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Designing multi-objective whole landscape scenarios at the catchment scale

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**Designing multi-objective whole landscape
scenarios at the catchment scale**

by

Adrian Southern

CSERGE Working Paper EDM 10-14

DESIGNING MULTI-OBJECTIVE WHOLE LANDSCAPE SCENARIOS AT THE CATCHMENT SCALE

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Abstract

A critical task facing humanity is the creation of a shared vision for a sustainable society. This brings the question of the future to the strategic forefront of decision making, where decisions often need to be formulated in the face of profound uncertainty and complexity. In such circumstances scenario analysis and planning can offer a structured way of dealing with the many uncertainties that lie ahead. However, the fusion of quantitative and qualitative data in scenario design, which combines computational modelling with societal values, is still in its infancy presenting significant methodological challenges. This paper reports the findings of a participatory scenario development process using the 115 km² River Glaven catchment in North Norfolk, England as a case study. A range of data sources were integrated to model soil erosion, ecological connectivity, land use change and agricultural economics. In addition a wide range of stakeholders were engaged with to design two landscape scenarios for the catchment in 2020. One scenario was driven by agricultural production and world trade, the other by the enhanced protection of ecosystem services and multi-objective land use. Based on the results of this case study we present recommendations for implementing integrated participatory and model-based scenario design processes for both practitioners and researchers.

Key Words: scenario design, integrated modelling, ecosystem services, land use, catchment management.

Acknowledgements

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1. INTRODUCTION

A critical task facing humanity is the creation of a shared vision for a sustainable society, one that can provide fair and equitable prosperity within the biophysical constraints of the natural world (Costanza 2003). This brings the question of the future to the strategic forefront of scientific research, policy deliberation, forward-thinking organisations, and concerned citizens (Carpenter 2005). However, the governance of social-ecological systems continually requires decisions to be made where control is difficult and uncertainty is high. In such circumstances scenario analysis and planning can offer a structured way of dealing with the many difficulties that lie ahead (Peterson *et al.* 2003). A key area of uncertainty emanates from the challenge of adequately modelling the biophysical constraints, which are themselves notoriously problematic to understand, and integrating them with the unpredictability of the human dimension (Berkhout *et al.* 2001, Shearer 2005). Nonetheless, it is essential to integrate the social and the natural components of coupled social-ecological systems if society is to be guided towards sustainable outcomes (Folke *et al.* 2005). Essentially; there are no panaceas. In the face of such pervasive uncertainty science has been unable to generate simple models of linked social and ecological systems and deduce general solutions for their governance (Ostrom *et al.* 2007). Nevertheless, there are important tools such as scenario analysis and planning that can assist navigation toward greater sustainability (Peterson *et al.* 2003, Carpenter 2005, Shearer 2005).

1.1. The use of scenarios in the governance of social-ecological systems

Scenario-based investigations of possible futures have been used since the middle of the 20th century to help decision makers and scientists cope with high levels of uncertainty where system manipulations are difficult or impossible (Peterson *et al.* 2003). This has led to the development of a variety of scenarios across a broad range of sectors and disciplines such as corporate business management, economics, environmental science, political science and public administration (van Notten *et al.* 2003, Shearer 2005).

Scenarios describe possible futures of what could be rather than what will be, they are not designed to present the most realistic state, predict or forecast the future (Tress & Tress 2003, van Notten *et al.* 2003). Berkhout *et al.* (2001) describes them as “learning machines” designed to stimulate people to reassess their beliefs. Scenarios can be used by a wide range of stakeholders and experts to explore the uncertainty surrounding the future consequences of decisions, provide insight into drivers of change, reveal the implications of current trajectories and illuminate decision options (Peterson *et al.* 2003, Nassauer & Corry 2004). Often this is achieved by developing two or more contrasting scenarios designed around key driving forces that encompass realistic projections of current trends, qualitative predictions and or quantitative modelling that capture system transformations (Peterson *et al.* 2003). This requires that the internal dynamics of the scenarios must be plausible and consistent, but this does not preclude the use of extreme futures, though it is important to link them to a description of the present situation as a basis for comparison (Nassauer & Corry 2004). Additionally, design assumptions and who makes them are central to the final outputs and should be clearly articulated (Johnson & Campbell 1999, Hulse *et al.* 2004).

Attempts have been made to develop scenario typologies (van Notten *et al.* 2003, Westhoek *et al.* 2006), but the boundaries between discreet classifications have in reality proved to be fuzzy (Shearer 2005). However, for the purposes of this study it is useful to define scenarios within the context of three broad characteristics:

1. *Normative and descriptive scenarios.* In normative scenarios the future is pictured as a single state that should, or could be (Opdam *et al.* 2001, Nassauer & Corry 2004). On the other hand descriptive scenarios outline an ordered set of possible events leading to an outcome. They also tend to be less value laden than normative scenarios which more purposefully take social values and interests into account (Rotmans *et al.* 2000). In

practice these approaches to scenario design get mixed into various blends running from the poles of normative to the purely descriptive.

2. *Backcasting and forecasting approach.* Normative scenarios are often used in a back casting fashion to explore dynamics, decisions and the capacity of social agents to make the changes necessary to lead to them (Berkhout *et al.* 2001, Shearer 2005). The back casting approach usually involves the specification of a desirable future as a tool to explore the implications and feasibility of different policy mechanisms and goals (Hojer & Mattsson 2000, Kok *et al.* 2006). Conversely, the forecasting approach explores the future consequences of a sequence of assumptions (Rotmans *et al.* 2000). List (2004) suggests these two procedures can often be mixed in what he describes as “middle casting”.
3. *Quantitative and qualitative scenarios.* Qualitative scenarios describe possible futures in the form of words rather than numbers, which is commonly manifest as a “storyline” of narrative text, often developed through stakeholder engagement (Alcamo *et al.* 2006). On the other hand quantitative scenarios are often based on computer models that provide numerical information in the form of tables, graphs and maps to both explore the consequences of assumptions and often to assess the consistency of the scenario set developed (Rotmans *et al.* 2000). Again, it is more realistic to say there is a spectrum running from scenarios that are purely quantitative to those that are purely qualitative.

Integrated numerical modelling, scenario analysis and participatory approaches have increasingly been used to investigate possible futures in natural resource research where uncertainty is high and control is difficult (Figure 1). The fusion of quantitative and qualitative data is still challenging methodologically and is a critical research area in scenario development (van Notten *et al.* 2003, Malczewski 2004, Walz *et al.* 2007)

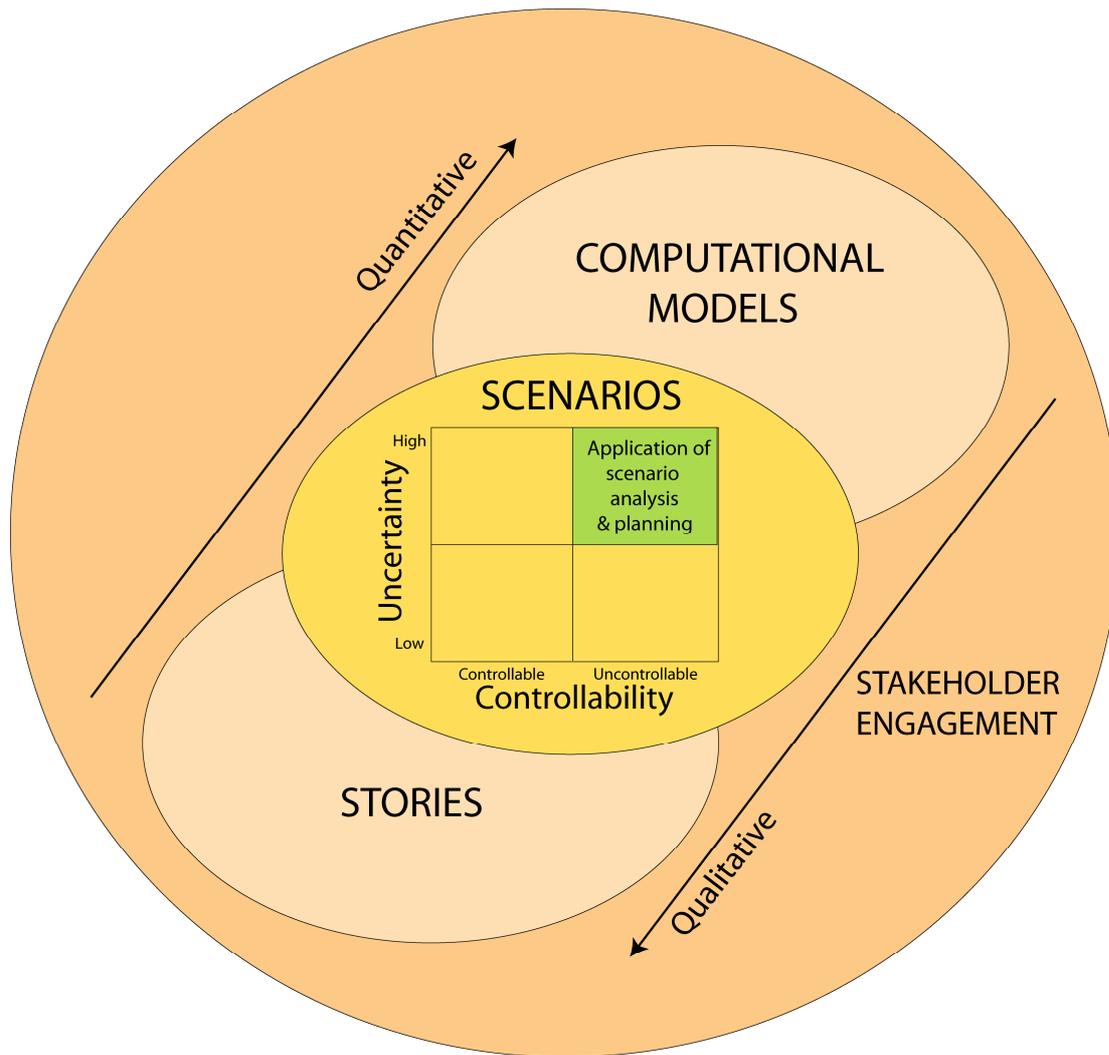


Figure 1. Scenario design and the integration of quantitative and qualitative approaches (based on Nakicenovic *et al.* 2000, Peterson *et al.* 2003).

1.2. Fusing quantitative and qualitative data in scenario design

Stakeholder involvement in the scenario design process is important because it can improve the quality and acceptability of the final outputs and contribute to a wider process of engagement in the management and governance of the system (Hulse *et al.* 2004, Stringer *et al.* 2006, Walz *et al.* 2007). Incorporating stakeholders into the design process can be time consuming but, it can also be a creative source of mutual learning for all those involved (Alcamo *et al.* 2006). In addition, seeking to incorporate a variety of world views into the design process can prevent singular assumptions from dominating (Peterson *et al.* 2003). It is also important to recognise that scenarios designed in this way are a useful tool in the process of transdisciplinary working to facilitate the integration of both academic, “scientific” and practitioner, “lay” knowledge (Tress & Tress 2001, Tress & Tress 2003). Furthermore, the democratisation of the planning processes is leading to increased involvement by a diverse range of actors in the decision making process (Moss 2004, Correlje *et al.* 2007, Macleod *et al.* 2007).

This progress in scenario development has been paralleled by the increasing accessibility of key technologies such as Geographic Information Systems (GIS) for spatial modelling and analysis (Malczewski 2004). From a scenario evaluation perspective, computational modelling can be used to test scenarios. However, an important part of a scenarios plausibility can also be evaluated through the response of the actors involved in the system

under investigation to the model results. This can form a critical part of the validation process (Dolman *et al.* 2001, Peterson *et al.* 2003). Ultimately, scenario design that engages stakeholders can provide a forum for policy creation and evaluation, and stimulate participants to think more strategically about the future and how their individual and collective actions can influence this (Peterson *et al.* 2003). However, as of yet, there is no consensus on how this integration can best be achieved (Dougill *et al.* 2006), let alone how to then incorporate integrated knowledge into meaningful management and governance mechanisms (Folke *et al.* 2002). To date the literature on specific case studies generally shows a bias towards either qualitative social science or the numerical modelling perspective and there is a need for more balanced approaches (van Notten *et al.* 2003, Malczewski 2004, Walz *et al.* 2007).

Nevertheless, there are a few publications that demonstrate the integration of computational modelling with a range of stakeholder interactions for scenario design in research areas such as catchment management (Hulse *et al.* 2004, Santelmann *et al.* 2004, Lovett *et al.* 2006, Hiscock *et al.* 2007), regional landscape change (Walz *et al.* 2007), regional climate change (Shackley & Deanwood 2003) and whole landscape design (Dolman *et al.* 2001). Together these studies portray the incorporation of varying degrees of lay and expert stakeholder knowledge with the integrated computational modelling of land use change; ecology; ecosystem service provision; economics; nitrate and groundwater modelling; urban development and the linking of climate change modelling to regional socio-economic scenarios. The process of linking the two poles is shown in all the studies to require an iterative process of stakeholder engagement using various techniques such as questionnaires, electronic voting procedures, workshops, focus groups and email list servers. Typically, initial consultation was conducted with a range of stakeholders that informed the modelling process and facilitated greater understanding of the system by the research team. This was followed by a period of modelling prior to some form of “validation process” either as workshops, expert meetings or focus groups. The Willamette river basin study Hulse *et al.* (2004), demonstrated a particularly focused two and a half year period of constant engagement involving monthly, quarterly and ad hoc meetings with a range of actors in the system. However, despite these studies there is still little accumulated past experience upon which to build (Shackley & Deanwood 2003), and few of the projects published a detailed account of the approach (see Lovett *et al.* 2006).

1.3. Aims of this research

In this study the aim was to develop two normative multi-objective land-use scenarios for the year 2020 by integrating the stakeholder and computational approaches to scenario development based on a comprehensive catchment scale GIS database. The construction of the futures was driven by the following question, how might agricultural landscapes change as a result of Common Agricultural Policy (CAP) reforms? To achieve these aims we have taken a case study approach focused on the River Glaven in north Norfolk, England. Based on this study recommendations for the improved integration of qualitative participatory and quantitative model based techniques in scenario design are made for application in other research projects and by practitioners.

1.4. Case study policy context

Approximately 70% of the English landscape is farmed (Defra 2008a), and landowners and other stakeholders have had to operate within a shifting tapestry of policies, regulations and institutional arrangements, particularly during the last five years. The key drivers for this have been world trade policy and reforms to the CAP, European Union (EU) Directives (e.g. the Water Framework, Nitrate, and Habitat Directives) and “surprise” global events, such as a food “crisis” in 2008, an economic “crisis” in 2009 and a growing realisation that climate change could be more serious than previously thought (New *et al.* 2009).

The 2003 CAP reforms have led to the emergence of a new policy paradigm of a multi-functional agriculture, supported by associated policies and institutional frameworks. This is set within the context of commodity market liberalisation and declining farm profitability, the decoupling of farm subsidies from production support and linking them to environmental measures, biofuel policy, food security and the “sustainable intensification” of agriculture that maintains ecosystem functionality (Gorton *et al.* 2008, Jongeneel *et al.* 2008, Royal Society 2009). CAP reform in conjunction with the EU environmental directives and the adoption of an ecosystem based approach (Defra 2007c), are driving a need for greater integrated planning based on hydrological boundaries and the inclusion of socio-economic systems in parallel with environmental systems, as well as the incorporation of wider public participation in the land use planning process (Moss 2004, Correlje *et al.* 2007, Macleod *et al.* 2007). The key aim of this participatory approach is to improve decision making and governance through a transparent process that incorporates a wide range of stakeholders, thus enabling greater understanding on which to base decisions, and inform improved ways of working together (O’Riordan *et al.* 1999, Studd 2002, Stringer *et al.* 2006).

The governance structures currently in place within England to deliver sustainable landscape planning are still fragmented in the sense that policy and operational responsibilities are divided between an array of organisations (Figure 2), with sometimes competing and contradictory objectives and a disconnection between national, regional and local scales of governance (OECD 2006, Kidd & Shaw 2007). This is despite the establishment of a new “integrated”, Natural England (NE) in 2006, that combines the responsibilities of what were formerly three separate organisations into one integrating wildlife and conservation activities with public access, recreation, landscape protection and the delivery of agri-environment policy to deliver a broad sustainability remit (Defra 2006).

Catchment scale planning and management is the main responsibility of the Environment Agency (EA), although numerous other agencies and stakeholders are ultimately responsible for delivery, including multiple land managers and their advisors, private water companies, and NE (Kidd & Shaw 2007). The EA are responsible for the development of River Basin Management Plans, Abstraction Management Plans and Catchment Flood Management Plans. These are either focused on specific issues (e.g abstraction licensing) or have a regional emphasis that as yet has made little impact on landscapes, although they have been informed by a degree of stakeholder consultation. The EA also administer Nitrate Vulnerable Zones (NZVs) which were expanded in 2007 to cover approximately 70% of the country, imposing additional nitrogen related measures on land management (Defra 2007b). Although the EA are the lead body delivering the EU Water Directives, with key monitoring and regulatory duties, NE administers the primary mechanism for its delivery through the Catchment Sensitive Farming (CSF) Delivery Initiative which was launched in April 2005 and now covers approximately 40% of England’s agricultural area (Defra 2010). The initiative directly addresses the issues of diffuse agricultural pollution, placing particular emphasis on the reduction of nitrogen, phosphate and silt pollution. The approach is voluntary, and implementation is through project officers who are appointed for specific catchments. Capital grants have been made available and workshops for farmers, agronomists and other farm advisors have been arranged to raise awareness of the issues and facilitate the utilisation of mechanisms within new agri-environmental schemes to reduced diffuse pollution.

At the strategic level England has a sustainable development strategy which outlines sustainable development principles that have been agreed by all levels of government (HM Government 2005), recognising that sustainable land use cannot be achieved without addressing how societies as a whole can learn to live sustainably and nurture the land and its dependent communities (O’Riordan 2010). Spatial planning has also been given a central coordinating position in the Government White Paper “Planning for a Sustainable Future” (Communities and Local Government *et al.* 2007), which has generated a degree of regional spatial planning that is still far from integrated and hampered by a planning system

administered by local authorities which is complex, bureaucratic and in need of reform (Kidd & Shaw 2007). There is consequently a need for a greater emphasis on the landscape scale, a review of sustainability planning and the development of a vision for sustainable landscapes that can be translated into practice (O'Riordan 2010). It is unfortunate that recent reviews of sustainability policy in England point to the development of good mechanisms, but a poor implementation track record (Russel 2007).

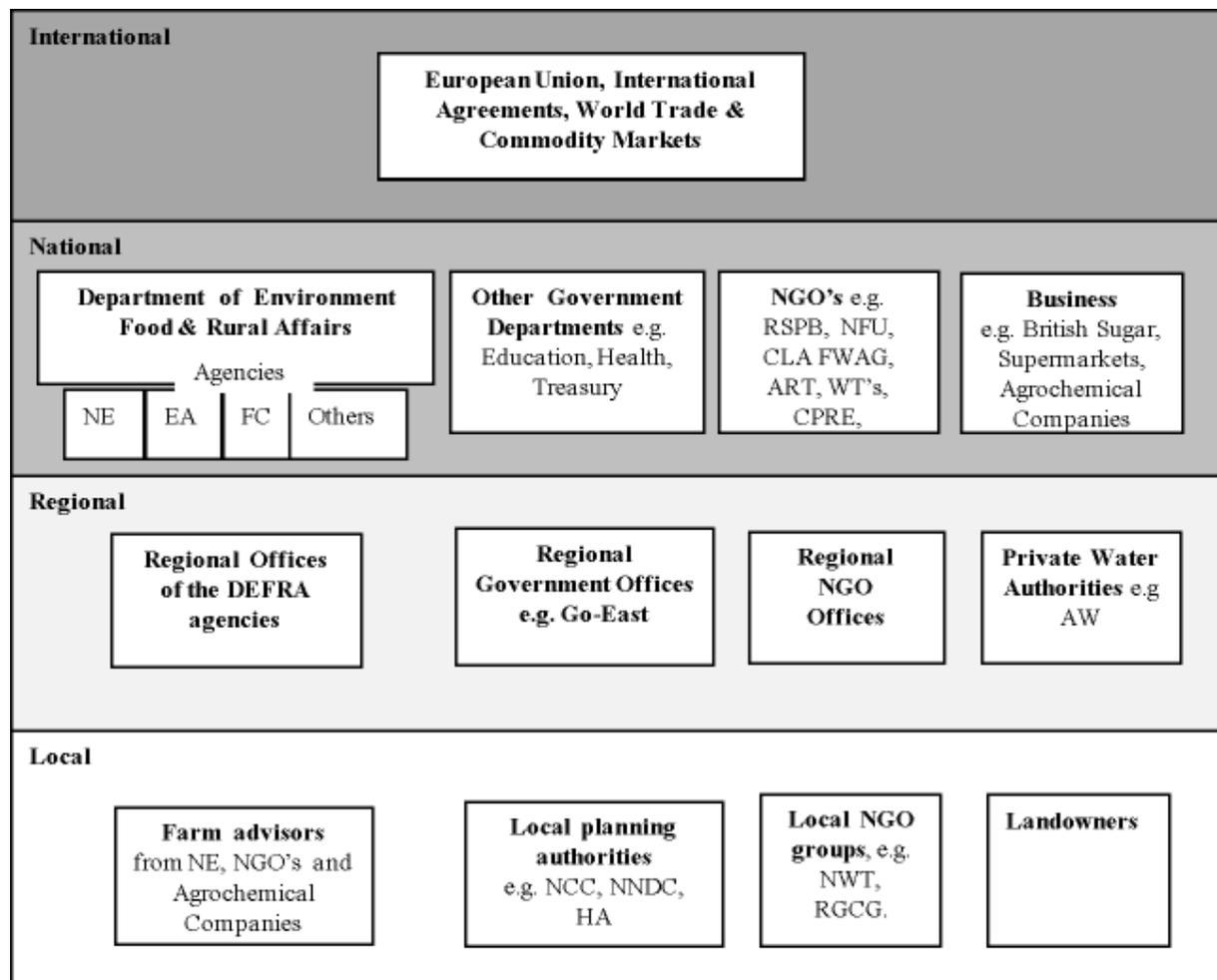


Figure 2. Institutional arrangements for the delivery of landscape policy in England, acronyms used (arranged in alphabetical order); ART = The Association of River Trusts; AW= Anglian Water; CLA = Country Land and Business Association; CPRE = The Campaign to Protect Rural England; DEFRA = The Department for Environment Farming and Rural Affairs; EA = Environment Agency; FC = Forestry Commission; FWAG = Farming and Wildlife Advisory Group; HA = Highways Agency; NCC = Norfolk County Council; NE = Natural England; NFU = National Farmers Union; NNDC = North Norfolk District Council; NWT = Norfolk Wildlife Trust; NGO = Non-governmental Organisation; RGCG = The River Glaven Conservation Group; RSPB = Royal Society for the Protection of Birds; WT's = Wildlife Trusts; WTT = Wild Trout Trust.

1.5. The Glaven catchment

The rural River Glaven catchment in north Norfolk (115km², 11,500 ha) has a population of approximately 7,900 people (CDU 2008), and is a microcosm of many of the issues, policies and institutions relevant to the integrated delivery of landscape management in lowland England (Figure 3). For instance the Glaven is typical in terms of experiencing many of the environmental problems associated with surface water catchments, particularly, river siltation and the associated erosion of the free draining sandy soils. It is this siltation that has resulted in the inclusion of the Glaven in the Catchment Sensitive Farming (CSF) Delivery Initiative (Dollman 2006). Other forms of diffuse water pollution, particularly nitrogen and phosphate from agricultural activities, and the abstraction of water for crop production and domestic use, along with the changing economics of rural land management are implicated in the declining integrity of the Glaven ecosystems throughout the 1970s and into the 1990s (RGPG 2002).

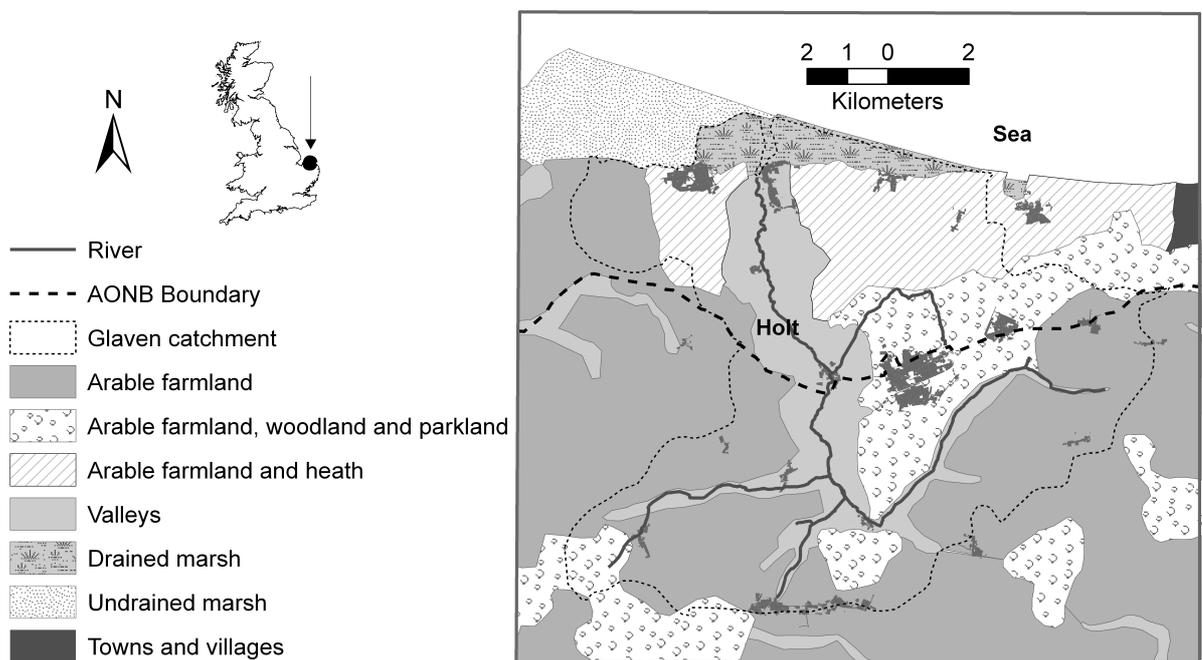


Figure 3. Study site location and landscape character (adapted from NNDC 2008), the AONB boundary indicates the southern extent of the designation.

The system has essentially been influenced and altered significantly by human activities for centuries with arable agriculture currently dominating 63% (7240ha) of the land use. Crop production on the mostly Grade 3 (average quality) agricultural soils is predominantly wheat, malting barley and sugar beet together with some high value vegetables, mostly potatoes and carrots. Livestock production in the catchment has declined in the last 30 years in line with regional trends although outdoor pig production is still important on the large estates. Three estates cover a quarter of the land area within the catchment and approximately 120 other holdings have agricultural interests in the area. There are also forestry (198ha) and conservation organisations (267ha) with significant landownership within the catchment.

The landscape is characterised by the long shallow Glaven valley and rolling farmland interspersed with woods, parkland and heathland underlain by a Cretaceous chalk geology that strongly influences the Glaven's ecology and associated mosaic of wetlands. The landscape beauty and riparian ecology has inspired strong grass roots conservation efforts in the form of the River Glaven Conservation Group (RGCG) which established itself in 1999 and is dedicated to the conservation and restoration of the river. The scenic value of the

Glaven is important economically and 45% of the catchment falls within the North Norfolk Area of Outstanding Natural Beauty (AONB). This is essentially designated on the grounds of landscape beauty, with the management vision of enhancing countryside character, recreation of wildlife habitats, improved recreational access, greater stakeholder involvement in decision making, and the promotion of more integrated approaches to land management (North Norfolk AONB 2004). The catchment also forms an integral part of the North Norfolk Coast Conservation Area which has virtually every environmental designation under UK, European and international legislation.

2. METHODS

2.1. Overview of the scenario development process

The scenarios were developed over a thirty-four month period between December 2004 and September 2007. The process was designed to be iterative and flexible to incorporate stakeholder preferences, as well as producing scenarios with the following characteristics:

1. They must be underpinned by good science.
2. They must include stakeholder participation throughout the design process.
3. They must be designed in a transparent and repeatable way for application of the method in other landscapes.
4. They must be plausible to stakeholders yet sufficiently different from each other to contrast key stakeholder values.
5. They must be appropriate for communication to a wide range of stakeholders who are actively involved in landscape management and related fields.
6. They must model both field and whole catchment scales.
7. They must be compared to a 2005 baseline condition of the system.

The design process had four distinct stages (Figure 4). Firstly, between December 2004 and April 2005 semi-structured interviews were conducted with twenty-seven farmers and twelve non-farming landowners to develop ideas about possible futures (see Southern 2009 for a detailed account). Secondly, two futures were developed for the catchment in 2020 based on the landowner interviews, a review of the relevant policy literature and the latest science. This required the construction of an ArcGIS database for the catchment in 2005 using ArcMap™ 9.1 (ESRI 2008a), to serve as a baseline from which the scenarios were built and compared. One scenario was driven more by agricultural production and world trade (2020ag), and the other driven more by the enhanced protection of ecosystem services and multi-objective land use (2020eco). The construction of the scenarios was assessed based on a pragmatic set of five parameters representative of a range of ecosystem services; land-use change, ecological connectivity, soil erosion, nitrate concentrations in the river water and agricultural economics. Thirdly, an initial iteration of these scenarios was discussed with seventeen key stakeholders in three separate group meetings and four individual meetings to receive feedback on their feasibility, as a form of stakeholder “validation”. All the meetings involved a presentation of the draft scenarios followed by a discussion based on their opinions regarding the plausibility of the scenarios. Findings from the stakeholder validation process were then incorporated into the final iteration of the scenarios before they were used in a backcasting fashion at a multi-stakeholder workshop attended by twenty-six participants in October 2007. The workshop was designed to address the question, “What mix of policies, institutions and delivery mechanisms would best deliver a multi-objective whole landscape for the Glaven catchment?” (see Southern 2009 for a full account of the workshop). At the end of the workshop the scenarios were evaluated by stakeholders in a self completion questionnaire based on a five point Likert scale. The questions sought to assess if the scenarios had clarified key issues in the catchment, and if they had helped with an understanding of how a multi-objective whole landscape may look in the future.

Throughout the scenario design process, active engagement with the wider stakeholder community provided a deeper understanding of the Glaven system and provide additional support for the scenario design process. This included attending a National Farmers Union (NFU) sugar beet growers meeting; a farm open day attended by approximately fifty local stakeholders; attending seven River Glaven Conservation Group (RGCG) committee meetings as well as informal discussions with various agency, Non-Governmental Organisation (NGO) representatives and farmers. Also, an important aspect of this work was the regular support from, and communication with representatives from the Norfolk Coast AONB.

The final scenarios were not intended to be prescriptions of what to do on specific parcels of land. Rather, they were intended to inform and inspire multiple stakeholders to look beyond the existing landscape and their own interests to consider a greater whole. What follows is a detailed description of the modelling process and how the stakeholder engagement informed the assumptions inherent in the scenario design, based around the five core elements of their construction.

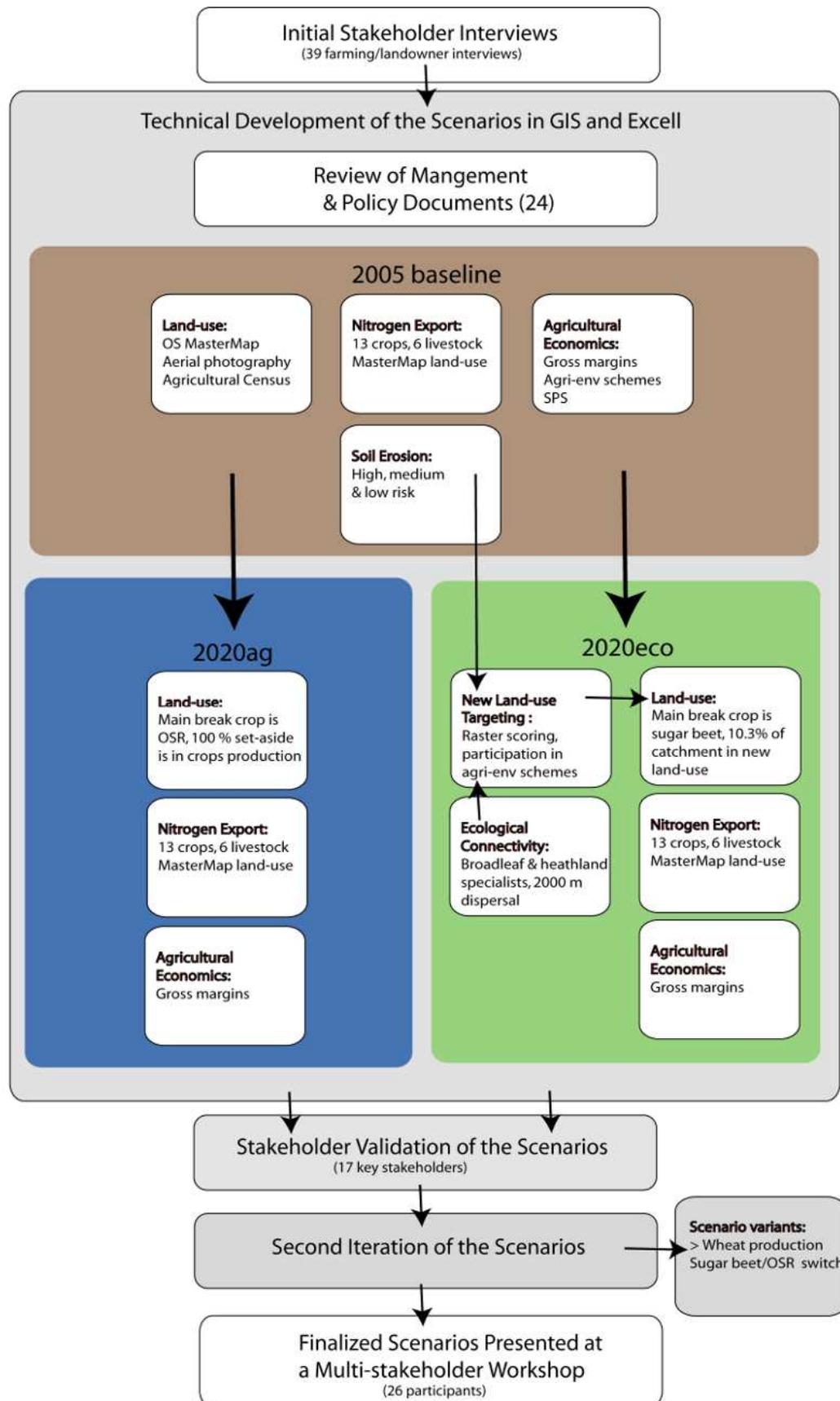


Figure 4. Overview of the scenario design process, the boxes shaded grey are the primary focus of this paper. For a detailed account of the initial interviews and final workshop see Southern (2009).

2.2. Modelling land use

The land-use categories for the 2005 baseline were based on an edited Ordnance Survey (OS) MasterMap[®] Topography Layer obtained from the EDINA Digimap service (EDINA 2008a). This made it possible to model both the whole catchment and field scales. The editing process involved checking all polygons against aerial photography dating from 1999 (purchased from Bluesky 2008). This resulted in the definition of ten primary land use categories (Figure 5), with four subdivisions of the grass category (rough, wet, agricultural and amenity), which were used to add detail to the ecological connectivity and nitrogen modelling. The semi-natural habitat categories were then checked and edited further based on three land designations, Sites of Special Scientific Interest and Ancient Woodland which were both obtained from the Multi-Agency Geographic Information for the Countryside (MAGIC) data portal (MAGIC 2008), and County Wildlife Sites obtained by special request from the Norfolk Wildlife Trust. The reliability of the land use classification was also augmented by driving the main roads transecting the catchment, three farm tours and walking several of the main trails.

The OS MasterMap data do not capture the detail of arable field cropping, so this was incorporated by using the 2003 agricultural census data available from the EDINA AgCensus service (EDINA 2008b) to define thirteen crops types for arable fields in each of the 2 km² census cells. This level of detail was essential to form the basis for the nitrogen and agricultural economics modelling for each scenario. Once this 2005 baseline was developed it was used to build the 2020ag and 2020eco scenarios.

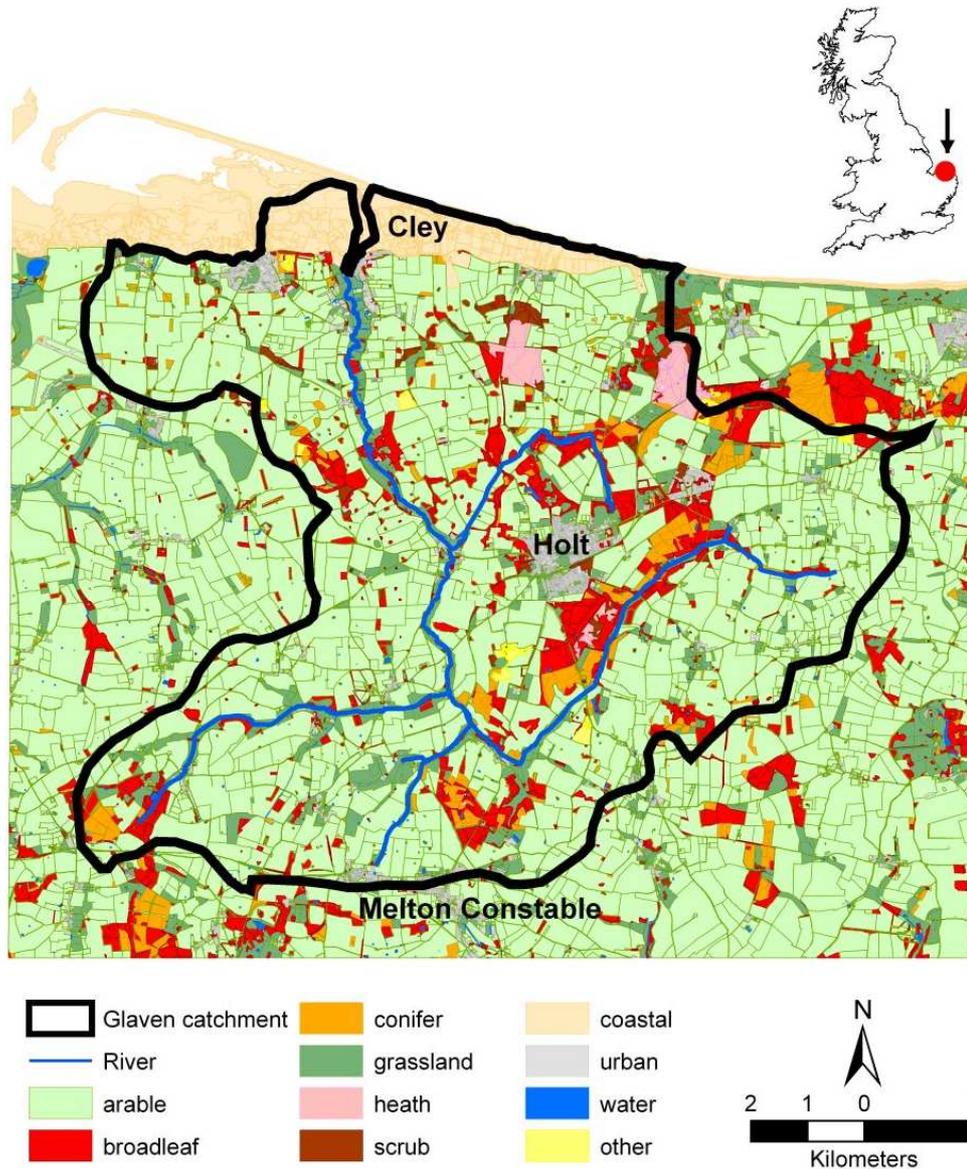


Figure 5. land use structure in 2005 based on Ordnance Survey (OS) MasterMap[®] Topography data (Ordnance Survey 2008b) and aerial photography.

Both scenarios were modelled using the 2005 baseline as a starting point by changing six key land-use parameters and developing four sensitivity variants based around break crop and wheat crop changes (Table 1).

Table 1. Land use parameters changed for the two scenarios and their variants compared to a 2005 baseline*

Scenario/variant	Sugar beet (ha)	OSR (ha)	Set-aside (ha)	New Land-use (ha)	Wheat (ha)	Winter Barley (ha)	Arable margins (ha)	Pigs ^a
2005 baseline	1214	231	740	0	924	1371	343.3	134 (4022)
2020ag scenario	421	1208	0	0	1417	1335 ^f	458.8	178 (5363)
2020eco scenario	1355	20	0	1196	1067	1199	364	134 (4022)
Break crop sensitivity								
2020ag - sugar as the main break crop	1267	362	0	0	1417	1335	458.8	178 (5363)
2020eco - OSR as the main break crop	406	970	0	1196	1067	1199	364	134 (4022)
Wheat crop sensitivity								
2020ag - 40% of the winter barley crop to wheat	421	1208	0	0	1984	786	458.8	178 (5363)
2020eco - 40% of the winter barley crop to wheat	1355	20	0	1196	1494	772.4	364	134 (4022)

*This excludes the proportional adjustments of the other arable crops and grass within the arable land-use category to compensate for changes in arable crop area as result of the primary changes reported in this table.

^a Pig numbers are in parentheses.

1. *Break cropping of sugar beet and oilseed rape (OSR).* In 2005 sugar beet was a significant break crop making an important contribution to the profitability of most farm enterprises in the catchment. From the landowner interviews it was clear that reforms to the sugar beet subsidies had the farmers concerned about the future profitability of the crop, and consequently there were doubts whether they would continue to produce it (see also Giha *et al.* 2006). During the interviews four farmers said they were interested in growing OSR as an alternative if the biofuels market were to become more profitable. Indeed, one farmer in the catchment was already growing the crop for this market and 56% (15) of the farmers expressed an interest in growing biofuels in the future. This reflected a national trend in England where there was a 23% increase in the production of OSR in 2007 (Defra 2007d). However, among the farmers there was a general desire to continue growing sugar beet and maintain similar rotations as long as there was some profit in the crop.

Thus, the initial interviews provided the rationale for converting 70% of the 2005 sugar beet production to OSR in the 2020ag scenario, and for the retention of sugar beet as the primary break crop in the 2020eco future. Additionally, to force a greater difference in the river nitrate concentrations between the scenarios, the OSR crop in the 2020eco scenario was reduced by 90% and replaced by sugar beet assuming market forces drove farmers to maximise sugar beet production. Finally, based on comments made by stakeholders during the validation interviews, it was important to explore the sensitivity of river nitrate concentrations and agricultural economics to this shift in break cropping for both of the scenarios. To achieve this once the scenarios had been developed, variants within each scenario were calculated by converting 70% of the OSR crop in 2020ag to sugar beet and 70% of the sugar beet crop in the 2020eco scenario to OSR.

2. *Arable conversion to “new land-use”*. In the 2020eco scenario 16.4% (1196 ha) of the arable area was converted to a “new land-use” representative of a range of semi-natural habitats forming an ecologically connected mosaic. This was targeted around a broadleaf ecological network analysis. Additionally, as a result of reducing the arable area in this scenario the remaining crop proportions were based on the 2005 baseline ratios. Support for these assumptions was derived from three key sources. Firstly, the landowner interviews supported an average of 10.9% (788 ha) reduction in arable area with a consequent increase in semi-natural habitat. Secondly, during the stakeholder validation interviews there was clear support for a mosaic of habitats rather than a focus on just one such as broadleaf woodland or heathland. Thirdly, there was a strong drive for the creation of an ecological network by the Norfolk Biodiversity Partnership and the Norfolk Wildlife Trust (Forestry Commission 2002, Land 2005) and increasing support for the approach in agri-environmental policy (Defra 2005b) and the scientific literature (Jongman & Pungetti 2004, Quine & Watts in press). However, because it was important to make the scenarios sufficiently distinct from each other, a compromise had to be reached between reducing nitrates in the river water by one grade¹ and meeting the average arable land use change suggested by the landowners. It is for this reason that 5.5 % (408 ha) more arable land was taken out of production than the average suggested by the landowners during the initial interviews with them. Nevertheless, this assumption was considered plausible during the stakeholder validation interviews.
3. *Set-aside*². During the scenario validation meetings it was clear that the stakeholders felt that set-aside should be withdrawn from the scenarios entirely, and that it was plausible that all of the set-aside, including the marginal land, could become economically viable if commodity prices continued to rise. For the 2020ag scenario the 740 ha designated as set-aside in the 2005 baseline were cropped with 70% wheat and 30% OSR production. The situation is slightly different for the 2020eco scenario, as more than 740 ha of the arable land is converted to new land-use, so in this case all thirteen crops are modelled based on the same cropping ratios as in 2005.
4. *Field margins*. The trajectory of current agri-environmental policy is for the promotion of field margins and hedgerow maintenance and creation (Defra 2005c, 2005e). Therefore, it was assumed this policy would increase these boundary features in the 2020ag scenario and remain the same as 2005 levels in the 2020eco scenario, the policy in this future

¹ Nitrate classification of river water quality in England is based on a 1 (very low) to 6 (very high) grading system (Environment Agency 2008).

² Set-aside was first introduced in England in 1988 to reduce production of cereals and other arable crops. It became obligatory in 1992, requiring farmers to set-aside a specified percentage of land for which they would receive direct payments. Since the policy was introduced the required percentage of land set-aside has varied from between 5 and 15%. The scheme was set at 0% in September 2007 as a consequence of the 2003 CAP reforms and food production concerns stemming from an emerging food “crisis” (Defra 2008c).

favouring blocks of habitat rather than boundaries. Thus, the area of margins was calculated based on an average 3m margin around the perimeter of all arable polygons in the 2005 baseline and 2020eco scenario and 4m margins for the 2020ag scenario. The increase in field margins was also supported by the initial interviews where there was very strong support for at least a 5% increase in the area of field margins (96% of respondents) and hedgerows (92% of respondents).

5. *Number and area of pigs.* During the initial interview stage outdoor pigs were identified as an important high value niche for the three large estates, and there was a desire to enhance production by the owners of these enterprises. This was implemented in the 2020ag scenario by increasing the pig numbers by 33% which required an additional 44 ha to be included in the arable rotation.

6. *Wheat and winter barley.* During the course of this research between late 2004 and August 2007 wheat prices increased significantly from around 86 £/t to £188 £/t (Farmers Weekly 2007). Stakeholders during the validation interviews felt it was important to explore the sensitivity of the system to this price shift, and it was incorporated into the modelling process by creating another two scenario variants. In both scenarios 40% of the winter barley crop was converted to wheat in order to compare the impact on whole catchment economics and nitrogen loadings.

2.3. Modelling ecological connectivity

A growing awareness of the adverse effects of habitat fragmentation on ecosystems is leading to increased efforts to design ecological networks in whole landscapes, going beyond the traditional protected areas and parks approach to species conservation (Jongman & Pungetti 2004). To target land use change in the 2020eco scenario an ecological connectivity analysis was performed based on the general ecological principles of species movement between source patches in fragmented landscapes (Adriaensen *et al.* 2003, Watts *et al.* 2004). Broadleaf woodland and heathland habitat were chosen as a focus for this based on their prominence in the landscape and the high value stakeholders in the catchment place on them (Forestry Commission 2002, Harding & Smith 2002, Land 2005).

A least cost modelling approach was used (Adriaensen *et al.* 2003, Watts *et al.* 2004, Catchpole 2006) which required the generation of two raster layers, a source layer and a resistance layer. The source layer consisted of the existing habitat patches from which species are assumed to move through the landscape. To create this, woodland and heathland polygons were extracted from the edited OS MasterMap® layer. These habitat polygons were then edited further to integrate adjacent small woodland and heathland polygons using a cluster tolerance of 6 m followed by the removal of all habitat polygons with a perimeter/area ratio > 0.05. Broadleaf habitat patches were then selected from these to include all designated Sites of Special Scientific Interest (SSSI), Ancient Woodland and County Wildlife Sites (CWS) regardless of their size, in addition to all remaining broadleaf woodland ≥ 2 ha in size. This amounted to 78% (829 ha) of the broadleaf woodland in the catchment. For heathland, all habitat patches, regardless of designation and size were used for the connectivity analysis. The resistance layer was based on the existing landscape which was generated from the edited 2005 OS MasterMap® land-use categories rasterised at a 1 m cell size resolution for a 275 km² area centred on the catchment extent. This layer was reclassified with resistance values based on the ability of broadleaf and heathland generic species to disperse through the eighteen different land use types in the landscape (Table 2). The resistance values ranged between 1 for the target habitat, either broadleaf woodland or heathland, and 50 for the most impermeable land use types, such as urban areas. Values for both generic species groups were derived from expert opinion and included habitat preference, area and dispersal ability assumptions (Watts *et al.* 2004, Catchpole 2006).

Table 2. Land-use resistance values used for the broadleaf and heathland connectivity analysis. A value of 1 assumes a minimum resistance to species movement and 50 assumes a maximum cost to species movement through the landscape.

Land use	Broadleaf woodland specialist	Heathland specialist ^a
Broadleaf woodland	1 ^{a,b}	40
Conifer woodland	5 ^{a,b}	10
Scrub	3 ^b	20
Heathland	20 ^{a,b}	1
Grass - rough	25 ^{a,b}	50
Grass - wet	25 ^{a,b}	1
Grass - agricultural	30 ^a	50
Grass - amenity	20 ^b	50
Arable cropland	35 ^{a,b}	50
Water	40 ^a	50
Coastal	50 ^{a,b}	50
Roads & tracks	50 ^b	50
Urban area	50 ^b	50
Other – caravan site	50 ^b	50
Other - reedbed	20 ^a	50
Other - quarry	20 ^b	50
Other - landfill	35 ^b	50
Other - orchard	20 ^b	50

^a Catchpole (2006), ^b Watts *et al.* (2004).

Finally, ecological networks were identified for broadleaf woodland and heathland species which are less sensitive to fragmentation and could utilise relatively small individual habitat patches (Watts *et al.* 2004, Catchpole 2006). The two generic species groups consist of species that could disperse up to 2000 m in unfragmented habitat (Watts *et al.* 2004). This was achieved by setting the “Cost Weighted” tool in the ArcMap 9.1 Spatial Analyst (ESRI 2008b) extension to 2000 m and applying this to the above source and resistance layers. This identified land which was within a 2000 m maximum dispersal range of the source habitat based on the ability of species to move through different land use types.

2.4. Modelling soil erosion

Soil erosion of arable fields was modelled using three risk categories; high risk (where 30% of the field is > 7 degrees slope with a height difference of > 15 m across the field); moderate risk (where 30% of the field is between 3° to 7° slope with a height difference of > 15 m across the field), and lower risk for the remaining fields based on Defra parameters (Evans 1990, Defra 2005a). An OS digital elevation model with a 50 m resolution (Ordnance Survey 2008a) was used as a basis to calculate slope angle and height using the ArcMap Spatial Analyst extension (ESRI 2008b). This was overlaid with all OS arable field polygons greater than 1ha, and each field was classified according to the above risk categories according to the level of risk present (high, moderate or low). All soils were assumed to be light sandy loams, which are the predominant soil type in the catchment (NSRI 2008),

2.5. Modelling arable field conversion to “new land-use” in the 2020eco scenario

A “new land-use” category was created in the 2020eco scenario to represent the conversion of arable land to semi-natural habitats that formed part of a connected habitat mosaic. This category was defined in five stages based on the broadleaf ecological network, soil erosion risk and the potential willingness of landowners to convert arable fields to a new land use reflecting their existing agri-environmental participation. Firstly, using the ecological network layer generated from the process described in Section 2.3, all the polygons within the network that contained only one habitat patch, except those ≥ 5 ha, were removed from the ecological network. This was done to improve the network structure based on habitat patches that were functionally connected to at least one other patch, or were important because of their size. Secondly, this new layer was overlaid with the edited OS MasterMap layer and the percentage of the ecological network in each arable field calculated to identify all arable fields with $\geq 3\%$ of their area containing a portion of the network. Thirdly, to aid field prioritisation a 0-6 raster based scoring system was applied using the following five criteria:

1. All landowners participating in Entry Level Stewardship (ELS) score 1
2. All landowners participating in the Countryside Stewardship (CSS) or Higher Level Stewardship (HLS) score 1.
3. All landowners participating in a farm woodland scheme (FWPS and/or FWS) score 1.
4. All arable fields with a medium risk of soil erosion score 1.
5. All arable fields with a high risk for soil erosion score 2.

Fourthly, the output of this scoring system was overlaid with the layer of arable fields containing $\geq 3\%$ of their area containing a portion of the network and fields with a median score of 3 or greater were selected. On visual inspection one 42 ha outlying field was removed. The remaining arable polygons were then converted to the “new land-use” category. Following on from this two lines were digitally sketched to represent axes connectivity, running from east to west and south-west to north-east through the ecological network layer. These axes were then buffered by 500 m and overlaid with the arable field layer. All arable fields ≤ 5 ha that intersected this buffer that had not yet been identified in the above process were also included in the “new land-use” category. This helped to identify smaller fields that may be more appropriate for arable conversion than larger fields. Finally, to bridge a large gap between two patches in the south-west of the catchment, a least-cost-path was calculated based on the broadleaf movement resistance layer. This was required to identify an additional link in the network to complete the connection between two clusters of ancient woodland, one straddling the catchment in the north-east, the other just outside the catchment to the south-west. These were identified as important areas of habitat to connect in county and regional ecological networks reports (Forestry Commission 2002, Land 2005).

2.7. Modelling nitrogen export

An export coefficient model (Johnes 1996, Worrall & Burt 1999) was used to model current and future nitrogen levels as a response to changes in key land use parameters:

$$L = \sum_{i=1}^n E_i [A_i (I_i)]$$

where L is loss of nutrients; E is the export coefficient for nutrient source i , A is area of catchment occupied by land-use type i , or number of livestock type i , or of people; I is inputs of nutrients to source i (e.g. fertiliser applications). The export coefficient E_i expresses the rate at which nitrogen is exported from each land use type in the catchment. For this study these were derived from various experimental sources (Table 3). Inputs of nutrients from precipitation were assumed to be included in the published coefficients. The hydrologically effective precipitation which for the purposes of this study is defined as the component of precipitation that reaches the river as direct runoff from the land was then used to calculate a river nitrate concentration in mg l^{-1} for the entire catchment.

Table 3. Model parameters used to model nitrogen export and agricultural gross margins (arranged in descending order of N loading).

Land-use type	Nitrogen				Economics	
	N loading (kg ha ⁻¹ year ⁻¹)	Fertiliser inputs or animal waste (kg ha ⁻¹ year ⁻¹) ^a	Published coefficients and loadings ^b	Export coefficient used or adjusted loading	Gross margins (£/ha or per stock) ⁱ	
					2005	2007
Oilseed rape	25.56	197.7	0.39 ^d	0.134	230	248
Peas	24.6	0	71.4 ^e	-	140	166
Potatoes (maincrop)	21.06	179.8	0.34 ^c	0.117	1275	1381
Beans	15.5	0	45 ^e	-	185	234
Wheat	15.24	192.3	0.23 ^c	0.079	290	1224
Vegetables	13.65	116.5	0.34 ^c	0.117	1775	2050
Other cereals	12.28	118.8	0.31 ^e	0.103	185	235
Spring barley	12.04	112.7	0.31 ^c	0.107	185	235
Winter barley	9.6	146.7	0.19 ^d	0.065	180	248
Bulbs	8.03	116.5	0.2 ^g	0.069	290	359
Linseed & Maize	7.77	112.7	0.2 ^g	0.069	125	109
Temporary grass	6.26	181.7	0.01 ^f	0.034	-	-
Agricultural grass	5.66	117.3	0.14 ^e	0.048	-	-
Sugar beet	5.26	109	0.14 ^{c&e}	0.048	1180	672
Set-aside	1.723	0	5 ^j	-	-	-
Bare Fallow	0.55	0	0.16 ^g	-	-	-
Woodland & scrub	0.14	0	0.04 ^h	-	-	-
New habitat	0.14	0	0.04 ^f	-	-	-
Field margins	0.07	0	0.02 ^f	-	-	-
Other, coastal & urban ^k	0.07	0	0.02 ^f	-	-	-
Rough grass & heath	0.07	0	0.02 ^f	-	-	-
Cattle	3.87	70.2	0.162 ^g	0.055	49	-
Human	0.74	0	2.14 ^g	0.214	-	-
Pigs	0.93	18.7	0.145 ^g	0.050	-	31.5
Fowl	0.02	0.3	0.153 ^g	0.053	-	8.10
Sheep	0.52	8.9	0.170 ^f	0.059	16.3	-
Dairy herd	3.87	70.2	0.162 ^g	0.055	544	-
Goats	0.52	10.1	0.170 ^f	0.059	16.3	-

^a Fertilizer inputs are derived by averaging 2000-2002 field application rates (Defra 2001, 2002, 2003); ^b before modification for the Glaven catchment model. ^c source: Shepherd & Lord (1996), vegetables were given the same value as potatoes; ^d source: ASWAN (as used in Lovett *et al.* 2006); ^e source: NSA Fields (as used in Lovett *et al.* 2006); ^f source: Hagarth *et al.* (2003); ^g source: Johnes (1996), goats were given the same coefficient as sheep; ^h source: Silgram *et al.* (2004); ⁱ based on the average yields published in Nix (2004, 2006), with the exception of wheat which is based on an average of the feed and milling wheat prices at 188 £/t (Farmers Weekly 2007) using Nix (2006) yield and variable costs. The use of this approach results in a high absolute “best case” value that does not account for the increases in other inputs such as oil and fertiliser. This was useful in order to express a range from a very low 2005 value to a potentially very high future price.

Initially, an export coefficient model was generated using an Excel spreadsheet for the 2005 baseline. This involved using land-use data exported from the edited OS MasterMap layer augmented by the AgCensus 2003 data (EDINA 2008b). A human population of 7900 derived from the 2001 Population Census (Caseweb 2008) and an effective precipitation

input of 105.5 mm (min 9.8, max 230 mm) was based on a 10 year mean of the Met Office Rainfall and Evaporation Calculation System (MORECS) square 121 (Met Office 2008) recorded between 1997 and 2006. Fertiliser inputs were obtained by averaging 2000-2002 field application rates (Defra 2001, 2002, 2003) for the different crop types in the catchment, and the export coefficients and nitrogen loadings for the different land-uses were derived from the literature or unpublished studies (Table 3). The model was calibrated to meet the observed mean nitrate concentration of 32.5 mg l⁻¹. This was derived from data supplied by the Environment Agency for six sample points collected at monthly intervals along the main river channel between Jan 2001 and Jan 2006, (n = 402, min 17.9, max 47.8, SD 5.9 mg/l).

The coefficients and loadings published by Haygarth *et al.* (2003) were used as a baseline and all the others used were scaled down by a factor of 10 to match the same proportions as those published in the Haygarth report (Table 3). This was necessary because Haygarth's set of land-use coefficients were an order of 10 smaller than the other published coefficients and they didn't differentiate sufficiently between multiple land-uses and crop types. Each of the coefficients was then multiplied by a factor of 3.445 to achieve the observed annual mean concentration of 32.5 mg l⁻¹. This type of calibration to meet field observations is fairly common in export coefficient studies (e.g. Johnes 1996, Worrall & Burt 1999). The approach was then used to explore the gross impacts of land-use change and the differences between the two scenarios rather than attempt to model real outputs.

2.8. Modelling agricultural economics

Gross margins for thirteen crop and six livestock categories were calculated using Nix (2004) for the 2005 baseline and Nix (2006) for the scenarios and their variants unless otherwise stated (Table 3 coefficients and gross margins). The gross margins are defined here as the enterprise output minus variable costs, usually expressed in £/ha. For instance, for an arable crop the enterprise output is crop yield multiplied by the market price per hectare and the variable costs are seed, fertiliser, sprays, casual labour for harvesting, and other sundry or crop-specific items (Nix 2006). Gross margins are not the same as profit this is because fixed costs (specialist machinery and other overheads) are excluded as they can vary significantly from farm to farm and are therefore more difficult to model.

Catchment scale economic returns were also calculated for eight land management schemes, whose extents were defined from spatial data provided by Defra, or obtained from the MAGIC website (MAGIC 2008). These included Entry Level Stewardship (6506 ha) (Defra 2005c); Organic Entry Level Stewardship (203 ha) and the Organic Farm Scheme (24 ha) (Defra 2005d); the Farm Woodland Premium Scheme (78 ha) (Defra 2007a); the Farm Woodland Scheme (29 ha) (Forestry Commission 2007); the Countryside Stewardship Scheme (3222 ha) and Higher Level Stewardship (47 ha) (Obtained from Natural England by special request in December 2006). Additionally estimates for the Single Payment Scheme (8332 ha) were derived from an average of ten Glaven farm enterprises found on the Farmsubsidy.org web site (Farmsubsidy.org 2007).

2.9. Stakeholder scenario validation

The term "validation" as used here is value laden with stakeholder perspectives, rather than a detailed numerical validation of the models. The meetings also served the purpose of ascertaining how best to communicate the scenarios. The validation process was conducted over a three month period between June and August 2007. It included four individual meetings with landowners and farmers and three mixed group meetings with NGO and government agents, comprising of two groups of four and one group of five stakeholders. The participants consisted of landowner, agency and NGO practitioners, and were selected based on an understanding of the stakeholder community that had developed during the course of the research. All meetings were conducted in the stakeholders' offices, meeting

rooms or homes and involved an initial presentation of the draft scenarios. This presentation was followed by a semi-structured discussion guided by the following six questions:

1. What do you like/dislike about these scenarios?
2. What would you incorporate into the scenario design if you were building these scenarios yourself?
3. Do you think the scenarios are plausible?
4. What do you think the workshop objective should be?
5. Do you think we are communicating clearly the objectives of this study and the scenarios?
6. Do you think the Glaven case study is applicable to other catchments and/or landscapes in the area?

Additional questions were asked depending on the specific interests of the individual or group, so that more detailed farming system questions were asked of farmers, and wider policy delivery issues were discussed with government agents. The meetings were also iterative in the sense that lessons learnt from earlier meetings were incorporated into the discussions of later groups.

All of the validation meetings were digitally recorded and an abridged transcript was created for each, extracting the relevant and useful portions of the discussion (Krueger 1998). A list of items that should ideally be incorporated into the scenarios and research design process was distilled from these transcripts. Changes to the modelling were based not only on stakeholder feedback, but also on what could be achieved within the time frame of the project. Using this method, it was difficult to quantify the relative weights stakeholders placed on their desired changes, although some of this could be inferred from how much time was spent discussing different issues, and the emphasis placed upon them by the participants.

3. RESULTS

3.1. Overview of the scenarios

The two landscape scenarios had at their heart, agricultural productivity, countryside care and ecological integrity, while reflecting reform of the Common Agricultural Policy (CAP) and compliance with the Water Framework and Nitrate Directives. However, one was driven more by agricultural production and world trade (2020ag), and the other by the enhanced protection of ecosystem services and multi-objective land use (2020eco). In Table 4 each scenario is compared to a 2005 baseline using four key evaluation parameters land-use, ecological connectivity, surface water nitrate levels and agricultural economics.

Table 4. Summary of the 2020 scenario parameters compared to a 2005 baseline.

Criteria	2005	2020ag	2020eco
Arable cropping	62.9% (7248 ha) of the catchment area is in arable production with a gross margin value of £2.87 million (£365 per ha)	62.9% (7248 ha) of the catchment is in arable production with a gross margin value of £3.64 million (£501 per ha).	52.5% (6087 ha) of the catchment is in arable production, with a gross margin value of £3.41 million (£559.6 per ha).
Break cropping	10.5% (1214 ha) of the catchment area is sugar beet contributing 50% (£1,432,991) to the total crop gross margins which average £1180 per ha driven primarily by sugar beet subsidies. (Sugar price £32.5/t).	10.4% (1208 ha) of the catchment area is OSR contributing 8.3 % to the total crop gross margins which average £248 per ha driven by new biofuel markets. (OSR price £150/t) Sugar gross margins are reduced by 57% to £672 per ha (sugar price £22.67/t).	11.7% (1355 ha) of the catchment area is sugar contributing 26.7 % to the total crop gross margins which average £672 per ha driven by a profitable sugar market less reliant on subsidies and new biofuel markets for lower grade sugar. Sugar gross margins are reduced by 57% to £672 per ha (sugar price £22.67/t).
Wheat	8% (924 ha) of the catchment area is wheat contributing 9.3 % (£ 267,953) to the total crop gross margins which average £290 per ha (wheat price 89 £/t).	12.2% (1417 ha) of the catchment area is wheat contributing 47.7 % (£ 1,734,959) to the total crop gross margins which average £1224 per ha (wheat price 188 £/t).	9.2% (1067 ha) of the catchment area is wheat contributing 38.3 % (£1,305,861) to the total crop gross margins which average £1224 per ha (wheat price 188 £/t).
Set-aside	6.5% (749ha) of crop area is in set-aside	100 % of the set-aside land is in arable production	50% of the set-aside land is in production and 50% in "new land-use".
Livestock	4022 pigs produced per year, for an outdoor niche market, on 1.2% of the catchment (134 ha).	5363 pigs produced per year, for an outdoor niche market, on 1.5% of the catchment (178 ha).	4022 pigs produced per year, for an outdoor niche market, on 1.2% of the catchment (134 ha).

(Table continued on next page)

Table 4. (Continued)

Criteria	2005	2020ag	2020eco
River nitrates	Mean nitrate concentrations are 35.2 mg l ⁻¹ Environment Agency nitrate classification grade 4 "high"	Mean nitrate concentrations increase by 32.3 % to 43.1 mg l ⁻¹ . Environment Agency nitrate classification grade 5 "very high"	Mean nitrate concentrations decrease by 9.5 % to 29.4 mg l ⁻¹ Environment Agency nitrate classification grade 3 "moderate"
Nitrate Vulnerable Zone (NVZ)	4.6 % (530 ha) of the catchment is designated as an NVZ	100 % of the catchment is designated as an NVZ ^a	100 % of the catchment is designated as an NVZ ^a
Soil and phosphate management	No organised approach across the catchment	17.1 % (1254 ha) of arable land is assessed as at medium or high risk of soil erosion, all of these are under appropriate erosion control measures.	Of the 17.1% (1254 ha) of arable land assessed as at medium or high risk of soil erosion 33.7% (433 ha) are under new land-use, and the remainder are under appropriate erosion control measures.
Ecological connectivity	The riparian corridor is disconnected from the flood plain along much of the river length with a number of barriers to migratory fish, e.g. Sea Trout (<i>Salmo trutta</i>).	Connected and buffered riparian corridor with restored flood plain areas, wet meadows and movement for migratory fish species.	Connected and buffered riparian corridor with restored flood plain areas, wet meadows and movement for migratory fish species. In addition 10.3% (1196 ha) of the catchment is under new land-use which contributes to a connected habitat mosaic
Hedgerow and arable field margins	3 % (342 ha) of the landscape is arable margins and hedgerow (average 3m margin on each field) representing 4.7% of the arable area.	4 % (459ha) of the landscape is arable margins and hedgerow (average 4 m margin around each field) representing 6.3% of the arable area.	2.4% (278 ha) of the landscape is arable margins and hedgerow (average 3m each field) representing 4.6% of the arable area.

^aRegulations formally designating new NVZs covering approximately 70% of the country, and including the Glaven catchment were laid before Parliament in September 2008 (Defra 2008d).

3.2. Scenario evaluation: land use

The desired landscape structure as expressed by the interviewees formed a key initial building block for the scenarios. Broadly, the landowners envisaged an open agricultural landscape not too dissimilar from the current configuration. Both scenarios and their iterations encapsulate this. Although a key feature in the 2020eco scenario is the conversion of arable land to a “new land use” that contributes to an ecologically connected habitat mosaic, the remaining landscape remains open and productively farmed. Therefore, the dominant land-use in both of the scenarios is arable agriculture (Figure 6).

In 2005 and the scenarios, arable land-use is dominated by two cereal crops, barley and wheat and two break crops, either sugar beet (2005 and 2020eco) or OSR (2020ag). Additionally, the end of set-aside policy has important implications in the 2020ag scenario by increasing the productive capacity of the land by 6.4% (740ha). However, there is a small (2.7%) decline in production levels of crops other than wheat and OSR in the 2020ag scenario. This is a modelling artefact resulting from converting all the available set-aside to wheat and OSR production while increasing the area of field margins and pigs by 34% (117 ha) and 33.1% (44 ha) respectively, thereby reducing available land for the production of other crops. All other land use categories remain unchanged (Figure 6).

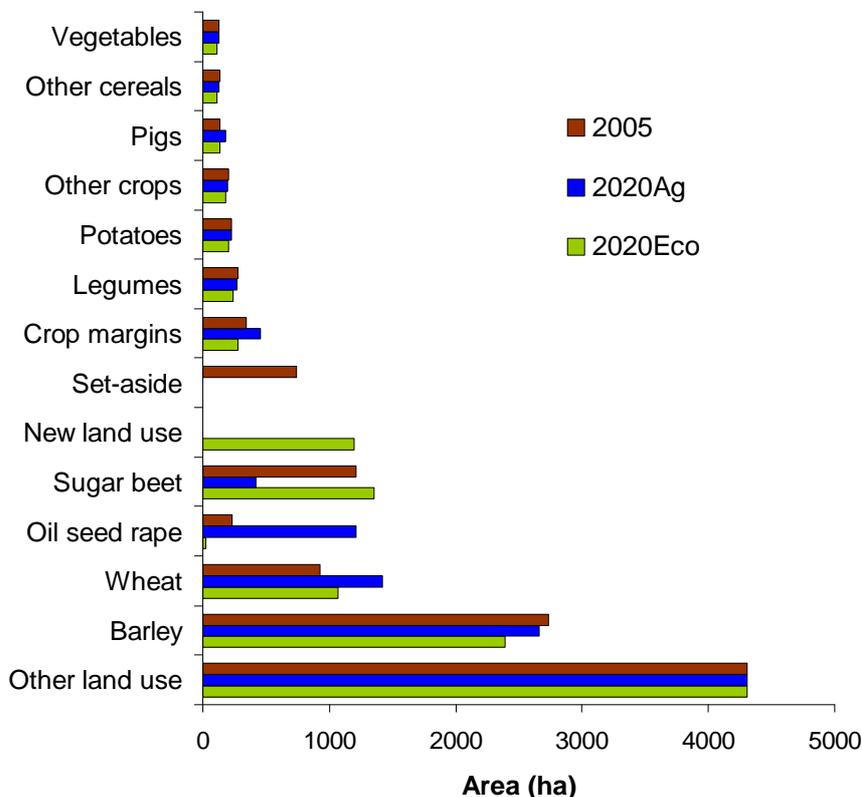


Figure 6. Landscape structure of the two scenarios compared to a 2005 baseline. The other land use category includes broadleaf and coniferous woodland, heathland, grassland, scrub, coastal habitat, urban area, water and other miscellaneous types of land use such as quarries, caravan sites and landfill.

In the 2020eco scenario the broadleaf ecological network used to inform the “new land use” category contained (Figure 7a & 7b), 85.5 % (908 ha) of the broadleaf woodland, 78.8% (287 ha) coniferous woodland, 31.2 % (296 ha) grassland, and 29.6 % (46 ha) of the heathland. Additionally, the soil erosion modelling indicated that 17.1 % (1254 ha) of arable land in the catchment was at medium or high risk of soil erosion. Approximately a third (423 ha) of this area is contained within the new land-use category.

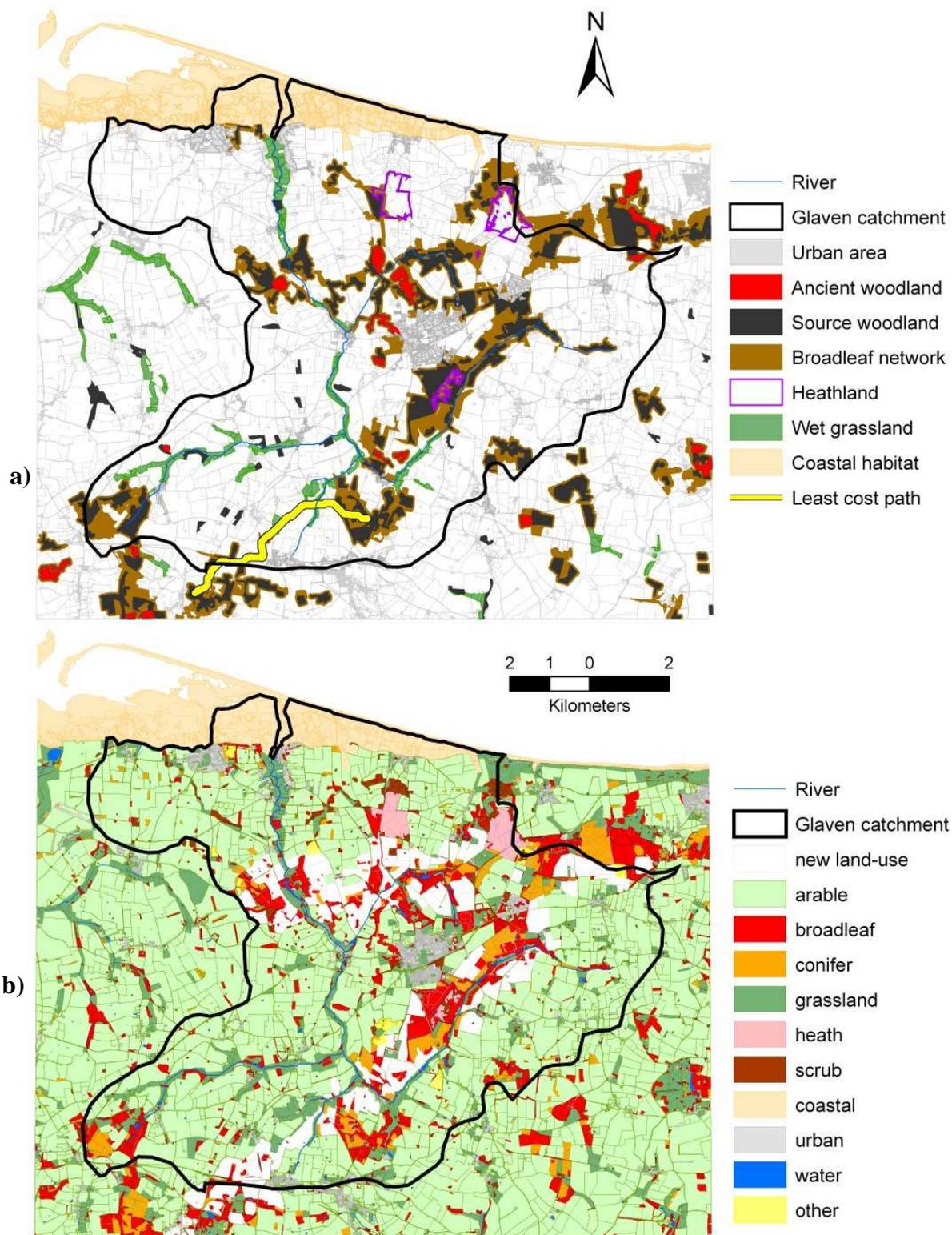


Figure 7. (a) The 2005 mosaic of semi-natural habitats and broadleaf ecological network which contains the connected source woodland, ancient woodland and a proportion of the heathland habitat; (b) The land-use of the 2020eco scenario.

3.3. Scenario evaluation: nitrate concentrations in the river

The two scenarios had very different nitrate exports to the river. Whilst in the 2020ag scenario nitrate concentrations increase by 32.3%, there is a decrease of 9.5% in the 2020eco scenario when compared to a 2005 baseline (Figure 8). The higher nitrate loadings in the 2020ag scenario are driven by two key drivers. Firstly, and most significantly, high OSR production in the 2020ag future contributes 27% of the total catchment N loading, compared to only 0.7% in the 2020eco scenario and 6.8% in 2005. Essentially, of the two key break crops, OSR is much “leakier” than sugar beet. This is clearly illustrated by subjecting both scenarios to a switch in OSR/sugar beet hectares. This switch results in an 18% decrease in river nitrate levels in the 2020ag scenario and a 20.1% increase in the 2020eco scenario (Figure 8a). Secondly, converting 100% of the 2005 set-aside quota into crop production contributes a further 11.4% to the N loading in the 2020ag scenario. In contrast, the reduction in river nitrate levels observed in the 2020eco scenario is due primarily to the use of sugar beet as the most significant break crop and because OSR is grown on less than 1% (20ha) of the crop area. The conversion of 16.4% (1196 ha) of the arable land to “new land-use” also contributes to this reduction, although the effect is offset by the end of set-aside policy, effectively only taking out 6.2% (456 ha) from arable production compared to the 2005 baseline. However, all the new land-use contributes little (0.2%) to the N loading for the entire catchment.

Cereal production is the most important single contributor to the N loadings, contributing 53.3% (2020ag) and 43.5% (2020eco) to the overall N budgets for the scenarios (Figure 8b). However, cereals occupy between 58.7% (2020ag) and 52% (2020eco) of the total arable areas and nitrate concentrations are less sensitive to changes in cereal crops than to changes in break cropping. This is illustrated by increasing wheat production by 40% in both of the scenarios which increases nitrate concentrations by 2.6% and 3% for the 2020ag and 2020eco scenarios respectively (Figure 8a).

Of the remaining crops, it is important to note that potatoes (3% of arable land in 2020ag and 3.3% in 2020eco) and legumes (3.7% of land in 2020ag and 4% in 2020eco), while only a small proportion of the total crop area, contribute a relatively high amount to the catchment N loading (3.9% in 2020ag and 5.1% in 2020eco for potatoes, and 4.5% in 2020ag and 5.9 % in 2020eco for legumes).

Of the other land-uses, livestock is an important contributor to N loadings in the scenarios, contributing 12.5% (2020ag) and 9.6% (2020eco) in the two scenarios. The 33% increase in pigs in the 2020ag scenario adds 1% (1253 kg ha^{-1}) to the overall N budget.

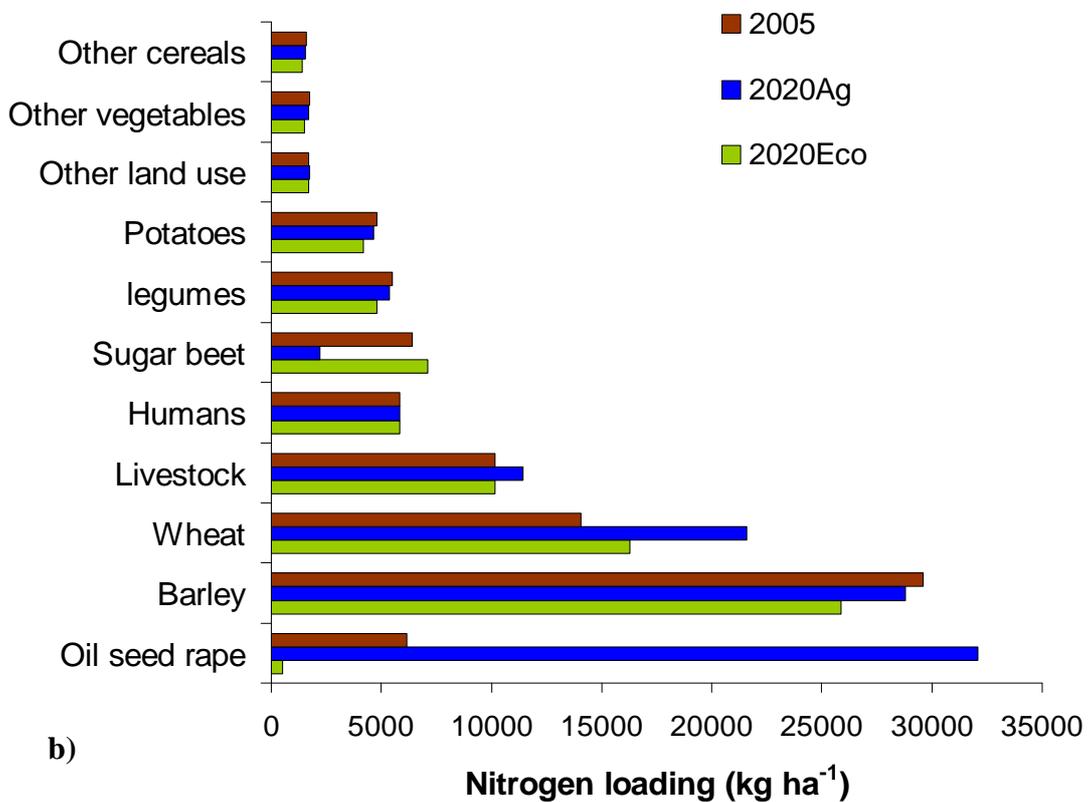
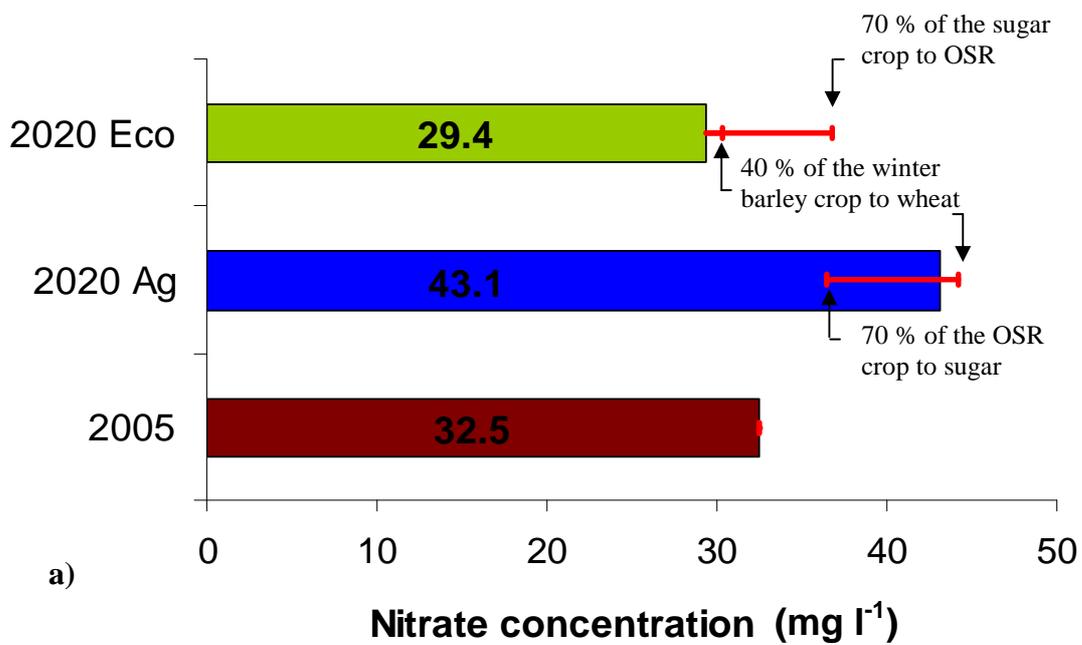


Figure 8. Mean annual nitrate concentrations in the river and nitrogen loadings per land-use type compared to the 2005 baseline; (a) mean annual river nitrate concentrations for each scenario; (b) nitrogen export for land-use type, human population and livestock.

3.4. Scenario evaluation: agricultural economics

In 2005 the agricultural income for the whole catchment was estimated to be £4.85 million, with arable crop production the most important contributor (59%). The second most important contributor was the Single Payment Scheme (30.6%) highlighting the significant reliance on subsidies and the less substantial overall contribution of agri-environmental schemes (5.1%) and livestock production (4.8%) (Figure 9a).

No attempt was made to model the economics of future subsidies such as the Single Farm Payment, agri-environmental schemes, or diversification income, and both scenarios assume the need to increase revenue from other sources as subsidies diminish. The 2020ag scenario focuses more on increasing crop production, while the 2020eco seeks to enhance profitability through greater levels of agricultural diversification and alternative land use. Given the continuation of recent changes in global commodity prices both scenarios do see an increase in the profitability of arable cropping but they both fall short of meeting the 2005 baseline total income which includes the 30.1% contribution of the Single Payment Scheme (SPS). This does, however, indicate the potential for a new age of agricultural prosperity (Figure 9c).

A key driver for the increase in crop profitability despite a 56.9 % decrease in sugar gross margins is the 422.1 % increase in wheat gross margins for the whole catchment. Wheat production alone contributes almost half (47.7%) to the total budget in the 2020ag scenario and slightly less (38.3%) in the 2020eco scenario (Figure 9b). Furthermore, the 26.7 % contribution of sugar beet to the total gross margins in the 2020eco scenario is critical to maintaining higher crop margins compared to a switch to OSR, as seen in the 2020ag future. The relatively small £230,620 difference between the gross margins of the two scenarios is driven primarily by the different break crop regimes; this is also the driver behind crop margin per ha being 10.5 % (£59/ha) lower in the 2020ag scenario compared to the 2020eco.

Both scenarios are very sensitive to increases in wheat production and price. This was explored by increasing wheat production by 40 % of the winter barley area (Figure 9c). This shift alone represents an increase in total gross margins of 15.2 % (2020ag) and 12.2 % (2020eco). Exploring the wheat price sensitivity further, if the 2005 wheat price of 86 £/t is used for the two scenarios rather than the much higher 2007 market price of 188 £/t, then the total gross margins decrease by 29.2 % and 21.1 % for 2020ag and 2020eco scenarios respectively (Figure 9c).

Barley continues to be grown extensively in both scenarios, with little change in overall economic performance, contributing between 17 % (2020eco) and 17.7 % (2020ag) to the gross margins. Similarly, high value crops such as potatoes continue to make an important contribution to overall margins contributing between 8 % (2020eco) and 10 % (2020ag), although they occupy a relatively small proportion of the arable crop area.

Livestock profitability (with one exception) remains at 2005 levels reflecting the trend of poor financial performance in this sector. The exception is a 33% increase in outdoor pigs adding a further 18% (£42,348) to livestock margins in the 2020ag scenario; otherwise the livestock gross margins remain constant across the scenarios and 2005 baseline at £233,745 per year. However, these margins do not include poultry, calculated to be £858,600 in 2005 this is because one farmer has 94.3 % (100,000 birds) of the total production in the catchment and it was felt that this would not be representative of the livestock situation across the whole of the catchment.

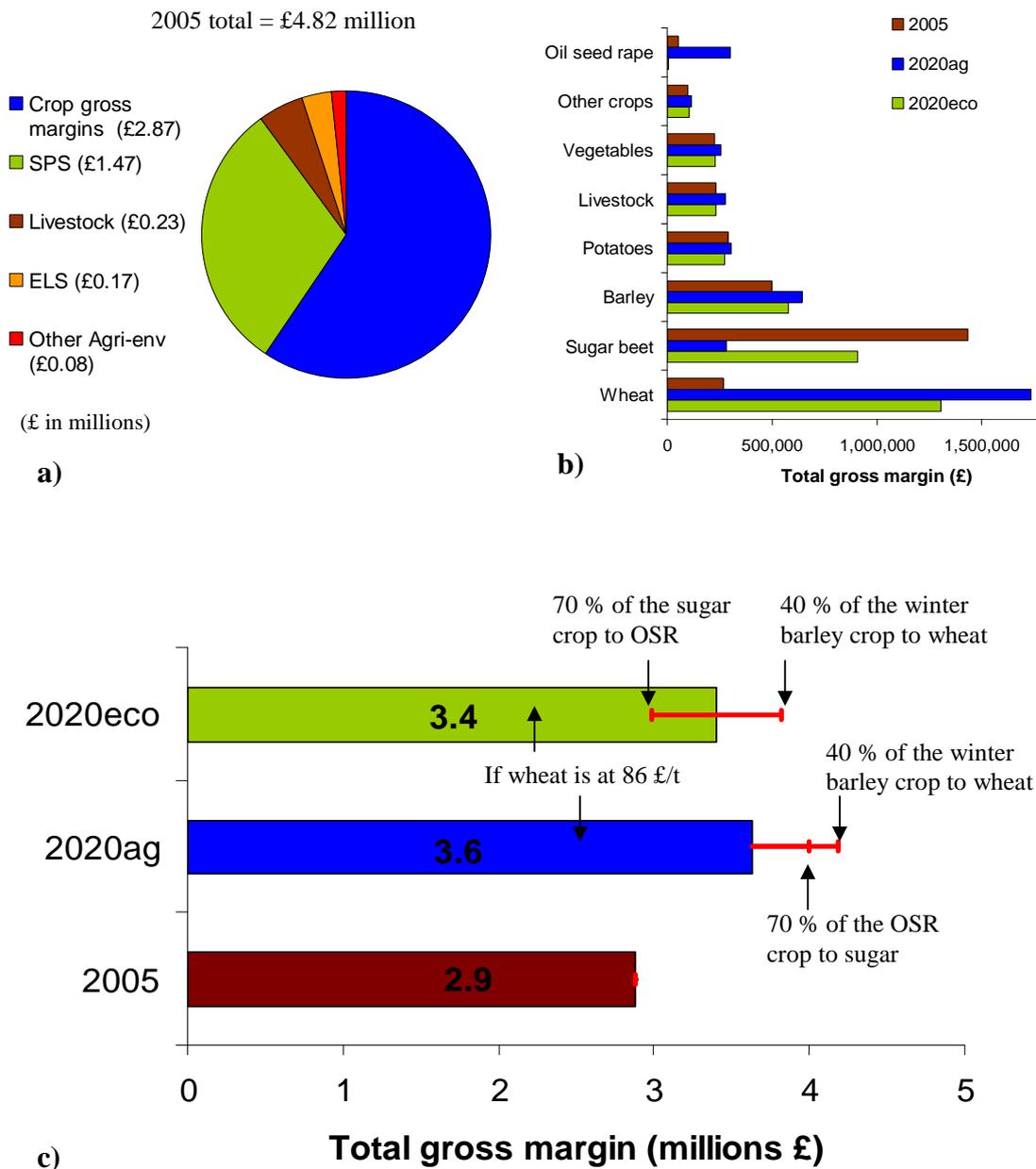


Figure 9. Whole catchment agricultural economics for the two scenarios compared to the 2005 baseline (a) proportional breakdown of the 2005 economics (b) main-crop economics (c) whole catchment crop margins.

3.5. Stakeholder evaluation of the scenarios

There was general agreement among the landscape practitioners who participated in the validation of the scenarios that the process was transferable to other landscapes. They suggested the approach was particularly applicable in areas with a diversity of stakeholders and strong countryside character. However, concern was expressed about the time involved developing the scenarios and engaging with stakeholders which would make wider practitioner implementation of the process difficult. Furthermore, there was some

disappointment that other factors were not included in the scenario design, in particular water abstraction; pesticide use; carbon budgeting; energy budgeting; the impacts of change on countryside character and landscape aesthetics and a more detailed economic analysis that would encompass agricultural diversification and tourism.

From a farming perspective the process was considered interesting and was met with enthusiasm by some, however the research was also perceived by others as a threat to their business:

“We wish that this work had been done somewhere else at the moment... but if it becomes a pilot and there was some money put in to see what could be achieved, we might all feel slightly differently, but at the moment this is seen as mostly a threat” (Glaven Farmer).

Nevertheless, the evaluation of the scenarios in the stakeholder workshop was positive, 95% of the participants (21, n = 22) agreed, or strongly agreed, that the presentation of the two scenarios helped them understand the issues in the Glaven catchment. In addition 64% of the participants (14, n = 22) agreed the two scenarios helped them to understand how a multi-objective landscape may look in the future, with only one participant disagreeing. In the view of a farm advisor:

“I do think the work that is being carried out in this catchment is innovative, it does capture a lot of useful information” (NGO Stakeholder).

4. DISCUSSION

4.1. Results of the scenario analysis

The scenario analysis focused on the potential impacts of Common Agricultural Policy reforms on land use change in systems dominated by arable agriculture, using the Glaven catchment as a case study. The baseline assessment clearly showed that the farmers were heavily reliant on agricultural subsidies to maintain profitable businesses. The scenarios themselves contrasted the key drivers of improving agricultural profitability with increasing demands for greater multi-functional land use. While no attempt was made to model future subsidies, it is clear from the economic analysis that without some financial support it is difficult to envisage a sustainable landscape without radical change in global markets or the structure of the local economy.

It may seem that the 2020ag scenario is more plausible based on recent events in the system, such as the withdrawal of set-aside policy, increased commodity prices and the drive for a sustainable intensification of agriculture. It is also plausible that societal choice could dictate a more locally-based diverse economy that could foster a future similar to 2020eco. The 2020ag future clearly showed the potential for radical changes in land use, in this case stemming from the reform of sugar subsidies that could directly conflict with EU water directives if policy measures are not adopted to mitigate the increased use of “leakier” crops. The issue of diffuse pollution management is also highlighted from a different perspective in the 2020eco scenario where quite radical land use change was required to reduce nitrate concentrations in the river, suggesting that other control mechanism will be required (see also Lovett *et al.* 2006, Hiscock *et al.* 2007). A recent example of the implementation of promising management measures is through the Catchment Sensitive Farming Delivery Initiative (Defra 2008b).

4.2. Lessons in scenario design

The scenarios proved to be a useful tool for the holistic exploration of system dynamics, and they provided a useful framework on which to base a structured dialogue with a range of stakeholders. Additionally, the initial interviews with the landowners and farmers formed an

excellent basis on which to construct the scenarios, and the validation interviews improved their quality, plausibility and interpretability. This in turn built confidence in their use during a stakeholder workshop designed to explore future governance mechanisms for the Glaven (see Southern 2009).

However, it was difficult to rigorously incorporate the quantitative data collected during the initial interviews into the design process. As a consequence, whilst the scenarios are grounded in stakeholder values, these are incorporated into the scenarios much more qualitatively than was hoped for at the outset of the project. This is because of the necessary trade-offs that were made to develop scenarios that contrasted key stakeholder values and policy drivers. It is likely that any project attempting to incorporate quantitative social data will have similar issues (see also Walz *et al.* 2007). Nonetheless, the stakeholder validation process and the evaluation of the scenarios at the governance workshop indicate the scenarios successfully served their purpose.

Despite this issue, it was clear that throughout the scenario design process it was critical to maintain a flexible and intuitive approach for both the qualitative and quantitative components. This was important for two main reasons. Firstly, to be responsive to stakeholder input requires balancing trade-offs between different perspectives and matching key issues with modelling expertise, within the time constraints of the project. It should be anticipated that fundamental changes during the design process will be required and that computational models need to be flexible to allow for these alterations. Secondly, the process needs to be responsive to key changes in national policy and global scale drivers. For example, in this study the withdrawal of set-aside policy and the substantial increase in global wheat prices had a significant impact on the final scenarios at a late stage in their development. This reflects the inevitability that scenarios are a product of the time frame in which they are made and can quite rapidly become dated, particularly during periods of intense systemic transition. Thus, for this system the potential for a switch in the break cropping has diminished due to restructuring within the sugar industry and a focus on production in Norfolk, although this scenario may be more applicable to sugar beet growers in other parts of England who lost out during the restructuring.

Nonetheless, it was recognised that the design process was also about cultivating greater stakeholder understanding of the system. In this case study, there were indications throughout the process that the stakeholders' sense of the whole landscape and their role in it was enhanced. Moreover, a critical component of the validation process was to engage key stakeholders in the future use of the scenarios, which resulted in general agreement for a multi-stakeholder workshop designed around how to deliver a more multi-functional landscape (see Southern 2009). Thus, the process of scenario design was intimately intertwined with the building of a greater level of cooperation between the various stakeholders and developing "buy-in" to the process. The participants certainly took the process seriously, seeing real potential for it to have an impact on their professional activities and livelihoods. However, it was impossible to design the ideal scenarios that would have resulted from incorporating all stakeholder input. These "ideal" scenarios would have required significantly more time, expertise and research for their development. This has implications for the growing policy and research emphasis on ecosystem services. Nevertheless, the participants comments on what could be an "ideal" set of scenarios proved insightful and contributed to the improvements to the design process discussed in the next section.

There were also key scientific challenges with the modelling approaches used, highlighting important gaps in the scientific basis for whole landscape design. This was particularly obvious when selecting export coefficients for the nitrate modelling, where significant modification to existing coefficients was required to make them "fit" the system. Additionally, the use of connectivity analysis for habitat targeting is still controversial, while it is seen as

intuitively valuable from a practitioner perspective and the approach is a significant improvement on existing methods, it is still unclear how most species actually use the landscape and thus how valuable de-fragmentation measures might be (Catchpole 2006, Dolman *et al.* 2007). That being said, the modelling provided a higher degree of confidence and legitimacy to the scenarios than if they had been purely qualitative and it greatly enhanced reflection on the future trajectory of the system.

4.3. Improving the design process

A key design issue for both practitioners and researchers was the time commitment required to implement the process. If a holistic scenario design process is to become more useful as a tool for the governance of social-ecological systems then it will need streamlining in addition to addressing key technical issues of integration. Based on this study there are four areas where the process applied in this research can be improved:

1. *Identify and target key stakeholders.* It is vital to identify and incorporate key stakeholders early in the design process. The methodology outlined in this research could be streamlined by engaging from the outset with a stakeholder group similar in composition to the validation group. This would cut out the in-depth landowner component but still ensure their views were represented. One can speculate that a holistic systemic understanding lies dormant within the collective understanding of key stakeholders, and it is this that must be stimulated to emerge. To this end the study lacked good representation from business outside of the farming and tourist industries as well as artists and free thinkers. It would also be essential to include key decision makers to lend greater legitimacy to the process and increase the likelihood of support beyond the scenario design process. Santelmann *et al.* (2004) and Hulse *et al.* (2004) present excellent examples of wide ranging stakeholder engagement, broadly backed by senior decision makers, although the approach in Hulse *et al.* (2004) was particularly time consuming.
2. *Improve data integration.* In England there has been substantial improvement in the accessibility and integration of environmental data through the development of the MAGIC (2008) data portal, as well as improved polygonised OS landscape scale data for detailed field-by-field modelling (Ordnance Survey 2008b). However, it was still necessary to obtain data from twelve different sources for this project and further integration is still required. Additionally, from a whole landscape design perspective the confidentiality surrounding the spatial extent of landownership is particularly problematic and had to be resolved through individual meetings with farmers.
3. *Improve the modelling tool kit.* It is necessary to develop a user-friendly tool kit that has the capacity to calculate carbon, nitrogen, water, energy, sediment and phosphate budgets and ecological connectivity. These tools should be integrated with the capacity to cost for ecological services. The intention would be to test future scenarios for impacts on these key indicators accounting for new policies, and land management practices, including agrochemical use and climate change. Currently the science and practice of social-ecological system governance is nowhere near this level of integration, though there are other studies that are pioneering this modelling approach (e.g. Hulse *et al.* 2004, Santelmann *et al.* 2004). The Country Land and Business Association have also produced an interesting first attempt at on-farm carbon footprinting for land managers (CLA 2008). There will be a need to temper the development of this kind of decision support tool with the practical realities of implementing complex tools the literature is littered with examples of decision support tools that are not used in practice (Malczewski 2006). This suggests a need to engage more fully with a range of practitioners during decision support tool design.

4. *Demonstrate and test the modelling tool kit in long term social-ecological case studies.* Whether such a comprehensive tool kit should be widely available is open to debate. It would take considerable resources to develop and measures would have to be implemented to ensure that such tools were used by “experts” who knew their limitations. However, the science and governance of social-ecological systems requires “real life” whole system laboratories to demonstrate tools and analysis including scenario design over the long-term (20-30 years minimum). This approach would need to make use of case studies that go beyond the current time frames of most research and practitioner based case studies.

In addition to the above issues it will be important to get the current governance systems, which are far from integrated, to cooperate in the implementation and testing of novel policy approaches by genuinely seeking to act on the outcomes of scenario visioning exercises with communities.

4.4 Conclusions

The scenarios that emerged from the process contrasted the key drivers of improving agricultural profitability with increasing demands for greater multi-functional land use. It was difficult to envisage a sustainable landscape without radical change in global markets or the structures of the local economy. The 2020ag scenario clearly showed the potential for radical changes in land use that could directly conflict with EU water directives, conversely the 2020eco scenario illustrated the need for either radical land use change or the implementation of other control mechanisms to adequately reduce river nitrate concentrations.

The scenario design process formed a valuable framework for the exploration of system dynamics as well as providing a useful process of structured transdisciplinary dialogue between researchers and stakeholders. However, whilst the initial landowner and farmer interviews formed an excellent basis on which to construct the scenarios, they were very time consuming. The approach could be streamlined by beginning the process with a group similar in composition to the participants of the validation group. The validation exercise was very important in improving the quality, plausibility and interpretability of the scenarios. Ultimately, whilst the scenarios are grounded in stakeholder values, these are incorporated into the scenarios much more quantitatively than was hoped for at the outset of the project. It is likely that any project attempting to incorporate quantitative social data will have similar issues which often resulted from the trade-offs between contrasting stakeholder viewpoints.

It is vital that an integrated scenario design process incorporates the capacity for flexible and intuitive engagement with stakeholders. This, in turn, must dovetail with flexible computational models that can accommodate both genuine stakeholder engagement and ongoing shifts in the system resulting from external drivers. It is important however, to view the final scenarios not as an end but the beginning of a long process of learning and working together towards greater sustainability.

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