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Operationalising sustainability science for a sustainability directive? Reflecting on three pilot projects

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The implementation of the Water Framework Directive (WFD) will challenge traditional single discipline or single issue approaches to research, requiring instead new forms such as 'sustainability science'. Sustainability science requires the integration of multiple perspectives to resolve place-based problems. This paper will illustrate some of the challenges and emergent understandings that were observed during three research projects that could be characterised as attempting to practice sustainability science. The first two projects focused on designing and developing an integrated assessment approach to analyse possible programmes of measures for the WFD. The third project is an evaluation of a European project that piloted specific measures that might be implemented under WFD. The findings highlight the institutional changes required to deliver sustainability science. To summarise, both the 'rules-in-use' and the 'play-of-the-game', to use the language of the institutional analysis and development framework, will have to change to provide sufficient incentives to make the transition from traditional science to sustainability science.

KEY WORDS: Scotland, Water Framework Directive, evaluation, sustainability science, institutions, water management

Introduction

Debates in the integrated water management (IWM) literature focus on the delivery of sustainable outcomes: improving the quality and quantity of water available for present/future generations and ecological functions. There is an increasing interest in the social, political, economic and cultural dimensions of water management, as environmental challenges (acidification, salinisation, eutrophication, flooding, drought etc.) are created, or at least amplified, by human actions (Broderick 2005; Everard 2004). These issues require an integrated approach (Castelletti and Soncini-Sessa 2006; de Groot and Lenders 2006) and plans have to be accepted and implemented by actors at the local, regional, national and/or global scale (Lankford *et al.* 2004). We use the term 'water management' to describe the cycle of describing, analysing, planning, implementing and evaluating measures. Thus the term includes measures for both quality and quantity; and extends to include management of the whole catchment.

The European Water Framework Directive (WFD) (Council of European Union 2000) aims to promote sustainable water use based on the long-term protection of available water resources; deliver enhanced protection and improvement of water quality; and contribute to mitigating the effects of floods and droughts. The authors have heard the WFD being labelled as a sustainability directive by several policy actors at a variety of WFD-related workshops (Rural & Economic Land Use Conference January 2005; River Basin Management Planning workshops in Scotland August–October 2004; Area Advisory Group meetings October–November 2006). If WFD is a sustainability directive (World Wildlife Fund and European Commission 2001; Tippett

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2005) it will require integrated and interdisciplinary ways of understanding and managing water.

Integrated approaches will require researchers, policymakers and managers to change their practices (Witter *et al.* 2006) and are likely to stimulate new institutions (the formal and informal rules, conventions and norms enacted through individual and collective practices) (Dolsak and Ostrom 2003). This paper looks specifically at the changes required from researchers. We adopt the concept of sustainability science (Kates *et al.* 2001) to evaluate to what extent researchers moved away from single discipline and/or single issue approaches towards innovative interdisciplinary approaches. We stress that sustainability; traditional science is not a binary opposition but can be thought of as positions on a spectrum, allowing an analysis of shifts in emphasis. We adopt the Institution Analysis and Development framework (IAD) (Ostrom 1990) to explain how such a transition may be enabled or resisted. This paper explores the application of the new integrated approach, as in spite of frequent calls for such research, there is little discussion of what happens when implemented (Maasen *et al.* 2006).

Contextual literature

This paper is interested in research for sustainable water management. Several authors, including Newson (1997), Rhoades (1997) and Mitchell (2005), in both developed and developing world contexts, have argued for integrated and interdisciplinary approaches to water management. These new approaches require an understanding of the systemic nature of water management, recognising the relationship between water quality and water quantity; different uses of water resources (as a source and as a sink for natural and anthropomorphic processes); upstream incidents and downstream consequences. Because water is a common pool resource, it requires an understanding of how biophysical, economic, political, social and cultural systems intersect and pattern both the resource uses and their consequences over space and through time. It is this recognition of the social construction of water management that sets new IWM approaches apart from the historic focus on biophysically defined or regulatory/technologically focussed approaches in the past (Ison *et al.* 2007).

These changes suggest researchers will have to answer new questions with different forms of evidence and analysis, based on a view of self-organising, complex adaptive systems (de Groot and Lenders 2006). Such insights, particularly the desire to evolve methods for a more holistic understanding, are not new (Innes and Boohr 1999). Indeed the broader literatures on ecosystem functioning (Gunderson *et al.* 1995), environmental governance (Evans 2006), managing public goods (Oakerson 1992), systems thinking (Schlindwein and Ison 2005), sociology of science and knowledge (Jasonoff 2005) and perspectives on policy analysis (Fischer 2003) all highlight this issue, not to mention the literature on interdisciplinarity (Petts *et al.* forthcoming). This paper adopts sustainability science as an analytical framework because the concept neatly captures the multiple dimensions of these literatures.

Sustainability science is a phrase coined by Kates *et al.* (2001), which recognises the limitations of reductionist disciplinary approaches to understanding systems. Instead, Kates *et al.* urge an integration of the four areas they identify (biological; geophysical; social and technological) to consider how the earth, its ecosystems and its people are interdependent. Sustainability science is integrative as it requires bridging different disciplinary perspectives to develop new understandings resulting from the creative interaction of multiple perspectives. Not only does sustainability science require new forms of integration, but also it requires the synthesis of theory and practice to resolve pressing societal problems. Furthermore, sustainability science utilises multiple forms of knowledge production, requiring the interaction of academics with other stakeholders. Thus, sustainability science is not just interdisciplinary, but also requires a transition in conceptualising why, how and by whom science is practised.

Sustainability science is profoundly geographical, as such integrative endeavours must be situated in place, where the complex interactions become 'tractable, understandable and manageable' (Kates 2000, 2). Geography's focus on scale, both spatial and temporal, is also one of the key challenges of sustainability science, and of IWM, as both require understanding the inter-relationships between multiple scales (Newson 1997). Furthermore, as Harrison *et al.* (2004) illustrate, geography has welcomed different epistemological treatments of society and space in ways that generate new and improved scientific understandings. This combination of social and biophysical processes is at the heart of sustainability science.

In what ways does the WFD require sustainability science? The WFD is the formal expression of a desire to move water regulation towards a more holistic characterisation of the aquatic system – one that recognises both causes and consequences of impacts on water quality. The holistic characterisation also recognises the interaction between human practices and water resources, supported by methods that combine previously separate ways of analysing the components of the system. Furthermore, the WFD formally requires the active involvement of interested parties, which echoes the shift to working with non-academic stakeholders and, implicitly, to recognising the social construction of knowledge. The cyclical approach to River Basin Management Plans (reviewed every six years) and their implementation on multiple scales (from huge trans-national basins to tributary scale sub-basins), also suggests taking a systemic approach. Finally, the objective to secure good status for all water bodies by 2015 is problem orientated.

The concept of sustainability science reflects the literature on the changing relationship between science and society (Lubchenco 1998; Cortner 2000), whereby research is expected to contribute to the wellbeing of the society which funds its existence. The concepts described above also echo the shift between 'mode 1' and 'mode 2' science (Gibbons *et al.* 1994). Mode 1 science can be understood as the dominant disciplinary form of knowledge production characterised by abstract cognitive theorising, whereas mode 2 is primarily a problem orientated and interdisciplinary form of knowledge production, often characterised by learning through doing (Owens *et al.* 2004). Within this new science–society interaction, academic institutions are only one site of knowledge creation and sustainability science requires us to do research with, rather than on, other groups involved in managing the water environment.

For example, Robinson and Tansey (2006) distinguish between weak and strong stakeholder engagement processes in research. Echoing a long-running debate in literatures on public participation (see Arnstein 1969 through to Kemmis and McTaggart 2005), these terms relate to the roles and responsibilities within research relationships that involve stakeholders (including the public). Often stakeholders are informed or consulted on the research but do not define, participate in or evaluate the research itself. Thus, the stakeholders provide information whilst the power remains with the researchers (Blackstock *et al.* 2007). On the other hand, the new IWM approach suggests social learning and co-construction of knowledge where all parties are involved in, and transformed by, this experience (Ison *et al.* 2007). Involving non-disciplinary, non-academic, researchers challenges, extends and transforms what is researched, the assumptions underpinning the methodologies used and the meaning of the results (Maasen *et al.* 2006). Thus reflexivity and co-learning between actors is crucial to sustainability science, requiring reflection on how individual prejudices and experiences influence research practices, as well as drawing attention to the socially constructed and contested nature of 'evidence'.

Central to understanding new ways of researching water management is an understanding of the institutions that frame these activities (Gearey and Jeffrey 2006). An institution can be thought of as a set of formal and informal rules, social norms and conventions that govern behaviour to allow cooperation and maintain social order in situations of complexity (North 1991; Vatn 2005). The Institutional Analysis and Development (IAD) framework (Ostrom 1990) highlights the importance of considering the 'action arena' (the context within which the institutional actors function including the biophysical and social characteristics); the 'rules-in-use' (the formal and informal policies, laws, codes and norms, which are constrained or enabled by actors' individual competencies) and the 'play-of-the-game' (how actors behave). The different mechanisms that govern choices by actors are one aspect of the 'rules-in-use' and these are often distinguished into three categories: economic, legislative or voluntary. All three can be formal or informal; implemented or ignored; and can function at the operational, strategic or constitutional level (Cowie and Borrett 2004). Of particular interest to the context of interdisciplinary research teams, choices regarding voluntary collective mechanisms can be explained by the concept of transaction costs (Singleton and Taylor 1992) whereby actors decide if the costs involved with seeking, setting up and maintaining cooperation outweigh the benefits.

Although evolution is central to institutional theories, the mechanism explaining how change occurs remains implicit. Transition theory (Rotmans *et al.* 2001; van der Brugge *et al.* 2005) helps to conceptualise how and why social systems, and their institutions, evolve. Change occurs when several events from different domains and at different spatial scales intersect and positively reinforce one another. This can create what appears to be a rapid shift to another state, but this shift is often due to the co-evolution of several slow change variables[1]. This theory helps to explain why some analyses of institutional evolution point to both internal and external factors (Heikkila and Gerlak 2005). However, it is important to also recognise stability, particularly given the role that institutions play in maintaining order and predictability.

Policy analysts such as Lindblom and Woodhouse (1993) or Hass (1992) argue that changes to policies (one form of rules-in-use) are incremental as policymakers tend to interpret and respond to problems using existing conceptual and operational resources, rather than developing new solutions (building on theories of bounded rationality and case based reasoning; Kahneman 2003; Ajzen 1991). Notions of path dependency, whereby choices become more and more constrained due to

Table 1 Descriptions of the case studies

	Project one	Project two	Project three
Researchers	Nine scientists within one academic organisation from six disciplines (computing science, hydrology, sociology, anthropology, economics, geography). No stakeholders involved due to delay in coupling the models	Twenty-three researchers from seven academic organisations from multiple disciplines (from hydro-geochemistry to philosophy). Stakeholders representing policymakers (government and NGOs) attended final workshop	Nine researchers from six organisations, two were practicing academics but other researchers represented regulatory agencies or local government. These had some academic training (generally natural science or engineering) but identified themselves as practitioners not researchers
Funding sources	Scottish Executive Research Programme	Rural Economics and Land Use Research Programme	European Union (Local Government partnership)
Objective	To build computer modelling simulation tools to explore the implementation of policy options	To scope out an integrated assessment approach to explore the implementation of policy options and apply for a grant	To demonstrate possible approaches to implementing measures to mitigate diffuse pollution
Target catchment	Models based on a sub-catchment of the Dee but no new fieldwork undertaken there during the project	Purely abstract ideas for the workshops and papers although proposal based on implementationin three catchments including Dee	Three sub-catchments of River Dee
Required outputs	Academic papers	Grant proposal and discussion papers	Progress reports, final report and workshops

economic, technological, social and political 'lock-in' to the current system, have been applied to explain why incrementalism occurs (Arthur 1994; Kirk *et al.* 2007). These ideas help to explain why it is difficult to tell if a transition is occurring and why the intersection of several events in different domains is required to overcome the systemic resistance to change.

In short, sustainability science is used to consider to what extent new research approaches are being implemented. Institutional and transition theories are used to explain why such changes can take multiple forms, may follow punctuated nonlinear routes, and will face resistance. Three case studies explore these themes.

Projects

The three projects involved strategic and applied research on the implementation of the programmes of measures under the WFD in Scotland. All projects aimed to be integrated and interdisciplinary, to take account of a variety of spatial scales (from in-field measures to policy changes) and to involve the perspectives of multiple stakeholders beyond academia. All have a common focus on WFD in Scotland, based on a tributary of the River Dee, but have very different histories, composition and trajectories (see Table 1). Any one case study could have formed a full paper but the three cases illustrate the evolution of approaches to sustainability science, illustrating where there are common institutional factors.

The first project (2003–6) was an attempt to link previously disparate pieces of research on mitigating diffuse agricultural pollution. The project used a story and simulation approach – developing scenarios of plausible futures (based on a deliberative workshop with staff) and then running linked model applications to simulate how the system behaves under each scenario. The challenge was to link two model applications – an agent-based social simulation (ABSS) model of land management behaviour and a distributed phosphate transport model – in order to illustrate whether and how land managers responded to changing levels of diffuse pollution arising from implementing the measures (Blackstock *et al.* 2006).

The second scoping study (2004–5) developed an integrated assessment framework. During three workshops and writing discussion papers, we sought to understand different ways of characterising a river basin and potential methods for assessing measures; the multiple perspectives, interests and values lying behind these choices; the implications of working at multiple scales; how to overcome linguistic and conceptual differences in order to work across disciplinary divides; and how to work more effectively with non-academic partners (Carter *et al.* 2005). The project culminated in a (unsuccessful) research funding proposal.

The third project (2003–6) was set up in response to an INTER-REG call to pilot the implementation of the WFD. The Scottish component required partner organisations to work together to mitigate diffuse pollution in tributaries of the River Dee, using measures such as buffer strips, sustainable urban drainage, and wetlands to polish effluent and provide habitat. The project also developed educational resources; engaged in information provision and stakeholder awareness raising; and undertook an evaluation of partnership working throughout the project (Blackstock and Carter 2006).

Data collection and analytical framework

The paper uses these projects to illustrate changes in research practices and institutional arrangements. The methodological approach is primarily participant observation – the authors were involved in each of the projects[2] and used field notes to reflect on our own, and our colleagues', practices as researchers. This section describes the methods used to generate the data for this paper's analysis, rather than describing the methods used in each project.

The reflections on the first project are based on an analysis of the field notes taken by the participating author at each team meeting; the scenario workshop; the action points arising from each meeting; and the internal annual reports on the project. It was the experience of reflecting on field notes during this project that encouraged us to explicitly collect data on our research practice in future. An earlier analysis of the strengths and weaknesses of the project was shared with the team using a draft conference paper (Blackstock *et al.* 2006) and feedback influenced the subsequent analysis for this paper. This technique of validating our interpretations of the data by requesting feedback from participants has been used in all three projects.

The reflections on the second project are based on an analysis of field notes taken by participating authors at the three workshops, supplemented by voice recordings for some of the interactive sessions; the power point presentations given (including those generated during the workshop, illustrating the emergent themes arising from our deliberations); and the results from our pre- and post-project questionnaires. The questionnaires were designed to capture individual perceptions of social learning during the life of the project. They were distributed at the first and last workshop, with reminders going out by email. We received 16 'start up' questionnaires and 15 'ending' questionnaires (giving response rates of 70% and 68%, respectively) providing 14 pairs of surveys for analysis. The analysis of this data was reviewed by the project team before the project report was finalized (Blackstock *et al.* 2005).

The reflections on the third project are based on analysis of meeting transcripts, interviews and questionnaires. The authors attended, recorded and analysed eight (28%) steering group meetings and five (10%) working group meetings between February 2005 and May 2006, plus four additional workshops. Steering group members completed a questionnaire in 2004, 2005 and 2006, giving a total of 16 questionnaires (response rate of 65%). Steering group members and the project coordinator were interviewed twice, one member from each working group and each of the steering group's line managers were interviewed once. This gave a total of 25 interviews. Our analysis was shared with the participants before the project report was finalised.

The analytical framework (Figure 1) builds on authors such as Pretty (2003), Claude (2002) and Allen *et al.* (2006) who advocate linking the outcome to processes (middle and right-hand columns). Process includes both actions and structures (Giddens 1984), as implied by the IAD framework. Equally, any institutional framework that emphasises change through time has to look at the historical origins that shape the unfolding process (left-hand column) (Maddock 2004; Ison and Watson 2004). Any institution shapes, and is shaped by, the wider context (Richards and Smith 2003; Collins 2000), or in the language of the IAD framework – the institutional 'arena' (grey shaded area). Changing rules, norms and practices involve individual actors, the collective project team and their organisations (Maddock 2004; Bellamy and McDonald 2005). Recognising these three horizontal layers deepens the debate about research team composition. Figure 1 therefore operationalises these various ideas into one analytical framework. The multiple and complex interactions between each component are illustrated by the mixing of red and blue to make the different shades of purple.

This framework provided a structured approach that allowed us to explore common elements of institutional change. Each project was reviewed to consider how outcomes were related to the project's origins, structures and actions, relating to choices made by individuals, the project team and their organisations.

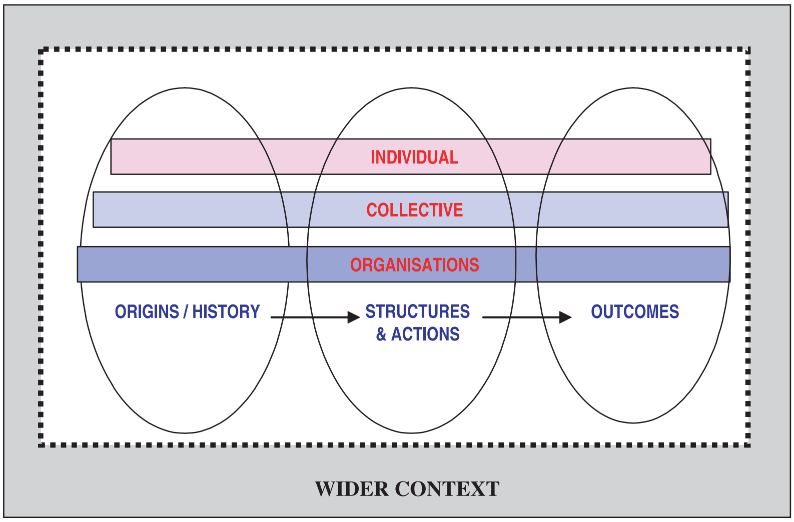

Figure 1 Analytical framework

The project data were also analysed to see:

- If the research could be characterised as sustainability science. (Was it integrated, interdisciplinary, place based, problem orientated, multi scale and did it involve perspectives from outside academia?)
- Was there evidence of a transition from 'traditional' towards 'sustainability' science?
- Was this transition enabled or resisted – what were the 'rules-in-use' and 'play-of-the-game' involved?

Findings

This paper is a response to the plea to share our experiences, for it is often by analysing the difficulties experienced that the lessons for future research are learned (Cash *et al.* 2003; Redford 2005; Maasen *et al.* 2006). Thus, the analysis focuses on the barriers to doing sustainability science rather than the positive outcomes achieved. All three projects were considered successful, were enjoyed by their participants, and members of the three teams continue to work together. An overview of the projects' similarities and differences are found in Table 2, whilst the text focuses on drawing out the findings related to the analytical framework.

Project one

Outcomes The project achieved progress in developing integrated assessment techniques and increasing our understanding of the complexity of managing agricultural diffuse pollution. There was only limited progress with the story and simulation method – the two models have been 'coupled' successfully but the results still require calibration and validation before the models can be run under the different scenarios[3]. The project increased our understanding of each other's methods and tested the models for their ability to work in these new, more flexible ways. The project also pooled our different disciplinary understandings about land management, farmer behaviour, policy options, diffuse pollution transport processes and modelling techniques, enriching and informing our research practices. The outputs remain generally disciplinary or multi-disciplinary. Of the five conference papers, two working papers and 13 journal paper submissions, only two conference papers reflect on the project as a whole, although the lack of papers on the results of integration reflect the fact that the integration has yet to be completed.

Origins The project was a result of three separate research proposals being merged by senior management seeking to demonstrate interdisciplinarity (project leader, personal communication). The original proposals all focused on mitigating diffuse pollution by working with stakeholders. But each proposal was situated within a distinct discipline and had a specific methodological approach. The interdisciplinary approach was therefore bolted on and implemented in a 'top down' manner. This history helps explain why the project did not establish a common vision – the overarching purpose of the project had to be revisited regularly during project

Table 2 Similarities and differences between the case studies

	Project one	Project two	Project three
Sustainability science	Mainly multi-disciplinary (five disciplines). Integrated methods – yes (coupled models and scenarios). Problem orientated – yes (resolving diffuse pollution). Multi-scale – yes (field measures, policy and societal preferences). Place based – nominally (centred on sub-catchment but varying abstraction). Stakeholder involvement – no	Glimpses of interdisciplinarity but mainly multidisciplinary (+10 disciplines). Integrated methods explored but not implemented. Problem orientated – yes (improving programmes of measures). Multi-scale – yes (field measures, policy and societal preferences). Place based – no. Stakeholder involvement – minimal (at workshops)	Beyond disciplines (mainly agency staff). Integrated methods – yes (environmental, economic, social, policy measures). Problem orientated – yes (improving water quality). Multi-scale – yes (field measures, policy and societal preferences). Place based – yes (three sub-catchments). Stakeholder involvement – yes (collaborative research)
Transition	Not achieved but increased capacity	Not achieved but increased capacity	Partially achieved
Play of the game	Individuals tended to pursue own interests within the three strands	Emerging interdisciplinarity at workshops but retreat to disciplines for final outputs	Evolution from single issue to holistic actions as procedures evolved to support cooperative delivery
Rules in use	Project leader lacked sanctions or incentives to influence researchers in other depts; prioritization of time spent on interdisciplinary research affected by reward structures	Failure to win funding removed main incentive, PI lacked sanctions or incentives to influence researchers in other organisations; lack of funded time to learn and share	Funding provided incentive but also created problems; coordinator lacked sanctions or incentives to influence; divergent remits complicated joined up delivery; lack of funded time to deliver

meetings in 2004 and 2005 – and why the project was characterised by three distinct disciplinary themes (stakeholder analysis, ABSS modelling and pollutant transport modelling).

Structure and actions This lack of 'ownership' of the overall vision may explain why members of the sub-teams chose to stay in their disciplinary comfort zones and tended to focus on developing, implementing and writing up their own components. These actions were also influenced by the structure of the project. The project was structured with integration and stakeholder involvement planned to occur towards the end of the project. Because the model applications developed at a slower speed to the other components and there were subsequent difficulties in linking the models (Blackstock *et al.* 2006), this meant that it was expedient to keep working in the three sub-themes until all themes were ready to be integrated and shared with stakeholders. Furthermore, the project leader could only directly influence staff in their own research group. When individuals had conflicting demands on their time and had to prioritise tasks, the project leader had to rely solely on persuasion and was unable to enforce project milestones.

These delays and difficulties were not the only reason that the researchers retreated to their disciplinary homes. The interactions of origin, actions and structures have been mediated by organisational policies and individual attitudes (the rules and play of the game). Despite identifying the need for problem-orientated interdisciplinary research, the organisation was perceived as slow to reward the risks involved, maintaining the pressure on individuals to publish high-impact peer-reviewed papers and rewarding individual researchers based on the number of publications (internal memo). The fact that the high transaction costs for integration were not perceived as being rewarded explains why the project remained multi-disciplinary and academically orientated rather than interdisciplinary and engaged with stakeholders.

Project two

Outcomes Most researchers experienced modest to significant personal learning on both procedural aspects (how to conduct interdisciplinary research), and subject-specific learning (different perspectives on water management research) (see Blackstock *et al.* 2005 for full results). The shift to systems thinking, particularly understanding who decides what is 'sustainable' and the importance of involving stakeholders with different, often conflicting, views on water management, can be demonstrated by the fact 'communication and understanding within the catchment' had become the top priority for our research by May 2005. However, social learning – sustained changes in practices – was not achieved during the life of the project. As with project one, only one of the eight working papers developed during the study involved collaborating across the social–natural science divide[4]. The grant proposal was unsuccessful and although most (n = 14) of the survey participants wished to continue to collaborate, there have been no follow on projects involving the full consortium[5].

Origins Unlike project one, a self-selecting group of researchers formed a consortium to apply for cross-research council funding. Controlling for relationships between researchers who work in the same organisation, 62% (n = 10) of researchers returning their questionnaires had worked with others in the consortium before. Thus, theoretically, the project was 'owned' by the participants, built on existing connections and had the added incentive of applying for funding to maintain the group cohesion.

Structures and actions The desire to move towards interdisciplinary IWM science was illustrated at the three workshops. For example, discussions regarding characterisation of water bodies for the WFD started with the legislative requirements for biophysical and ecological parameters, but quickly incorporated social, economic and cultural concerns; discussions around scale required all those present to reconsider their assumptions about time and space; and the final workshop saw an animated debate over the use and meaning of commonly used terms, again forcing all present (academics and stakeholders) to reconsider their assumptions. However, these transitions to new research approaches were not sustained. As with project one, there was a tendency to retreat to disciplinary comfort zones, albeit involving collaboration between different organisations, away from the face-to-face interaction of the workshops.

These choices to retreat to comfort zones were made by individuals in response to the interplay between the structure of the project and the academic/organisational context. The project was set up to maximise the inclusion of multiple perspectives and disciplines in deliberative face-to-face processes. Due to the high travel and subsistence costs involved in such workshops, the budget could not pay participants for their time, and there was an assumption that the possibility of a grant would be sufficient incentive for their ongoing engagement. However, the need for more funded time to commit to interdisciplinary working was the most cited recommendation in the final project survey (n = 6). The project leader relied on persuasion with no available sanctions for those who were unable or unwilling to honour their commitments. Once the funding proposal was refused, the major incentive for ongoing collaboration was removed, leaving only goodwill and professionalism to motivate individuals to complete their tasks.

There are also issues regarding the wider academic context. Firstly, one-third of survey participants (n = 5) suggested that 'maintaining motivation when not rewarded' was a challenge for interdisciplinary working (ranked third overall). During the last workshop, researchers spent time discussing where and how to publish material from the study and concluded that the time and effort required to generate an interdisciplinary output, coupled with the low impact factor of identified journals (compared to disciplinary journals in the natural sciences), were not appealing in the run up to the Research Assessment Exercise. Thus the top challenge for interdisciplinary projects highlighted by survey participants – integration of different perspectives – and the second most cited challenge – difficulties in cross-disciplinary communication – had combined with the third challenge – poor reward structure – to militate against the production of interdisciplinary papers. The fact that the same barrier – costs of interdisciplinarity being judged to outweigh the benefits – existed in this multi-organisation project as in project one indicates it is not just an organisational problem.

Project three

Outcomes Again, there was an emphasis on individual procedural and topic-based learning. Most (n = 9 from a possible 12) interviewees felt they learned more about the WFD and its implementation (e.g. flood management, causes and consequences of diffuse pollution). They also developed transferable skills (e.g. project management, stakeholder engagement) and valued their increased understandings of each other's organisations, breaking down stereotypes about how others behave and improving communication. Finally, participants were able to experiment with innovative regulatory and engineering solutions and to develop demonstration projects that can be used to support ongoing implementation of the WFD (e.g. bio-engineering techniques; educational resources). These tangible and concrete outputs are an important difference to the previous two projects, which focussed on scientific understanding but not implementation of solutions.

Origins The project was set up by a self-selecting group of organisations who need to work together to implement the WFD. Some of the partners were excited by the prospects for learning in order to generate strategic solutions for potential challenges, but the others were more focussed on their operational role as competent authorities. (Note that this division between strategic and operational aims is not absolute but refers to relative differences interpreted from interviews). The more operationally focussed actors played a lesser role in the project design, partly due to staff availability and partly due to the strategically focussed actors having greater experience with European funding applications. Although all the steering group members had worked with at least one other member before, it was the first time the six organisations had formally worked together.

Structure and actions The origins of the project, resulting in different levels of familiarity with the funding application, led to misunderstandings between the representatives on the Steering Group about the mandate of individuals to act on behalf of the project; the project objectives; and the ability to reconcile project objectives with different organisational objectives. In turn, this meant the ways in which decisions were made, how funds were spent, how individuals interpreted objectives and delivered (or not) their milestones became areas of contention in the first 18 months of the project (as highlighted in minutes throughout 2003–5 and the agenda of the two away days in 2004 and 2005). These issues shaped the delivery of the outcomes above, at first compromising mutual understanding but the process of resolving these problems contributing to the social learning outcomes. Initially, there was a similar tendency for individuals to retreat to their comfort zones – in this case focussed on organisational remit not disciplinary training. However, during the project, trust between individuals and, to some extent their organisations, increased, resulting in more support for integrated actions (comparing, for example, the first outreach event focussed on a waste water treatment plant to the third event focussing on all aspects of the project).

Again, these actions were influenced by the structure of the project (funding and team composition) and the context in which they worked (organisational strategies). The European funding structure meant a significant proportion of the budget had to be spent within the first year, amplifying the difficulties created by the project origins. On the other hand, the European budget milestones provided a major incentive to move beyond deliberation to learning through doing. It funded both time for participants to learn together (although still felt not to be enough), and provided capital to allow innovative solutions to be implemented rather than just discussed – resolving two of the problems highlighted in the previous projects.

The group self-consciously adopted a flat governing structure, as evidenced in their terms of reference (August 2004, revisited and agreed in June 2005) with no lead organisation, and this lack of authority to ensure commitments were delivered was compounded as the coordinator did not have any authority over other individuals and organisations. Again, delivery relied on goodwill and commitment to deliver actions. Judgements about personal conduct and commitment intertwined with deliberations over the lack of hierarchical structure in the interview and meeting transcripts, illustrating the interplay of the rules and the play of the game.

However, the challenge of how to achieve delivery without authority was amplified by the diversity of organisational actors involved in this project. The partnership consisted of six organisations with differing constituencies, funding sources and strategic objectives (see, for example, Witter *et al.* 2006). Four of the six have statutory obligations for environmental protection but these obligations are enacted through different legislation. The difficulty in reconciling the project requirements with the requirements asked of them by their organisations was a strongly emerging theme from the interviews and was a frequent discursive strategy employed to explain why milestones were slipping during group meetings. Here, we believe that the context and organisational components interact. The problems of ‘serving two masters’ (finding time to commit to the project given the pressure of their day jobs) could be explained by their organisations not adequately prioritising the project. However, all the line managers of participants ranked the project as important or very important to their organisation. The line managers offered an alternative argument, suggesting that ‘being too busy’ has become endemic to public agencies, which are expected to do more with fewer resources (Sherlock *et al.* 2004).

Discussion

Our discussion of the three projects suggests that there is an important distinction between outcomes and outputs within each project. In every case, most researchers appreciated the need for integrated and interdisciplinary research by the end of their projects. They were able to learn about issues normally defined as beyond their particular competency and this emergent knowledge was seen as a positive outcome. The outputs from the first two projects remained more multi-disciplinary than interdisciplinary. The third project delivered outputs that required the partners to work together, delivering emergent solutions that could not have been delivered by any one organisation. Thus, being able to 'celebrate small wins' (Tippett 2005; Oliver 2001) helped generate social capital, which in turn, supported further integration. However, the outcomes – thinking and researching in new ways – even if not yet carried forward into new outputs, may be an interim step in the process of transition to sustainability science, as it may be too early for evidence of long-term changes.

Our framework indicates the relationship between achieving these outcomes and the origin, structure and actions within the projects. One common theme regarding the origins was that the problem-orientated aspect provided the common ground for the integration and interdisciplinarity. Taking a real life case study was also more appealing to researchers (academic and practitioners) who needed to demonstrate the relevance of their work. These findings echo literature on the use of boundary objects in social learning processes (SLIM 2004) whereby discussing a specific problem in place improves the opportunities for communication, translation and mediation between different forms of knowledge (Cash *et al.* 2003). Another common finding is the importance of identifying a problem that requires an interdisciplinary approach and building a coalition of the willing who see the opportunities provided by these new practices.

The composition of the research team is an important structural issue influencing actions within the project. Involving researchers spanning the spectrum from basic science to operational delivery was challenging. In both project one and project three, there were differences in the way objectives were interpreted and the speed at which different elements could be delivered. Different researchers worked at particular spatial scales, simultaneously highlighting the need for, and the difficulty in, working across levels (Newson 1997). Despite such challenges, the greatest co-production of knowledge was demonstrated when such divisions, including the divide between theory and practice, were bridged in order to deliver actual outputs in the third project. Involving stakeholders, who tended to frame issues differently and were less wedded to disciplinary traditions, acted as a catalyst to bridge disciplines and build on traditional science.

Another structural issue with consequences for actions and therefore outcomes was a perceived lack of time to develop these new practices. In all projects, researchers wanted more time. New modes of researching necessarily take much longer (consider, for example, the investment required to learn to understand one another). Our results indicate that researchers tended to revert back to familiar concepts, techniques and practices as they felt they did not have enough time to learn new alternatives (Huby *et al.* 2004). But perhaps more importantly was the relative emphasis given to new research practices as opposed to more traditional disciplinary approaches. In all projects, most researchers were spending the large majority of their time thinking and acting traditionally and very little of their time as sustainability scientists.

The structure of projects whereby there was a lack of sanctions and lack of incentives to motivate delivery was another common theme. Project one and project three had some economic incentives regarding payment for salaries, and in the latter project, there was budget for capital spend. However, the problem remained of how to ensure delivery using voluntary mechanisms (Koontz 2003; Mitchell 2005). Every project struggled with issues of flat hierarchy and the lack of sanctions to ensure compliance. This emphasised the role of social capital in delivering such sustainability science projects, echoing findings from evaluations of natural resource management collaborations (Heikkila and Gerlak 2005). Social capital also provides a mechanism to improve coordination when economic or regulatory sanctions are unavailable (Wondolleck and Yaffee 2000; Pretty 2003; Sobels *et al.* 2001). Leadership is required to inspire others and to create shared visions and mutual objectives (Ison and Watson 2004; Sobels *et al.* 2001). The ability to demonstrate leadership and to generate social capital is linked to the time spent working together.

These structural issues – team composition, time available and incentives for voluntary collaboration – influence choices made by the individual researchers within the projects. Motivation and commitment varied between individuals. It often took time for the benefits of the new approach to become apparent to individuals, and only those firmly embedded in the projects really embraced the need to make the transition from traditional approaches to sustainability science. Our findings illustrate that individuals make choices about what is best for them and for their organisations, with few projects developing a sufficient counterweight to the demands of career structures and organisational priorities.

Sustainability science requires new 'rules-in-use', i.e. conventions, rules and norms governing methodologies, that can handle problem-orientated, place-based enquiry and the interplay of multiple scales (as recognised by the design of project one and two). These methodologies have to be able to surmount the problems regarding differing degrees of abstraction, different scales of analysis, the time required to deliver various components, and the tendency to incrementally build on previous experiences and bodies of (disciplinary) knowledge. However, we would argue that sustainability science also requires particular ways to 'play-the-game' given the importance of communication, personal conduct and relationships in each of the projects (Bracken and Oughton 2006). Thus, any sustainability science project will need to think about how individuals think, speak and act as much as what they do (Marzano *et al.* 2006).

There were also different interpretations regarding what was considered 'good' research practice, although as highlighted above, there was convergence around the need for integrated solutions. We wish to skip over the debates about epistemological clashes inherent in interdisciplinary research (Harrison *et al.* 2004) to highlight a more practical issue that emerged strongly from all projects – the need for new 'rules-in-use' for *evaluating* sustainability science outcomes. In all three projects, the learning and process outcomes were recognised by the project members but were perceived to be unimportant to those in authority external to the project. Our results indicate that researchers wish to transform their practices but perceive that the transactions costs of doing so exceed any rewards they, and their organisation, would receive (Cortner 2000; Cowie and Borrett 2005). (The argument regarding the benefits of such a transformation to broader society is another matter; Lubell *et al.* 2002.) These 'cost–benefit' calculations draw attention to the need for incentives for new research practices.

One solution to enabling a transition to sustainability science would be to ensure all researchers worked full-time on such a project. However, our findings on outcome incentives may contradict this. Unless sustainability science outcomes and outputs are recognised as more valuable by organisations and the wider peer group community than those produced under traditional modes of research, there is little incentive to pursue integration. Involving stakeholders further complicates these issues, as generally non-academic actors and organisations have different motivations for project delivery, and different metrics for evaluation. Therefore, involving stakeholders can raise the stakes regarding what the project should deliver, for whom and by when – particularly when failure to deliver any tangible short-term outputs may increase stakeholder fatigue and decrease trust in researchers. It is evident from our analysis that researchers, their organisations and policymakers think sustainability science, including stakeholder involvement, should be encouraged (Lowe and Phillipson 2006). However, the actual 'rules-in-use' are yet to fully evolve to support and reward the practicalities of delivering sustainability science.

We feel that adopting a complex, multi-faceted analytical framework has provided a suitable structure to illustrate the interwoven relationships between individuals, the project collectives, their host organisations and the broader socio-cultural context in which we work. It has highlighted what changes might be required to help achieve a transition. It has helped us keep the notion of nonlinear relationships through time at the heart of the analysis, and our findings illustrate the importance of evolution when considering possible transitions. Due to our focus on understanding the institutional arrangements and how change is enabled or resisted, there has been less room to ground the analysis in place-based specifics and the materiality of the rivers, land use and water users themselves. This was a deliberate trade-off given the lack of academic focus on research practices as opposed to the expanding literature on why we need IWM to resolve the challenges thrown up by material processes. However, as highlighted above, it is the very real issues regarding environmental, social and economic wellbeing that engaged the researchers in these projects and continue to inspire their interest in IWM.

There are a number of issues regarding interdisciplinary working that we have not discussed, such as the availability of data, the socialisation of academics or the politics of stakeholder involvement. Within the paper, we touch on issues such as authority or the discursive construction of 'good' science but do not include an explicit analysis of power relations. Both sustainability science and Ostrom's approach to institutional theory appear to be silent on this issue, yet power relationships underpin the intersection of actions and structures at individual, collective and organisational levels, in particular the definition of the 'rules of the game' and the 'play of the game'. The omission was deliberate to provide space in which to explore the utility of using sustainability science principles to evaluate research designed to inform sustainable water management, and the application of institutional theory to explain the challenges faced. However, the relationship between power and research practices to support WFD is the focus of ongoing research and will be developed in future papers (Blackstock forthcoming).

Furthermore, whilst the paper did not intend to deconstruct the concept of sustainability science but to use it as an evaluation framework, it is important to offer some cautions. As highlighted earlier, we believe that the difference between traditional and sustainability science (or mode 1 compared to mode 2) is exaggerated. Traditional or mode 1 science has often blended different forms of knowledge and utilised insights from academia (Barnes and Edge 1982; Jasonoff 2005). Furthermore, the call for integrated water science is not new (Chorley and Kates 1969) and future users of the concept may wish to consider to what extent it is 'old wine in new bottles'. These cautions make the notion of a sudden and rapid transition to a new paradigm more problematic, and we suggest characterising this transition as evolution rather than a step-change.

Conclusions

The paper has illustrated how sustainability science helped evaluate new approaches to sustainable water management research. Sustainability science requires integrated, interdisciplinary, place-centred, multi-scale, collaborative, problem-orientated research, which chimes with many of the arguments for IWM research in the literature. For example, in project one, simulation modelling became more responsive to the interplay between farmer decision making, land use and water quality; in project two, we developed a methodological proposal that took upstream–downstream consequences for water quality, economy and society seriously; and in project three, narrow operational concerns evolved into a focus on delivering multiple benefits (habitat, water quality, rural development, flood mitigation) with multiple actors cooperating for the first time. However, the concept of sustainability science prescribes what kind of research is needed and why this might be so, but does not provide many pointers regarding how such research might be implemented in practice.

Drawing on institutional theories, we argue that recognising the interactions between origin, action and structure within particular contexts (i.e. how the rules-in-use are enacted within the institutional arena) can help to illuminate how and why doing research differently might be enabled or constrained. We have argued that sustainability science requires new rules, conventions and norms governing methodologies, research relationships and evaluation criteria. The paper indicates that sustainability science extends tradition science in the way it is used, who is involved and what the objectives are. The paper illustrates that this change needs adequate resources (time, capacity and commitment) which in turn require adequate incentives. We suggest that our experiences highlight how informal practices are changing but the formal structures are lagging behind.

These topics map onto three areas that may explain the barriers to implementation. Firstly, new methodologies and relationships require sufficient time and attention to embed and become productive. Secondly, sustainability science requires cooperation between individuals which can be enabled though building up stocks of social capital if other incentives are not available. Thirdly, choices about investment in relationships will be made in light of how such investments are rewarded. These arguments are not new, but collectively help to explain the outcomes of our three projects.

The use of transition theory reminds us that our snapshot from three projects needs to be placed in a broader context (Cash *et al.* 2003). With hindsight, will our experiences be interpreted as part of a transition to a state where sustainability science is 'normal'? The answer to this question will depend on whether the ongoing evolution in multiple social, political, intellectual and environmental domains coincide to overcome the systemic inertia. Changing relationships between science and society; increasing need to integrate multiple policy drivers; increasing interest in new theoretical and methodological synergies; and pressing environmental problems indicate that such a convergence may be occurring.

Each project resulted in far greater mutual understanding and increased capacity as sustainability scientists than if such a transition had not been attempted. The researchers now recognise the need for 'scientifically *and* socially "sound science"' (Maasen *et al.* 2006, 398, emphasis in the original). Sustainability science is not a new magic bullet for addressing enduring social, environmental and economic problems, given the institutional changes required to allow sustainability science to contribute to delivering sustainable water management. However, improving our understanding of the institutional evolution required can help to explain challenges faced in IWM research, making them easier to resolve. Certainly, we believe that traditional science alone will not be able to deliver effective, efficient or equitable programmes of measures, making the need for the transition all the more pressing. Geography, being a discipline that seeks to bridge bio-physical and social approaches, and delivers science located in specific places, should be at the heart of this transition.

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Notes

1 There are similarities to the theory of socio-ecological systems (Walker *et al.* 2004) but space doesn't allow a full discussion of this – transition theory is more appropriate for this paper as it focuses on the implications for social systems rather than the dialectic between social and ecological systems.

2 Blackstock was actively involved in all aspects of three projects, whereas Carter was involved in the scenario aspect of the first project and acted as a joint PI for the other two projects.

3 Aspects of the project are being taken forward under new funding, including an intention to test the scenarios and assess the results in terms of to what extent the methodology provides results that could be of use to policymakers. Future work plans for the researchers include simulation and scenario approaches more generally, but there are no plans to continue to couple these specific models.

4 However, most papers involved cooperation between different organisations and between disciplines, e.g. ecology and hydrochemistry.

5 Individual members of the project continue to work together, although these inter-organisational collaborations tend to reinforce, rather than cross, disciplinary divides (personal communication).

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