Bioeconomic modelling methods development report

Submitted as Milestone 2 – Burnett Mary Water Quality Improvement Plan

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Introduction

Bioeconomic modelling describes models that have both economic and biophysical components. 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. Like any model, results from a bioeconomic model are only as good as the underpinning data and assumptions on which the model is based.

Descriptions of bioeconomic modelling approaches and further reading material can be found in Appendix 1. This bioeconomic modelling methods report summarises the methods and process, used to date, to develop the Burnett Mary Water Quality Improvement Plan (WQIP) bioeconomic model. This model, along with the Investment Framework for Environmental Resources (INFFER) will be used to assess the costs and benefits of achieving set WQIP targets.

Methods and process used

Principles

The following principles guide the development and implementation of the bioeconomic model:

1. Use the best available information, such as available paddock and catchment scale modelling and economic analysis
2. Supplement with local knowledge and technical expertise
3. Use a collaborative and participatory approach
4. Make assumptions and results available for review and discussion

5. Adapt the model based on review and discussion if/as required, whilst maintaining independence from pre-conceived views about 'right answers'
6. Acknowledge limitations and uncertainties with respect to the model
7. Use outputs to underpin the WQIP which BMRG are comfortable with

Overview of methods, participation and model construct

This section gives an overview of the main work elements needed to construct the bioeconomic model, with additional details provided in the next section.

Biophysical modelling

SourceCatchments outputs using 2008-2009 baseline data is used as the basis of pre- management practice loads. Whilst SourceCatchments considers a number of land types, the bioeconomic model only focussed on sugar cane, grazing, streambank and gully erosion sources; thus target pollutant load reductions can only come from these land type classifications.

We met with Reef modellers and scientists (Rob Ellis, Banti Fenti, David Waters, Mark Silburn, Mel Shaw, Scott Wilkinson in particular) who supplied data and advised us about scaling assumptions based on available Paddock to Reef modelling. The Burnett Mary region has been broken up into 597 units (finest scale pollutant load reporting unit), and reporting units can be aggregrated within 34 subcatchments, 11 catchments and 5 River Basins (Burnett , Mary, Baffle, Burrum and Kolan). Scaling assumptions for cane and grazing land uses have been based on Paddock to Reef modelling advice from Mark Silburn. The effectiveness of streambank and gully remediation has been based on information and discussion with Scott Wilkinson.

Construction of representative land uses

Pollutant loads are reported as one of 597 units within the Burnett Mary catchment. To be able to partition pollutant loads into both land use (cane, grazing, streambank, gullies) and management practices (based on the ABCD framework) construction of representative farming and management systems are required. Construction needs to strike a balance between capturing sufficient management and cost heterogeneity, whilst recognising the relative coarseness of the catchment modelling outputs. We conducted workshops and individual follow up with local cane and grazing representatives to decide the number and type of farming systems as well as to collect information on the profitability, costs and non-profit related barriers associated with management practice changes using the ABCD framework.

For cane Trevor Wilcox, Matt Leighton, Trevor Turner and Wayne Stanley have provided critical inputs. Three cane farm sizes (small, medium, large), two soil types (well drained, poorly drained) and two cane districts (Bundaberg/Isis, Maryborough) were agreed upon.

For grazing Damien O'Sullivan, Fred Chudleigh, Marie Vitelli, Noel Brinsmead, Katie Muller, Tracy Rockemer and Peter Crawford provided information on which grazing systems were appropriate for model development. Three grazing property sizes (small, medium and large) on three land productivity classes (high, medium and low) were developed.

Streambank and gully length information for each of the 597 units was supplied by Banti Fenti and Rob Ellis.

Feasibility of ABCD management practices

Practices developed through the ABCD framework were used as the basis for assessing the benefits (profitability) and costs (upfront, maintenance and consideration of non-profit related barriers) associated with management practice changes. Workshops with local cane and grazing representatives provided information which was then used by economists to assess benefits and costs associated with locally relevant ABCD management practice combinations.

Cane economics

Martijn van Grieken (CSIRO) conducted the analysis to assess net equivalent annual benefits associated with management practice change in cane. He used previous economic analyses conducted in other regions to tailor for enterprises in the Burnett Mary region. Martijn used the FEAT model (courtesy of Queensland DAFF), supplemented by local technical input (Trevor Wilcox, Matt Leighton, Trevor Turner and Wayne Stanley) as the basis for cane economic analysis. FEAT modelling does not consider non-profit related barriers; David Pannell has incorporated this aspect and figures have been recalculated. A 6% discount rate has been used. Whilst the equivalent annual benefits have been calculated over a 10 year period (cane technology is likely to change substantially over longer periods) the figures have been assumed over a20 year period (same time period as for grazing).

Grazing economics

David Pannell has conducted the grazing analysis; we had hoped to contract Megan Star, DAFF however this was not possible due to limited time availability of DAFF staff. As much as possible we have used previous reports from Megan Star, Giselle Whish, Miriam East, John Rolfe and Stuart Whitten. Damien O'Sullivan and Fred Chudleigh in particular provided critical local inputs and knowledge on profitability of grazing enterprises in the Burnett Mary region under high, medium and low productivity land classes. A 6% discount rate and 20 year time period was assumed.

Streambanks and gullies

Costs of streambank and gully remediation has been simply based on a per km basis, using the same time period (20 years) and discount rate as for cane and grazing. No allowance has been made for land taken out of production as a result of fencing.

Construction of the bioeconomic model

Craig Beverly developed the bioeconomic model using input data collected by Anna Roberts, Fred Bennett and Geoff Park from participants through workshops and follow up where required. Fred Bennett has sourced and processed all required spatial data. The model construct is available in a detailed Excel spreadsheet. The model has been developed using the Generalised 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. To achieve the targets set for a particular scenario the bioeconomic model can select between management practices (A, B, C, D levels) and land uses (grazing, cane, streambank, gully management).

Construction of the model itself and data input assumptions will be made available to interested people who have provided us with inputs. We anticipate holding a workshop in the first quarter of 2014 open to those who have provided information and the technical panel for the Burnett Mary

WQIP. We also anticipate that construct of the model will be reviewed by Graeme Doole, University of Waikato New Zealand.

Additional details of the bioeconomic model construct and methods

Targets

Targets are required to be set so that the feasibility and net benefits or costs associated with meeting them can be tested through the bioeconomic model. Pollutant load reduction targets will be developed by Jon Brodie and TropWater. Initially two sets of targets will be developed:

1. Burnett Mary portion of the GBR
2. Ecologically meaningful targets

Targets will be set for each of the 5 river basins but if possible we want the ability to aggregate to region wide. Targets set are likely to be for DIN, PN, PP, TSS, PSII pesticides (atrazine, diuron, tebuthiuron, ametryn, hexazinone); possibly for TN, TP (TN=sum of DIN+DON+NP: DOP+ FRP+ PP=TP); unlikely DOP, DON.

Baseline pollutant loads

Outputs from SourceCatchments 2008-9 will be used as the baseline.

Units

- 5 River Basins (Burnett , Mary, Baffle, Burrum and Kolan)
- 11 catchments
- 34 subcatchments
- 597 units in SourceCatchments

Land types/uses

SourceCatchments considers the following land types/uses: water, conservation, urban, dryland cropping, cane, forestry, irrigated cropping, grazing open, grazing forest, gully and streambanks.

Given the limited information available for many of these categories, plus the emphasis on Australian and Queensland government investments, the bioeconomic model will focus on only cane, grazing, streambank and gully erosion sources.

All other categories will be combined into 'other' and load reductions required to meet the set targets, will not come from all of these categories from the bioeconomic model optimisation. Effectively it means that this bioeconomic model will only allow load reductions from the cane and grazing industries, including gully and streambank sources. It can be updated/revised to include additional land uses as new knowledge becomes available at a later stage.

Note that current load exports from SourceCatchments occur from each of the 597 subunits within land types. Export rates have had to be redefined to account for initial areas assumed to be under A, B, C and D management practice in 2008-09, whilst ensuring the baseline loads from Source are matched.

Cane systems

- 3 Regions – Bundaberg, Maryborough and Isis. Bundaberg and Isis are considered together, Marborough separately
- 3 farm sizes – small 75 ha, medium 125, large 250 ha (assume large and corporate are similar for simplicity even though we know they function differently). Farm sizes were based on a combination of Kevin McCosker data 'All Regions 3RC Sugarcane ABCD revised 25 Oct2012.xls spreadsheet (Bundaberg average farm size 20,000ha/270 growers=74 ha; Isis 15,073/128=118ha; Maryborough 12,500/100=125 ha) and discussion with cane representatives. Note that cane reps said that there are a number of smaller farms (e.g. 30-40 ha in size and these often also have other horticulture operations where cane can be a minor portion of the effort and income. We decided to ignore these farms as the complexity of accounting for horticulture is too difficult.
- Farm size distributions. Based on cane workshop discussion with local cane representatives (contained in Cane Workshop –results v3 Maryb.doc)
    - Bundaberg and Isis 60% small, 30% medium, 10% large
    - Maryborough small 30%, medium 40%, large 30%
    - See spreadsheet Copy of cane_soil table+cane districts.xls which ascribes soil categories (well and poorly drained and Bundy/Isis and Maryborough districts).
- Initial farm practice distributions – from Kevin McCosker 'All Regions 3RC Sugarcane ABCD revised 25 Oct2012.xls spreadsheet baseline. The mean of Bundaberg and Isis has been used for Bundaberg+Isis with Maryborough results used separately for the initial practice distributions under A,B, C or D management.
- Soil type differences for some practices (red/well drained versus other/poorly drained). David Freebairn provided soil categories (excel spreadsheet 131016 DMF cane soils distribution.xls) which were:
    - Well drained – dermosols (sealing loamy surface) including non-sodic chromosols/kurosols/kandosols; ferrosols; dermosols (structured clay, loam surface); tenosols/rudosols/podosols (sandy); rudosols/tenosols (sandy)
    - Less well drained – sodosols (loamy surface) including sodic chromosols/kurosols/kandosols/calcarosols; hydrosols (sandy surface); dermosols (sandy surface) includes non-sodic chromosols/kurosols/kandosols/calcarosols; hydrosols (sealing sandy surface); vertosols; hydrosols (structured clay/clay loam surface) including organosols; sodosols (shallow <=0.5m sandy surface) including sodic chromosols/kurosols/kandosols; sodosols (mod deep >=0.5m sandy surface) including sodic chromosols/kurosols/kandosols
- Apportioning relative differences between A, B, C and D practices (for each constituent) - Silburn look up tables (red dermosols – represents good soils, redoxic hydrosols represents poor soils from Cane synthesis table Burnett Mary.xls).
- Apportioning individual practice differences was not considered. In future the Sugarcane WQ risk ratings could be used as the basis to relative practice differences, however because the AEB (annual equivalent benefits in $/ha) calculated by Martijn van Grieken only cover the practice suite combinations (namely D-C, D-B, D-A, C-B, C-A, B-A) the bioeconomic model will not go to the individual practice level. In future it would be possible to do so but it would require a fair amount more detailed economic analysis.

Grazing

- 3 property sizes – small 288 ha, medium 880 ha, large 4143 ha, based on Agforce analysis (see Marie Vitelli email 10/12 with calculations done by Noel Brinsmead).
- 3 land productivity classes (high, medium, low) - areas determined for each of 597 units
- Farm size distributions – will use this at the River Basin level – assumed as per Agforce calculations (10/12 email from Marie Vitelli) in terms of area percentage: small farms 12%, medium farms 32%, and large farms 56%. Reference map used is labelled BMRG_Reef_Rescue_Investment_Areas_2013.pdf. From this map it is apparent that there are a higher area proportion of larger farms in the inland and mid Burnett areas than in the other areas (coastal catchments and Mary). It is not readily possible to (see comments from Fred Bennett in 13/12 email) to refine this, so we have assumed the following:
    - Inland and mid Burnett – assumed 66% area large farms, 27% medium and 7% small farms (i.e. 10% more large farms and 5% less of each medium and small)
    - Coastal catchments and Mary assumed as 46% area large farms, 37% medium, 17% small farms – this is all units in the Mary, Baffle, Burrum and Kolan
    - Have assigned 1=inland and mid Burnett, 2= lower Burnett, coastal catchments and Mary in spreadsheet Copy of Sourcecatchments+ascribing farm sizes
- Initial farm practice distributions – from Kevin McCosker 'All Regions 3RC Grazing ABCD revised 25 Oct2012.xls spreadsheet (i.e. total area 2,861,889). We have assumed the same proportions (note Source grazing areas total is 3,626,528 ha, so McCosker areas will be distributed in proportion over Source areas) over the entire region as we have no other basis to assume otherwise.
- Single Silburn 'global' lookup table (email from 25/11) apportion relative load differences between A, B, C, D – Munduberra A 0.071; B 0.38; C 1; D 1.95
- Grazing WQ ratings to apportion relative differences between practices 1-4 – from Grazing WQ Risk Framework_ReefPlan3.docx – have used P1+P2=0.6, P3=0.25, P4=0.15. These have been multiplied by the Munduberra A, B, C, D ratings to account for individual practice differences.

Streambanks and gullies

- Each subcatchment has an associated gully density and stream length. We will simply accept the lengths per subcatchment and calculate costs of remediation based on these lengths. We will assume none are currently fenced.
- Gully data contained in excel spreadsheet 'Copy of Average Gully Density.xlsx' (email from Fred Bennett 19/12)
- Limited information about low v high erodibility. We know that streambanks are the major source of sediment for the Mary catchment – and that in the order of 85% are eroding (Johnson 1997 ref mentioned by Ian Butler at BMRG forum). Have discussed assumptions about effectiveness of streambank and gully remediation with Scott Wilkinson – see document 'Gully and streambank effectiveness assumptions for Burnett Maryv3.doc' .
- Will assume that no gullies or streambanks have been fenced (D practice) and that remediation has the same costs and effectiveness estimates everywhere as no basis to assume otherwise.
- Will use TSS effectiveness of 35% (i.e. first table in document referred to in the above dot point 1.25-0.9 for gullies and 1.1-0.75 for streams) for each of gully and stream. PP, Npartic,

Ppartic and TSS assumed as 25% effectiveness. DIN, DON, DRP, FRP and pesticides (assume zero effectiveness as not likely to be much of these forms in grazing lands anyway) assume zero% effectiveness.

Benefits and costs of practice change

Cane

- Worked through ABCD framework for each of soils, nutrients and pesticides at a cane workshop and through follow up contact with cane representatives Trevor Wilcox, Matt Leighton, Trevor Turner, Wayne Stanley and Fred Bennett. We assessed the combinations of management changes that were sensible and feasible e.g. D-C, C-B, B-A etc. Results contained in word document 'Cane Workshop –results v3 Maryb.doc.   Indicative up-front and maintenance costs have been included as well as a ranking for profitability and non-profit barriers information.
- Martijn van Grieken has used a combination of cane workshop results, his previous analysis in other regions and additional FEAT modelling with input from face-to-face meetings with Trevor Wilcox and Matthew Leighton to develop figures for 'annual equivalent benefits in $/ha for shifting between practice suites on 2 soil types –well drained (contained in excel spreadsheet 'Copy of ANALYSIS Annuity-fmd3.xlsx') and poorly drained ('Copy of ANALYSIS Annuity-sff1.xlsx'). In total there are 44 figures to go into the bioeconomic model – 6x AEB $/ha figures for each of small, medium and large farms for well-drained soil (i.e. 6x3=18 for well-drained soil) plus 6x AEB for poorly drained 3 farm sizes.
- David Pannell has developed a simple method for accounting for additional non-profit related barriers; currently sent and to be reviewed by Martijn van Grieken. Recalculated net AEB figures are in the spreadsheet CaneProftBarriersv4.xlsx.
- Note that for cane only practice suites of all A, all B, all C and all D were able to be considered by Martijn.

Grazing land management

- Worked through the ABCD framework with grazing representatives – Katie Muller, Tracey Rockemer, Peter Crawford, Marie Vitelli, Michael Moller and Fred Bennett.
- In the absence of detailed economic analysis for the Burnett Mary region we had extensive follow up by phone and email with Damien O'Sullivan (extension officer) and Fred Chudleigh (DAFF economist Toowoomba).
- David Pannell has come up with the required level of incentive payments (see excel spreadsheet 'Grazing annuity integrated results v1.xlsx' email 19/12) for practices 1-4 (note streambanks P5 and gullies P6 are handled separately because in SourceCatchments they have loads separate from land management practices) . The calculations have been based on coming up with a level of incentive payment which are based on best available information on profitability (e.g. gross margins from Fred Chudleigh on high, medium and low productivity land types), Damien O'Sullivan comments that there is unlikely to be difference in profitability between A and B class practices and available reports (e.g. from Whish 2012 and Star et al. 2012). Sources of information and assumptions also include that farmers have more to gain by BMP adoption on high productivity land, and adjusting the profitability rankings accordingly from those collected at the grazing workshop – originals contained in

word document 'Grazing workshop- results v3.doc'. Other sources of information that went into the thinking are contained in 'Grazing workshop profitability considerations v6.doc. Note that for each farm type David has assumed the proportion of the farm in a particular ABC or D classification is as per 'All regions 3RC spreadsheet , i.e. 15.7% in A class, 51.6% in B, 24.8% in C and 7.9% in D.

- In 'Grazing annuity integrated results v1.xlsx' there are currently 10 practice suite combinations for each of small, medium and large farms so 30 in total. We will keep P1 and P2 separate in the first instance but given they are highly related the model will also have the ability to tie them together (ie if P1 gets selected then P2 automatically gets selected). If P1 and P2 are separate the number of practice combinations is 30, whereas if tied, the practice combinations are reduced to 21; we have selected the higher level of payment required (eg P1 D-C payment $75.05 whereas D-C P2 payment is $50.05, so have selected the $75.05 option, on the basis that need to be conservative.

Streambanks and gullies

- Assume for each of gullies and streams to move from D-B practice (from no fencing to fully fenced on both sides and watering points each km of stream or gully. For streams assume 20% of fencing costs added once every 10 years to cover for some wash outs. For gullys no maintenance costs have been assumed. A calculator spreadsheet has been developed – see Gully cost calculations.xlsx.

Comments on the bioeconomic model

This is the first time such a comprehensive and integrated bioeconomic model has attempted to be constructed for GBR water quality using available biophysical and economic modelling. Many assumptions and simplifications have had to be made and as such the heterogeneity of both biophysical conditions and net benefits/costs of practice change is not fully represented. Model outputs cannot be thus expected to be an absolute representation of reality, but provide 'ballpark' figures; the model will be as strong or weak as the underpinning assumptions and their sensitivity to outputs.

Because of commonly high non-profit related barriers, sometimes high costs and relatively low profitability per ha, grazing management practice changes appear to always incur net costs, whereas in sugarcane some practices have net benefits. There appears to be some inconsistency in information provided – for example, if some sugarcane practices are indeed relatively profitable, then one could expect high levels of practice adoption with minimal need for incentives. Review of logic and assumptions for both grazing and cane will be important.

Given previous experience in Victoria, we anticipate that the bioeconomic model and INFFER analysis will reveal some unpalatable results. For example it is likely to show the limited feasibility of meeting targets to achieve outcomes (in fact this is already known from SourceCatchments modelling of 'all A' practices), high costs, room for improvement in selection of incentive payments and choice of policy tools and/or management practice changes that are not acceptable to stakeholders. BMRG may need to make some active decisions about how best to decide appropriate targets and use of outputs from the bioeconomic model and INFFER analysis in the WQIP.

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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