments from a paddock model (e.g Howleaky) or from a generic concentration estimate. Overall there appear to be potential for errors caused because of the way processes are aggregated or split and then represented in the model. For gullies in particular separating out costs and potential for load reductions from either hillslope or gullies requires an artificial separation of the lumped load between the two before costs can be partitioned.

Potential for error: Moderate. If the landuse/constituent processes are not adequately represented then this reduces confidence in results.

Different paddock scale models used. Three different paddock scale models (APSIM, HowLeaky and GRASP) have been used to inform sediment and nutrient loads in Source (cane, grazing and cropping – note that we have not considered cropping in the bioeconomic modelling). These models have different strengths in terms of which management practices they can handle, as well as which constituents can be modelled. APSIM has been used for cane and is a relatively sophisticated model compared with GRASP. While GRASP can capture management practices, only a limited set of landscape/climate/management combinations have been used to inform GBR modelling. Thus the full suite of landscape/climate/management scenario has not informed management effectiveness outputs. The implication of this is that some land uses and constituents are better represented than others, and parameters in APSIM for example can be 'tuned' to fit data more so than in say GRASP. Errors associated with comparison of management impacts from grazing compared with cane could occur because of the different model constructs which are not real.

Potential for error: High, on the basis that apples (eg APSIM) and oranges (eg Howleaky, GRASP) are being compared rather than apples with apples and the issue that paddock scale models have represented the full suite of landscape/climate/management scenarios.

Linkage between paddock and catchment modelling. . Paddock and catchment models have been linked to enable Source to report load reductions of constituents such as DIN and Pesticides. The modellers have thousands of (daily time-step) simulation outputs representing many specific soil/climate/management combinations relevant to GBR. For any given scenario (such as the 'baseline', 'Report Card 3 change' etc) they proportionately accumulate the relevant simulation outputs into a single daily timeseries of pollutant generation for every land use in every individual subcatchment and these timeseries representing daily pollutant generation (considering differences in soil/climate/management) are passed into the Source Catchments model. These accumulation and transfer processes are done with purpose built tools.

The relativity between generation rates of land uses has been known to cause issues, not just in Burnett Mary. Modellers have some idea of the relative rates of expected generation rates between land uses, but may have to move specific generation concentrations up or down to achieve in-stream loads similar to those seen in validation data sets.

Potential for error: Low, compared with some of the other issues raised. Modellers have spent a lot of time on this and developed purpose built tools.

Approaches to identification of practice effectiveness estimates from A, B, C, D practice suites for cane and grazing. Different approaches have been used to identify practice effectiveness for cane and grazing land uses and as previously described different modelling approaches have been used. There are also inconsistencies in the scale of effectiveness estimates for the A, B, C and D practices for the two land uses. For grazing, a very simple approach based on a 'global' lookup table (email from Mark Silburn 25/11) apportioned the relative load differences between A, B, C and D practices based on a site at Munduberra (A 0.071; B 0.38; C 1; D 1.95). A combination of APSIM and Howleaky were used to estimate practice effectiveness in cane systems from P2R modelling. We suspect the effectiveness estimates are optimistic (eg DIN 0% loss In A, 6% B, 100% C, 100% D on red dermosol). Gully and streambank effectiveness has an acknowledged very limited basis; for example we have used Scott Wilkinson's best estimate based on limited data from the Burdekin on gully practice effectiveness (25% effectiveness for TSS for C→A). The combination of limited data and different models used to assess practice effectiveness has large potential to generate results with significant anomalies.

Potential for error: High on the basis that there is very limited data to test management practice effectiveness and we are suspicious of very high load reductions from C-B practice in particular. This might be due to aspiration as much as evidence.

Stream loads and lengths. Related to the issue of land use, constituent and process representation In Source Catchments, discussed earlier, a further issue is that of stream load contribution and relationship to stream length. All streams that have an applicable 'streambank' process assigned also have a length (in metres) which is accessible, like gully volumes for land uses. These are calculated from GIS analysis, so there is some uncertainty about the extent to which stream lengths represent reality. A major issue is that there are significant areas in a 'coastal strip' where no GIS-derived stream is calculated, hence these stream representations have no length attribute nor a streambank process contribution. Another challenge is that independent work contracted by BMRG in the Burnett catchment suggests the possibility of large discrepancies between modelled loads and loads calculated based on geomorphology.

Potential for error: Moderate on the basis of the discrepancies between modelled loads and geomorphology work and the known issue in coastal areas.

Model constraints: Bioeconomic modelling results are highly sensitive to how the model is constrained. For example if we allow farm sizes to change then farms will move to larger and more profitable farms to achieve targets at least cost. If we constrain the model to no land use management going backwards (eg practices in B practice must remain in B or move to A) then this can lead to very different results (much more expensive) than having a less constrained model.

Potential for error: Medium on the basis that people are unlikely to have informed views about how much to constrain the model and are prepared to accept output results unless they look odd (which they have done when the model has been constrained at different times in response to discussions).

Challenges with the model inputs

Effectiveness of practices themselves. There is limited field data to validate modelled impacts of BMPs. This means that modelled outputs are heavily relied upon, and there has been relatively limited scrutiny on individual BMP efficiency estimates, most emphasis having been on defining suites of ABCD practices which has been a simple and convenient way to bundle practices into a digestible form. Given both the number of practices and the relatively short-term investment into assessment of practice impacts, strong field validation would be extremely difficult.

Potential for error: Moderate, given the limited field data on practice effectiveness.

Relative contributions between different practices (Risk framework): In addition to the effectiveness of practices themselves, there is also the issue of relative contributions of practices within a practice class (A, B, C, D). We have used the P2R Risk Framework to assign relative practice differences between practice classes. The Risk Framework is based on expert opinion and as such is the best available information.

Potential for error: Moderate, extremely limited data on which to base estimates on.

Land use discrepancies: There are discrepancies in land use data from different data sets. The most obvious issue is with cane, which has been picked up because cane areas are the well-known by industry groups. The issue is about discrepancy between QLUMP (used in Source) and ABS data. We have used a scaling factor to scale back cane areas to be more in line with industry data. Overall, whilst land use discrepancies are important in terms of models having credibility with industry, this source of error is likely to be less significant than many of the other issues raised.

Potential for error: Low compared with some of the other issues.

Lack of information on some land uses: Some land uses, for example horticulture, have limited data on land use areas. Whilst it is important for large load land use load generators such as horticulture to have more scrutiny in terms of management practices that can be adopted to reduce nutrient and sediment loads, overall the potential for large error is likely to be less important than for some of the other challenges.

Potential for error: Low, at least the large land uses are covered.

Farm heterogeneity: In reality there is huge farm heterogeneity and for the bioeconomic model we have had to make simplifications. We know that farm heterogeneity (soil/productivity class and farm size) are major drivers in profitability and costs of practice change. While we know we have by no means catered for farm heterogeneity within the farming population, we have tried to strike a balance between available biophysical data (modelling nutrient loss at paddock scale does not cater for farm size and different BMP effectiveness associated with farm management capacity) and the known impact of farm size on costs (work from Martijn van Grieken in cane and Megan Star et al in grazing). We believe that, given the uncertainties in other areas, we have represented farm heterogeneity in terms of land productivity and farm size at sufficient, albeit simplistic detail, to not be out of balance with the other bioeconomic modelling challenges.

Potential for error: Low-Medium on the basis that we have captured some heterogeneity in size and costs and that the coarseness of Source has meant that we have already had to artificially separate loads to beyond where we are comfortable.

Profitability and costs: We have improved upon profit and cost information in both the cane and grazing industries in the Burnett Mary region. The quantitative inclusion, albeit simply, of non-profit related barriers, is a first to our knowledge in Australia. We suspect that grazing results are either realistic or slightly pessimistic (grazing management practice changes always appear to always incur net costs, this could be so industry wide but will be overly pessimistic for leading producers) whereas cane results could be over-optimistic. BMP adoption in cane is suggested as profitable to B class practice, which contrasts with practice adoption at scale in the real world.

Potential for error: Low-Medium on the same basis as for farm heterogeneity.

Conclusions

There are a number of sources of error and uncertainty in constructing an integrated modelling framework such as this. Construction of the bioeconomic model has been akin to constructing a jigsaw with missing pieces. Some of the missing pieces were not apparent when we started. That we have encountered such challenges is not surprising and construction was always ambitious given the relatively short time frame of this project as well as the short history of modelling and water quality data collection within the GBR program. The results appear sensible and furthermore it has received a detailed and favourable independent review (see Appendix 3). We believe we have represented the science and economics as well as possible given time and data limitations.

Construction of the bioeconomic has forced greater integration of previously available economic analysis with biophysical modelling and has highlighted many factors which may assist in improving decision-making in future. In particular it highlights the importance of thinking about integration of discipline-based research efforts in program design rather than assuming an integration 'miracle' will occur once there is sufficient knowledge within a discipline. Thinking about the fundamental issues of land productivity and farm size, as well as what we suspected have been overly optimistic assumptions about practice adoption, have resulted in particularly useful practice change based assessments of benefits and costs within grazing and cane.

An unintended but very positive result has been Fred Bennett's development of a loads tool. The tool was developed to pull out information required to construct the bioeconomic model and is proving useful for BMRG in other applications.

Figure 1. Land uses and constituents represented by processes in SourceCatchments (ticks indicating load output from Source)

Landuse	Constituent	Hillslope	Gully	Streambank	Diffuse Dissolved	Point Source	Undefined
Sugarcane	N - dissolved inorganic				✓		
Sugarcane	N - Dissolved organic						✓
Sugarcane	N - Particulate	✓	✓				
Sugarcane	P -Dissolved organic				✓		
Sugarcane	P -Filtered reactive				✓		
Sugarcane	P -Particulate	✓	✓				
Sugarcane	Sediment –Coarse						✓
Sugarcane	Sediment - Fine	✓	✓				

Landuse	Constituent	Hillslope	Gully	Streambank	Diffuse Dissolved	Point Source	Undefined
Grazing	N – dissolved inorganic				✓		
Grazing	N – dissolved organic				✓		

Grazing	N - particulate	✓	✓				✓
Grazing	P – dissolved organic				✓		
Grazing	P – filtered reactive				✓		
Grazing	P - particulate	✓	✓				✓
Grazing	Sediment -coarse						✓
Grazing	Sediment - fine	✓	✓				

Landuse	**Constituent**	**Hillslope**	**Gully**	**Streambank**	**Diffuse Dissolved**	**Point Source**	**Undefined**
Stream	Sediment - coarse			✓			
Stream	Sediment - Fine			✓			
Stream	N – dissolved inorganic					✓	
Stream	N – dissolved organic					✓	
Stream	N - particulate			✓			
Stream	P – dissolved organic					✓	
Stream	P – filtered reactive					✓	
Stream	P - particulate			✓			

APPENDIX 3: PEER REVIEW OF THE BURNETT MARY GAMS MODEL

Graeme J. Doole 25 May 2014

Introduction

First of all, I would like to thank *Natural Decisions Pty Ltd* for this opportunity to comment on the Burnett Mary catchment model developed by Dr Craig Beverly, of the Department of Environment and Primary Industries Victoria. I am well qualified to comment on its rigour, given that it is loosely based on the Land Allocation Management (LAM) framework (Doole, 2014) that I have applied in numerous catchments over the last five years (e.g. Doole, 2012; Doole et al., 2013). I also have a decade of experience with coding in the GAMS language, especially as related to the analysis of the environmental implications of agricultural land use.

I have worked with Dr Beverly before and communicated a number of times during this project; however, I believe I have remained impartial in my review. He has been very helpful in explaining the structure of the model, which differs from many applications, and helping to resolve any misunderstandings that I have had.

I have conducted this review using a variety of approaches:

1. I have read two documents:
    a. Construction of a bioeconomic model to estimate bet benefits of achieving water quality targets in the Burnett-Mary Region, Queensland. 18 pp.
    b. Challenges associated with the bioeconomic model. 3 pp.
2. I have examined each sheet of the Microsoft Excel worksheet entitled "GAMS_Reef_data.xls". This was done with a focus towards understanding the data inputs and how they relate to the GAMS model.
3. I have read the GAMS model entitled "ReefGams.gms". In particular, I have focused on the identification of errors arising from the inherent repetition present in the model.
4. I have examined the baseline solution of the GAMS model for the entire catchment in aggregate and each individual catchment. I have examined each model through testing the implications of alternative sets of pollutants, different degrees of reduction in each pollutant, different costs for alternative mitigation options, and fixing different areas of cane and/or grazing. These models were solved using the same solver as Dr Beverly. Interestingly, the models could not be solved on older versions of the solver in the GAMS package, but are easily solved on more recent versions. This is rare for a linear programming model, but likely indicates the way that the model has been constructed with an atypically low reliance on matrix generation.

General overview

It has taken significant effort to interpret the code and models provided. The code is comprehensive and constitutes 12,000 lines; 2,500 different elements (parameters and variables); and six models.

In my judgement, I believe the models are fit for purpose and contain no apparent errors that are likely to bias the results. Of course, this assessment is based on the degree to which I have been able to assess the models over a limited time period. However, I think based on my experience that the time I have spent is sufficient to highlight that there are no significant errors present.

Overall, I would rate the framework as good as any others applied to study pollutant mitigation at the catchment level throughout Australasia. It is meticulously coded, contains numerous self checks, and contains a logical structure that has been developed to deal with atypical data. I would have been very pleased to have constructed this model myself to this very high standard, especially given the tight time constraints under which it has been built. For Dr Beverly to have constructed this model with very little background in linear programming, from what I understand, is truly remarkable.

Overall comments

1. Overall, the models appear to be meticulously coded. The use of subsets to distinguish between different basins is very advanced and is a real standout of the code. The meticulous coding of the model is aided by the replication present in its structure, but it also raises the question whether it has been coded by a human or not (!), as it appears almost flawless with regards to the accuracy of the coding. It is almost faultless in this regard. In a code of this size, every modeller would expect to find numerous errors, many of them easily apparent. Indeed, based on my experience with people who I have taught to use this framework throughout New Zealand (including both experienced and inexperienced modellers), I was expecting to find many such errors, but there were very few.

2. The database management contained in the code is among the best I have seen. It is thorough and contains numerous, painstaking cross checks to make sure that the data enters from external sources correctly, data manipulations are sound, and data from different sources is consistent. Moreover, the modeller has added numerous lines of code to ensure against division by zero errors, indicating attention to detail in the coding.

3. The conceptualisation of the model is excellent given the data available. I have never encountered studies or settings where land use change needs to be represented in an optimisation model as a shift along a continuum defined according to its impact on environmental quality. However, the model structure makes sense and I believe it carefully and consistently applies this conceptualisation such that the output is reasonable.

4. The variable and parameter names are very meaningful and have been constructed such that a new user can gain an understanding of the model structure quite quickly, especially relative to a situation where this was not done well. This is good for future users of the model. One concern was that the terms “practice” and “productivity” were used, but meant different things though appearing quite similar. This was a problem, especially in the model documentation, and could perhaps have been called more broadly different names.

5. My only concern with the coding would be a perceived lack of efficiency within it. This does not affect the operation of the code, aside perhaps contributing to an inability to solve the model on older optimisation solvers, but may be something to think about if the framework is redeveloped in the future. The GAMS code could have been much shorter (maybe up to 75%) if meaningful indexing

were used. For example, the decision variable for area allocation could have been defined instead as: AREA(region, landuse, soil/productivity class, transition option). This approach is more standard in the GAMS community. It has a number of advantages. One, it would have made it easier to link the five catchments together. Two, it could arguably have made the code more easy to interpret and employ. The use of indexing to improve coding efficiency is the true power of GAMS, relative to many other modelling languages. This is especially so in linear programming applications that involve catchment models, given that they are typically characterised by large data matrices and a low number of equations in the GAMS framework. The fact that indexing was not used may reflect habit developed from experience with other languages, difficulties associated with proofreading a model that contains multiple indices, complexities associated with a reliance on ordering statements (ORD in the GAMS language) to limit computations to certain subsets, and/or difficulties associated with disparity in the number of transitions for cane and grazing activities. Together, these could be significant enough to motivate a modeller not to use indexing, though this would be converse to standard applications.

Specific comments

I do have some specific concerns that would be good to reflect on. I believe they will likely not change model output, but I think it is important they are discussed to ensure they are correct. I actually think you will be aware of most of them, but I feel they need to be highlighted.

1. The model documentation does not really provide much insight into the model structure, data, or assumptions. It needs much development before it provides clear and comprehensive insight into the framework applied.

2. The model document outlining the challenges faced with the bioeconomic model is detailed and extensive. However, I felt it was also quite pessimistic. It may be worthwhile stating there that the qualitative insights obtained from the model remain very significant given that it can bring together different data from a variety of places and process them in an integrated way. This is alluded to in the conclusion of the relevant document, but I think it should be more apparent.

3. The model documentation highlights that non-profit barriers are dealt with in a quantitative way. However, I could not see how this was done, based on the information available. The only profit data I have seen is the profit per ha values for each enterprise option and the costs associated with gully and streambank management.

4. The GAMS code contains a low-moderate level of internal documentation. This was probably not a focus for the modeller, but could be useful to add if the model is to be used in the future, especially as the external model documentation is still a bit light. Some commands useful in this regard are the EOLCOM command and the * command that allows a user to add lines of text throughout the code. An example from my work that may be useful is provided in Appendix 1.

5. The Microsoft Excel sheet used for data input is comprehensive and has been developed such that numbers can be updated as better information becomes available. This is evident in the structure of the sheets that receive output from Source Catchments. However, some additional notes could be useful here as well, if the model is to be used in the future.

6. It appears that there is no Dissolved Organic Nitrogen loads arising from sugar cane crops. Is this correct?

7. It appears that sugar cane area does not contribute to particulate N exports. Is this correct? See lines in the code that define:

```
BaseAgPN_R1 = sum(basin1,NPartgnhs_R1_gz(basin1));

BaseAgPN_R2 = sum(basin2,NPartgnhs_R2_gz(basin2));

BaseAgPN_R3 = sum(basin3,NPartgnhs_R3_gz(basin3));

BaseAgPN_R4 = sum(basin4,NPartgnhs_R4_gz(basin4));

BaseAgPN_R5 = sum(basin5,NPartgnhs_R5_gz(basin5));
```

8. It appears that gully and streambank erosion do not count towards DIN load. I think this is correct, but perhaps worth checking?

9. Attenuation is based on computed delivery ratios that remain constant when different land management scenarios are optimised in the model. The extent to which this assumption is biophysically sound is perhaps worthwhile reflecting on. My feeling is that it is probably appropriate given the difficulty added to the modelling exercise if it were relaxed.

10. The data input done using the GDXXRW utility could be separated from the model code. This makes solving the model faster, as you do not have to import data from Microsoft Excel each time you solve the model. The two .gms files (data input and model solution) are typically linked using the SAVE and RESTART commands in the command line, if this is done.

11. Each of the linear programming models is typical of its class, containing more decision variables than constraints. This is typically termed underdetermination in the optimisation literature and perhaps suggests that there will be flat relationships between the level of pollutant reduction and the associated cost in the optimal solutions in the model, at least in some vicinity of the optimum.

12. I could not understand one thing primarily in the model code:

```
SSedmax = max(PData("1","A"),PData("1","B"),PData("1","C"),PData("1","D"),

          PData("8","A"),PData("8","B"),PData("8","C"),PData("8","D"));

SSedweightA_caneS1=PData("1","A")/SSedmax;

SSedweightB_caneS1=PData("1","B")/SSedmax;

SSedweightC_caneS1=PData("1","C")/SSedmax;

SSedweightD_caneS1=PData("1","D")/SSedmax;
```

```
SSedweightA_caneS2=PData("8","A")/SSedmax;

SSedweightB_caneS2=PData("8","B")/SSedmax;

SSedweightC_caneS2=PData("8","C")/SSedmax;

SSedweightD_caneS2=PData("8","D")/SSedmax;
```

I wonder if SSedmax should be defined separately for the good soil and poor soil? That is, is it appropriate to use such a "max" (maximise) formalism in the first line of this code? At present, the code highlighted in yellow (good soil) and the code highlighted in blue (poor soil) states that the data is divided by an overall level of SSedmax, which does not seem to make logical sense to me. Should not each soil have their own particular level of SSedmax? I just wonder if this requires some explanation. The same comment relates to the other pollutants, as well. I am happy to be wrong, but I think it should be checked.

References

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Appendix 1

```
*###########################################################################
*GENERATE INITIAL SET OF COWS
*###########################################################################

$eolcom ->
sets
t   time index              /1*365/
y   year                  /1*2/
lac lactations for cows     /1*9/
tot number of cows          /1*500/ -> maximum number for a farm of 100 ha
num maximum cows of age     /1*100/ -> cows of given age

fid key inputs for cows vary through genetics/pvm,lwt,wfa,wfb,wfc,wpa,wpb,wpc/         -> pv milk,
liveweight at calving, Wilmink parameters (a,b,c) for fat, Wilmink parameters (a,b,c) for protein
fod key outputs for cows vary through mgmt    /cav,bco,lip,lwt/                        -> calving, body
condition, lipid, liveweight over time
```

*parameters for generation of random cows
parameters
swi switch random variation between cows on and off (swi equals one means variation exists and swi equals zero means it does not)
bac baseline number of cows present in initial point
mva(tot,fid) list of mean values for herd for different values in set fid;

swi=1; -> switch=1 yields random cows and switch=0 yields deterministic cows
bac=300; -> baseline level of cows
mva(tot,"pvm")=4406+163; -> baseline milk value (4406) plus mean for jersey*fresian cross cows
*mva(tot,"pvm")=4406+492; -> baseline milk value (4406) plus mean for NZ fresian cows
mva(tot,"lwt")=450; -> value of liveweight for jersey*fresian cross cows from DairyNZ Facts and Figures (2012)
mva(tot,"wfa")=3.59; mva(tot,"wfb")=2.24; mva(tot,"wfc")=0.00465; mva(tot,"wpa")=3.08; mva(tot,"wpb")=1; mva(tot,"wpc")=0.00337;