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Integration for sustainable catchment management

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Abstract

Sustainable catchment management requires increased levels of integration between groups of natural and social scientists, land and water users, land and water managers, planners and policy makers across spatial scales. Multiple policy drivers, covering urban and rural communities and their relationships with land and water use, have resulted in the need for an integrated decision making framework that operates from the strategic national scale to the local catchment scale. Large gaps in integration between policies are resulting in uncertain outcomes of conflicting and competing policy measures. The need for further integration is illustrated by little or no reductions in nitrate and phosphate levels in surface and ground waters in England and Wales. There is a requirement for natural scientists to consider the socio-economic setting and implications of their research. Moreover, catchment system level science requires natural and social scientists to work more closely, to provide robust analysis of the state of the environment that fully considers the bio-physical, social, political and economic settings. The combined use of spatial technologies, scenarios, indicators and multicriteria analysis are increasingly being used to enable improved integration for sustainable catchment management.

Keywords: Integration; Analytical-deliberative; Adaptive models; Land management; Catchment

1. Introduction

There is growing recognition that to meet the goal of sustainable catchment management there is a need for improved 'integrated' catchment management (ICM) (Giupponi et al., 2004; Harvey, 2006; Novotny, 1999; Turpin et al., 2005; Van der Helm, 2003; Waterton et al., 2006). Combining policies, their interdisciplinary evidence base and their implementation within a common framework will enable shared intellectual constructs to be integrated across traditional philosophical and methodological divides. We believe that, for truly integrated catchment management to occur requires:

1) the legislation and policies that aim to achieve ICM, must be combined with existing and future legislation and policies,
2) the science that is required to support ICM and provide the evidence base also needs to be integrated across natural and social science disciplines,
3) the management of catchments should be based on integrating land management with a wide range of stakeholder requirements, policies and scientific evidence base.

Before sustainable catchment management can be achieved, policies that embrace the full range of pressures faced by surface water bodies are required e.g. water

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abstraction, nutrients from urban and rural land uses, climate change, current and future financial drivers of land use and spatial planning regimes that control local and regional land use. Taking water quality as an example, concentrations of nutrients (nitrate and phosphate) in surface and ground waters have increased significantly since the 1940s in England and Wales (Environment Agency, 2006). Efforts to reduce urban point sources through the introduction of the Urban Waste Water Treatment Directive (UWWTD) (91/271/EEC) have not solved the problem of river water quality, highlighting the importance of rural diffuse sources (EEA, 2005). Recent monitoring data across England and Wales indicates that there has been little if any improvement in water quality with the percentage of rivers that exceed 30 mg nitrate per litre changing from 29.9% in 1995 to 28.3% in 2005 and the percentage of rivers exceeding 0.1 mg phosphate per litre increasing from 50.3% to 51.5%, between 1995 and 2005 (Environment Agency, 2006).

In this paper we examine how integration between policies, the social and natural science evidence base and their implementation can be increased for sustainable catchment management. Providing water of 'good quality' is an important function of sustainable catchments. We use the pressures faced by surface and ground waters from rural land uses in England and Wales to illustrate the need for further integration. We review, tried and tested methods from the social and natural sciences, including spatially explicit models, indicators, scenarios and multicriteria analysis (MCA) techniques to integrate policies, the science base and their implementation. ICM requires interdisciplinary scoping of the issues, collaborative planning of interventions, collaborative action and ongoing social learning, so that dependencies of individual disciplines are avoided. The successful integration of knowledge, experiences and actions into management schemes is conditioned on the ability of the different participants to accommodate and make sense of each other's worlds (Burgess et al., 1998). We hope that this paper will bring integration one step closer.

2. Evidence for the need to improve integrated catchment management: water quality in England and Wales

The presence of high levels of nitrates and phosphates in discharges to surface waters leads to eutrophication of rivers, estuaries and coastal waters (Vollenweider, 1968). The inputs of nitrates and phosphates from urban land uses are often easier to assess and manage than rural diffuse sources in England and Wales due to the presence of a regulated system of sewers and treatment works. The magnitude of diffuse sources of nitrates and phosphates from rural land uses are more difficult to assess (Novotny et al., 1985). Uncertainties in the location, timing and magnitude of diffuse sources of nitrate and phosphate makes management problematic. As urban point sources are reduced, rural diffuse sources become relatively more important (Marsden and Mackay, 2001). A large amount of scientific activity has been carried out over 20 years to better understand the sources and pathways of nitrate and phosphorus in the environment (e.g. (Dunn et al., 2004; Haygarth et al., 2005a, 2000; Jarvie et al., 2003; Scholefield et al., 2005; Webb et al., 2005)). Natural scientists have reported back to the policy makers what is required (Haygarth et al., 2005a; Jarvis, 2000). This has resulted in policies addressing single pollutant issues. An example of this being the setting up of Nitrate Vulnerable Zones (NVZ). The Nitrates Directive (91/676/EEC) requires that the extent of NVZs and the effectiveness of the Action Programme measures applied in the zones are reviewed every four years. Further research indicated that the proposed measures were likely to reduce nitrate leaching by 5% and that greater reductions are required in some areas to tackle eutrophication and reduce nitrate levels in waters used to supply drinking waters (Defra, 2002). In 2002 the use of NVZ was extended from 8 to 55% in England, in an attempt to combat the rising nitrate levels in surface and ground waters. Limited success in reducing surface water nitrate and phosphorus concentrations is leading to an increase in interdisciplinary research involving stakeholders to better understand the complexity of water pollution e.g. (Waterton et al., 2006).

3. The need for integration between policies, the science base and their implementation

There is clearly a need for increased levels of integration across policies, the science base and their implementation if we are to reach our goal of sustainable catchment management. Fig. 1 helps to show how international and macro economy drivers and multiple policies are linked to land and water use straddling the social and natural sciences. In this section we examine how increased levels of integration between policies, the science base that these policies are based on and their implementation can be achieved.

3.1. Integration between policies for sustainable catchment management

Multiple policy drivers covering urban and rural communities, and their relationships with land and water use, have resulted in the need for an integrated decision

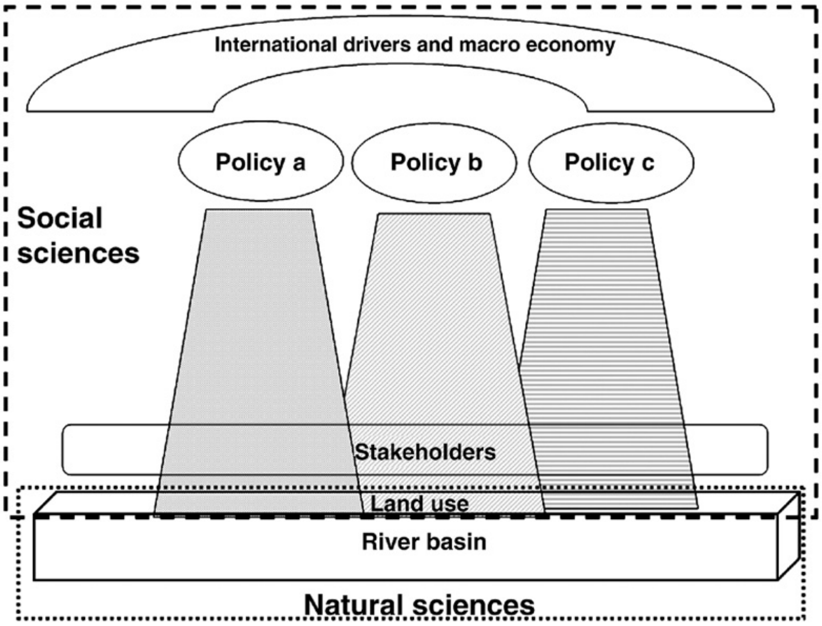

Fig. 1. External drivers and multiple policies are linked to land and water use straddling the social (denoted by large dotted line) and natural sciences (denoted by smaller dotted line).

making framework that operates from the strategic national scale to the local catchment scale, linking together biophysical pressures and socio-economic drivers to enable better and more transparent decision making to support sustainable catchment management. Management plans covering: river management, catchment management, planning and development, fisheries and biodiversity along with major agricultural reforms of the European Common Agricultural Policy (CAP) have lead to the need for an integrated framework to aid decision making where conflicts and complimentaries are present in policies.

In the EU, the Water Framework Directive (WFD) (2000/60/EC) is driving raised levels of regulatory activities in member states. The WFD is based on the principles of 'integrated planning' and 'public participation' placing a new emphasis on the consideration of socio-economic systems in parallel to environmental systems. The surface water catchment will be the basic administrative and management unit, with river basin management plans (RBMPs) the main planning instrument. The WFD requires the use of spatial data in reporting and public participation at various stages in the planning cycle, highlighting the need to integrate social and natural science approaches. The provisions of the earlier EU water legislation have been integrated into the WFD, allowing the earlier Directives to be repealed in a phased approach. But the WFD is not intended to replace some more recent pieces of legislation and it will complement the UWWTD, the Nitrates Directive and the Integrated Pollution Prevention and Control Directive (96/61/EC). The preamble to the WFD legalisation states "Further integration of protection and sustainable management of water into other Community policy areas such as energy, transport, agriculture, fisheries, regional policy and tourism is necessary. This Directive should provide a basis for a continued dialogue and for the development of strategies towards a further integration of policy areas." The potential implications of the WFD on domestic planning in the UK have been highlighted (Howe and White, 2002). The adoption of the WFD will lead to the current spatial planning system having to take account of RBMP and a greater emphasis on the link between domestic planning and environmental indicators (Howe and White, 2002). In the UK regional spatial plans are under consultation. The Planning and Compulsory Purchase Act 2004 will lead to regional level Regional Planning Guidance to be replaced by 'Regional Spatial Strategy' and at the local level local development frameworks are being formulated.

Environmental policy units across the EU are rethinking their approaches to ICM e.g. Millennium ecosystem assessment (Millennium Ecosystem Assessment, 2003). The ecosystem approach is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. It requires the application of appropriate scientific methodologies focused on levels of biological organization which encompass the essential processes, functions and interactions among organisms and their environment. Whilst recognizing that humans, with their cultural diversity, are an integral component of ecosystems (Millennium Ecosystem Assessment, 2003). Currently, the potential of a range of policy measures are being examined by Depart for Environment, Food and Rural Affairs as part of the Catchment Sensitive Farming (CSF) Programme aimed at tackling diffuse water pollution from agriculture to help meet objectives of the WFD in England and Wales. For water quality outcomes, the CSF programme focuses on all pollutants and takes account of delivery of commitments under the Nitrates Directive through the NVZ Action programme. CSF takes account of the costs of proposed measures and their effectiveness.

3.2. Integration between scientists for sustainable catchment management

Increasingly, natural and social scientists are finding themselves working in interdisciplinary teams, which often include both social and natural scientists from a range of disciplines to address natural resource policy questions. The need to work in larger interdisciplinary teams is in part due to the requirement to link the contributions from individual specialists to enable a better understand of the 'system' under study (Haygarth et al., 2005a). In addition, the 'system' under study is increasing spatially and temporally for a large number of natural scientists, examples include the rise of papers on gene to landscape scale systems biology as discussed recently by Bothwell (2006) and from process focussed plot scale to policy driven catchment scale studies (e.g. Haygarth et al., 2005b; Page et al., 2005; Wood et al., 2005). Funtowicz and Ravets (1990) coined the term 'post normal science' to describe the scientific activity where natural scientists are forced by stakeholders to tackle specific problems in time and space, unable to use traditional reductionist approaches.

Increasing levels of integration at the personal, team and larger community level is leading to natural and social scientists to rethink the skills required to succeed in this changing research environment. For a scientist to excel in this new environment of integrated research, a common set of qualities are required to achieve integration, these include: curiosity, confidence, credibility, capacity, communication, collaboration and connections. Integrative activities are expensive in terms of time to keep abreast of the latest advances in more than one scientific discipline and the intellectual energy required to balance disciplinary and interdisciplinary excellence. This is increasingly being recognized by research funders, with more capacity building awards for interdisciplinary research networks e.g. Rural Economy and Land Use (RELU) joint research councils programme in the UK. Journals spanning the social/natural science divide are gaining recognition. Their profile in both the natural and social science communities needs to be raised to enable the evidence base to grow to support truly integrated catchment management.

3.3. Integration in management for sustainable catchment management

In the past, risk assessment and risk management have been separate activities, with the former providing the scientific analysis and characterisation of adverse effects of environmental hazards, where qualitative approaches are applied before quantitative analysis (Pollard et al., 2002; Stern and Fineberg, 1996). Risk management was based on identifying and assessing alternative regulatory options, based on broad economic, social and technological aspects. The rigid divide between risk assessment and management has been found to be lacking (Stern and Fineberg, 1996), since isolated analytical activities do not provide the required understanding to address risk decisions (Scott et al., 1999).

The analytical aspects of risk analysis need to be balanced by the appropriate involvement of interested and affected parties in all stages of the decision making process, including those leading the risk characterisation. The National Research Council report on 'Understanding risk' (Stern and Fineberg, 1996) proposed an iterative analytical-deliberative approach for improved risk characterisation, resulting in more acceptable decisions to interested and affected parties. The focus was to improve risk characterisation, through integrating it with the entire process of decision making. Successful risk characterisation requires input from three groups: analytical experts, such as natural and social scientists; decision makers; and interested and affected parties to the decision. Analysis is based on rigorous replicable methods developed by experts to answer factual questions. Whereas, deliberation is based on discussion, reflection, and consideration of relevant issues that increases understanding allowing substantive decisions to be made. New information is brought to the process through analysis and new insights, questions and formulation of new problems are provided by deliberation. The level and approach to analysis and deliberation will be determined by the nature of the decision. Deliberation is not new to the natural scientist, since it is part of the scientific process allowing the scientific community to arrive at collective consensus, this was highlighted by Kuhn (1970) when he referred to deliberation helping to uncover errors and deepen understanding by considering evidence from several perspectives.

Increased resources are being placed in the use of analytical-deliberative approaches to natural resource management; since better decisions can result when the analysis is decision relevant by giving participants a guiding role, leading to "deliberation frames analysis, analysis informs deliberation, and the process benefits from feedback between the two" (Stern and Fineberg, 1996). Adaptive management is an example of an analytical-deliberative approach to natural resource management approaches which assumes that policies and their implementation are dynamic based on new scientific and socio-economic information (CAMNet, 2005). Adaptive management conceptualise a catchment as an uncertain, complex, non-linear and dynamic system. Adaptive management includes development of models abstracting the behaviour of a system of interest. The model that emerges is then used to screen credible hypothesis to be tested in management experiments. The role of models is to eliminate outlier hypotheses that are not worth considering further. In the second phase a range of potential actions screened in the initial phase are incorporated into research and management plans to evaluate those actions as competing alternatives. This will guide future management choices and fill knowledge gaps.

To enable holistic risk characterisation for ICM there are additional requirements to link individual stakeholder behaviour with catchment scale processes. The problems and solution mechanisms for catchment management are dependent on spatial extent and resolution under consideration (Grayson and Bloschl, 2000). Scale is a major issue when trying to integrate natural and social sciences and is jointly dependant on social and biophysical processes (Lebel et al., 2005). The mismatch of scale between the spatial extent of research and the spatial extent of management decisions is important because the outcome of ecological investigations often depend on the scale of study. This leads to the conclusion that many of the traditionally sanctioned techniques for ecological research are not appropriate at large scales. Increasingly, multiple models are being used to gain ecological understanding compared to the traditional technique of hypothesis testing (Johnson, 1999). Recent increases in the level of integration between policies, the interdisciplinary scientific evidence base and their implementation provides an optimistic future for our water bodies. Sustainable land management and the use of appropriate scientific tools to enable integration between policies, science and their implementation are essential components of sustainable catchment management.

4. Sustainable land management: the key to sustainable catchment management

ICM requires a spatially explicit understanding of how land and water use, ecology and bio-physical resources interact, and of the relevant socio-economic and environmental driving forces governing these interactions. It is increasingly being realised by policy makers that the traditional natural science approach to analysis requires greater consideration of the societal choices facing natural resource protection. Thus, catchment management has to link land use and its drivers to the quality of water bodies (e.g. considering the implications of CAP reform on the implementation of the WFD). The study of land use dynamics, a major determinant of land-cover changes, involves the consideration of human behaviour. Through the use of land use change models, the causes and consequences of land use dynamics can be better understood. Without understanding the dynamics behind land-use, we cannot understand changes in land cover, nor estimate the utility of policy intervention (Veldkamp and Verburg, 2004). Land use models need to be constrained by regulatory rules and governance, so that the full range of socio-economic drivers are considered when assessing future land use changes. There is a growing realisation that socio-economic and physical factors need to be considered together when dealing with diffuse pollution caused through land management (Boardman et al., 2003). Cortner (2000) argued that, technical fixes have not resolved environmental problems since they fail to consider the behavioural and social aspects of human action. For example, it is increasingly accepted that tackling diffuse pollution is about changing land use practices, rather than technology (Koontz, 2003; Novotny, 1999).

ICM requires integrating different conceptualisations of catchment processes. The concept of narratives is widely used in the social sciences. Narratives are used to define the problem and system under study, making theoretical assumptions explicit. Narratives can be viewed as differing perceptual models that exist in the wider model space, where different parts of the system are utilised in different narratives, but with consistent common parts/entities to enable integrated analysis. Narratives and their allied perceptual models need to be developed and documented in a structured and transparent way. With each problem there are multiple narratives that lead to multiple articulations and result in a decision. Good problem definition is the first stage, this is followed by the collection of differing narratives from different stakeholders e.g. farmers and regulators. Our limited understanding of the natural processes controlling catchment scale processes needs to be considered when we develop detailed models based on sparse observations (Beven, 1996). It is important to acknowledge and incorporate these systemic uncertainties throughout ICM. This means ICM must contend with uncertainty due to imperfect scientific knowledge and the indeterminacy of complex processes (Van den Hove, 2000).

5. Scientific tools to support increased integration

The integration of socio-economic datasets with biophysical datasets is becoming more common and is a requirement of the WFD. Socio-economic factors are related to landscape characteristics and can be explicitly linked with bio-physical data to give a more realistic indication of catchment conditions and future scenario development. In this section, we review the potential of tools and techniques that can increase the level of integration between policies, the science base and their implementation. These include spatial technologies (including models), scenarios, indicators and the use of MCA. We highlight current integrated approaches that are using these tools and techniques to link sustainable land management to integrated catchment management.

5.1. The use of spatial technologies (including models) to support ICM

The structure of a geographic information system (GIS) database reflects a formalised model of knowledge about the world. The linkages between GIS and environmental modelling have been demonstrated by Goodchild et al. (1996). The use of GIS databases supports the development of a number of land use change models that will represent a series of working hypothesis describing the relations between drivers and land use (Aspinall, 2004). Data from a range of sources can be combined and interrogated to address complex spatial problems in a transparent and useful way to meet the requirements of legislation such as the WFD and CAP reform to manage catchments from the field to landscape scale. An important component in spatial decision support systems (SDSS) is their interaction and/or inclusion of a GIS as shown in Fig. 2. In this example external data is provided from a GIS. A growing number of SDSS have been produced and are in use to support sustainable land management e.g. MLURI Land Allocation Decision Support System (LADSS) (Milne and Sibbald, 1998).

Creating an environment to facilitate analysis and deliberation in a group decision setting is the purpose behind participatory GIS (Jankowski and Nyerges, 2001). Public participation in spatial decision making involves the use of GIS tools to help lay people understand the spatial consequences of proposed projects, evaluate alternatives and create new solutions. Fig. 3 demonstrates the pivotal role of participatory GIS in the convening and process constructs of the 'Enhanced Adaptive Structuration Theory' of Jankowski and Nyerges (2001). Ball (2002) suggested that participatory GIS can provide a visual tool that can express the various imagined future environment(s), allowing stakeholders to discuss and plan to achieve these visions. GIS is often used to enable active involvement by interested parties as it can be an important facilitator allowing stakeholders to explore relationships

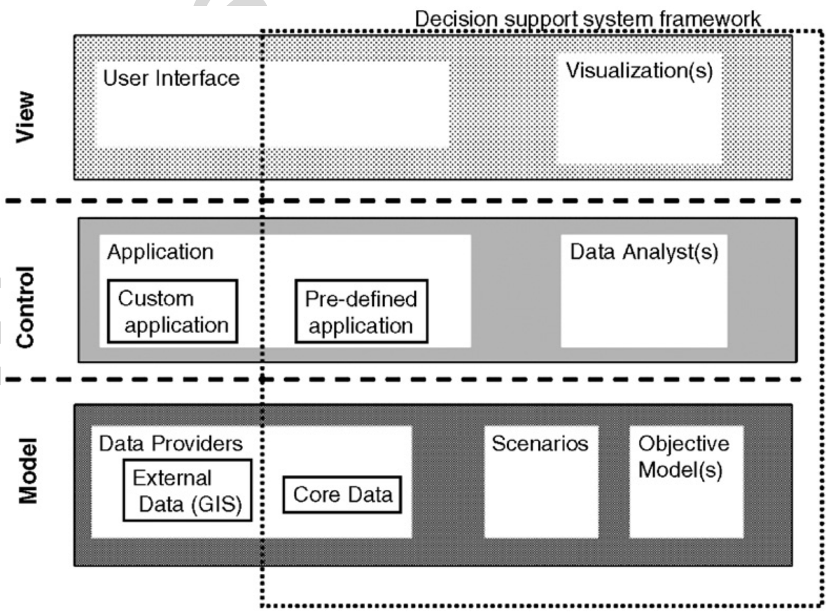

Fig. 2. Role of GIS as a data provider in a decision support system framework (adapted from (Morley et al., 2004)).

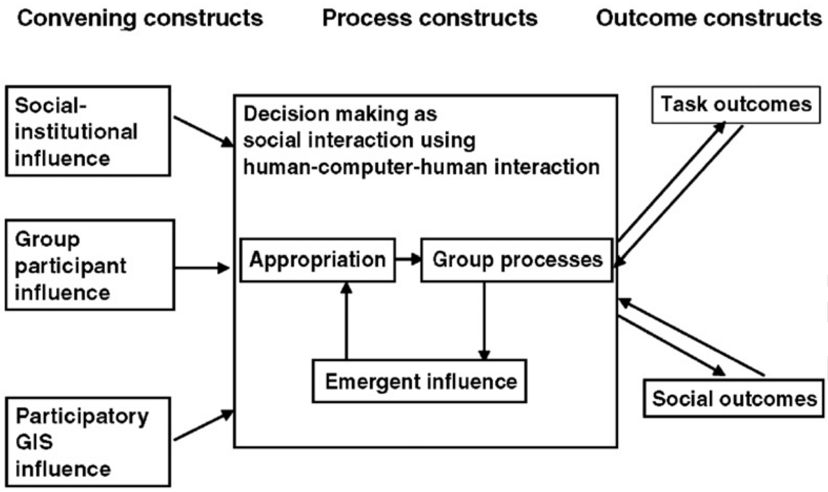

Fig. 3. Enhanced Adaptive Structuration Theory 2 (EAST2) demonstrating the role of participatory GIS in a group decision situation (Adapted from (Jankowski and Nyerges, 2001)).

that are perceived to exist among bio-physical and other aspects of a landscape and a range of environmental, social and economic outcomes. These can be represented at different scales and over different time periods. Whilst GIS is often just used to frame and georeference information provided by stakeholders, it can also be used as a tool to foster social learning and participatory decision making or implementation; and can act as a fast and efficient way to map a resource base that requires collaborative management as demonstrated by Ball (2002) and Gonzalez (2002). Previous studies have used GIS in representing farm household decision making under sanctions of agricultural and rural policy change (MacFarlane, 1996). More recently, joint learning within a GIS framework has highlighted a new way to manage natural resources in a participatory way (Gonzalez, 2002).

Ball (2002) stated that GIS can actually empower individuals by allowing them to explore scientific data and models on the same footing as the 'experts'. In conclusion, Ball (2002) identified three key principles for public participation GIS:

- Accessibility — the information technology and data must be freely accessible
- Understandability — the system, and their limitations and uncertainties, must be understood by all users
- Accountability — the way in which the information is used should prevent 'capture' by powerful and self-interested parties.

The importance of spatially explicit models in assessing and managing diffuse pollution is well known. A large number of catchment scale hydrologic and diffuse pollution models are available and have been recently reviewed (Borah and Bera, 2004). What has been lacking from these integrated diffuse pollution models is the inclusion of the 'social' aspect. Farmers will react quickly to changes in commodity prices and economic incentives within the constraints of access to market, topography, rainfall and soils. Socio-economic factors operating at the national and local scales have lead to a move away from mixed farming with livestock to distinct arable and livestock systems over the last 40 years in parts of the EU (Mathieu and Joannon, 2003; Souchere et al., 2003). Models and other discussion/decision support systems e.g. GIS, can help meet the requirements of integrating analysis with deliberation by enabling a wide range of interested parties to be involved in more sophisticated and better informed analytical-deliberative processes. Meta-models are being developed, whereby reduced forms of complex models are used to facilitate understanding of how systems work. In addition the outputs from one or more models are being used as inputs to another (Boorman, 2003a; Boorman, 2003b). Recently, an EU funded project has produced an open source 'wrapper' that aims to aid the bolting of existing models together (Moore and Tindall, 2005). Part of this process will require illustrating the socio-economic assumptions built into models of hydrological and land use processes; and the bio-physical assumptions that are integral to models of economic production and consumption; answering the calls by Ravetz (2003) to unpack the 'black box' of individual models.

The ability to understand and model land system is highly dependant on data availability and quality. There is a need for comprehensive linking of the social, biophysical and geographic domains in human-environment interaction studies. The challenges of linking social data at the household scale with a community/landscape scale have been reviewed by Fox et al. (2002). These challenges have resulted in a lack of integration between spatially explicit land studies and the social economic approaches in human-environmental studies (Nagendra et al., 2004).

Recent developments in human-environmental impact assessment include: quantification and visualisation of the effects of land use change to support land users and policy makers in their decisions (Stoorvogel et al., 2004); the analysis of biophysical and socio-economic properties at multiple scales (Aspinall, 2004), the integration of land use models in integrated assessment models (De Nijs et al., 2004) and the use of agent based modelling incorporating actual decision making processes (Evans and Kelley, 2004).

Agent based models are simulations based on large scale consequences of interactions between individual members of a population. The behaviour of the individuals is controlled by a set of rules, their characteristic parameters and the environment in which they operate. Agent based models have been widely used to understand urban and rural development (e.g. (Veldkamp and Verburg, 2004)). Agent based models simulate decision making by individual agents of land use change, through analysis of the interactions of agents, emergent properties of the system can be observed. Several multi-agent models have been developed (e.g. (Evans and Kelley, 2004)). Currently, these models are only able to simulate simple relationships in hypothetical landscapes as the number of interacting agents and factors in real landscapes that are needed to understand real land use change are too numerous and complex.

5.2. The use of scenarios to support ICM

The use of scenario based studies for future land use and its consequences for ecosystem services is growing (e.g. recent editorial (Verburg and Rounsevell, 2006)). They provide a method for ordering perceptions about how decisions will impact future environments. Scenarios are descriptions of journeys to possible futures. Scenario analysis is a useful tool in future-oriented environmental assessment, especially where there are large uncertainties making predictions impossible. The scenarios help combine narrative descriptions of different futures with detailed quantitative information provided by integrated modelling exercise. Recently, the Millennium Assessment scenarios have explored future changes to ecosystem services. They enable the exploration of the consequences of differing assumptions about policies towards ecosystem services (Carpenter et al., 2006). Scenarios will allow policy makers and other stakeholders to assess possible solutions, without the risks of actually having to implement them. This is particularly valuable for potentially costly, yet ineffective measures, for example, scenarios showed that large reductions (50%) in fertilizer use in the Ouse catchment could result in reductions in the nitrogen load delivered to the Humber Estuary that are significant, but of a smaller magnitude (6–16%) (Boorman, 2003b).

5.3. The use of indicators to support ICM

To assess if a policy approach is effective in reducing nutrient losses from agriculture, then scientifically robust indicators are required. There is growing interest in agri-environmental indicators (AEIs). OECD (1993) defines AEIs as attributes of land units which are policy relevant, analytically sound and measurable. The development of useful indicators at the European scale requires both spatial and conceptual aggregation (Niemeijer, 2002). Schroder et al. (2004) recently reviewed the effectiveness and efficiency of a range of indicators and concluded that there does not seem to be a single indicator that is efficient, effective, comprehensive, responsive and attributable at the same time. The EU has adopted a set of sustainability development indicators to assess its progress towards sustainable development (Ledoux et al., 2005).

5.4. The use of multicriteria analysis (MCA) to support ICM

MCA enables options to be compared and ranked using a large number of criteria. MCA is increasing being used with deliberative processes for addressing issues such as incommensurability of values and uncertainty (Munda, 2004). MCA also provide information that is not available through other ‘valuation’ methods (Munda, 1996). Fuzzy as well as crisp MCA approaches have been developed to enable uncertainties in our knowledge to be incorporated into the analysis process (Brans et al., 1986; Geldermann and Rentz, 2001). Participatory MCA (PMCA) involves participation by the stakeholders in the assessment process. Combining an analytic stage with the measurement of performance of options against criteria and a deliberative stage where the arguments and reasoning used by participants are recorded (Stirling, 2006). PMCA aids policy decisions when values and knowledge are in dispute. MCA and integrated modelling have shown that alternative land uses can be evaluated and the best compromise between economic return and environmental pollution can be identified (Koo and O’Connell, 2006). Koo and O’Connell (2006) demonstrated that MCA and GIS can be successfully integrated to better understand diffuse nitrate pollution.

5.5. Current approaches to integration

The sustainable management of water resources must be based on a spatially explicit understanding of hydrological and biogeochemical processes together with the relevant socio-economic and environmental driving forces (Cave et al., 2003). In recent years, researchers have begun to apply consistent methods to the study of multiple analytic-deliberative processes in relation to river basin management (e.g., (Leach et al., 2002)).

The need for progress with ICM requires consideration to what extent existing natural and socio-economic science (data, models, and analyses) are adequate for multi-objective catchment management. Identification of relevant qualities of the system under investigation need to be characterised, then modelled and evaluated in response to specific goals set by relevant stakeholders. Ideally, this would be carried out at multiple scales. One approach is to use land use maps with web based diagrams. These shared mental models use land cover maps linked to multi-criteria performance web diagrams, showing the level of attainment of a number of biophysical and socio-economic indicators, which can illustrate processes at different scales, as suggested by Giampietro (2004). Multi-criteria performance spaces can contain indicators assessing environmental stress, household type composition, indicators assessing the performance according to socio-economic benefits e.g. income per capita and indicators assessing the performance of productivity. Analysis over spatial scales is not a simple task due to complex linkages and the lack of information on causality (Giampietro, 2004). Recent multilevel modelling of land use from field to village level has demonstrated that hypotheses that explicitly take scale and levels into account can be developed and tested (Overmars and Verburg, 2006).

One study that has used GIS to link ecological and economic modelling in agricultural land use scenarios is the Danish project ‘Land use and landscape developed by scenarios-interactions between nature, agriculture, environment and land management’ which has been running since 1997 (Munier et al., 2004). The aim of the project was to explore methods to enable interactions between policy areas at the farm scale to reduce antagonistic interactions and promote synergistic ones. Policy areas covering agricultural production, nutrient losses, landscape and nature conservation were included. The policy objectives were identified and one or more policy measures were evaluated in a target area using an economic model or a decision tree or a combination of the two using a GIS. The GIS was used to generate input files from a number of data sources for a range of socio-economic and biophysical models.

The AgriBMPwater project produced a framework to assess the cost effectiveness of several best management practices in several European watersheds on a three dimensional space defined by environmental effectiveness, associated economic consequences and social acceptability by farmers and land users (Turpin et al., 2005). The authors found that when physical and economic models were solved separately and successively they failed to capture feedback effects between the economy and environment. This led them to conclude that multidisciplinary modelling is required to assist the implementation of agri-environment policy.

Interdisciplinary modelling, through the coupling and integration of models from different disciplines, enables the simultaneous description of effects due to economical, ecological and regulatory changes of land management. Socio-economic land use model and hydrological models can be linked through the use of decision support tools e.g. MULINO (Giupponi et al., 2004). The MULINO decision support system was designed with the aim of being a ‘facilitator of the operational implementation of the WFD (2000/60/EC) principles in real-world decision making’ (Giupponi et al., 2004). The driving force–pressure–state–impact–response framework (DPSIR) is used widely in Europe to manage the connectivity between human activities and the environment. The advantage of the DPSIR framework is that it structures the user's thinking to understand the whole picture and dynamics of the system. Giupponi et al. (2004) transformed the static DPSIR approach into a more dynamic framework through dividing the approach into: 1) causal chain (DPS) of the effects of human activities which can be assessed using models, 2) the conversion of the model outputs into indicators for MCA in the impact section (I), and 3) allowing the response (R) to take account of group decision making and to link the DPS chains with the management options. At the heart of MULINO is a hydrologic model and MCA routines. Approaches based on spatial technologies, scenarios and MCA linked by land use are increasingly being used to help support ICM and manage diffuse pollution (e.g. (Giupponi and Vladimirova, 2006)).

6. Conclusions

There is a growing awareness that greater integration is required to achieve sustainable catchment management. Integration between existing and future legislation and policies must be supported by greater integration by natural and social scientists who provide the evidence base. Integration between the full range of stakeholders (including scientists and policy makers) in catchment management is required. The WFD is a first step towards ICM. Further research is required to better understand how competing policies are linked through urban and rural land uses and their effectiveness to meet environmental targets using adaptive management approaches. We have argued that before ICM can lead to sustainable catchment management, there is a need for three important changes:

1) the legislation and policies that aim to achieve ICM, must be combined with existing and future legislation and policies,
2) the science that is required to support ICM and provide the evidence base also needs to be integrated across the natural and social science disciplines,
3) the management of catchments should be based on integrating land management with a wide range of stakeholder requirements, policies and scientific evidence base.

The wider use of spatial technologies combined with scenarios, indicators and MCA by policy makers, scientists and stakeholders with an interest in sustainable catchment management will assist in providing an analytical-deliberative approach to catchment management that is truly integrative.

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