Water Policy Impact Assessment – Combining Modelling Techniques in the Great Barrier Reef Region

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EXTENDED ABSTRACT

The Reef Water Quality Protection Plan (Reef Plan) defined a landmark for policy in the Great Barrier Reef (GBR) region. It identifies actions, mechanisms and partnerships, and builds on existing Government policies, industry and community initiatives for the purpose of "*halting and reversing the decline in water quality entering the Reef within 10 years*" through, "*reducing the load of pollutants from diffuse sources in the water entering the Reef.*" A range of different indicators proposed for the nine strategies of the Plan define policy goals that require an integrated assessment of the Great Barrier Reef region.

In this context, decision support systems could help simulate the impact of potential policy options. Policy options involving water quantity and water quality questions and the underlying context of land use imply a variety of environmental, economic and social consequences. Effective decision support requires an integrated view.

Policy is often focused on system boundaries that result from formal responsibilities. This means that a natural resource manager is mainly interested in decision support on the scale at which he or she operates. Often the indicators used in such a decision making process are highly aggregated. For instance, a policy maker is interested in increasing income levels for the whole region but much less in income levels of each and every family. This emphasises the relevance of mean values across the population. On the other side, social reasons often require spatial disaggregation, like unemployment peaks in a focus area. Environmental problems in the GBR region require both types of simulations, for example, the net run-off into the GBR lagoon on an average level, but also spatially explicit dynamics to identify increasing risks for biodiversity.

This paper shows an approach developed for the GBR region, which combines a Computable General Equilibrium (CGE) model and an agent-based model (ABM) for integrated policy impact assessment. The paper explains the applied work in the context of water policy that targets water quantity and quality concerns. It shows that while CGEs allow the quantification of trade-offs between economic sectors, catchments and values, agent-based models make land-use decisions spatially explicit. This applied modelling approach shows that strengths of different modelling techniques can be combined to more effectively support water policy decision making. It also points out that methodologies of different disciplines need to be modified to serve the emerging need for integrated modelling techniques.

The current process integrates stakeholders in the model development to capture their potential use that specifies policy options for the scenario definition. Additionally, stakeholders define a set of indicators simulations will have to report on. To facilitate the process a proof-of-concept stage of PIA and SEPIA was developed to give stakeholders a better idea of model characteristics important to users.

1. INTRODUCTION

The goal of achieving sustainable development opened gaps for policy makers in a number of domains. For a long time formal indicators for policy performance and investment prioritisation were easily derivable as they represented mostly just the economic dimension (e.g. income per capita). Sustainability focused policy requires multi-dimensional indicators (Parker et al. 2002, Gilmour et al. 2005). Integrating multiple dimensions opens the question about how to combine understanding from different disciplines to focus on these different dimensions.

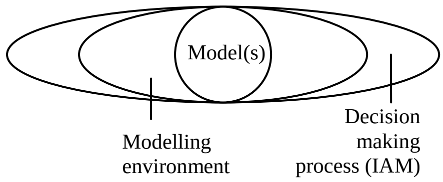
Integrative Assessment and Modelling (IAM) brings understanding from different disciplines on different scales into a process, in which stakeholders inform their decision making using models (Parket et al. 2002, Rotmans and van Asselt 1996). The model development is therefore integrated in the decision making process that links scientists and policy makers. Wastney et al. (1998) defines models as "tools that are used to predict the structure and the behaviour of a system." Argent et al. (1999) states that integrated models have to include the system components and the interactions between them.

In IAM the whole decision support process becomes important and modelling is not isolated from stakeholders (Jakeman and Letcher 2003). From a policymaker's perspective, Caminiti (2004) argues that "if models or decision support systems are used to help develop priorities, then sufficient understanding of the processes and input is required to have confidence in the outputs on which the priorities are based." In order to develop Decision Support Systems (DSS) for sustainability focused policies, science departs (a) from an isolated position in the decision development process and (b) from single-disciplinary modelling approaches.

Van Daalen et al. (2002) develops four roles for models in environmental policy; as eye-openers, as arguments in dissent, as vehicles to create consensus, and as models for management. It might be argued that models can be developed in isolation from stakeholders' participation to identify problems. The more the role departs from being an eye-opener and the closer it comes to the management position, the more clearly an integrated approach seems to be needed. Without an integrated process stakeholders do not have trust in the DSS and therefore are unlikely to use models.

If models are used in the decision making process they are mostly just used once as Rizzoli and Davis (1999) argue: "A broader application requires at least object oriented technology, flexibility in terms of space and time scales and ability to implement context-specific models." This defines the need for a modelling environment for which the Integrated Catchment Management System (ICMS) (Rahman et al. 2004), the Catchment Modelling Toolkit (www.**toolkit**.net.au), and DIAS (Sydelco et al. 1999) are good examples.

From this argument three levels appear to be distinct: the core model(s), the modelling environment, and the decision making process (=IAM).



Marston et al. (2002) and Brinsmead (2005) focus mainly on the core area and give excellent overviews on integrated modelling approaches. It becomes obvious that most approaches are very limited in the way they integrate different dimensions. This identifies the necessity of a modification of existing modelling techniques. While in past decades, disciplines developed modelling techniques that allowed researchers to focus on specific and discipline-related questions, sustainability widens the focus. This opens two options: (1) the development of flexible modelling environments to integrate multiple disciplinary models; or (2) modification of methodology to integrate system elements from different foci. This paper argues that both are necessary and focus on the second point: methodology.

The application of this methodological research is located in the Great Barrier Reef (GBR) region. The GBR requires effective environmental protection and policymakers have to find strategies to secure such protection without endangering social and economic values. Bringing the human element into the bio-physical analysis is therefore a core task, especially since the Reef Water Quality Protection (RWQPP) plan defined as a political goal to stop the decline of the reef by 2013. Assessing net impacts of policy options becomes highly significant.

This paper describes the situation in the GBR region and develops first steps for IAM in the GBR with a methodological focus.

2. INTEGRATED PROCESS IN THE GBR

The GBR marine ecosystems have a complex interdependent relationship with the adjacent river systems. Some 30 major rivers and hundreds of small streams drain into the GBR lagoon.

Declining water quality, principally from agricultural land use, threatens the viability of downstream marine based activities in the GBR, in particular tourism, which contributes $4.3 billion to the State and regional economies and exceeds the contribution that agricultural activities make to the economy ($3.2 billion) (Productivity Commission, 2003). These economic values only partially reflect the broader value of the GBR to Australians as a cultural icon, as a place of high biodiversity and world significance, and as a provider of ecosystems services to coastal communities.

This complex and interconnected ecosystem is managed through an equally complex array of legislation and policy, spanning both Queensland and Commonwealth jurisdiction. The GBR is also identified as a World Heritage Area with international obligation for management.

In recognition of the water quality issues for the GBR, the Australian and Queensland Governments established the Reef Water Quality Protection Plan (Reef Plan) (Queensland Government 2003). The Reef Plan identifies actions, mechanisms and partnerships, and builds on existing Government policies, industry and community initiatives for the purpose of "*halting and reversing the decline in water quality entering the Reef within 10 years*", through "*reducing the load of pollutants from diffuse sources in the water entering the Reef*" and "*rehabilitating and conserving areas of the reef catchment that have a role in removing water borne pollutants.*"

Nine strategies are proposed for implementation by governments, community and industry: self-management approaches; education and extension; economic incentives; planning for natural resource management and land use; regulatory frameworks; research and information sharing; partnerships; priorities and targets; and monitoring and evaluation. The implementation of the Reef Plan is funded primarily through two national environmental programmes, the Natural Heritage Trust (NHT) and the National Action Plan on Salinity and Water Quality.

Given the clear links being made between increases in nutrient loads entering the GBR lagoon and land management practices in the catchment, it was necessary to approach the landuse planning process from a whole of system perspective. The scope of the Reef Plan actions indicates the complexity of individual sector responsibilities. Overcoming the fragmentation of these responsibilities for catchment management requires information to be provided at a local, regional and whole of system scale and for the heterogeneity of the systems to be adequately accounted for.

3. INTEGRATED MODELLING IN THE GBR

3.1. Policy perspective and DSS

The need for an integrated approach stems from policy requirements to consider environmental, economic and social goals simultaneously. Policy is often focused on system boundaries that result from formal responsibilities. This means that a natural resource manager is mainly interested in decision support on the scale at which he or she operates. Often the indicators used in such a decision making process are highly aggregated. For instance, a policy maker is interested in increasing income levels for the whole region but much less in income levels of each and every family. This emphasises the relevance of mean values across the population. On the other side, social reasons often require a disaggregated view, like unemployment peaks in a focus area. Environmental problems in the GBR region require both types of simulations, for example, the net run-off into the GBR lagoon on an average level, but also spatially explicit dynamics to identify increasing risks for biodiversity.

In other words, policy requirements demand 'big picture' information and following from there the next question is 'If this happens, *where* does it happen?'. Smajgl et al. (2005) describe two other domains of policy question likely to follow in an integrated assessment process: "If this simulation shows what is likely to happen, what is a better or an optimal path?" and "How likely are the simulated and the optimised path?" Although our IAM approach covers all three questions – (1) What will happen, (2) What should happen, and (3) How likely are these trajectories - this paper is focused solely on the first dimension, which splits into two scales of aggregation, the mean and the distribution.

An integrated Computable General Equilibrium (CGE) model simulates the GBR on a catchment level and an agent-based approach makes dynamics spatially explicit within these regions. The following sections explain the concept of these two approaches and explore the potential of broadening traditional instruments in order to allow the integration of heterogenous system components. As modelling techniques are often developed within one discipline, such modifications are necessary to enable DSSs to including indicators from other disciplines.

3.2. Integrated modelling on a catchment level

The catchment level is simulated with an integrated CGE model called PIA (Policy Impact Assessment). While the core structure of PIA is based on CES (Constant Elasticity of Substitution) production functions, it also integrates crucial hydrological and ecological response functions (Smajgl 2005). Water can be integrated as an input to production sectors in a similar way to labour and capital. Formulation 1 shows the nesting used in PIA for irrigation sectors.

$$py_{IRR,r} = \left(\left(\left(\left(pk_{IRR,r}^{\rho_{KW}} + pwi_{IRR,r}^{\rho_{KW}} \right)^{\rho_{KWN}/\rho_{KW}} + pntr_{IRR,r}^{\rho_{KWN}} \right)^{\rho_{KWNL}/\rho_{KWN}} + pl_{IRR,r}^{\rho_{KWNL}} \right)^{\rho_Y/\rho_{KWNL}} + pa_{ss,r}^{\rho_Y} \right)^{1/\rho_Y} \tag{1}$$

The nesting of the CES function (1) shows that the production sector can first substitute water (*pwi)* for capital (*pk)*. This simulates increasing water efficiency through better irrigation schemes. On the next level, fertiliser input (*pntr)* enters as an input factor, followed by labour (*pl)*, and intermediates (*pa)*. For non-irrigation sectors (1) simplifies to three inputs, *pk*, *pl*, and *pa*.

Traditional CGE models (Ginsbergh and Keyser 1997) explain shifts from one equilibrium to a new equilibrium by prices that signal changes in production constraints. Such a price-signal based approach works very well in a (highly competitive) setting where just prices give signals. Natural resources – like water in (1) – can be added into a CGE as an input factor to simulate the shadow price for changing constraints. Climate change is a classic example (Nordhaus 1992, Bernstein et al. 1999) in which CGE models simulate carbon trading according to different emissions constraints. Results describe the likely price for tradable CO_2 quotas, like Hillebrand et al. (2003) and Smajgl (2002) show for an emissions trading scheme in the EU.

Integrated CGE models will have to go a step further and allow responses within a non-market system. While almost all CGE models focused on climate change policy limit their approach to evaluating shadow prices, water related problems in the GBR require the simulation of flow on effects within the hydrological system and the ecological system. This means that additional to economic production functions with input and output variables that are coordinated by prices on markets, 'production functions' for groundwater and surface water have to be implemented.

Existing water focused CGE models remain on the same level as climate change CGE models, and implement water as an input factor without including non-market systems such as hydrology or ecology (Berck et al. 1991). Excellent examples are Decaluwé et al. (1997), Goldin and Roland-Holst (1995), Horridge et al. (1993), Seung et al. (2000), and van der Mensbrugghe (1998).

Smajgl (2005) shows how a water cycle can be approximated on a catchment level. Crucial indicators for an integrated assessment are remaining water volumes in streams and in aquifers. Irrigation from surface water (2) is based on the input components 'water in streams' (*psw)* and 'rain' (*pswf)*. The output side is defined by outtake (*pwi)* and recharge that adds to the groundwater table of the next period (*pgwtl)*.

$$\left(pwi_{IRR,r}^{\rho_{SWO}} + pgwtl_{IRR,r}^{\rho_{SWO}} \right)^{1/\rho_{SWO}} = \left(\left(pswp_{s,r}^{\rho_{SWQ}} + psw_{s,r}^{\rho_{SWQ}} \right)^{\rho_{SW}/\rho_{SWQ}} + fswf_{s,r}^{\rho_{SW}} \right)^{1/\rho_{SW}} \tag{2}$$

$$\left(pwi_{IRR,r}^{\rho_{GWO}} + pgwtl_{IRR,r}^{\rho_{GWO}} \right)^{1/\rho_{GWO}} = \left(\left(pgwp_{s,r}^{\rho_{GWQ}} + pgw_{s,r}^{\rho_{GWQ}} \right)^{\rho_{GW}/\rho_{GWQ}} + pgwt_{s,r}^{\rho_{GW}} \right)^{1/\rho_{GW}} \tag{3}$$

Groundwater irrigation has on the input side the groundwater (*pgw)* and the aquifer at the beginning of the period (*pgwt)*. The output side is the outtake (*pwi)* and the remaining groundwater table for the next period (*pgwtl)*. In (2) and (3) the option of permits is implemented on the input side. This allows the assessment of political quantity restrictions for water availability. Including rain allows for a climate driven quantity restriction.

While impacts on production add up to a change in Gross Regional Product (GRP), an important and highly aggregated political indicator, changes on the non-market side are also taken into account. Smajgl and Hajkowicz (2005) show how water related benefit in the GBR is structured by using Multi Criteria Analysis . Most water issues impact human well-being through ecosystem services. Therefore, PIA defines a series of response functions for ecosystem services and species. As economic activities such as tourism partly depend on ecosystem services, some elements feed back into the market driven system.

An example for integrating ecosystem services into a CGE are nutrients: PIA integrates nutrient flows on the water quality side. The application of fertiliser is economically driven, as shown in (1). But the application 'consumes' a virtual variable (*fnm)*, which indicates water quality, shown in (4).

$$pntr_{s,r} = \left(pftl_{s,r}^{\rho NTR} + fnm_{s,r}^{\rho NTR}\right)^{1/\rho NTR} \quad (4)$$

The consumption of *fnm* changes the quality available for other processes such as seagrass. As seagrass is a food source to other species like dugongs, their habitat is impacted. Furthermore, tourism operators need not only capital (e.g. busses and boats) and labour (e.g. guides), but also the tourist attraction (e.g. dugongs). If the attractiveness of the tourism attraction declines for quantity or quality reasons, tourism based revues are also likely to decrease.

$$fsg_r = \left(fpp_r^{\rho SGR} + fnm_r^{\rho SGR}\right)^{1/\rho SGR} \quad (5)$$

$$fdu_r = \alpha_{dug} \cdot fsg_r \quad (6)$$

$$py_{TOU,r} = \left(\left(pk_{TOU,r}^{\rho KL} + pl_{TOU,r}^{\rho KL}\right)^{\rho Y/\rho KL} + pa_{ss,r}^{\rho Y} + fdu_r^{\rho Y}\right)^{1/\rho Y} \quad (7)$$

The CES production functions (5) to (7) integrate seagrass (*fsg)*, phytoplankton (*fpp)*, and dugongs (*fdu).* The seagrass dugong link is an example. The full list of variables is provided in Smajgl (2005). PIA is solved as a MCP (Mixed Complementary Problem) (Ferris and Munson 2000) using the algebraic modelling system GAMS MPSGE (Brooke et al. 1998, Rutherford 1995).

An integrated CGE model is able to assess the impact of policy options taking not only market-based values into account but also non-market aspects related to IAM. As these indicators are highly aggregated crucial questions on spatial and temporal distributions are not included. Therefore, the integrated CGE model PIA is developed in combination with an agent-based model, the Single Entity Policy Impact Assessment (SEPIA).

3.3. Integrated modelling on a farm level

The agent-based model SEPIA (Single Entity Policy Impact Assessment) simulates land use and water use related decision making in the GBR region. Agent-based models allow the analysis of interactions in a spatial distribution and are therefore very promising in the complex domain of agro-ecological systems (Parker et al. 2003). As Berger (2005) points out, agent-based models can also provide a collaborative learning framework for policymakers and scientists (also Roeling, 1999; Hazell et al., 2001; van Paassen, 2004).

SEPIA assumes that human decision making follows rules, in which the decision making process is defined in what-if formulations. Land users, for instance, make decisions depending on perceived values of certain indicators, such as market prices and rainfall. Within a GIS based visualisation the spatial distribution of a decision can be analysed and linked to a wider range of bio-physical and socio-economic indicators.

The SEPIA model simulates land use decision making enacted by agricultural agents. Agents' cognitive processes are mental models of decision making (Smajgl 2004), resulting in the enactment of one of a number of possible land use options. The effect of these land use decisions in turn has an effect on conditions on the ground and agent payoffs associated with agricultural production. Environmental impacts are then estimated based on the new conditions.

Agent decision making is a composite of both market and non market conditions. Hence information for both is available to agents, and decision making cumulates in a preference based non-market utility function and a costs and revenues based economic payoff function. Agents perceive random variation and develop their expectations.

On the non-market side of decision making, we understand that several streams of benefits that are not represented in markets accrue to individuals. Specific to the operation of agents with the SEPIA model, a utility function is calculated based on the conditions of several environmental attributes that are not generally found in markets (or where price signals are not reflective of the condition's state).

The variables included in the utility function are drawn from the multiple criteria analysis. Agents also maintain a threshold for non-market values. If the utility threshold is not met, agents flag their dissatisfaction, which limits the possible set of strategies that agents can undertake if the community at large identifies their dissatisfaction.

Market based conditions associated with agricultural production were drawn from a number of secondary literature sources. From these, a list of costs and revenues associated with production of agriculture commodities were drawn. The inclusion of some costs and revenues and their amounts obviously change depending on local and individual conditions such as market access, environmental limitations, government assistance and regulations, or other conditions.

Agents have the ability to alter the set of inputs into production, based on expectations of return in the changing conditions of the marketplace and farm level productivity. System dynamics occur (agent behaviour and environmental responses) within a spatial landscape of GIS vector polygons. This allows for the specific identification of where particular impacts occur. Indicators are measured for cross disciplinary metrics and displayed using a GIS user interface. Indicators of interest include social activities such as the adoption of land use practices, economic metrics such as production and financial returns, and environmental metrics such as sediment and nutrient contributions.

SEPIA is currently developed with key stakeholders in the GBR region. The calibration of agents will be based on a series of case studies in the rangelands and the floodplains. The current process integrates stakeholders in the model development to capture their potential use that specifies policy options for the scenario definition. Additionally, stakeholders define a set of indicators simulations will have to report on. To facilitate the process a proof-of-concept stage of PIA and SEPIA was developed to give stakeholders a better idea of model characteristics.

4. CONCLUSIONS AND RECOMMENDATIONS

Integrated Assessment and Modelling is an essential process for sustainable development. The modelling component requires not only improvements on the side of modelling environments that allow combining different models, but modelling techniques themselves have to be modified in order to capture multi-disciplinary system descriptions. The GBR focused project described in this paper broadens existing CGE modelling in order to integrate non-market values and their physical dynamics, instead of purely market driven dynamics. Additionally, an agent-based model is developed to make simulations more spatially explicit.

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