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Using participative Multi Criteria Analysis to facilitate recovery from aquatic acidification: a case study in South-West Scotland

by

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Abstract

Environmental problems are frequently characterised as being particularly complex, urgent and involving conflicting objectives. Tackling such problems would be greatly facilitated by the development of effective Decision Aids but traditional approaches, developed within the established rational-technical paradigm, are increasingly perceived as limited and exclusive. Integrative methods, combining traditional techniques with participative approaches, offer a way forward to new, more inclusive policy making. One such method is Participative Multi Criteria Analysis (PMCA), involving the use of Multi Criteria Decision Making technique with several stakeholders. This study reports the development of a new PMCA technique: Simple Multi Attribute Rating for Enhanced Stakeholder Take-up' (SMARTEST), developed from an existing method (SMARTER) of Edwards and Barron (1994). SMARTEST involves innovations designed to increase ease-of-use and acceptability to participants which retaining robustness, using iterativity to facilitate engagement. The study reports the prototyping of SMARTEST in a case study examining remediation strategy for the River Cree in South-West Scotland, which shows retarded biological recovery following acidification. SMARTEST was used to identify and compare six recovery options against twelve criteria with representatives of six stakeholder groups. Results indicated that SMARTEST was easy to use and encouraged engagement in decision making as the process was instrumental in enabling stakeholders to re-examine their initial positions and to compare them with those of other stakeholders. Using a three dimensional model of participation developed specifically for this study – termed the *Breadth-Impact-Depth* model – indicated that SMARTEST was able to facilitate greater impact of participation than previous studies. Effectiveness of SMARTEST was contingent, however, on the nature of the inter-stakeholder relationships and interactions between stakeholders and facilitator. Participative MCA has the potential for opening up new ways to tackle environmental problems and further study is needed to develop and evaluate SMARTEST.

Contents

List of figures

List of tables

List of equations

Abbreviations

ANC	Acid Neutralising Capacity
AS	Acid Sensitive
BaU	Business as Usual
BID	Breadth, Impact, Depth
CBA	Cost Benefit Analysis
CCF	Continuous Cover forestry
CL	Critical Load
CLRTAP	Convention on Long-Range Transboundary Air Pollution
CVCWT	The Cree Valley Community Woodlands Trust
D & G	Dumfries and Galloway Council
EMEP	European Monitoring of Emissions Programme
EPC	Extended Peer Community
EU	European Union
FCS	Forestry Commission Scotland
FWG	Forest Water Guidelines
GFT	Galloway Fisheries Trust
IA	Integrated Assessment
IM	Impact Matrix
IPCC	Intergovernmental Panel on Climate Change
LRTAP	Long Distance Transport of Air Pollutants
MAGIC	Model of Acidification of Groundwater in Catchments
MAUT	Multi Attribute Utility Theory
MAVT	Multi Attribute Value Theory
MCA	Multi Criteria Analysis
MCDA	Multi Criteria Decision Aid or Analysis
MCDM	Multi Criteria Decision Making
MCE	Multi Criteria Evaluation
MCM	Multi-Criteria Mapping
NGO	Non-Governmental Organisation
NO_x	Nitric Oxide (NO) and Nitrogen Dioxide (NO_2)
OECD	Organisation for Economic Co-operation and Development
PAR	Participative Action Research

PMCA	Participative Multi Criteria Analysis
PNS	Post Normal Science
PUS	Public Understanding of Science
ROC	Rank Order Centroid
ROD	Rank Order Distribution
RR	Rank Reciprocal
RS	Rank Sum
RT	Rational Technical
SAC	Special Area of Conservation
SEPA	Scottish Environmental Protection Agency
SMART	Simple Multi Attribute Rating Technique
SMARTER	SMART Exploiting Ranks
SMARTEST	Simple Multi Attribute Rating Technique for Enhanced Stakeholder Take-up
SMARTS	SMART using Swings
SMCE	Social Multi Criteria Evaluation
SNH	Scottish Natural Heritage
SPA	Special Protection Area
SQ	Status Quo
SSK	Sociology of Scientific Knowledge
SSSI	Site of Special Scientific Interest
SSWC	Steady-State Water Chemistry
UKAWMN	United Kingdom Acid Waters Monitoring Network
UNECE	The UN Economic Commission for Europe
UNESCO	United Nations Education, Science and Culture Organisation
WFD	Water Framework Directive

Chapter 1. Introduction

1.1 The nature of the problem: Environmental Decision Making

"*… Along the flowery banks of Cree …*" Robert Burns (1759–1796)

When Robert Burns, Scotland's national poet, wrote of the "flowery banks of Cree" the industrial revolution had scarcely begun. The river Cree, in rural South West Scotland, might then have been seen as a pristine, pastoral idyll. In the intervening two centuries the world has been transformed by science and by the technology that science has enabled. Industrialisation has brought enormous benefits in terms of health and well-being, but also huge costs in terms of damage to ecosystems, some of which are only now being revealed. But during the two centuries that have elapsed since Burns wrote those lines the physical appearance of the River Cree has changed little. Its banks remain 'flowery' and have not been marred by factory development, nor have its waters been contaminated by their outflows. The pollution of the Cree is of a more insidious type - one that was virtually unknown until the second half of the twentieth century - that of aquatic acidification arising from gaseous discharges that have been emitted hundreds of miles away. Aquatic acidification was one of the first recognised examples of transboundary pollution, where contaminants arising in one country cause environmental damage in another, and provided a crucial step in our understanding that pollution is a global, as well as a local, problem (Schindler 1988; Monteith and Evans 2005).

This acidifying pollution has now been studied for over forty years and many of its complexities have been disentangled. Initially, however, the science of how such pollution affected aquatic systems was highly contested (Elsworth 1984). It was only after prolonged and sometimes heated debate, which encompassed both the academic and the political spheres, that agreement emerged in the 1970s. It was then established that atmospheric emissions – primarily of sulphur and nitrogen oxides from power stations and automobiles – were responsible for the damage to aquatic and forest ecosystems (Monteith and Evans 2005). The actions that were then taken following this consensus were dramatic in their impact: acidification seemed to be the first transboundary environmental problems that could be solved through science-informed policy. The resulting international treaties were remarkably successful at both the political and environmental levels and seemed – for a time – to control global emissions. Monitoring of the affected waters showed that chemical recovery was well advanced and that biological recovery had begun (UKAWMN 2001). By the start of the new millennium a perception developed that aquatic acidification was a problem solved; the attention of the public, the media and of many scientists turned to other, more pressing environmental problems.

The question of aquatic acidification has therefore gone through the entire cycle common to many environmental problems: lack of awareness turns to concern and media attention that in turn generate controversy before sufficient consensus is reached to force institutional responses (Jordan and O'Riordan 2000). However, it is possible that the cycle is now about to restart, as monitoring shows global emissions again rising while ecosystem recovery is far from complete (Bouwman et al 2002; Colls 2002, Richter et al 2005). Indeed, in some areas biological improvement of acidified ecosystems lags far behind chemical recovery (UKAWMN 2001; Davies et al 2005; Monteith and Evans 2005). The precise reasons for such retarded recovery remain unclear and subject to dispute (Ledger and Hildrew 2005). As a consequence, there is little agreement on what steps can and should be taken to speed up recovery from acidification. This apparent complacency that acidification has been solved may well be misplaced: the problem of aquatic acidification might be about to return.

If acidification does become recognised anew as a pressing environmental problem it will merely be one among many. The environmental crises facing the world at the beginning of the 21st century seem virtually insurmountable. The multiple complexities of the problems are unprecedented while the risks of failure may be cataclysmic.

No consensus has so far emerged, however, as how to tackle these questions. Furthermore, the very goals of environmental policy are, frequently, highly contested. Thus environmental problems – and their solutions – are not only technical but also social and political (Sloep and van Dam-Mieras 1995); society has yet to learn how to create agreement from this current discord.

Making progress in this respect is hampered, however, by fundamental disagreements concerning methodologies that have arisen from this realisation that environmental problems belong to the social as well as the natural world. Traditional scientific approaches, which only a generation ago would command widespread respect, are now greeted with suspicion or even hostility by significant proportions of the population (Irwin and Wynne 1996, O'Riordan 2000b), following widely publicized alarm concerning BSE, GM foods, nuclear power and other crucial environmental issues (Carolan 2008; France 2010). Furthermore, elements within the academic community have provided a comprehensive critique (often labeled 'post-modernist') of the epistemological assumptions upon which science is based. Science, once accepted as the best solution to most societal problems, is now perceived by many as the source of those problems itself (Allan 2002). There are multiple examples – for instance in renewable energy policy, waste disposal and, most acutely, in climate change – where policy is paralysed as the best scientific advice is rejected by significant parts of the populace. Democratic societies, with their implicit assumption that difficult decisions can only be carried out with widespread consensus, seem hamstrung by this confrontation between science and its critics: environmental policy is, too often, in a deadlock.

This conflict, between science and its detractors, is exemplified in the field of environmental decision making. Established methods based within the scientific tradition, that can be termed 'Rational-Technical' (RT), seemed at one time to offer ideal, systematic techniques to make the best decisions. Multi Criteria Analysis (MCA) (often termed Multi Criteria Decision Making - MCDM), for instance, was developed within Operations Research using mathematical modelling. MCA is a structured, systematic approach to decision making (Proctor and Dreschler 2006). Its key distinguishing feature is the recognition that for many problems there exists a plurality of objectives (Edwards and Barron 1994); that is, there are several different criteria by which the outcomes will be evaluated, hence its name (and thus distinguishing MCA from methods such as Cost Benefit Analysis which utilise only a single criterion: Messner et al 2006). MCA requires that all relevant criteria are identified, as are all potential solutions (usually termed options). Most types of MCA also recognise that criteria are not equally important so that each is given a weighting. Each option is then analysed with respect to the likely impact on each weighted criterion, allowing overall comparisons of options to be made. MCA is a quintessentially logical, rational technique that has been widely used in management science for an array of business decisions.

It would appear, therefore, to be a straightforward matter to apply the same successful approach to environmental problems. But the more general scepticism concerning the applicability of the scientific method has undermined the perceived legitimacy of such methods. MCA and related Rational-Technical techniques have become increasingly censured for their perceived narrowness and exclusivity. They are seen by many as representing a top-down model of expert decision making, characterised by technical complexity that renders them inaccessible to many, that can provide a cover for the power of establishment elites to make policy in their own interest. The notions of objectivity and disinterestedness, key concepts in the scientific method, are seen by some as, at best, an unrealizable ideal, at worst a subterfuge. Consequently, public confidence in such methods, required if difficult policy decisions are to gain legitimacy, has often been eroded. However, the critics of the Rational-Technical approach have in their turn failed to offer straightforward alternative methods that have been evaluated and shown to be effective. The gulf between those advocating conventional scientific decision making methods and their detractors remains unresolved, resulting in an impasse that impedes, in some cases, the decision making process and, in others, undermines the acceptance of those decisions that are made.

One way forward from this deadlock is to develop innovative ways of tackling environmental problems that encompass the best scientific principles, but also acknowledge the validity of those criticisms that their application to decision making is often exclusive and undemocratic. Such integrative, synthesising methods stress the importance, therefore, of ensuring meaningful participation in the decision making process.

Participation itself, however, is an imperfectly understood concept (Reed 2008), bundling together both quantitative and qualitative aspects: the former, which can be termed inclusivity, denotes not only the numbers of those involved in a decision (termed here the breadth of participation) but also the extent to which they come from outside the normal decision-making groups (depth of participation); the latter, that can be termed deliberativeness or impact, relates to the extent to which participants exert control over the decision making process itself[1]. Integrative methods that can synthesise the power of the Rational-Technical tradition with the democratic legitimacy of participative decision-making offer the prospect of breaking out of the impasse in environmental policy. Such methods, if they could be developed, would command greater public confidence and engagement while also delivering solutions most likely to succeed. Such methods would combine effective outcomes with acceptable processes. Unfortunately, integrative methods of this type are still at the developmental stage and have yet to be widely accepted as having proven effectiveness.

This is illustrated within the field of environmental decision-making by the example of participative MCA (PMCA). As the name would imply, the aim of PMCA is to adapt the systematic, mathematically-based decision-making power of the MCA technique for use in an inclusive, deliberative process. While traditional MCA focused on providing a single decision maker with the best possible solution to a problem, there was usually less emphasis attached to the insights provided into the underlying nature of the problem (Henig and Weintraub 2006). Participative MCA, in contrast, emphasises the importance of stakeholder engagement with the process and of working with several stakeholders, rather than one (Paneque et al 2009). Claims have been made that this offers participants greater understanding of the problem and of the nature of differences between stakeholders, thus expediting conflict resolution (Hostmann et al 2005). Potentially such an approach offers a type of integrative method that combines rationality with a more inclusive, deliberative process, thus securing better decisions which attract more widespread acceptance.

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[1] This analysis, based on the idea that participation is multi-dimensional, is developed further in section 2.4.1

There would be great advantages in the development of effective PMCA. However, while various types of PMCA has become increasingly used for environmental problems, systematic and comprehensive evaluation has seldom been carried out and there is no general agreement concerning which specific techniques are best suited to such use. This study will argue, furthermore, that much of that effort has been misplaced or ended in failure: very few so called examples of PMCA involve any significant degree of participation. The MCA method itself often remains technically complex and inaccessible to the non-expert participant. Moreover, few attempts at PMCA have genuinely addressed inclusivity or involved proper deliberation. Stakeholders are often selected from narrow, elite groups; where a more inclusive approach has been used, stakeholders have had no engagement with the process. For instance, some studies have used survey method to gain information on attitudes that were then fed into the decision making process, without participants having any control over how this is done (or in some cases, even awareness that their views are used in this way) (for instance Tzeng et al 2002; Duke and Aull-Hyde 2002). PMCA in practice – and with a few noteworthy but little known exceptions such as Mander (2005) - is often disappointing, falling short of its own stated aims, and not only failing to deliver significantly enhanced participation but also having little impact of the decision outcome. Participative MCA is, as yet, a promise unfulfilled.

1.2 Aims, objectives and the research question

This study aims to contribute towards the development of PMCA by prototyping a highly participative type of Multi Criteria Analysis and evaluating this in a case study of recovery from acidification of the River Cree. It does so through building on and extending previous developments of PMCA by developing and trialling a highly participative, iterative new version of an existing MCA technique, termed the 'Simple Multi Attribute Rating Technique for Enhanced Stakeholder Take-up' (SMARTEST).

SMARTEST has been developed from the 'Simple Multi Attribute Rating Technique Exploiting Ranks' (SMARTER), which in turn was developed from the earlier SMART method (Edward and Barron 1994; Barron and Barrett 1996a and 1996b). This is a simplified, straightforward form of MCA. SMARTEST makes some minor but nevertheless significant technical changes to SMARTER in relation to the weighting of criteria and adds major innovations in the process by which it is applied, building in significant iteration, deliberation and reflection for use with multiple stakeholder participants. SMARTEST was designed to avoid those technical complexities of many MCA techniques that render them inaccessible to many participants, with the intention of facilitating transparency and group working and overall impact.

The evaluation was carried out using a case study of recovery from acidification of the River Cree. The topic of acidification was selected for a number of reasons. First, as outlined above, there has arisen considerable complacency concerning acidification that may, arguably be misplaced. That is, this is an issue that now seems less pressing than other environmental problems but which may be about to re-emerge as an urgent question. Second, it stands as representative of that type of environmental problem, with complex causes, outcomes and mediating variables, that attract sharply contested views from different stakeholders. Furthermore, acidification is especially relevant to Scotland through a combination of that nation's geographical location in relation to sources of pollution, its geology, land-use and its economy.

In the development of this study it is also significant that acidification of the Cree was the subject of the author's M.Res dissertation study, which immediately preceded the current work (and subsequently formed the preliminary year of this Ph.D.). In that work, the author conducted an experiment to investigate the extent to which recovery of tributaries of the Cree might be linked to the underlying geology or to land-use (specifically, to coniferous afforestation). The results of the study showed that all six of the streams examined showed good chemical recovery but that, in some, there was evidence for significantly retarded biological recovery where invertebrate biodiversity was very low. Both geology and land-use seemed to be indicated as contributory causal factors. The background to this study, together with the implications of the results for recovery options, is discussed in chapter 5, section 5.3. Most importantly for the current study, however, was the author's realisation during the research process that possible solutions to the acidification problem in this river were not entirely technical; that is, it was not a straightforward question of establish the local causal factors and selecting appropriate remediation methods. Equally, or perhaps even more important were the social and political factors: several organisations –from the statutory and voluntary sectors – had significant vested interests in the problem and, in some cases, clear but conflicting ideas of the best way forward. The issue seemed, therefore, to be one that required the sort of decision making aid that participative Multi Criteria Analysis was designed to be. It was from this insight that the rationale for the present study developed[2]

The aim of the study was, therefore, to evaluate the effectiveness of a new participative MCA technique (SMARTEST) in collective environmental decision making using a case study. The objectives, required to achieve this aim, were:

1. To develop the new participative technique;
2. To identify potential stakeholders;
3. To use the new technique with the stakeholders;
4. To evaluate the effectiveness of the method in facilitating the decision making process.

The formal research question was: to what extent is SMARTEST, a new version of a PMCA technique, an effective method for enhancing participative decision making?

[2] The abstract of the M.Res study is included as Appendix 7.

1.3 The study area

The trial and evaluation of SMARTEST was carried out in the setting of a case study of developing policy options for the recovery of a river from acidification. The river selected for this was the River Cree in South West Scotland, lying within the Galloway hills. This had been the setting for the author's M.Res research that preceded this study. In addition, the area had been subject to considerable previous research, including some of those that were seminal in the identification of aquatic acidification as arising from transboundary pollution (Rendall and Bell 2008). Despite the fall in global acidifying emissions, chemical recovery did not advance as quickly as expected (Helliwell et al 2001). The Scottish Environmental Protection Agency annual report of 2006 identified the Cree as an area of specific concern with regard to acidification, with some streams showing very retarded biological recovery. The report went on to suggest that both the underlying igneous geology and the very extensive coniferous forestation of the catchment were implicated in this retardation (SEPA 2006). However, there was no consensus as to the relative contribution of these factors to the extent of the problem and consequently there was disagreement as to the best policy for recovery. The Cree was therefore identified as an ideal location for the study.

1.4 The approach adopted to research methodology

The evaluation of SMARTEST was carried out using a case study design frame. Thomas (2010) suggests that in a case study a clear distinction should be drawn between the subject of the study (the case itself) and the object, which is the analytic frame through which the case is examined. In this example, the subject of the study was the process by which stakeholders developed policy for the river's recovery from acidification; the object was the role played by the SMARTEST MCA technique in facilitating this process.

The study itself, conducted over 18 months between 2008 and 2010, used an interpretivist approach in the form of Participatory Action Research (PAR). PAR conducts research at the same time as it attempts to influence some form of outcome (Learning for Sustainability 2011). Thus the author of this study worked closely with the participants (the stakeholders) on policy development. While the aim of this study was the evaluation of the SMARTEST MCA technique, the purpose of the PAR itself was also to facilitate the decision making process and thus arrive at appropriate policy for the river's recovery.

1.5 Significance and originality

This study aspired to break fresh ground in exploring the extent to which participation may be built into the decision making process while maintaining the systematic and rationalist rigour of the underlying MCA technique. An innovative analytical technique termed the BID model (an acronym referring to its examination of *Breadth, Impact* and *Depth* of participation) was developed for this study and used in a review of a sample of the published literature on the use of MCA in environmental problems. This review showed that none of the papers reviewed had utilised methods that were as fully participative as that employed in this study.

If that evaluation of the technique shows it to have the capacity to be an effective participative MCA method then there are clear potential impacts on environmental decision making, in that such decisions may be made quicker, with broader and wider support and thus secure greater legitimacy.

The study also contributes to that body of knowledge concerning the nature of decision making, participation and the relationship between experts and decision makers. It also provides a new analysis of the role of theoretical perspectives on such processes, with a review of the utility of approaches such as Post-Normal Science. Finally, the study will add to the understanding of aquatic acidification recovery in general and, more specifically, how such recovery may be designed for upland rivers in Scotland.

1.6 The structure of this thesis.

Chapter 2 explores some of the issues outlined in this chapter in the context of environmental policy making. In particular it examines the apparent dichotomy between traditional rational approaches and their post-modern alternatives, before identifying trends that attempt to fuse these two strands. One of these trends – the use of extended participation – is discussed in some detail, as is the emerging paradigm of Post Normal Science, which is often used to justify such an approach.

Chapter 3 then outlines one of these 'fusion technologies' – MCA – in some detail, and in particular discusses the potential of PMCA. It examines a sample of studies that claim to use MCA participatively and identifies relatively few exemplars of good practice. These serve as models for the development of the SMARTEST method.

The subject of this case study – recovery from aquatic acidification - is a complex and contested area. In order to provide a clear understanding of the context within which SMARTEST is used in this study, Chapter 4 provides an overview of the science of acidification. It summarises the considerable body of research conducted from the 1960s onwards into the causes, proximal and ultimate, of acidification and its effects.

The methodology used in this study is reported in chapter 5 and the results presented in chapter 6, which also provides a critical analysis of how SMARTEST was used in the case study. Chapter 7 commences with a discussion of the implications of the results of this study, but then moves to a broader discussion of the lessons for environmental decision making. Finally, some conclusions can be drawn and, from these, recommendations made.

Chapter 2. Environmental Policy and decision making – conflict and convergence

2.1 Introduction: the contested nature of environmental policy analysis

Chapter 1 of this study outlined some of the epistemological and methodological difficulties that confront environmental policy makers. These are explored further in this chapter, where it is proposed that one of the most significant underlying problems is the contestation between those advocating traditional Rational Technical (RT) approaches and their critics. It is further proposed that an integration, which provides a synthesis of these opposing views, is under development.

Policy Analysis may be divided into 'Analysis of Policy', which is descriptive, and 'Analysis for Policy', which is the process that supports decision making. The latter can be defined as the identification of which policy alternative will achieve a specified set of goals (Nagel 1999) and can thus be regarded as a form of decision making (McGrew and Wilson 1982). In this study the term 'policy analysis' is used to denote the broad context within which policy is developed while 'decision making' refers to that part of the process where specific options are selected.

This chapter commences (section 2.2) with a brief introduction to the distinguishing features of traditional technical-rational methods before considering some of the criticisms directed not only at the methodology but also at its underlying epistemology. Section 2.3 then critically reviews some of approaches, which can be described as post-modernist, that have been put forward as alternatives, focusing on some of those most frequently used in environmental policy. These are often characterised by an emphasis on the value of subjectivity in policy formulation, and this in turn leads to explicit calls for transparency and, consequently, participation. Section 2.4 considers this problematic issue of participation, what it entails and how it can facilitated. From this discussion a new analytical framework for the analysis of participation is developed, labeled the BID model to denote its three dimensions of *Breadth, Impact* and *Depth,* in section 2.4.1. This enables comparisons to be made between different activities in terms of their degree of participation in each of these three aspects. It is then proposed, in section 2.5, that the dichotomy between Rational-Technical methods and postmodernist approaches is, to a significant extent, misleading, masking confusion between prescriptive and descriptive analysis on the one hand and a failure to recognise the growing convergence between methods on the other. Section 2.6 examines some of those frameworks that have emerged from this convergence, including Co-constructionism, Civic Science, Citizen Science and Post-Normal Science (PNS). This review concludes that PNS appears to represent one of the most widely accepted vehicle for a synthesis between traditional rational methods and postmodern, subjectivist alternatives. The chapter concludes with a brief consideration of the practical implications of these new approaches to environmental policy making and, in particular, how participatory Multi Criteria Analysis (MCA) may become a valuable new method therein.

2.2 The rational-technical approach to decision making and its critics

The dominant tradition within policy analysis has been characterized as managerial and objectivist, emphasizing the importance of empiricism (House 1978, Owen et al 2004) and using cumulative and stepwise methods (Bochel and Duncan 2007). McGrew and Wilson (1982) argued that such policy formulation, which they termed the rational decision making model, was characterized by a separation of outcomes, objectives and goals on the one hand and the means of achieving them (the alternative courses of action that are available) on the other. Furthermore, rational methods use rule-based processes to compare the outcomes associated with each course of action. The central justification of the rational approach is, therefore, that it based its judgments on the extent to which outcomes meet objectives[3]. Typically, this systematic process involves firstly the identification of overall policy objectives, then the consideration of the range of the alternatives available, and finally a

[3] In this approach, objectives are set at the beginning of the process. This can be contrasted to those approaches in which policy objectives are constantly shifting during the policy making process, or where policy can be justified in relation to serendipitous outcomes. More fundamentally, policy making in a post-modern framework may be set free from linkage with objectives altogether.

methodical comparison of each alternative in relation to each policy objective (Carley 1981, Richardson and Jordan 1979).[4] Such stage-based techniques, emphasizing as they do the necessity of logicality and rationality, and often developing more or less complex mathematical techniques to support them, are termed 'Rational-Technical' (RT) methods in this study.

A further and important distinction was drawn by Simon (1976) between two forms of rationality. The stronger form of rationality, which he termed 'substantive rationality', is characterised by high levels of certainty with regards to outcomes thus allowing fully objective judgments to be made which invariably allow the optimum alternative to be identified. In most cases this idealised, 'rational-comprehensive' model (Richardson and Jordan 1979) is not realisable, however, and policy making must be based on a weaker form, called by Simon 'procedural rationality' - a less robust process characterized by uncertainty. Such policy-making cannot claim to invariably find the single best solution, according to Simon, but in contrast can claim to be the outcome of 'appropriate deliberation' (Simon 1976 p 88). Problems with the exact meaning of this phrase – and how one can decide on what is 'appropriate' - underlie much of the controversy and confusion that characterize discussion on policy analysis.

Rational-Technical techniques and the theory on which it is based have, however, been subject to comprehensive and growing criticism, which is outlined in the following sections. While this critique was initially directed at the specific use of Rational-Technical techniques applied to Policy Analysis, there has been a second postmodernist strand of analysis that has focused on the underlying epistemology of the Rational-Technical approach (Fischer 1993).

The first strand of criticism of the Rational-Technical approach derives from Simon's binary classification of substantive and procedural rationality (Simon 1976). He argued that quantitative methods, derived from assumptions based on substantive rationality, were inappropriate when applied to real-world problems with high levels of uncertainty. Such

[4] These stages prefigure the first three steps in Multi Criteria Analysis, as discussed in the next chapter. MCA can be seen to have developed, therefore, from the direct lineage of rational methods.

techniques were, therefore, unrealistic and failed to reflect the illogical realities of much policy making. Simon (1972) questioned the assumption, implicit in Rational-Technical techniques designed for substantive rationality contexts (typically, theoretical economics), that perfect knowledge is attainable and that humans have the cognitive processing capacity required to manage such complexity. On the contrary, Simon maintained, rationality is severely constrained, resulting in what he termed 'bounded rationality'. Consequently much decision making, in reality, involves what he termed 'satisficing' – finding the first alternative that meets minimum requirements – rather than the rational optimizing that underpins Rational-Technical assumptions. Real-world policy problems are typified by lack of information, uncertainty and imperfect cognitive abilities; within such constraints the policy maker can optimally only make a 'good enough' decision: one that demonstrates that 'appropriate deliberation'.

In the same period that Simon was developing his model of bounded rationality, Lindblom (1959, 1979) introduced the idea of incremental decision making as a description of policy as it is often conducted in practice. He suggested that such 'disjointed incrementalism', rather than an uninterrupted rational progression, was common. Policy makers react, he proposed, to changing circumstances – which might involve amending original objectives – in a series of 'baby steps'; policy development is thus seen as evolutionary rather than revolutionary. Lindblom (1959:79) called such processes 'muddling through': a term subsequently frequently quoted (and possibly misquoted). It should be noted that Lindblom's model is essentially descriptive, not prescriptive. However, it seems likely that in some cases it has been cited as a normative justification for a reactive policy process that fails to attempt a more proactive, planned method. Nevertheless, Lindblom's critique clearly suggests that Rational-Technical techniques failed to provide an accurate description of 'real' decision making.

This thread of criticism of Rational-Technical methods was summarized by Hall (1982) and Glasser (1998). They identified a number of respects in which the 'Comprehensive Rationality' approach, exemplified by Rational-Technical techniques, is unrealistic. Firstly, criteria (that is, objectives) may be ill-defined and impossible to quantify. Secondly, available information is often imperfect while obtaining further information is often too costly (in time or resources), forcing policy makers (the actors involved in the process) to fall back on subjective judgment. Furthermore, individual preferences are often incomplete, fluid and dynamic: they will change with circumstances. Finally, the actors themselves are often in competition in an essentially political process, resulting in a 'zero-sum game'.

There are, therefore, two elements of such criticisms: firstly, that as a prescriptive approach Rational-Technical technique cannot attempt to describe the realities of policy analysis (Lindblom); secondly that Rational-Technical is impractical in its aspirations insofar as the actuality of the policy context prevents it from being attained (Simon and Glasser). The first argues that Rational-Technical fails as a descriptive technique in analysis *of* policy; the second, that it fails as a normative approach in analysis *for* policy. Furthermore, this second element is derived from a more fundamental indictment: that the underlying epistemology of the Rational-Technical method is inappropriate and is, indeed, flawed.

Traditional Rational-Technical methods are located within a scientific, objectivist and positivist epistemology (Owens et al 2004). Debates during the middle of 20th century between logical positivists (of the Vienna school) and postpositivists (such as Kuhn and Popper), resulted in the emergence of an apparent consensus of the epistemological basis of the scientific method (which might be equated with Popper's critical rationalism). However, there has subsequently been a developing critique of this position. For instance, De Marchi and Ravetz (2001) argue that science needs to move away from the "outdated notions of positivism and absolute knowledge" (p6). One strand of this attack on the positivist basis of rationality has coalesced around the ideas of social constructionism[5] (Norton 2001, Sardar and Loon 2001).

Social constructionist theorists argue that all knowledge – including scientific knowledge - is the product of the specific human society or culture within which it emerges. Contrary to the

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[5] The terms constructionism and constructivism are used interchangeably here, although 'constructionism' derives from sociology and 'constructivism' from philosophy.

ideas of realism[6], all knowledge is, therefore, relative. As Eckersley (1992) reasons, the way in which reality is perceived changes constantly over time. Moreover, knowledge is contested and forms the currency of conflicts between societal groups (thus the often abused phrase 'knowledge is power'). As Hannigan (2006) contends, in the context of the development of understanding of environmental issues, progress depends on 'claims-making' by various social actors. In other words, one's understanding of an environmental problem at any given time has been created by social forces, or as Stirling and Mayer (2001: 530) assert, it is "fundamentally context dependent, subjective, and thence political in character"[7].

The extension of this line of reasoning is that policy formulation is less about a reasoned and objective assessment of options in relation to objectives, and more a political struggle between competing players intra- or inter-organizationally[8]. Modern versions of the rational approach applied to policy analysis, such as Evidence-based and Forward-looking policy, have similarly been opposed for their positivist assumptions which neglect the realities of power relationships and fail to acknowledge the belief systems that underpin them (Bochel and Duncan 2007). According to this view, 'how to decide' may be less important than 'who decides', especially in complex and controversial issues. Rational methods, it can be argued, assume a simple linear process wherein objective experts inform single decision makers (Owens et al 2004). In contrast, these critics argue, decision makers are often part of competing coalitions. Experts become tied into the decision making loop in complex ways which undermine their apparent objectivity and disinterestedness. Moreover, decision makers may set the initial parameters of policy analysis by formulating what constitutes the

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[6] Or "epistemological naive realism" as Funtowicz and Ravetz (1994: 577) characterise it.

[7] The more extreme, postmodern versions of the social constructionist position were the subject of severe counter attacks from within the scientific community during the so-called 'science wars' of the 1990's, as illustrated by the Sokal hoax of 1997. Sokal wrote a spoof article that argued that the value of π (pi) was socially constructed, and managed to have it published in the prestigious, peer-reviewed postmodern journal 'Social Text' (Franklin 2012). The fact that the more excessive forms of the relativist position have been held up to such ridicule does not, however, automatically invalidate the more moderate and reasoned constructionist views.

[8] This proposition – that policy formulation is essentially a political process – was most notably stated in Allison's (1971) seminal analysis of decision making during the Cuban missile crisis, discussed further in chapter 3 (Hall 1980; McGrew and Wilson 1982).

initial problem. As Glasser (1998) suggests there may be plural rationalities, involving different values.

Furthermore, this critique of the positivistic approach inherent in Rational-Technical methods asserts that the aspiration towards objectivity is unobtainable and unrealistic for social, rather than psychological reasons (as Simon (1976) contended). This 'critical approach' holds that reality – including our scientific understanding of it - is socially constructed (Khakee 1998). Thus science is seen as being far from the impartial, dispassionate and independent activity that its proponents claim. On the contrary, it is argued, science is value laden, influenced by the organizational setting and its finance ('who pays') (Wynne and Meyer 1993). France (2010), for instance, in the context of the debate on Genetic Engineering in New Zealand, outlines the concerns about how independent science was of the commercial interests that funded it, and how increasingly there was a public perception that science was controlled by business. France (2010:2) goes on to quote the New Zealand Parliamentary Commissioner for Science as saying "*... there's a widespread perception that the soul of science is, or has been, bought...".*

This is perhaps one end of the constructionist spectrum, which more generally perceives science as a culture which, as with any other, has its own set of socially constructed beliefs, values, discourses and norms (O'Riordan 2000). Decision making will thus involve compromise between competing value and belief systems, and is viewed as a social process, not centered on the isolated, objective, uninvolved individual that is presupposed by comprehensive rationality (Glasser 1998). Similarly Barbarente et al (1998) assert that disinterested knowledge does not exist – there are always tacit premises. From this postmodernist deconstruction of science and its methodology, comes the view of the "the social embeddedness of science" (Liberatore 1995), within which scientific findings are translated into economic and policy terms in complex interfaces.

A third, and associated, strand of criticism of Rational-Technical methods and the scientism upon which it is based contends that science in practice is flawed by its elitism and exclusiveness (O'Riordan 2000b). Blok et al (2008) explore this through the idea of the "lay-expert discrepancy" perspective in the context of "technical decision-making" (that is, the intersection of scientific /technical and political issues). They argue that expert-based "regulatory science" lacks "public understanding and legitimacy". While the public lacks access to expert institutional contexts, experts are thus given "cognitive authority" via their memberships of exclusive epistemic communities (Liberatore 1995). According to Barbarente et al (1998) modernity is characterized by a break with traditional social organization insofar as problems are left to experts who have specialist technical knowledge. Thus expert knowledge and the experts who are its gatekeepers become more important – and powerful – as society becomes more complex and dependent on technology. But at the same time such experts – especially scientists – become more removed and isolated from ordinary citizens whose lives are largely determined by their work. For Hannigan (2006), the material benefits brought by such modernity blinded its potential critics for much of the 20th century. The environmental crises that emerged in the 1970's represented the beginning of a realization that this over-reliance on expert opinion was potentially dangerous to societal well-being.

Popular disenchantment with the perceived elitism of scientists, coupled with concern over supposed failings of science to deal with environmental problems, led in the last decades of the 20th century to declining popular support for science. Science seemed to have alienated itself from the public, leading to a questioning of science's very credibility (Allan 2002). This led to a radical response from within the scientific establishment: the 'Public Understanding of Science' (PUS) movement, stimulated by the Royal Society's 1985 Report with that title (Tomei et al 2006). This explicitly linked the need for greater public support for science with national economic prosperity, but also suggested that the public understanding of science would raise "the quality of public and private decision making "(Royal Society 1985:2). The 2000 House of Lords report 2000 *Science and Society:* described a crisis in confidence in science, undermined particularly by high profile controversies such as those surrounding BSE and biotechnology, resulting in widespread mistrust. Henriksen and Frøyland (2000) chart the process by which such suspicion of science influences and undermines the way in which lay (that is, non-expert) public engage with science[9]. The

[9] Although this section concentrates on growing mistrust with science specifically there is evidence

relationship between the scientific community on the one hand and wider society on the other – once characterized by a general respect and deference of the latter to the former- became a thoroughly troubled one, with suspicion more frequently apparent than respect (Irwin and Wynne 1996, O'Riordan 2000b).

The PUS response to this crisis, which was intended to allay such suspicion, was, however, based on the notion of a "knowledge gap": that the lay public was lacking in knowledge and understanding, and so needed to be educated in science, in accessible ways, that would reduce the apparent gap between scientists and lay persons. PUS itself became the target for sustained criticism, however, especially from within the Sociology of Scientific Knowledge (SSK) school. Irwin and Wynne (1996), for instance, labeled PUS as a "deficit model", based on normative assumptions of the ignorance of the non-scientific public and which demoted other forms of knowledge, such as experience and skills (Tytler et al 2001). PUS, according to Irwin and Wynne, problematises the general public rather than scientific institutions in an attempt to deflect legitimate criticism[10]. Furthermore, Irwin and Wynne (1996) maintain that current ambivalence about the status and the authority of science can turn into hostility among some groups who oppose aspects of modern technological civilization, such as (some) animal rights activists. This leads to a further distrust of expert scientific opinions and belief that demand for scientific proof can be a way of delaying action[11]. The postmodernist position would argue, moreover, that the public 'ignorance', which is implicit within the PUS deficit model, is a socially constructed concept that is it is

for a more generalised decrease in confidence in all expert-based policy making approaches (Stirling 2006)

[10] This position adopts a democratic and participative agenda which emphasises the detailed and sophisticated knowledge that non-scientists may have concerning particular environmental problems. Tytler et al (2001), for instance, cite Wynne's comparison of the "reflexivity and subtlety of the thinking of local Cumbrian farmers with the less flexible, and somewhat arrogant, position taken by the scientists involved" (p334). For a critique of this analysis see Durant (2008), who accuses the critics of PUS of "imputing demons to scientists in order to exorcise them and imputing haloes to the lay public in order to admire them" (p18). Partially as a response to such criticisms, PUS may now be metamorphosing into PES: 'Public engagement with Science', a more interactive and democratic relationship between scientists and the general public.

[11] Irwin and Wynne (1996) suggest that a particularly clear example of this arose from the claims made in the 1970s by scientists working for the Central Electricity Generating Board and the UK government that there was no scientific basis for claims that emissions from UK power stations were leading to acidification of lakes in Europe.

dependent on who has the authority to label others 'ignorant' (Norton and Dovers 2001). The postmodernist criticism of science again hinges, therefore, on the latter's claim to objectivity and the former's assertion that such objectivity is neither feasible nor, indeed, desirable.

The charge, that science is not as disinterested as it is claims to be as it predisposed to support the interests of those who pay for it, is further extended by some critics into equating it with a free-market ideology. De Marchi and Ravetz (2001:3), for instance, suggest that the use in environmental problems of economic models based on consumer choice and monetary valuation is based on "science and rationality"; they claim, that is, that the ideology of the neo-liberalism is derived directly from the scientific paradigm. Cost-Benefit Analysis (CBA) is the most commonly used representative of these methods, rooted in the rational tradition and explicitly adopting the language of the market[12]. By extension, the ecological services approach uses a similar underlying rationale. De Marchi and Ravetz go on to contrast such approaches with those based on "justice and democracy" (p3). In this sense, then, science is seen as being closely identified with a particular political agenda. Similarly, the Economic Modernization theory (for instance Mol and Spaargaren 1995), which has become widely adopted as a justification for much environmental policy formulation, rests on the assumption that technological development and a capitalist mode of production are inextricably inter-related: one cannot have one without the other[13]. The claim is made, therefore, that rationality and ideology are intertwined; science cannot, according to this analysis, be non-ideological.

The postmodern critique on the claims of science, and thus of Rational-Technical methods, based as they are on a common epistemological framework, has been comprehensive and exhaustive. It goes beyond the simple notion that rational methods are 'utopian' (that is, idealist and unworkable) and extends to a more thoroughgoing examination of the fundamental claims of science to be objective and impartial. Indeed, it questions the entire

[12] One of the attractions of the Multi Criteria Analysis method is that it rejects some of the assumptions on which CBA is based: see chapter 5.
[13] For discussion of the Treadmill of Production theory, which provides the main theoretical critique of Ecological Modernization model, see Buttel (2004) and Hannigan (2006).

narrative of modernity based on a realist epistemology that is derived from expert knowledge (Durant 2008) and calls for a release from the 'straightjacket' of scientific rationalism (Bengs 2005). It also suggests that the claim to objectivity is protected from scrutiny by the elitist and closed nature of the scientific community. Science, and rational methods more generally, are – it is argued - socially embedded and subject to political forces as much as any other cultural movement.

For some commentators on the application of scientific methods to environmental problem, this epistemological critique becomes acute. Problems such as biodiversity loss, pollution and sustainable development are often characterised as multidimensional and requiring interdisciplinary (or transdisciplinary) solutions. Sloep and van Dam-Mieras (1995), for instance, argue that a tripartite interaction is necessary to address environmental problems, that is an interaction between Science, socio-political knowledge and societal norms. From this perspective, an exclusive and narrow positivist epistemological methodology alone cannot solve such complex problems[14]. Carolan (2008) summarizes this position: environmental problems are often complex and multidimensional, resting on epistemological, ontological and moral arguments. Natural science by itself cannot, therefore, provide answers, because the problems cannot be resolved through "materiality alone".

On the one hand, the postmodernist critique can also be seen – particularly in the context of environmental decision making techniques - as setting up scientific methods as caricatures, unfairly ignoring the complexity of such methods and the extent to which they already have begun to recognize the limits of rationality and objectivity and the political nature of much

[14] A derived but less relevant argument is that it is the Rational-Technical tendency towards reductionism that prevents it with dealing with the types of complexity found in environmental problems (for instance, Söderbaum 1998). However, much of contemporary scientific method has outgrown such criticism. Hannigan (2006) for instance traces the manner in which the science of ecology has overcome initial resistance from the traditional scientific community and has now, complete with its emphasis on higher-level, complex and non-reducible concepts, become widely accepted as the only vehicle for explaining some natural phenomena.

of the process, and thus the need for transparency and accountability. This view would suggest that the criticisms of the rational-technical approach has served not so much to demolish its legitimacy altogether, as some postmodernists seem to claim, but to expose its abuses and identify its omissions. Moreover, the argument is sometimes put forward that, because of increasing societal complexity there is a need for more, not less, rationality - and thus a retreat from extreme postmodernism. Thus the gulf between Rational-Technical and its postmodernist detractors may, therefore, not be as unbridgeable as initially seemed the case. This leads to the possibility of a convergence between the two approaches that previously seemed irreconcilable – an argument that is explored further below.

On the other hand, however, the postmodern and anti-positivist criticisms can be seen as a continuation of a long-running ontological conflict between realism and idealism, and of the corresponding epistemological debates between objectivism and constructionism. This in turn is manifested in ongoing methodological disputes, especially within the social sciences, between the experimental and quantitative approaches and a broad group of approaches based on interpretivism (such as Ethnography, Grounded Theory, and Discourse analysis). In recent years the balance of this debate has moved towards the latter. Post-modernism (which can be taken to be identified with the constructivist, intrepretivist school) has come to dominate much academic discussion and its critique of positivism seems widely accepted[15]. However, does the postmodern and constructionist approach propose practical methods as an alternative to the Rational-Technical? Some of the attempts to do so are discussed in the following section.

2.3 Alternative approaches to decision making

There is, then, by no means any consensus that the Rational-Technical approach, built on positivism and empiricism and located firmly within the scientific method, is a valid or useful one for environmental problem solving. The question must therefore be asked: what alternative methods have been developed, and what are their utilities? Two main

[15] This has been identified with a shift from a preoccupation with ontology to one with epistemology (that is, from 'what we know' to 'how we know it') (Lombardi 1998, Bengs 2005). See below for further discussion.

alternatives can be identified: firstly, those models that propose a more pragmatic approach to policy making and accept the limitations of knowledge available; second, approaches that explicitly reject objectivism and seek to substitute an overtly subjectivist method.

The first group includes those methods that can be characterised as accepting elements of Lindblom (1959) style 'muddling through' when tackling complex 'wicked problems'[16]. Adaptive Management and Transition Management both contain elements of this style of policy making, with an emphasis on small steps, reactiveness and flexibility.

Bryan Norton's Adaptive Management Theory developed from a North American tradition of pragmatism, with an emphasis on bottom-up, experimental procedures (see Leist and Holland 2000). Adaptive Management (or Adaptive Resource Management: ARM) stresses an iterative 'learning-by-doing' process, in which uncertainty is modelled using Bayesian inference. Holling (1978), who developed this methodology for environmental impact assessment and management, identified four key features of ecosystems which need to be taken into account in the policy development processes:

1. 'Organized connection': ecological subsystems interact selectively (not all connections are equally important; everything is *not* connected to everything else[17]);
2. 'Spatial (and temporal) heterogeneity': characterised by non-linear relationships;
3. 'Resilience': ecosystems are self-correcting (homeostatic) within limits (that is, they are not infinitely resilient);
4. 'Dynamic variability': ecosystems are characterised by constant change.

Holling's approach describes how this methodology can be used to tackle practical problems in a number of case studies, including most notably that of the Obergurgl alpine resort development, highlighting the need for policy processes to have a fundamental understanding of how ecosystems actually works. However, although the AM approach

[16] The term 'wicked problems' to denote a descriptive model for complex issues with limited alternatives, no clearly defined goals or simple decisions, which requires –according to this perspective - Lindblom's incremental approach, dates back at least to Rittel and Webber in 1973 (Hall 1980). Glasser's use of the term in his more recent (1998) critical rationality approach is discussed below.

[17] This is a reference to, and repudiation of, the simplistic notion that ecology suggested that 'everything was connected to everything else', popular during the 1970s and owing much to Garrett Hardin's 'Tragedy of the Commons'(1968).

can be seen to be firmly based within a traditional scientific framework, it also contains elements of the post-modernist alternatives. It does, for instance propose decision making that is dynamic and bottom-up, rather than a linear, top-down approach of the caricatured Rational-Technical method (Leist and Holland 2000). Adaptive management also assumes that there exists a consensus around management goals, which in reality might be conspicuous in its absence.

Transition Management (developed by Kemp et al 2007) is a more recent attempt to develop a "third way", incorporating the best aspects of logical incrementalism (as opposed to Lindblom's disjointed incrementalism) and planning (by having long-term objectives) in the co-evolution of socio-technical systems and social cultural changes (such as values and beliefs) (see Geels 2006). Both attempt to integrate science with an awareness of social and political issues; both may be censured for adopting an excessively self-limiting and unambitious agenda that accepts too readily the multiple limitations of incrementalism: that it is essentially reactive and responds to changes in the external environment, rather than attempting to pro-actively shape that environment. This incrementalist strand of the alternatives to outright positivism will not, therefore, be considered further in this study.

A second group of approaches is characterised not only by a radical critique of rationality but also by a recognition of the importance of cultural, spiritual and aesthetic values. Integral Theory, derived from the work of Ken Wilber, is a particularly interesting example of this type of approach that has been applied to sustainable development by Riedy (2005) and Brown (2005). Integral Theory is quintessentially postmodernist, including as it does a fusion of Eastern and Western philosophical ideas. For instance, it involves the recognition of two orthogonal epistemological dimensions: the individual-collective and the subjective-objective (or interior-exterior) (Riedy 2005). This results in four contrasting ways of knowing in the four quadrants, as shown in table 2.1.

Table 2.1. The fourfold epistemology of Integral Theory

	Individual	*Collective*
Objective	Behavioural	Systemic, social
Subjective	Psychological, self and consciousness	Cultural (Discourse/ worldview)

A key aspect of Integral Theory is the necessity of operating in all four quadrants simultaneously. Brown (2005) further argues that human development has entailed three overlapping stages (or levels) of human cultural evolution: the traditional, modernist and postmodernist worldviews. Integral Theory involves valuing all of these in what is termed the "all-quadrants, all-levels" approach (AQAL). Thus Integral Theory marks a departure from modernist, positive thinking in its appreciation of the subjective: of taking the "interior"into account. This type of view identifies the necessity of acknowledging the validity of the potentially conflicting views of all the participants. Brown (2005: 8) states: *"One reason it is so hard to execute the often brilliant ideas and novel systems that emerge from the sustainable development movement is because their design and implementation usually are not rooted in an understanding of—and tailored response to—vastly different stakeholder values"*.
Integral Theory therefore seeks to validate a plurality of viewpoints, whatever cultural traditions or societal traditions they represent. To some extent this approach prefigures that of the Millennium Ecosystem Assessment[18], which incorporates the view that pluralism requires recognition of varied epistemic frameworks, including those of indigenous communities whose ontological and epistemological frameworks may be diametrically opposed to those of rationalist science (Miller and Erikson (2009)[19].

However, Integral Theory has been widely criticized from within the academic community. Visser (2010), for instance, censures its apparent refusal to engage with normal academic discourse in peer reviewed journals, a reluctance to accept or indeed acknowledge criticism and a lack of scholarly integrity that resembles that of a cult. Moreover, Integral Theory – like other examples of this type of subjectivist, antipositivist approach - does not offer any

[18] The Millennium Ecosystem Assessment (MA), an international work program to assess the impact of ecosystem change on human well-being, was launched by the U.N. Secretary-General in June 2001. An important feature of its assessment was "the emphasis on including different knowledge systems, apart from 'scientific knowledge'. Furthermore the innovative governance structure "was representative of not only scientists and experts, but also UN conventions, civil society groups, and indigenous peoples" (Millennium Ecosystem Assessment 2005). Miller and Erikson (2009:308) contrast what the term the 'Epistemic pluralisation' of the Millennium Assessment with the more exclusively science- based, top-down approach of the IPCC.

[19] Miller and Erikson argue that, as democracy infers that each person affected by an issue should have a voice in decisions concerning it (itself a contested idea) then policy formulation needs to "bridge scales and epistemologies", by including epistemic frameworks very different to those of reason-based science (for instance those of some indigenous communities) .

specific techniques for realizing their exhortation for more pluralistic, deliberative environmental problem solving.

A rather different strand of the postmodern approach centers on the idea of the 'communicative turn', inspired by the work of Habermas and his Theory of Communicative Action (Bloomfield et al 2001)[20]. As with Integral Theory, this contends that all voices deserve recognition and should speak for themselves rather than be channeled through others, but it lacks its spiritual and mystical aspects. Within the 1990s the idea became widely discussed within planning and evaluation (Huxley and Yiftachel 2000). Central to this discourse was a rejection of instrumental rationality and an embracing of greater involvement and participation. No longer was planning conceived simply to be done by planners to 'the planned' (Lichfield 1998). Instead there was an aspiration for decision making to become central to participative democracy, with ideas such as 'community planning' and stakeholder involvement. At a more theoretical level, the communicative turn was viewed as a radical rejection of traditional methodological values and a shift from concern with the ontological to the epistemological; that is, from 'what we know' to 'how we know it' (Masschelein 1991, Lomardi 1998, Bengs 2005). A practical implication was that planning evaluation required consensus as much as technical expertise (Lombardi 1998) as part of a wider pluralistic discourse within which expert opinion is merely one voice among many (Slayton 2007, Kakee 1998, Barbanenete et al 1998). But how far does or indeed should this radical turn in emphasis go? Critics of the communicative turn argue that it can reinforce 'NIMBYism[21]' and lead to a rejection of expert advice (Huxley and Yiftachel 2000). Within such a discourse are all voices of equal value? If they are accepted as such, then it would appear that rational and evidence based knowledge becomes devalued, and on a par with hearsay or superstition. But if it is not, then what criteria can be used to determine the relative worth of some forms of knowledge as opposed to others?

[20] Habermas also argued that corporatist societies have used technocratic decision strategies to confer legitimacy on decisions that otherwise lack popular support, and that such elitist, 'scientistic' practices effectively depoliticise the policy process (Fischer 1993).

[21] 'NIMBY' is the acronym for 'Not in my backyard' and refers, often pejoratively, to opposition by residents to new developments, especially those that might be seen as having wider societal benefits (such as wind-farms) (Fischer 1993; Feldman and Turner 2010)

2.4 Participation

The two types of approach that have been discussed in the previous section have failed to secure general acceptance as practical alternatives to the scientism of the Rational-Technical approach. Both, however, share a stated objective for greater inclusiveness; that is, they advocate the inclusion of a greater range of voices in the policy making process. This goal, which can be loosely termed participation, has become the focus of much of the research (and the rhetoric) on new ways to conduct policy analysis[22]. Participation offers a conjunction of several of the criticisms of the Rational-Technical approach that have been discussed above: participation counters elitism and exclusiveness, offers a way of formalizing social constructionism, recognizes the political nature of policy formulation and fulfills normative ideas of justice and democracy (which have been especially influential in debates on environmental policy)[23]. This 'participatory turn' (Chilvers 2008) might, therefore, offer the key to developing new methods of policy formulation that meet the objections to the perceived elitism and managerialism of traditional Rational-Technical techniques.

The loose definition of participation used above includes two elements: deliberation and inclusiveness (Bloomfield et al 2001). The former refers to the extent to which the process is carefully considered, while the latter implies the involvement of a wide range of actors[24] (Bloomfield et al 2001). The meaning of the term 'inclusiveness' is more contested. Rowe and Frewer (2004: 512) define 'public participation' as

"the practice of consulting and involving members of the public in the agenda-setting, decision-making, and policy-forming activities of organizations or institutions responsible for policy development."

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[22] Bloomfield et al (2001) suggest that interest in participation has primarily arisen from the work of Habermas and his Theory of Communicative Action.

[23] For instance, see Eckersley 1992 on the importance of participation (especially in relation to New Left ideology and ideas of distributed power) in the development of environmentalism as a political ideology. Reed (2008) argues that this initial interest in participation went through several stages before encountering substantial criticism and disillusionment at the start of the millennium, but that a new 'post-participation' consensus is emerging.

[24] While a loose interpretation of the term implies both deliberativeness and inclusiveness, in practice deliberation is often exclusive and inclusion often lacks deliberativeness.

Reed (2008: 2419), in contrast, defines participation as

"a process where individuals, groups and organizations choose to take an active role in making decisions that affect them".

There is clearly a distinction being made here between the more inclusive 'public participation' of the former and Reed's narrower definition. Reed goes on to argue that his interpretation of the meaning of the term – which focuses on stakeholder participation – is more relevant in environmental problem solving on the basis that conservationists concentrate on engaging those with a direct or indirect stake. An alternative view, however, is that when dealing with diffuse environmental issues then all citizens have a stake. The subject of the current study – acid deposition – is a case in point. Atmospheric pollution has affected entire societies: all Scandinavian citizens were touched by the acid rain problem of the 1970s, at least to some extent, but some, such as those whose livelihoods were directly affected, could be regarded as more central stakeholders than others. The question of who should be included within the term 'stakeholder' and thus involved within the decision making process is, therefore, contested yet crucial. Yet the idea of the stakeholder is itself poorly defined. While Ananda and Herath (2003: p82) quote Grimble and Wellards' (1997) definition of stakeholders as"any group of people, organized or unorganized, who share a common interest or stake in a particular issue or system" they recognize how problematic the identification of specific representative stakeholders can be (see also Banville et al., 1998).

The importance of stakeholder participation has been increasingly recognized in the regulatory sphere. The Aarhus convention of 1998 - the UNECE Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters - specified a legislative framework for participatory rights (D'Silva and van Calster 2010). It also explicitly links environmental rights with human rights and states that *"sustainable development can be achieved only through the involvement of all stakeholders"* (UNECE 2010). UNECE goes on:

"The subject of the Convention goes to the heart of the relationship between people and governments. The Convention is not only an environmental agreement, it is also a Convention about government accountability, transparency and responsiveness"

By the end of 2010 the convention had been ratified by 44 countries as well as by the European Commission. Especially noteworthy is the latter's incorporation of Aarhus convention principles into the Water Framework Directive[25] of 2000, which requires stakeholder involvement and participation (although there is no prescription as to how such participation will be carried out, allowing member states to adopt different routes to its implementation: Mouratiadou and Moran 2007)[26] . Nevertheless the WFD sets ambitious goals for participation which, De Stefano (2010) argues, will be 'challenging' to meet[27]. Participation is now increasingly recognized as a democratic right (Reed 2008).

The need to ensure that participation is built in to policy making can be justified in several respects: its centrality to the democratic process[28], its involvement of and effect on stakeholders and its generation of greater understanding of the problem (Scott 2008). It can thus be seen as not only enhancing decision making outcomes but also facilitating the wider process within which that decision is made.

Fiorino's (1990) tripartite classification of the reasons or justifications for using a participative approach (as opposed to relying solely on technocratic methods) is often employed in this respect (for instance Stirling 2006, 2008). Firstly there is the *substantive* justification: that the quality of the decision-making may be enhanced by involving non-experts who may, for instance, have important knowledge or insights that are otherwise unavailable to decision makers. Participation, in this view, will increase the range of data

[25] Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy (European Commission 2010).

[26] See also Paneque et al (2009: 99) who suggest that the WFD participative requirement necessitates an extension of "the epistemological basis to knowledge other than scientific or technical;" as well as "involving relevant social actors in the governance processes acknowledging a key feature of water governance: plurality of interests, of perspectives, of values".

[27] An example of how the Directive has been incorporated in national policy is contained in the Scottish Government (2008) consultation document on the implementation the Water Environment and Water Services (Scotland) Act 2003. It is interesting to note that neither of the terms 'participation' or 'stakeholder' appears in this document.

[28] For instance, to make up the democratic deficit confronting many representative (or 'aggregate') democracies (Bäckstrand et al 2010).

being employed[29]. Thus participation is seen as a means to an end (that of securing better decisions).

The second reason for participation - the *normative* justification - is, in contrast, an end in itself: based on the argument that "a technocratic orientation is incompatible with democratic ideals" (Fiorino 1990: 227). Implicit within this statement is the idea that Western(ised) societies increasingly recognize as a core value the desirability of engaging a wide a mandate as possible in making decisions at all levels, as part of what Rawls argues is "the intrinsic social desirability of equity of access, empowerment of process and equality of outcome" (Stirling 2006: 96)[30]. This normative rationalization has also been strongly influenced by Habermas' communicative action theory which emphasizes fairness and the desirability of equalizing out power differentials between the different actors.

Finally, the *instrumental* justification contends that participation confers legitimacy and credibility, thus increasing confidence in the decision making process, as well as ensuring public acceptance (Reed 2008). Some interpretations, such as that of Rowe and Frewer (2004), suggest that this may result in tokenistic pragmatism, wherein the sole aim is to increase public trust – and mollifying critics –without any intention of seriously considering their views. Stirling (2006) labels this form of instrumental rationalization as 'strong' instrumentality, as opposed to a weaker and less manipulative form which that is less concerned with securing a particular outcome[31]. This might be equated with the need to reduce conflict by seeking consensus (Kallis et al 2006). Kallis et al also identify another, rather different, reason for using participation: that of "reducing ignorance through discursive education".

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29 See Wynne's argument, discussed above, that farmers in Cumbria will possess context specific local knowledge, highly relevant to some environmental problems, that would otherwise be inaccessible to experts.

30 Similarly Bloomfield et al (2001) argue that declining trust in established decision making processes is associated with a growing and pervasive sense of powerlessness, and call a need for more deliberative and inclusive decision making: a project to "democratise democracy" (p. 501). Such powerlessness might be equated with the ideas of anomie (a disintegration of normative beliefs) and alienation (of individuals from established structures).

31 The distinction between the normative, substantive and instrumental rationalisations can also be characterised as focusing on 'empowerment', 'quality' and 'justification' (Stirling 2006).

Four distinct justifications for participation in decision making can, therefore, be identified: to improve the quality of the decision, to pursue an empowering democratic agenda, to ensure (possibly cynically) public support and reduce conflict, and to enable participants to become better able to participate in future decision making through enhanced social learning.

The concept of 'participation' encompasses, therefore, a wide range of diverse activities. As a consequence, a number of typologies have been developed to categorize the very different types of participation that have arisen in quite distinct contexts (Reed 2008). Arnstein's (1969) 'Ladder of Participation' is often seen as the original and most often cited (Scott 2008). In this scheme, it can be assumed that engagement moves 'up' the ladder of participation as the level of involvement becomes greater (see figure 2.1). At the bottom of the ladder the participants are simply the passive recipients of information that is provided by those in control of the process with the intention of managing opinion.

Citizen control
Delegated power
Placation
Consultation
Informing
Therapy
Manipulation

Figure 2.1 Arnstein's ladder of participation (1969)

However, other typologies are, perhaps, more relevant in the environmental decision making context. Farrington (1998) distinguishes between 'consultative', 'functional' and 'empowering' participation (where 'functional' implies that the decision making process is enhanced through local knowledge) while Lawrence (2006) employs a similar scheme with 'transformative' participation as an alternative top level (see Reed 2008 for a detailed discussion of these typologies). Both of these can be closely aligned with Fiorino's model above. However, these classifications all neglect a vital element: the direction of communication. Rowe and Frewer (2000) use the direction of flow of information between decision makers and participants to conceptualize three types of participation:

‘communication’, which is a one-way process from regulators to the public, ‘consultation’ as the reverse one-way process (as in the gathering of information) and ‘participation’ itself, seen as essentially a two-way process. Such a two-way flow may implies a degree of iteration, where each stage in the process is informed by the previous stage and that may also include ‘loops’ where previous stages can be repeated and amended.

Table 2.2 compares these various approaches and attempts to compare the various terminologies. As can be seen, the extent to which iteration is involved is a powerful means of summarising the different classificatory schemes.

Table 2.2 A comparison of some classification schemes of participation

<table>
<tr><th>Arnstein (1969)</th><th>Farrington (1998), Lawrence (2006),</th><th>Rowe and Frewer (2000): communication flow</th><th>Nature of iteration</th></tr>
<tr><td>Citizen control</td><td>Empowering</td><td>Two-way</td><td>Comprehensive</td></tr>
<tr><td>Delegated power</td><td>Functional</td><td>Limited two-way (controlled)</td><td>Limited</td></tr>
<tr><td>Placation</td><td rowspan="5">Consultative</td><td rowspan="5">One-way communication flow</td><td rowspan="5">Absent</td></tr>
<tr><td>Consultation</td></tr>
<tr><td>Informing</td></tr>
<tr><td>Therapy</td></tr>
<tr><td>Manipulation</td></tr>
</table>

Rowe and Frewer (2000) also identify a number of criteria by which, they suggest, participation should be evaluated, including: the representativeness and independence of the participants, how early is their first involvement, their influence on final outcome, the transparency of the process, the degree to which the task is defined and the structuredness of the decision making process.

A group of rather different and more fined grained approaches attempt to classify participation along a number of separate dimensions. For instance Kallis et al (2006: 227) argue that

“On a practical level, a participatory method can be classified in terms of: (1) the selection and composition of participants (for example, identified stakeholders, random selection, open invitation); (2) the platform used for deliberations (for example, groups, panels, forums, workshops, polls); (3) the

tools used to facilitate deliberation and aid choice (for example scenarios, models, or multicriteria matrices)."

Fung (2006) similarly argues that participatory mechanisms vary along three dimensions: who participates and how representative are they (the degree of inclusiveness), how they interact and make decisions, and how their involvement actually impacts on the overall policy formulation. García-López and Arizpe (2010) discuss the problem of top-down versus bottom-up participation under three comparable headings: first who counts as a stakeholder, secondly what counts as participation (or as they term it "the role of mobilization") and thirdly who selects the stakeholders and the problem to be addressed (that is, who has ultimate power over the process). These various models, based on variations of a "who, where and how" theme, provide a more comprehensive framework within which all forms of participative decision making can be compared in some detail. It is developed further below where it is incorporated in to a new framework termed the *Breadth-Impact-Depth* (BID) model.

There are a growing number of techniques for participative decision making, which may be divided into those which are designed specifically for participation and those pre-existing procedures that can be (more or less readily) adapted to a participatory mode. Among the former are focus groups, visioning exercises, issue forums, planning cells and consensus conferences, whilst the latter includes interactive websites (Bloomfield et al 2001; Omann 2004; Tomei et al 2006; Chilvers 2008) and Multi Criteria Analysis (MCA).

The citizens' jury is an interesting example of a relatively new technique designed specifically to increase inclusiveness. Originating in Germany in the 1960s, it is an extrapolation of the Western model of the jury as used in legal proceedings. Juries are given a clear objective and are able to call expert witnesses; the process is organised by a facilitator. Jurors may be paid for their involvement in a process which may take several days. (Proctor and Dreschleer 2006).

There is, as yet, comparatively little evidence as to the efficacy of any of these methods. Whilst the normative justification for enhanced participation rests on *a priori* assumptions concerning the desirability of the participative process[32], the substantive rationalization makes claims that participation will improve the quality of decision making itself (that is, that it result in better outcomes). The empirical evidence for this contention has been examined in relatively few studies (Reed 2009), but the following are noteworthy. Beierle and Konisky (2001) reviewed a number of case studies of environmental decision making in the Great Lakes and found evidence that stakeholders involvement lead to benefits in four areas: the quality of decision, improved relationships between stakeholders, environmental management capacity and in overall environmental quality. Sultana and Abeyasekera, (2007) examined 36 sites in Bangladesh where NGOs were conducting community management of fisheries. They found statistical evidence that the 18 sites that used a participatory approach known as Participatory Action Plan Development (PAPD) had greater take-up of conservation relation interventions and less conflict than sites without PAPD. Danielson et al (2010) scanned 104 published environmental monitoring schemes and evaluated the impact of stakeholder involvement on the collection of data and on the rate and scale of subsequent decision making (which were concerned with resource management) . They found that projects involving scientists alone took longer (typically 3-9 years) and had little impact at village level, but that schemes involving local inhabitants were more effective at influencing decisions and usually took less than a year to implement. They concluded that "involving local stakeholders in monitoring enhances management responses at local spatial scales, and increases the speed of decision-making to tackle environmental challenges at operational levels of resource management" (p. 1166). Thus there is some evidence, albeit from a small number of studies, that greater stakeholder involvement leads to better quality decisions.

However, Reed's (2008) comprehensive review provides an important qualification on this, which suggests that the simple dichotomy between process and outcomes may obscure an important interrelationship between the two, in that there is some considerable evidence that the quality of the decision (outcome) is highly dependent on the quality of the process

[32] The normative justification has also be used to claim a number of others positive outcomes, such as increased trust (thus overlapping with the instrumental justification) and enhanced social learning (Reed 2008).

leading to it[33]. This suggests that a contingency based model is necessary for the development of best practice in participatory decision making: participation may indeed lead to better decision outcomes but only if certain process requirements are met.

There has not been unanimity, however, that participation invariably has positive outcomes. It may raise expectations among previously marginalised groups, which may in turn lead to conflict with existing power structures, or it may result in 'consultation fatigue' or a perception of a perpetual 'talking shop', leading to renewed cynicism (Reed 2008), while Lee (2006) found that those involved often saw participation as "superficial pageantry" (p18) . There are also multiple barriers to the development of more participatory approaches. Bloomfield et al (2001) suggest, for instance, that there may be insufficient incentives for citizens to participate and that established economic and political interests may dominate the process, while O'Neill (2001) argues that the problems of authorisation and accountability are often not addressed[34]. Participation in planning decisions has also been seen by many to be associated with increased costs and delays (Doak and Parker 2005).

Furthermore, there is little agreement on who should participate in environmental decision making. Does residence in an affected area give priority, or should involvement be proportional to potential impact on the individual irrespective of where one lives?

Mason and Michaels (2001) provide a case study of environmental decision making in the Adirondacks Park, New York State (a U.N. designated biosphere) that illustrates some of these issues[35]. Problems were often characterised by conflict between local residents, who

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[33] Reed identified a number of elements that seemed particularly important in determining the process quality, including the skill and experience of facilitators.

[34] O'Neill also points out that the representation of the interests of future generations and of non-humans creates especially difficult problems.

[35] Mason and Michaels (2001) characterise the views of local residents as championing 'private property rights' as well as following a 'conservationist/wise-use' ethic. Eckersley (1992), Roussopoulos (1993) and Hunter (2002) contrast the 'Resource Conservation Ethic' – originally advocated by Pinchot and advocating that natural resources should be 'rationally' managed to maximise their utility as commodities – to the 'Romantic-Transcendental Preservationist' ethic that seeks to set aside wilderness, undisturbed by humans, that was popularised by John Muir. Hunter goes on to add, however, that both viewpoints are essentially anthropogenic, and contrasts them to

generally favoured business-friendly solutions and 'outsiders' – often urban dwellers – who championed environmental issues. Thus the former campaigned for the recovery of storm damaged timber after a major hurricane ('the great blowdown of 1995'), while the latter lobbied for fallen wood to be left *in situ* as part of natural succession. Similarly, residents were against the reintroduction of wolves, proposed by environmentalists. Significantly, Mason and Michaels point out that in both case a resolution was achieved with the aid of specialist ecological knowledge: in favour of the environmental for timber reclamation but for local residents on the issue of wolf reintroduction. (It should also be pointed out that the resolution of both issues followed the precautionary principle[36]). Authoritative expert knowledge, respected by both parties, was thus essential for conflict resolution.

Scott (2008) provides a detailed case, furthermore, for a potential conflict between the normative aspirations of the political case for participation and the environmental imperative. She suggests that the sort of 'good governance' increasingly required by organisations such as the World Bank and the Organisation for Economic Co-operation and Development (OECD), which explicitly require transparency, accountability and participation in environmental decision making though mechanisms such as Strategic Environmental Assessments, can actually undermine the environmental originally embodied within SEA[37]. There is, according to this line of reasoning, no "inherent link

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the more ecocentric 'Evolutionary-Ecological Land Ethic' of Aldo Leopold. Eckersley (1992) and Shearman (2005) explore the implications of possible ecocentric alternatives to anthropocentrism.

[36] Proposed by Wynne and Mayer (1983), as a response to the perceived inadequacy of overly reductionist science to address environmental problems, the precautionary principle proposes that the burden of proof should be shifted from the traditional presumption that any new impact on the environmental will not be harmful until proven otherwise. In other words, the default position becomes one in which the absence of a negative environmental impact must be shown before a development (that involves any likelihood of risk to humans or the environment) is approved. The precautionary principle has been influential, for instance it was included in the 1992 Rio Declaration and in significant international agreements, such as the Convention on Biological Diversity. It has also been widely criticised as an example of how 'green' ideology impedes development. See European Commission (2000).

[37] Scott (2008) also argues that social learning, often thought of as desirable in environmental assessment, can often amount to little more than 'manipulation', that is a mechanism for ensuring public support (which corresponds to Fiorino's instrumental imperative). She uses this as an example of the tendency of some discussions of participation to emphasise supposed consensus, whereas environmental policy making is in fact often characterised by unresolved conflict. This provides additional salience to the 'participation paradox': that participation decreases as the importance of such decisions increases.

between public participation and sustainable outcomes" (p16), although this linkage is the cornerstone of much green political theory (Bäckstrand et al 2010: 5). Similarly Kidd and Fischer (2007) propose that participation can actually work against environmental interests by supporting dominant viewpoints.

Participation in environmental decision making is, perhaps, like virtue - widely extolled but poorly defined and probably not as widespread as one would wish. There does seem to be a developing consensus that some form participation is important - perhaps essential – in much decision making, both in terms of ensuring the best possible outcome and in securing credibility. This consensus – widely termed the Participatory Turn - has taken a number of forms depending on the context but is perhaps best characterised as

"indicated by a new language of openness, transparency, and deliberation as well as the proliferation of participatory arrangements and events" (Braun and Schultz 2010: page 405).

For instance in the European Union it has emerged as a discourse "insisting on the necessity of 'civil society' participation in decision-making processes" (Saurugger 2010: 471). There is, though, less agreement as to what constitutes participation or who should be involved. Although the research literature on participation has increased considerably in the last decade, there is still relatively little consensus about how to achieve effective participation in a given decision making context. The present study takes the desirability of participative decision making as a starting point. Furthermore, it is proposed that the mechanisms of participation remain little understood and significantly more work needs to be done before comprehensive theoretical models and effective practical techniques are fully developed. The primary aim of this study is to evaluate the extent to which one specific type of technique – Multi Criteria Analysis - can enhance participation, and to what effect.

One persistent problem that is encountered in any discussion of participation is the absence of a single, comprehensive model that can be used to evaluate the nature and extent of participation in a range of practical activities. The classificatory schemes discussed above have gained some currency but failed to provide a sufficiently all-embracing perspective that encapsulates the various disparate elements that participation involves. The following section proposes a model that attempts to provide such an inclusive analysis.

2.4.1 The 'BID' model of participation: *Breadth, Impact* and *Depth.*

As part of this research process a 'three-dimensional' model of participation is proposed. This takes as a starting point the work of Fung (2006)[38], which identifies three issues or aspects of participation in order to describe and compare specific examples. These three dimensions, which "constitute a space in which any particular mechanism of participation can be located" (p66) are: "who participates" (degree of inclusion), "how participants communicate with one another and make decisions together" (which Lee 2006 terms 'equity" and describes as the extent of transparency and good governance) , and "how discussions are linked with policy or public action" (which Lee 2006 terms consensus: the extent to which final decision carry agreement from participants).

However, ;inclusion' as outlined by Fung can be regarded in two ways: firstly in a simple quantitative fashion regarding the numbers of those involved (or represented) in the deliberative process and secondly as the extent to which those involved come from outside the usual decision making groups (that is, from outwith power elites). In the model describe here the former is termed '*Breadth*' and the latter '*Depth*' of participation[39]. This separation of inclusivity into two separate dimensions reflects the importance of power relations in shaping the very context of participation (Bailey 2010)

Moreover the 'equity' dimension in Fung's model can be regarded as a means to an end (of achieving consensus of agreement about what course of action is to taken). Accordingly, the equity and consensus dimensions can be rolled together into one aspect of the process which will be termed here '*Impact*'.

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[38] Fung's work also parallels that of Kallis et al (2006): see above.

[39] The terms breadth and depth are used inconsistently and ambiguously within the literature on participation which is characterised by "much confusion about the terminology" (Bailey p318). For instance Brand 2010 (in reviewing the seminal work of Patsy Healey) discusses breadth and depth of involvement in a way suggesting that that breadth can be equated to the size of the base whereas depth refers to the extent of engagement. (Similarly, see Koontz and Johnson 2004 and Farrington 1997). In this model the terms breadth and depth are used to refer to the two complementary aspects of inclusion, while the term impact is used exclusively to refer to the degree to which participation influences process outcome.

This model thus proposes that much variation between different examples of participation in practice can be captured by gauging each example along these three dimensions: *Breadth*, *Impact* and *Depth*. It is, accordingly, referred to here as the 'BID' model. *Breadth* and *Depth* both refer to the nature of the participants. *Breadth* is intended to be an indication not only to the simple numbers involved but also to the degree of representativeness of wider constituencies, if participants take part as delegates for organizations or groups. *Depth*, in contrast, signifies the extent to which the process moves beyond the traditional decision-makers to include those previously excluded (by the usual power dynamics) from the deliberative process. So if participation is broadened but not deepened (that is, there is greater *Breadth* but little *Depth*), a larger number of people are included in the deliberative process, but they are drawn from the same groups as previously were involved. For participation to be deepened (that is, for there to be greater *Depth*), in contrast, people from groups previously excluded from the decision making process need to be included. So, for instance an environmental problem, such as the bioaccumulation of Persistent Organic Pollutants in plastic pellets in the marine environment, that had hitherto only been discussed by academics from a chemistry background, but then came to include biologists or geographers, could be said to have gained greater *Breadth* but still showed little enhanced Depth of participation. If, however, members of NGOs, such as community based wildlife organizations, were to be invited to take part, then the *Depth* of participation would be increased. The *Depth* of participation depends, therefore, on the extent to which power is distributed. The third dimension of the BID model, *Impact*, refers not to 'who takes part' (the degree of inclusiveness) but rather 'how they take part' (the degree of deliberativeness). That is, what is the nature of the participants' involvement in and engagement with the decision making process: who controls it, what constraints are there imposed on it and (most importantly) what is their influence of the outcome (using Lee's terminology, this is the degree of consensus). This dimension is closest to those used by Arnstein (1969), Farrington (1998), Rowe and Frewer (2000) and Lawrence (2006) and summarised in table 2.2.

This model allows for a greater detail than single-dimension typologies (such as Arnstein's ladder) while allowing for easily comprehensible summaries. This is illustrated by considering two hypothetical examples of participative decision making processes. In Case A, an example of a traditional type of process, the decision is made by a small number of experts who carry out a simple consultative exercise through the use of a questionnaire to a large group of residents, with no degree of iteration. The experts' involvement might be classified as low *Depth*, low *Breadth* and high *Impact*, while the latter would be classed as High *Breadth* and High *Depth* (assuming that this group contained many usually not involved in such decision). The degree of *Impact* would depend partly on the extent to which the questionnaire results were taken into account, but given the simple one-way, non-iterative nature of the involvement it would probably not be judged to be low. In Case B, a small group of traditional decision makers uses a citizens' jury type of approach, with a representative group of stakeholders in a lengthy and highly deliberative process. This jury would have moderate *Depth* and *Breadth* (depending on the extent to which these stakeholder groups had previously been involved in such decisions). Again, the overall *Impact* of the jury would depend on the extent to which the jury's opinions were incorporated into the final outcome. It would be possible for a highly deliberative process to be ignored, for instance. At the other extreme, the decision makers could hand over the entire process to the jury and agree to be bound by its verdict. In this example, we shall assume a middle course, where the jury's conclusions form a major part of the final decision outcome and *Impact* is therefore moderately high. Figure 2.2 illustrates the two cases. These BID diagrams show the level of participation in the three dimensions as a triangle. The closer the apex of the triangle is to the centre of the diagram, the lower it is in terms of that dimension.

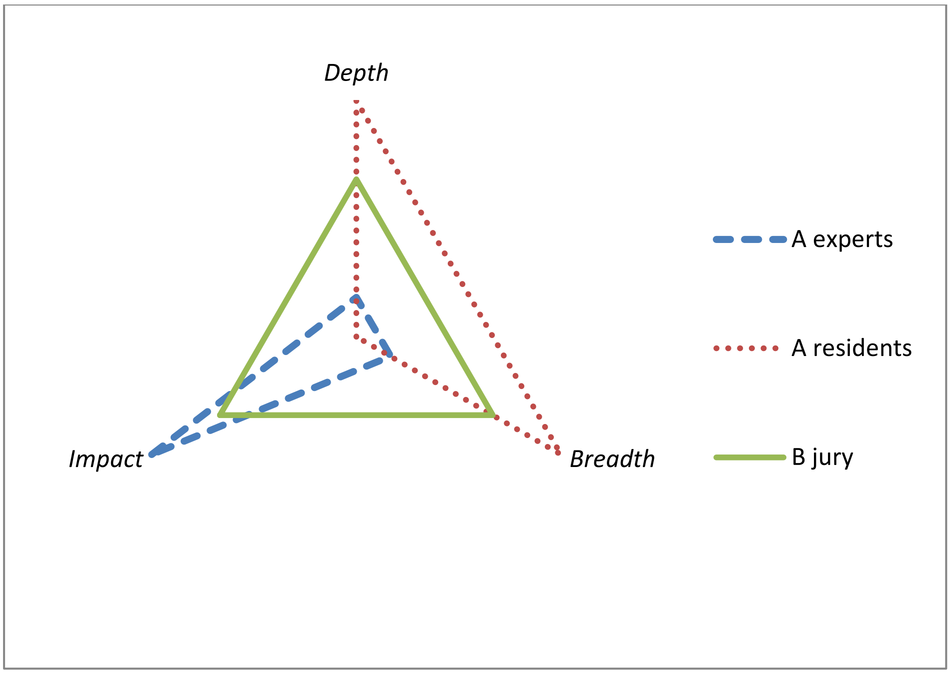

Figure 2.2 ***BID*** **analysis of two hypothetical case studies**

They graphically illustrate the degree to which overall decision making power (that is, *Impact*) is high in the traditional Low *Depth*, Low *Breadth* expert group in Case A, while in case B higher *Depth* and *Breadth* of participation by the jury group is accompanied by lower *Impact*. The Residents group in Case A have even higher *Depth* and *Breadth* but even lower *Impact*.

In a real case example, the method can be applied to the study of De Marchi et al (2000). They formed a trans-disciplinary team to help the local government of a town in Sicily formulate a policy on water use. Among other activities (including the use of Multi Criteria Assessment and a triangulation of methods) the team carried out field work involving interviews with a number of social actors and a survey of residents. The former involved in-depth interviews with a number of individuals representing 11 different organisations that played significant roles within the community, including local authorities, industries, farmers and environmental groups. This might be classified as being of medium *Depth* (as it included groups that were not usually intimately involved in such decisions) and medium *Breadth* (given the relatively large number of groups involved, although that does raise questions about how representative the individuals interviewed were of the groups as a whole). The latter involved questionnaires administered via face-to-face interviews with 148 residents, selected at random. This might be classified as high *Depth* (on the assumption that most of those selected would not normally be involved in such decision making) and high *Breadth*. Although the outcome of the process is not clear from the article (in terms of the influence the study had on the actual policy adopted by the town authorities), the triangulation method assumes that both the methods would have a potentially large *Impact* on the final decision, although the *Impact* level of the interviews might be necessarily greater than that of the survey, given the much greater detail involved.

The De Marchi et al study can be compared with that of Koehler and Koontz (2007), who examined citizen participation in watershed management via written surveys with 12 representative groups. The *Breadth* might be assessed as being moderate, but the *Depth* would be rated as medium-low, given that the authors reported that group members rarely participated in the groups, which were thus not highly representative. The *Impact* in this essentially research based study would be low. Figure 2.3 below graphically compares these two studies and shows how the BID model can capture the essentially participativeness of very different processes.

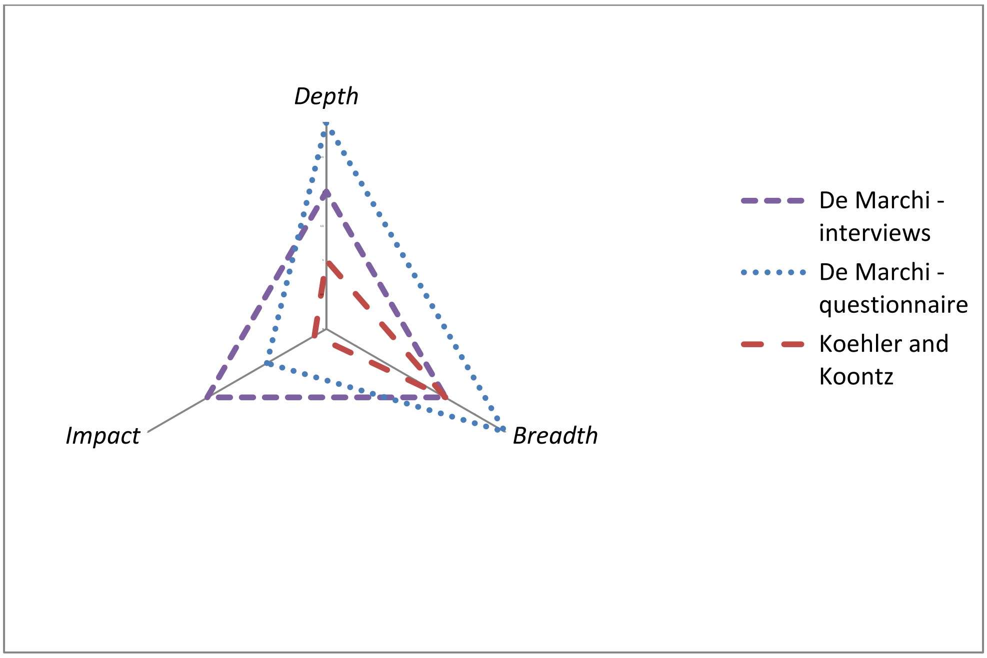

Figure 2.3 BID analysis of De Marchi et al (2000) and Koehler and Koontz (2007).

The *Breadth-Impact-Depth* model has the advantage of being able to communicate the extent of participation in three separate dimensions graphically. It will be used again later in this study.

2.5 A convergence of approaches?

To summarise the argument of this chapter so far: on the one hand there are those approaches which stress the complexity of policy making problems (especially those in the environment), their inherently social and political nature and the lack of human rational capability to address them; on the other hand there are those approaches that aspire to comprehensive knowledge and decision making founded, primarily, on the power of reason. The former are often descriptively correct: in much decision making the difficulty of the problem seems to confound the reason of the decision makers. Hence many environmental decisions have been made unwisely. As Glasser (1998:230) states, the history of environmental problems presents "a pattern of overexploitation and exiguous conservation practices" resulting from a lack of understanding of the likely results of human actions: decision making which is indeed 'muddled' but which can increasingly be seen to have failed the needs of both human society and natural ecosystems. The latter, rational approach, however, can often be viewed as idealistic and unobtainable; there are insufficient resources (human, material, conceptual and temporal) for many decisions to be made in the way that this method prescribes.

However, a reliance on the former, descriptive approach can be a council of despair: is it so pessimistic about the prospects for rationality that it fails to motivate any attempt at improving the degree of rationality? Thus decision makers may become complacent in 'muddling through', Lindblom style, to produce decisions that at best will satisfice. At the same time pure comprehensive rationality is clearly flawed, as Glasser (1998) contends. Is there an alternative to both overly bleak descriptive models and unrealistic prescriptive approaches, which is not merely a compromise between them that replicates some of the worst features of both? That is, can decision making go beyond mere satisficing without unrealistically attempting to optimise? Or is the debate concerning how policy should be made irrevocably polarized? It appears to be often dominated by a fractious dichotomy between 'analysis', caricatured as narrow, inflexible, quantitative, expert based, elitist and serving established power on the one hand and 'participative deliberation' on the other hand, seen as new, flexible, qualitative, inclusive, democratic and serving wider constituencies (Stirling 2006) but often being perceived as being of little practical value. Frequently there seems little attempt at dialogue between these two positions. This results in a problematic credibility for any environmental decision making process: while traditional technical and expert-based methods have lost authority, the alternatives deriving from their postmodern critics seem themselves to be flawed and often of little practical utility. Environmental decision making is, therefore, embroiled in a dilemma: traditional rational-technical methods (based on positivism) have been subject to a thoroughgoing criticism and thus have lost much of the legitimacy that requires widespread approval, but no widely accepted substitutes have as yet been recognized. The recent impetus to develop truly participative policy making methods has yet to be realized in practice: often the rhetoric of participation far outstrips the reality. There is, it seems, a methodological vacuum.

This void at the heart of decision-making methodology is further exacerbated by the trends within governance towards greater bureaucratization and top-down decision making. Messner et al (2006: 63) make the point that there is a tendency in environmental decision making that favours technocratic and bureaucratic methods "which de-emphasize the consideration of affected interests and local knowledge", leaving some groups disempowered and disaffected.

However, this apparent polarization and divergence of methodological approaches may obscure a more recent convergence. Stirling (2006) is one of several commentators who suggest that the two approaches (Rational-Technical analysis and inclusive, deliberative methods) have much in common. Stirling's argument revolves around his perception that the central dilemma facing both approaches to policy analysis is the choice between the 'closing-down' and 'opening-up' the policy discourse, as indicated above. With the 'Closing-down' approach:

"… the aim is to 'assist' decision making by cutting through the messy, intractable and conflict-prone diversity of views and develop instead a clear authoritative prescriptive recommendation" (p.101).

and thus arrive at a single, clear 'best option'. In 'Opening up', in contrast, the aim is

"... to include marginalised perspectives, focus on neglected issues, consider ignored uncertainties and highlight new option" (p.101).

Outputs are, therefore, plural and conditional. The process is at once more ambiguous yet more sensitive to initial framing conditions. Stirling's main point, however, is that both the Rational-Technical methods and their postmodern, deliberative rivals can serve either end of this dichotomy. Stirling's analysis proposes, radically, that the central opposition within decision making is not between methodologies but in the purpose of the decision itself. 'Opening-up' and 'closing-down' may both be legitimate aims at different stages of the policy development process: typically 'opening-up' is required at the start of the process, in order to consider as wide a range of solutions as possible, while 'closing-down' is necessary at the end, when concrete action is planned. The aims of decision making methods are, therefore, context dependent. One implication of that is that different methods might be used in different contexts, dependent on the initial framing conditions – that is, that there is a recognition that a plurality of methods, and implicitly of epistemologies, is required.

A rather different, but not incompatible, conclusion is that the apparent polarization between Rational-Technical and postmodern methods can be transcended through a synthesis of approaches. The extent to which this potential convergence can be realized in new methodologies (including the metamorphosis of older methodologies into quite new forms) is explored in this study, which specifically examines the extent that Multi Criteria Analysis fulfills the criteria for a successful synthesis. Such approaches, which attempt to straddle the gap between Rational-Technical and postmodernism, can also be examined through the perspective of Post-Normal Science. There are, however, other alternatives to rational technical methods (particularly those most pertinent to environmental decision making), which address postmodern criticisms, and which attempt to reintegrate the two previously divergent strands of policy, and are less concerned with epistemological purity than with the development of a synthesis that is context sensitive. Two of these are considered here: Integrated Assessment (Lee and Kirkpatrick 2000) and Glasser's (1998) 'Wicked Problems' approach.

Integrated Assessment (IA)[40] involves a closer integration between environmental assessment and economic and social appraisal, and the bringing together of these in a single evaluative process (Kidd and Fischer 2007). IA is a relatively new approach, emerging in the first decade of the 21st century[41]. IA involves using comprehensive models which include the inter-relations and feedbacks between sub-system components (Bell et al 2001), and considers multifaceted problems in terms of the interfaces between these subcomponents of complex systems (Kidd and Fischer 2007, Paneque Salgado et al 2009). It can therefore be classed as a systems oriented approach. IA can be regarded as a portfolio term, embracing a range of methods from those with rational, objective underpinning, such as those involving Input-Output measurements and material flow, and those taking a more subjectivist or idealist standpoint. One strand of the development of Integrated Appraisal has involved using Multi Criteria Assessment (Bell et al 2001). Messner et al (2006) discuss the combination of MCA, CBA and participatory approaches (in a case study of conflict over water use), that they term an Integrated Methodology Approach (IMA). Ness et al (2007) in a review of techniques used in sustainable development analysis, use the term Integrated Assessment to refer those methods that are used ex-ante for complex problems, and include Risk Analysis, Cost Benefit Analysis and Multi-Criteria Analysis itself.

A rather different approach is taken by Glasser (1998) is his proposals for how to deal with so-called 'wicked problems'. He used his objections to simplistic rationality as a lever for proposing a compromise, arising from critical rationality, between comprehensive rationality on the one hand and Lindblom's disjointed incrementalism ('muddling through') on the other. He proposes that complex 'wicked problems', where subjective judgments are needed to evaluate competing goals, necessitate participation and a "pluralism in methodology" (p234). Glasser proposes a 'deontological' multicriteria policy theory, rather than pure optimizing teleological approaches ("exclusively focused on narrow ends"), thus

[40] The alternative term Integrated Appraisal is generally used synonymously.

[41] Lee and Kirkpatrick (2000) argue that historically such integration has been regarded as relatively unimportant.

making 'muddling" more deliberate, reflective and systematic. He sets out a number of tenets for such a method, which include:

1. There should be recognition that there will be multiple conflicting objectives;
2. Some criteria may not only be qualitative but also incommensurable (that is, they cannot be measured or compared) resulting in a lack of fungability (interchangeableness);
3. The idea of the 'objective best alternative' may be fallacy;
4. Learning occurs through the process, which is thus dynamic;
5. The process should be adaptive, deliberative to clarify values, norms and accepting that the process is not entirely rational; descriptive rather than normative;
6. The widest range of alternatives should be considered to avoid bias;
7. It should be recognized that the process cannot be completely comprehensive;
8. Criteria must be aggregated, preferably in an iterative approach, rather than simple optimizing;
9. Decision Making is a social process and should encourage participation and "equal access for all stakeholders": involvement should be proactive rather than reactive, and not just technocratic, expert driven;
10. The decision framework must be conveyed in manner that is "transparent to experts and citizens alike" (p.239), which is intelligible despite its complexity. Clearly, there are significant similarities between Glasser's approach and that of Multi Criteria Analysis (MCA), which will be explored in Chapter 3. However, it is worth noting that Glasser has a greater explicit emphasis on iteration, participation and transparency than MCA has traditionally had, together with the inclusion of non-compensatory criteria.

2.6 Co-constructionism, Civic Science, Trans-science and Post-Normal Science

The convergence of approaches introduced above has been further underpinned by an emerging consensus, within the field of Environmental Sociology, around the idea of co-constructionism. As discussed above, traditional views of the contribution of science to policy centre on its rationality and objectivity. Scientific 'facts' are seen to inform a rational decision making process. However, the postmodernist approach views the perceptions of environmental problems as being socially constructed. Essentially, this view sees our knowledge of environmental problems as mediated by experts, and thus created by them and the relationship with their audience in the non-expert population. The development of this critique of the traditional approach coincided with the development of the Environmental movement: environmental issues such as pollution, acid rain and nuclear power were no longer of concern to only a small number of scientific expert and policy makers but became important to much wider groups of citizens. Environmentalism created the need for a shift in epistemological control away from a scientific, self-appointed elite. This implies a substantial shift in ontological and epistemological perspectives away from realism and objectivism. However, more recent developments within environmental sociology have resulted in a convergence around the idea of co-constructionism (see Hannigan 2006). This eschews the most extreme subjectivism and cultural determinism of post-modernism (as caricatured by the Sokal hoax). Co-constructionism may accept the objective nature of reality but also that human perception of that reality will change over time[42]. The implication of this approach for science and policy is that the former can be seen as an attempt to move constantly towards more useable truths. Science is, therefore, a negotiated process to improve understanding.

Co-constructionism represents, however, rather more than a compromise between the two positions of Rational-Technical and postmodernism, as it attempts to provide a synthesis of elements of both, and a rejection of their untenable aspects, accepting substantial agreement that, while environmental issues are rooted in a material reality, they can only become accessible to us through the processes of perception, discussion and interpretation, all of which are subject to substantial cultural context dependence. Environmental problems may, therefore, have a real ontological foundation but our awareness of them will be mediated by the particular interpretations of scientists, politicians, journalists and environmental activists, all of whom with have specific and partial views.

While co-constructionism has emerged within Environmental Sociology, other parallel trends have developed that advocate new ways of conducting science using a variety of labels such as Trans-, Civic and Citizen Science. O'Riordan (2000b), for instance, proposes

[42] As Cudwroth (2003:5) put it: "we construct 'reality' and it in turn constructs us".

that 'trans-science'[43] (wherein policy and science become more interconnected), and 'civic science' have begun to replace traditional models. The term 'Civic Science' has been used by some writers as interchangeable with participatory, citizen, stakeholder and democratic science (Bäckstrand 2003[44]). Civic science is seen as participatory and inclusive, as well as explicitly technical and moral with an interdisciplinarity that recognises knowledge as feeling. The civic science model requires, moreover, the blurring of boundaries between scientists and citizens:

"*civic science involves scientists as citizens and citizens as lay scientists in a process in which knowledge production is integrated with and therefore cannot be separated from […] the moral effects of political deliberation and choice*". (Shannon and Antypas 1996).

Science therefore becomes an integral part – but still only one part – of the process by which civil society would formulate policy. At the same time, societal, social and ethical concerns would be built in to the scientific process from its inception. Society and science become, therefore, holistically interdependent (Pierce, Fuller and Wrobel 2008. See also Bardati 2009). The civic science model is being increasingly used in diverse environmental problems, as evidenced by case studies from Weber et al (2010) on salmon recovery planning in Washington State, USA, and Scott and Barnett (2009), who examined civic science as used by environmental groups in contentious environmental issues in post-Apartheid South Africa.

While these developments require scientists to take on broader roles as citizens, the analogous idea of Citizen Science involves non-experts taking on roles of volunteer scientists (Irwin 1995, Reed 2008). This has become increasingly popular, as indicated by the increasing number of published papers based on the citizen science model, despite the skepticism of some scientists as the value of data collected by these methods (Bonney et al

[43] Weinburg (1972) developed the term 'Trans-Science' for those problems that arise out of impact of science and technology on society – such as many environmental issues - that cannot, however, be answered by science alone. He used the term, in some senses pejoratively, to denote the tendency for certain scientists to act as though all problems could be amenable to their scientific expertise. However, he later went on to suggest that whereas traditional science was built on deterministic explanations, trans-science accepted the centrality of uncertainty: this anticipated one of the cornerstones of the Post Normal Science rationale, discussed below.

[44] Bäckstrand goes on to provide three rationales for the promotion of civic science: first, that it will restore public trust in science, second, that it will aid science in dealing with the complexity of environmental issues and thirdly ensuring the democratic governance of science.

2010). Citizen Science has had enormous benefits in ecological studies, by providing large scale databases from monitoring and field experiments[45], as well as having a significant educational impact, developing public understanding of science[46]. In all of these examples the boundaries between the scientist and the non-expert citizen are evidently becoming blurred.

It is the idea of Post-Normal Science, however, that has dominated the debate on how a synergetic approach to environmental decision making can be developed (Dovers et al 2001). The title is derived from the work of Thomas Kuhn who, in his 1962 '*The Structure of Scientific Revolutions*', now widely regarded as seminal, introduced the idea of the importance of 'paradigm shifts', which underpin scientific revolutions, in the history of science. Central to this was the idea that science is usually carried out within clear boundaries in a routine orthodoxy: Kuhn called this 'normal science' and contrasted it with the periodic crises or scientific revolutions that resulted in paradigm shifts. However, the term 'normal science' has subsequently become, for some writers, a pejorative term, summing up all the problems of exclusive, elitist establishment science (for instance Turnpenny et al 2010[47]). Consequently, the emerging idea of an alternative, more inclusive practice became termed 'Post Normal Science' (PNS) (Ravetz 2004, Sardar and Loon 2001). The idea of PNS developed from a number of themes that emerged from the study of scientific practice in the last quarter of the 20th century, but provides a specific prescription of an alternative way in which science can and should work within society

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[45] In the U.K., the Royal Society for the Protection of Birds' (RSPB) annual 'Big Garden Birdwatch', which asks people to monitor birds they see in their garden for an hour over one weekend, is a prime example of how this can involve large-scale but low involvement activities, with over 100,000 forms being completed in 2011 (RSPB 2011). An illustration at the other end of the engagement scale is the Reef Check Foundation, an International environment organisation, partner in the U.N. Global Coral Reef Monitoring Network (GCRMN) and International Coral Reef Initiative (ICRI), which coordinates volunteer scuba diver/snorkelling teams in more than sixty countries to monitor and report on reef health (Goffredo et al 2004; WRAS 2005).

[46] A related but somewhat different idea is that of cooperative researcher, conducted by scientists in collaboration with other stakeholder groups, such as the fisheries industry as in the example described by Hartley and Robertson (2006).

[47] Turnpenny et al trace how Ravetz' early (pre-PNS) work critiqued Kuhn's argument that science progressed by revolutionary paradigm shifts, as well as providing a thoroughgoing criticism of what he called 'shoddy science': reductionist, narrow and industrialised.

PNS was designed specifically to address complex problems[48] where ''facts are uncertain, values in dispute, stakes high and decisions urgent" (Ravetz 2004 p. 349).' These four symptoms of PNS-requiring problems – uncertainty, contested values, high cost of failure and urgency – are frequently cited as being fundamental to many contemporary problems[49]. The diagram shown in figure 2.4 has become, according to Turnpenny et al (2010), the iconic image representing PNS. It identifies two of the four characteristics as key dimensions for classifying problems, and then maps three different ways of addressing such problems onto those two dimensions to illustrate the relationship of PNS to other types of scientific activity.

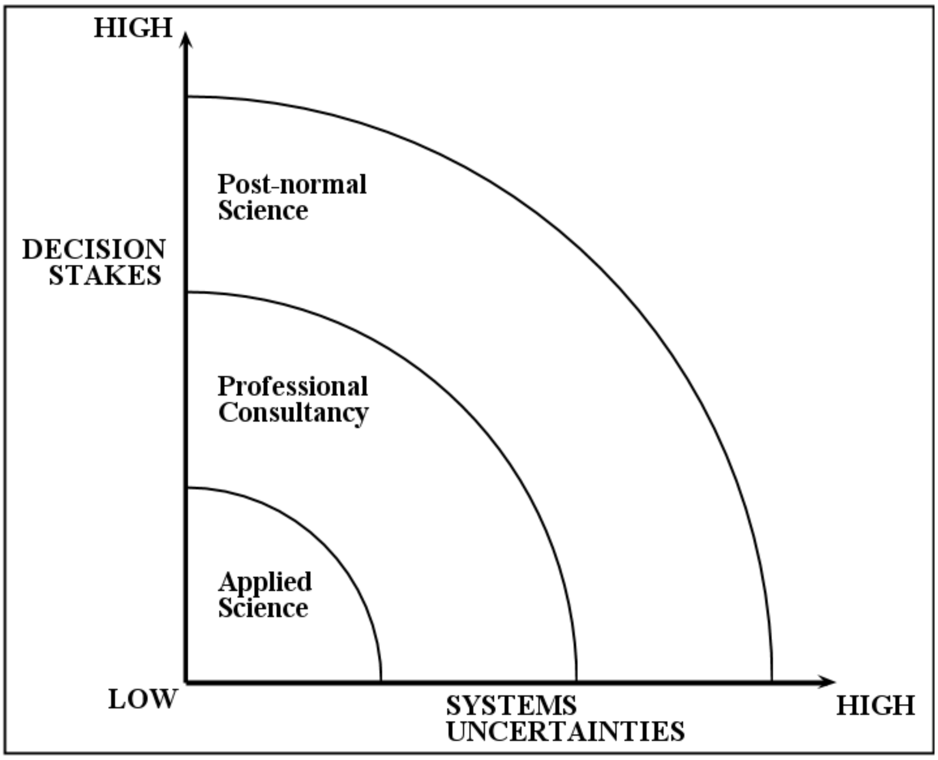

Fig 2.4 Modes of inquiry for different levels of uncertainty and decision stakes (Source: Funtowicz and Ravetz 1991, 145).

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[48] Funtowicz and Ravetz (1994a) distinguish 'ordinary' from 'emergent' complexity, with the latter being characterised by oscillations between hegemony and fragmentation. Systems displaying such emergent complexity are more chaotic and their behaviour more difficult to predict. Haag and Kaupenjohann (2001) suggest that ecosystems, being open and self-modifying, display emergent complexity and that traditional dynamical system models that have been applied to them are therefore inadequate.

[49] It is also worth noting that the same combination of characteristic problem features is often cited by those advocating MCA methods. See for instance Munda (2004) and also Dovers et al (2001).

Thus Applied Science and professional consultancy are characterized as being inapplicable when higher levels of system uncertainty are combined with high decision stakes[50]. These features (high stakes and uncertainties) are, moreover, regarded by PNS advocates as being especially characteristic of many large scale environmental problems (De Marchi and Ravetz 2001:6), and so the PNS approach is widely perceived as being especially relevant in the environmental context. It should also be noted that there are many similarities between the characteristic PNS problem with Glasser's 'wicked problems' and what Howard (2010) calls 'environmental nasty surprises': problems which are already well advanced by the time they become noticed and provide serious and long-term threats to human health or ecosystem survival. While PNS may be applied more widely to the contribution of science to the process whereby policy is formulated[51], it was designed for the environmental arena.

The idea of PNS was developed by Funtowicz and Ravetz in the 1990s (Funtowicz and Ravetz 1994; Luks 1999; Omann 2004), with a central feature in their formulation being the replacement of a search for truth with a concern for quality within a pluralistic convention of epistemological and ontological positions (Turnpenny et al 2010). This position implicitly concedes considerable ground to social constructionists and post-modernist argument that question the usefulness of the idea of 'truth'. As Kastenhofer (2010) argues, the implication is that PNS explicitly links epistemology with governance. PNS is, according to this analysis, better able to cope with the uncertainties and ethical complexity – characteristic of environmental problems - than traditional, 'normal' science. Because PNS recognizes the essentially subjective nature of 'facts' – that is, individuals will have different interpretations of what constitutes the facts and, to some extent, at least, their different versions must all be regarded as legitimate – then policy making requires much wider involvement to embrace a greater diversity of views, or as Healy (2010) puts it

[50] While being iconic this diagram is also open to criticism for being opaque and based on little evidence. Turnpenny et al (2010) provide a rare instance of a critique of this model.

[51] For instance, Frame and Brown (2008) argue that technological innovations for sustainability have often been disappointing because the "supposedly new organisational approaches remain embedded in managerialist, functionalist and anti-dialogic frameworks that are a significant part of the problem" (p 225) and thus propose the need for 'Post Normal Sustainability Technology' based on the principles of PNS.

"PNS involves integrating the contextually informed insights of lay stakeholders with those of technical stakeholders in 'extended peer communities' so as to generate 'extended facts[52]'."

Moreover, France (2010) argues that the scientific treatment of uncertainty (using statistical notions of probability) contradict the needs of citizens for clear answers to large scale issues (such as 'wicked problems' and 'nasty surprises'), and that it is this contradiction that has led to a general distrust of science and rationality more generally. PNS attempts to overcome this contradiction by opening up debate in a non-adversarial manner. It is this requirement for debate, discourse, involvement and participation with the extended peer community (EPC), leading to the generation of extended facts that is the clearest practical implication of PNS. Table 2.3 below summarises the characteristic features of PNS in comparison with those of 'normal' science (as seen by proponents of PNS). The central ideas of PNS can be summarized as: in the presence of uncertainty, risk, urgency and high stakes one must recognize the presence of multiple truths and thus the need for extended per community: problem resolution can only arise through discussion and debate to arrive at extended facts. PNS is thus process oriented (Omann 2004) and, clearly, not value-free.

Table 2.3 Normal and Post-Normal Science compared – a summary (adapted from Haag and Kaupenjohann 2001)

	Normal science	**PNS**
Epistemology	Essentialist Abstraction Seeks objective scientific truth	Constructionist Context Recognises pluralities of truths
Methods	Disciplinary	Transdisciplinary
Peer community	Closed, expert based	Extended peer community (stakeholders)
Uncertainty	Low	High
Stakes	Low	High

PNS requires, therefore, a more open, negotiated and iterative process of decision making, which can be characterized as involving greater reflexivity (Luks 1999). Reflexivity, in this context, refers to the tendency to use a method – such as that of scientific enquiry – to inspect and monitor the process of that enquiry itself. Science is therefore being asked to interrogate itself according to its own assumptions. By inference, such reflexivity leads to

[52] Such as local knowledge and unpublished material.

the need for debate and dialogue – or as Luks terms it, rhetoric - within the extended peer community.

This tendency to re-evaluate, reappraise and question the previously accepted knowledge base is, according to the influential ideas of Beck and his co-workers (including Giddens), typical of 'high' or 'second modernity' (Beck et al 1994, Luks 1999). In this reflexive modernization, the beneficial products of modernity come to rebound on society's wellbeing ; typical examples are of new, cutting edge technologies leading to previously unforeseen environmental problems (for example nuclear power, genetic engineering) so that increasing efforts need to be made merely to deal with these unwanted effects of modernity itself (Eden 1999). Because reflexive modernization is also seen as leading to greater individualization, it is accompanied by a demand for greater democratic control over science: democracy should not "end at the laboratory door" (Hannigan 2006). The idea of reflexive modernity is also central to the related concept of the 'risk society' (Beck 1992), which is dominated by the need to deal with the hazardous products of modernity (such as pollution) and which proposes that the monopoly of science on rationality has ended, so that science is necessary but not sufficient to tackle societal problems. Beck suggested that, as this new paradigm emerges, alternative forms of science will develop, more oriented towards influencing public opinion. As France (2010) argues:

"… The heart of the risk debate is the need for citizens to assert democratic control over the process" (p.6)

Such analysis leads to the conclusion that contemporary society is distinguished by its epistemological insecurity, which PNS both contributes to and attempts to resolve.

There are several claims that some scientific endeavours have already become post-normal. Healy (2010) is one of several commentators who note that this 'post-normal' condition, 'where the "distinctions between the spheres of facts, values and politics break down" (p.202) is increasingly becoming 'normal' in large scale environmental problems. Francis and Goodman (2010), for instance, argue that Nature Conservation is characterized by the inherent dangers of biodiversity loss, the urgency of the conservation task and the multiple uncertainties involved, as well as by the involvement in decision making and implementation of an extended peer community (including for instance volunteers with little or no scientific training) "with varying skills, perceptions and values" (p89). On that basis, they argue that Nature Conservation can already be termed a Post-Normal Science. France (2010) also argues that

".. environmental science comes closest to a practice of Post Normal science research where knowledge of a system will always be incomplete, surprise is inevitable and the system itself is a moving target because of human influences" (p.6).

Friedrichs (2011) similarly claims that climate science, as represented by the IPPC (Intergovernmental Panel on Climate Change) has "embraced post-normal science". He argues that

"In such post-normal situations, the issues at stake are too existential and too political to be left to scientific experts. The scientific peer community is therefore extended to include decision makers, interested citizens, media pundits, and others. In addition, debates over uncertainty go beyond technicalities and include radical doubt and ethical contestation." (p.3-4).

In a similar vein, Peterson et al(2010) propose that the Netherlands Environmental Assessment Agency 'unwittingly' took on a PNS model, following a scandal around that discredited aspects of the traditional technocratic model that had been deemed to fail in managing uncertainty. There have also been claims that Ecological Economics has become a Post Normal Science (Castro e Silva and Teixeira 2011). Kastenhofer (2010) concludes that that some aspects of PNS are already part of current epistemic practice, but cautions that a state of 'functioning post-normality'' has yet to be achieved. Similarly, Turnpenny et al (2010) conclude that there are relatively few instances of applying PNS to 'normal sciences'. Reports of the widespread usage of PNS as a practical method may, therefore, reflect a degree of wish fulfillment rather than general experience.

The concept of PNS is, furthermore, far from being unified. For some, its key distinguishing feature is the emphasis on problem oriented research and consequent transdisciplinarity (Omann 2004), for instance through the extended peer community. Others place a greater emphasis on increasing the plurality of views: in this sense PNS can be seen as a political movement, that sees science as "the final frontier of democracy" (Sardar and Van Loon 2001:

155)[53]. Participation has a key role in realising PNS, but the nature of that participation in PNS is itself contested. This can perhaps be best be analysed using the *Breadth* and *Depth* dimensions of the BID model of participation that was introduced in section 2.4.1. Transdisciplinary problem solving can be seen as a way of increasing *Breadth* of participation, but not *Depth*: it is not expanding the range of decision makers beyond the categorization that has traditionally been involved (that is, academics and professional specialists). The more political version of PNS, with its concern to democratize the process, is concerned with both to increase both *Depth* and *Breadth*.

Turnpenny et al (2010), in a comprehensive review of recent research on PNS, identify some further ambiguities inherent in PNS. They contend that Funtowicz and Ravetz were clear that reasons for using PNS were to provide better environmental problem solving, not to increase legitimacy. Using Fiorino's classification, this means that the extended peer community (that is central to the application of PNS) functions to fulfill the substantive imperative, rather than the instrumental or normative. More recently, however, research shows PNS becoming "strongly normative, with a clear social critique" (Turnpenny et al 2000:8). They conclude that a clear distinction needs to be drawn between PNS as a normative prescription and as a practical method.

Furthermore, the higher profile of PNS has led to it becoming subject to increasingly sharp criticism from a number of quarters. Rauschmayer et al (2009) note that the more participative, bottom-up approach of PNS may be laudable, but leads to problems such as the contestation of the "legitimacy of science itself" (p.51). This is evident from the crucial assertion of Funtowicz and Ravetz (1994a: 197) in PNS "... science is no longer imagined as delivering truth, ": this appears to be not only a capitulation to the more fundamentalist versions of constructionism, but also to be a gift to those, such as some climate change deniers, who are willing to use such careless statements to further their own cause. Thus Friedrichs (2011) proposes that:

[53] Friedrichs (2011) notes, for instance, that PNS as originally conceived had a distinctly radical agenda, with the intention that the 'extended peer community' should explicitly include those normally excluded from the political process, that is: empowering the disempowered.

"Climate scientists find themselves in a double bind between post-normal science and standard scientific values, which has painted them into a difficult corner. On the one hand, extending the peer community has intensified debate and galvanized part of the public for action. On the other hand, important sectors of the public do not forgive any dilution of scientific rigor" (p.472.)

So Friedrichs argues that, within much of the debate about Climate Change, scientists have engaged in PNS but that has undermined their credibility as they have had to compromise some rigor to engage in debate[54]. Furthermore this has opened them (scientists) up to further criticisms from sections of the press. Turnpenny et al (2010), for instance, note that the tabloid journalist Melanie Phillips, picking up on some of these injudicious quotes, targeted Post Normal Science explicitly in her column, arguing that it proved that climate scientists no longer sought truth. Ravetz (2010) himself chronicles the opprobrium his Post Normal Science interpretation of the 'climategate' incident brought on himself from climate change deniers. The debate that he records in notable for its lack of integrity and honesty, despite Ravetz arguing

"… we are on the same side, committed to the integrity of science" (p.149).

Wesselink and Hoppe (2011) further explore the ambivalences inherent in PNS, arguing that it has been promoted by its adherents as a new way of doing science that has the ultimate objective of

"remedying the pathologies of the global industrial system for which, according to Funtowicz and Ravetz (1993, 739) existing science forms the basis." (p.389).

They proceed to evaluate this claim critically by reviewing the empirical evidence as well as the theoretical basis of PNS. They conclude that, although PNS has been at the forefront of the critique of the limitations of 'normal science', it has failed to effectively address the questions that then arise concerning governance and the nature of the deliberative democracy that it calls for. They argue that PNS repeats some of the false assumptions of the normal science it seeks to replace: the idea that reasoned debate between actors within the EPC can replace the usual processes of political deliberation. They go on to trace the origin of "*this scientistic hubris*" (p.389) to the scientific background of its originators and call for a recognition of the centrality of the political in discussion on environmental policy. It

[54] Friedrichs goes on to argue that because Climate Change is a much larger scale and more intractable problem than any other environmental issue, the public reaction has been characterised by denial and self-deception, thus sabotaging the efforts of PNS advocates to promote a genuine debate.

appears, therefore, that PNS proponents, led by Funtowicz and Ravetz, criticize science for failing to enter into dialogue with the wider community, but have themselves neglected to recognize the extent to which the dialogues they have entered have been unsuccessful in promoting clearer understanding and problem resolution. PNS assumes that issues will be negotiated in good faith, that debates will be fair and participants show integrity (Turnpenny et al 2010). However, this can be seen as naïve, neglecting the realities of power relations in decision making, and provides a framework that can be exploited to forward one interest group, and could be captured by groups with other agendas[55].

It can be concluded that PNS has provided initial promise for a unified approach to a new, participative decision making which has failed to live up to its early promise. Nevertheless, PNS can be regarded as the foremost vehicle for a new approach to science in policy making, one that replaces a 'predict and determine' model with one of 'assess and consult' that is more sensitive to the problem context. It has developed a profile that has become known outside the narrow academic fields where it originated: for instance it has been referred to by the World Bank and discussed (controversially, as discussed above) in the popular press (Turnpenny et al 2010). To some extent any move away from traditional technocratic top-down model towards greater participation is now being labeled PNS, whether or not it was inspired by the specific PNS agenda. The term PNS can therefore be seen to have (at least) two meanings: as a general, all-embracing term (perhaps the 21st century version of the communicative turn) that refers to any attempt to widen involvement in decision making, integrating a number of already current ideas (Omann 2004) and a more specific meaning that is applied to the specific methods developed by Ravetz and his immediate collaborators. Wesselink and Hoppe (2010) argue that attempt to combine reform of science as democratizing, green political agenda has been "conceptually fuzzy and unhelpful" (p.390). They conclude that PNS has been successful as a "sensitizing concept" (p.380) (that is drawing attention to the need for a new approach to environmental problems

[55] Note that there are parallels here with Scott's argument (2008) (discussed above) that the use of participation to drive to incorporate good governance can actually undermine the environmental utility of the outcomes. Note also criticisms of PNS from scientists who believe that involving non-experts from the Extended Peer Community within the process will lead to anecdotal evidence and poor decision making.

that have high uncertainty and high stake) rather than as a fully-fledged theory or practical technique.

2.7 Environmental Decision Making: a summary

In this chapter it has been argued that policy analysis is a fiercely contested area that might now be approaching a resolution. The recent history of environmental policy development, in particular, has been characterized by a sharp debate between the rational technical approach and its postmodern critics. It has been argued, furthermore, that this debate has often been unconstructive and has hindered, rather than helped, those involved in the practical tasks of decision making. In particular, two assumptions have frequently been made in this debate that have obstructed progress: first, that rational techniques are inherently non-democratic and anti-participative; second, that democratic, participative methods are inherently non-rational and anti-scientific. These two diametrically opposed positions became so entrenched that dialogue became impossible.

More recently, however, there has emerged the beginning of a dialectic synthesis that points towards a consequent consensus. Sloep and van Dam-Mieras (1995), for instance, argue that a tripartite interaction is necessary to tackle complex environmental problems: a synthesis of Science, Socio-political knowledge and societal norms. Similarly, Owens et al (2004) suggest that the two approaches – the technical-rational and the deliberative - can be combined in a model involving learning and "sensitivity to context"[56], while Chivers (2008) contends that following the participatory turn there have developed new hybrid techniques which he calls "analytic-deliberative"; he includes Multicriteria Analysis within this group. Two features characterize such methods: first, engagement and participation occur early and 'upstream' in the policy formation process; second, they involve explicit attempts to break down divisions between expert scientists and citizens/stakeholders. Similarly Barbanente et al (1998) argue that there has been an epistemological shift away from straightforward, linear, one-to-one relationships towards what they call a 'complexity paradigm': that is

[56] They cite examples of environmental decision making in Finland where effective compromises were thereby achieved.

focused on emergent complexity (as argued by Funtowicz and Ravetz (1994a) and typified by modern theories of ecology). They suggest that the established models of policy choice, traditional rational model on the one hand and pluralism on the other, are being supplemented by a consensual, multi-agent decision theory[57].

However, the question then arises: how are these general framing conditions going to be met in practice? What techniques and methodologies can realize the aspirations for consensual, deliberative, inclusive and participative processes that nevertheless retain the best elements of the scientific tradition, with its emphasis on rigor, criticism? While Post Normal Science seems to have identified the types of problem that need this new approach it has failed to adequately address the details of how this can be done: in particular, what types of governance are required and what kind of deliberative processes are appropriate? Other approaches, such as civic science, offer a plethora of participative methods without clear ideas of how they can be integrated into established, rational techniques. Neither do they prescribe how the latter may be adapted to render them more open to deliberative processes.

Participative forms of Multi Criteria Analysis (MCA) may offer one way forward in answering these questions. While MCA has developed firmly within the rational-technical tradition, it has increasingly been adapted for wider, deliberative use. But this process is still in its early stages: the details of how MCA can be so adapted, and how effective it can be in retaining the advantages of rationality while widening involvement, have still to be addressed. The next chapter introduces the MCA technique and provides a framework for beginning to answer these questions.

[57] A rather different alternative to the two established models is the neo-incrementalist approach typified by Co-evolution and Transition Management, discussed in section 3.3 above. It has been argued that such methods involve excessively modest goals and an overly reactive, even passive, approach. It has been argued that a synthesis that incorporates the best of RT, that is anticipatory and goal-oriented, offers better long term solutions.

Chapter 3. Participative Multi Criteria Analysis

In the previous chapter it was proposed that it is feasible to develop methods for environmental problem solving that bridge the gap between traditional rational techniques and their deliberative critics. Multi Criteria Analysis (MCA) is a prime candidate for such a method, arising as it does from highly rational and mathematical origins but more recently embracing participation and stakeholder involvement. Those forms of MCA that have been designed specifically to enable such stakeholder engagement have been termed participative MCA (PMCA). This chapter examines these in some detail, providing a framework for the development of the SMARTEST technique, developed for this study, which is described in chapter 6.

Section 3.1 provides a brief overview of the key features of MCA and goes on to review its specific relevance to environmental decision making. Section 3.2 presents a brief history of MCA development. This has often been characterised by fragmentation into different approaches and schools, exacerbated by inconsistent use of terminology: section 3.3 attempts to clarify the terminological nuances and the differences between the various forms of MCA, before going on to summarise its mathematical basis. In order to illustrate how MCA works in practice, as well as introducing the methodological approach used in this study, the SMART (Simple Multi Attribute Rating Technique) family of methods is described in some detail in section 3.4, along with some of its derived variations.

Section 3.5 examines how MCA can be employed participatively, reviewing a representative sample of MCA usage in environmental problems. This review identifies three exemplars of good participation, which are discussed in some depth. Such participative practice requires, however, that MCA technique is accessible to the non-specialist stakeholder, and ease-of-use constraints are discussed in section 3.6. Finally, section 3.7 summarises the current state of participative MCA and outlines how this study aims to develop a new and more effective technique.

3.1 Introduction: MCA and environmental decision making

3.1.1 The characteristics of Multi Criteria Analysis

Multi Criteria Analysis (MCA) is a type of decision making tool, originating within the fields of mathematics and Operational Research, that structures and simplifies a decision problem (Proctor and Dreschler 2006). The term is used here to encompass a family of methods that is variously termed Multi Criteria Decision Aid or Analysis (MCDA) or Multi Criteria Decision Making (MCDM) (Belton and Stewart 2002). These variations in terminology do signify some important differences in the techniques employed and, most importantly, how they are used. However, in practical applications the terms MCDA, MCDM and MCA are often used interchangeably. Nevertheless, in this study, the term MCA will be used as an inclusive term for the whole family of such techniques.

Despite the variations between methods, all MCA techniques share the following processes (Banville et al 1998, Belton and Stewart 2002, Shmelev and Rodríguez-Labajos 2009):

1. The identification of options, that is the alternatives courses of action available;
2. The identification of criteria for making the decision, that is the goals or objectives, and establishing how they can be measured;
3. Evaluating the performance of each option in terms of each criterion;
4. Combining or aggregating these performances so as to arrive at a framework of comparison for all the options.

Before looking at the MCA technique in more detail, it will be worthwhile to consider the nature of the decision making process more generally.

The decision making process can be defined as the activity leading to the choice of a course of action, where two or more alternatives are present, in response to a problem. It may involve selecting one preferred alternative or ranking all alternatives in order of preference (Omann 2004). A distinction can be made between the terms choice and decision, with the former referring to a single event and a latter to a more complex process involving consideration not only of the ends to be attained but also to the means by which they are attained (McGrew and Wilson, 1982: 13-17).

Such a definition assumes that the necessity for a decision will only arise if the existing situation is either unsatisfactory or unsustainable. However, the outcome of a decision process may be to continue as before with the *status quo ante* – often termed the 'Business as Usual' (BaU) scenario – in which case the other alternatives may be perceived as being (even) worse than BaU.

Decisions may be clear cut in terms of making a choice between self-evident alternatives, or arise from a more vague sense of dissatisfaction with the status quo. In either case, a decision process ultimately requires a choice to be made.

Decision processes are embedded within daily life and many of them are relatively trivial: what to eat or wear, what book to read or film to watch. Even the more unusual or significant decisions can often be approached quite satisfactorily using intuitive skills and implicit heuristics. However, although such approaches might be adequate in many circumstances, where there is a lack of time or other resources to make a more thoroughgoing analysis, they may not provide the optimal solution – that is, the choice of the best alternative which most meets the decision maker's needs. Herbert Simon (1972, 1984) pioneered consideration of decision making is such sub-optimal contexts, and coined the phrase 'bounded rationality' to describe the constraints (especially of information availability) that preclude more rational approaches: this has been outlined in the preceding chapter. For routine decision making, therefore, decision makers will often 'satisfice': Simon's term for choosing the first option meeting a minimum standard or threshold that the decision maker encounters. In most everyday decisions such satisficing is a reasonable – and indeed quite rational – method.

Decision makers invariably operate within bounded rationality in this way, insofar as information, time and other resources are always finite. But it can, nevertheless, be argued that these boundaries of rationality can be pushed back, that more information can be collected (if resources allow), and decisions then made in a more 'rational' and informed manner. Decision problems that involve complexity and high costs of failure (or reward for success) can therefore justify more elaborate methods of this type of rational thinking. This is, in essence, the rationale for the development of a group of techniques often termed Decision Aids, of which many have been developed in the decades since 1950s. MCA is one type of Decision Aid approach.

MCA is distinguished insofar as it is explicitly designed to tackle those problems with many criteria. On this basis alone it is differentiated from techniques such as Cost Benefit Analysis (CBA) that address only one criterion in that it reduces all other criteria to a single measure of monetary value. Traditional economic approaches to environmental problems have often used CBA as it enables polices to be selected according to a straightforward measure of efficiency (Messner et al 2006).

CBA is based on the idea of commensurability that assumes the equivalence or comparability of measures: there is a single measure of values to which all others can be reduced. O'Neill (1993) provides a compelling case for a rejection of the CBA approach in complex problems in that it cannot deal with incommensurable, plural values, where more than one criterion exists. O'Neill goes on to argue that because environmental decisions are so often characterised by precisely this type of configuration then techniques rooted in neo-classical economic theory such as CBA are inadequate (see also Munda 2006, Messner 2006, Gamper and Turcanu 2007 for similar arguments).

MCA techniques are, however, designed specifically to address such problems, involving a number of criteria with different scales. As Hajkowicz (2006:124) contends, the decision problem is essentially one of "adding apples and oranges" onto a single metric. This is the essence of the MCA method, in that it allows a method for the commensuration of the otherwise seemingly incommensurable factors.

3.1.2 The relevance of MCA to environmental decision making

Many authors have commented on the particular complexity of many environmental problems. They are frequently characterised as involving a multiplicity of physical, chemical and biological factors interacting in multifaceted processes with social, economic, political and psychological issues. That is, such problems are not only quantitatively highly complex, but also involve a qualitatively different type of complexity that is less amenable to many decision aid techniques. Thus Funtowicz and Ravetz (1994) usefully differentiate 'ordinary' and 'emergent' complexity, with the latter characterised by the presence of intentionality (see chapter 2). Environmental problems are typically emergent, and thus not amenable to reductionist explanations. This emergent complexity and the presence of multiple, often very different – and thus incommensurable – objectives, makes MCA notably suitable as a Decision Aid (for instance Hostmann 2005, Marttunen et al 2005 , Messner 2006, Munda 2006, Proctor and Drechsler 2006, Gamper and Turcanu 2007, Chang et al 2008, Roca et al 2008).

Several other features of environmental problems are also addressed by the use of MCA. Typically, fundamental features of the problem are often perceived in very different ways by the various stakeholders (Mustajoki et al 2004) and heterogeneous stakeholder interests will be present (Hostmann et al 2005). Stakeholders may not only have diverse priorities but also may disagree in a fundamental fashion about the very nature of the processes involved: from this arises uncertainty (ontological and epistemological) compounded by contested values.

The case study of the Adirondacks Park in New York State, described by Mason and Michaels (2001) and discussed in chapter 2, provides a good illustration of this type of problem. The two different groups of stakeholders (environmentalists and local residents) had conflicting views not only of what park management should by trying to achieve but also of the ecological processes that such management depend on. It is invariably the case that such problems have no simple 'rational' solution (De Montis et al 2004).

The complexity and presence of multiple contested goals involved in environmental issues combine to produce typically 'wicked' problems (Glasser 1998), requiring particular forms of decision aid technique. MCA, which has as its central rationale the use of multiple criteria, has thus been increasingly recognised as a potentially essential tool. MCA is also especially well-suited for this role as it based on the ideas of compromise and arbitration (Banville et al 1998), as judgments are made on how to trade-off one option's advantage in one criterion against its disadvantages in another. There is no one optimum level, perfect solution or ideal outcome, so the process is quintessentially subjective. MCA can approach such problems by providing a model that predicts what outcomes actions will have, using available scientific evidence. Outcomes are evaluated in terms of their utilities (based on norms) by stakeholders working within defined socio-political frameworks.

The use of MCA in tackling environmental problems has become increasingly recognised at the Institutional level. Gamper and Turcanu (2007) identify a number of countries - including Spain and Italy – where MCA is an element within specified legal requirements, while in the United States of America MCA is an implicit legal requirement in water resource planning. The United Nations Framework Convention on Climate Change (UNFCCC) '*Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change*' states that MCA is "particularly applicable to cases where a single-criterion approach (such as cost-benefit analysis) falls short," and "MCA allows decision makers to include a full range of social, environmental, technical, economic, and financial criteria" (UNFCCC 2011). The European Commission Sourcebook of methods and techniques states that

"Through negotiation between stakeholders and explicit treatment of judgment criteria, the technique serves to give form to an unstructured reality. The strength of multicriteria analysis therefore, lies in the fact that it allows the values and individual opinions of several actors to be taken into consideration, and the processing of functional relations within a complex network, in a quantitative way" (European Commission 2009).

However, it goes on to note that problems of implementation restrict its use in this way, with the necessity for expert involvement inhibiting the extent to which the method is used interactively: the study reported in this thesis attempts to address this difficulty. Overall, then, MCA is recognised as a tool with great potential as a decision aid with multiple stakeholders, but this potential has yet to be fulfilled.

In the United Kingdom, MCA has been used by the Tyndall Centre for Climate Change Research in climate change mitigation planning (Brown and Corbera 2003). MCA has also been used as method of comparing the deleterious effects of various drugs. A team led by David Nutt, who the previous year had been removed from his post as chief government drugs adviser, published a paper in the Lancet that used MCA to provide comparative harm assessment of drug misuse and concluded that alcohol was, overall, more harmful than heroin or crack cocaine (Nutt et al 2010). The resulting controversy thrust the MCA method into the media spotlight, albeit briefly.

MCA is not a model of reality but a model of how people perceive their preferences (Belton and Stewart 2004). This important insight suggests why there has been a move away from MCA as a technique for finding 'the right answer' to where it facilitates the decision making process by articulating those preferences more clearly. This process – of integrating rational techniques with more deliberative processes – is at the core of the Post Normal Science agenda discussed in the previous chapter, and the extent to which MCA can meet these expectations is one of the key research questions of this study. However the origins of MCA lie firmly within the rational tradition with which much of the PNS discourse takes issue. In order to understand how this change has occurred a brief overview of the history of Decision Aid techniques is needed. This history was initially dominated by an apparently fruitless conflict between two schools of thought: those who saw such methods either as models of how decision making does occur and those for whom these techniques were merely an aid within a broader aspiration to make decision making a more rational process. It was only when this seemingly irreconcilable conflict was transcended that MCA began to make its transition from a rational decision making tool to a technique championed by deliberative PNS advocates. The following section will outline the course of these debates.

3.2 A brief history of decision theory and decision Aids

3.2.1 Early development and the descriptive versus prescriptive controversy

The origins of MCA lie in the growth, during and immediately after World War 2, in mathematically based approaches to business and politics (for instance Game Theory developed by von Neuman in the 1940s)[58]. However, the emergence of MCA in its own right occurred in the 1960s (Omann 2004; Keeney 2006). A key breakthrough, the development from the consideration of single-objective based problems to those with multiple objectives was made in a seminar paper by Raiffa in 1969 (Edwards and Barron 1994). Raiffa's insight was that when something is highly valued it is because of more than one of its qualities. This apparently simple observation was a powerful one, as it led him to propose that the outcome of an action can be best described by some aggregate of those different values. This work was developed by Keeney and Raiffa into Utility Theory (Keeney and Raiffa 1976)[59]. In the decades following MCA methods gained an international reputation (Oman 2004: p102).

These developments took place within a broader debate on the nature of decision making. The considerable literature on this subject from the 1950s onwards comes from a variety of disciplines including management, economics, politics and psychology, but it has also been subject to increasingly interdisciplinary study (McGrew and Wilson 1982). There was much debate within this field, however, surrounding the confusion between descriptive and prescriptive (normative) models of the decision making process. On the one hand there had been the development of prescriptive models deriving, according to Hall (1980) from the utilitarian practical philosophy of the 18th century. On the other hand there has been the increasing realisation that in practice decision making was often far from rationale, but rather involved complex psychological and organisational processes which may combine to result in decisions that are quite irrational.

[58] Although the intellectual roots of the MCA approach may lie much further back in time: Omann (2004) for instance suggests that it can be traced to the work of Condorecet in the 18th century.
[59] Where there is uncertainty concerning outcomes the term 'Utility' is usually employed, in contrast to the term 'Value' used in riskless situations (Edwards and Barron 1994)

The seminal work for this line of thought is often taken to be Allison's 1971 study of the 1962 Cuban missile crisis, wherein such irrational processes by all the actors involved almost resulted in global nuclear catastrophe. The realisation that such important decision making processes might be prey to such irrationality lead to a reconsideration of the fundamental processes involved. This identified a number of flaws in the so-called rational actor model. For instance information may be lacking or inadequate, or there may be conflict between explicit and implicit values and goals, while the overall process may be much more fluid and complex than supposed (Hall 1980).

Furthermore there was a growing body of evidence from studies in Psychology that human cognitive processes were fundamentally limited in certain important ways. Essentially the upper limit of what can be decided on by normal cognition is lower than one might expect. This, taken together with the complex nature of non-routine decision problems and the lack of relevant information that is normally available, results in Simon's 'bounded rationality'. This line of development led many to conclude that, in many cases, previously accepted rational models of decision making were unrealistic and that descriptive studies of how decisions actually occurred provided better insights into the underlying processes.

This critique of the rational model fails to appreciate that the rational actor model was, at its best, essentially prescriptive. Indeed, the development of rational techniques such as MCA can be interpreted as a response to the insight that decisions are often too complex for unaided human cognition. That is, decision aids such as MCA can help the decision maker, faced by a highly complex problem, to make more rational decisions.

We can conclude that the debate has now moved forward from a rather simplistic 'prescriptive versus descriptive' dichotomy: there is a realisation that decision making is often too complex – and indeed that rationality is often too bounded – for decision making to be straightforward or intuitively obvious. In such cases decision makers resort to a number of strategies that vary in efficiency. Such strategies include the 'recognition' and 'take the last' heuristics (Goodwin and Wright 2004) as well as Simon's (1982) 'satisficing'. Such heuristics are non-compensatory: the extent to which an option exceeds the minimum required threshold is not taken into account and cannot therefore be 'traded' against another criterion where performance of an option is just below threshold. However, these heuristic methods are often quite adequate for many decisions where the decision is of relatively little importance, little time is available, or the decision maker is unable or unwilling to invest much cognitive effort into the process (Goodwin and Wright 2004)

At the same time, however, there has been a growing acceptance of the argument that, for complex decisions of particular importance where the cost of 'wrong' decisions might be especially high, there are a number of techniques that can make the process *more* rational. As discussed in preceding sections, the underlying justification for the use of MCA is that many problems are too complex for 'normal' and 'everyday' decision making processes to be effective.

So for any particular problem, the decision maker is faced with question of selecting an appropriate strategy, taking into account the effort involved, time available, knowledge of the problem, the importance of choice, the need to justify to a range of stakeholders and, above all, the overall complexity. For simple decisions, where the cost of being wrong is relatively small or where there is insufficient time or resources to use a more elaborate method, straightforward heuristics may be justifiable. However, the proponents of rational decision making techniques argue that these will be, invariably, less efficient and/or effective than using systematic compensatory methods, such as MCA. By the 1970's the argument between prescriptive and descriptive approaches had run their course, and rational decision making techniques such as MCA had become increasingly accepted as essential tools within business and management.

3.2.2 Criticisms of the use of MCA in environmental problems

The take up of MCA by environmental decision makers lagged behind its use in business, however, and it was not until the 1990's that such use began to became more common. Furthermore, MCA in environmental decision became the target for a number of criticisms, including philosophical, political, technical and practical objections.

Rauschmayer (2001), for instance, contends that ethical considerations are inadequately addressed in the literature on MCA, and that Multi Attribute Utility Theory (one of the main approaches to MCA, and thus by extension MCA in general) is based on the same (flawed) assumptions of commensurability that have led to criticisms of CBA (see O'Neil's (2001) analysis above). Rauschmayer's underlying reasoning is that because all alternatives are evaluated in relation to their consequences it essentially amounts to the ends justifying the means, and contrasts this to a deontological approach, where actions are judged on their own intrinsic merits: that is the means and not purely their ends. He goes on to maintain that in this sense the inherent utilitarianism of MCA must be essentially anthropocentric and unable to incorporate contending, ecocentric values. This argument contains some inconsistencies, however: selecting courses of action based purely on their intrinsic features without consideration of their consequences is precisely what has led to so many environmental problems.

Other critics have argued that MCA represents a technocratic approach that was inappropriate given the complex nature of environmental issues. There is certainly a history of MCA methods being used in a top-down fashion, wherein the stakeholder is only marginally involved in supplying inputs into the process, but is disengaged from the actual process. Such uses of MCA may either supply a "false sense of security" to the decision makers (as Janssen 2001: 101 argues), or it may leave them feeling disempowered and unwilling to use the outcomes of the process. The review of more than fifty applications of MCA to the environment, discussed below, shows that in many cases the decision analyst retains control over all the steps in the process, with limited input from experts and often no input at all from wider stakeholder groups. Where a wider range of stakeholders is involved, it is frequently in a passive sense in that their attitudes towards the issue might be sought via, for instance, a questionnaire. The use of MCA in practice may thus perpetuate a division between the rational scientist and the ordinary citizen who is, by implication, perceived as less rational (Stirling and Mayer 2001:532).
It can be argued that such criticism of MCA is of the way in which it is used rather than the method itself. Alternately, it might be that the technique is inherently top-down, and cannot deal with the requirement for more deliberative and participative approaches. The following

section will look at some recent developments which have addressed these problems. The final section of this chapter will review some of the criticisms of MCA and demonstrate ways in which the methodology of this study aims to address some of the issues that arise from them.

The practical implications of this argument regarding the technocratic nature of MCA may be manifested in resistance from participants. Hostmann et al (2005:92) for instance indicate that some studies have shown that participants feel excessively constrained by the technique, preferring the "freedom of unaided decision making". There is also evidence, unfortunately much of it merely anecdotal, that the technical and cognitive demands of some MCA methods compound this resistance and result in further antipathy to the technique. Mander (2008) for instance found that 30% of participants did not complete the impact matrix stage of the MCA process as it was too time consuming. By the 1990s it was emerging that MCA had considerable promise in environmental problem solving but that new approaches were needed to address these objections.

3.2.3 Recent advances

Over the last twenty years the use of MCA has been guided by changing methodological principles (Roca et al 2008): at first it sought the best option, then moved to an emphasis on learning and facilitating the decision process. The current emphasis is of using this process-orientation to improve public participation: a move from a technocratic to a participatory orientation (Paneque et al 2009). Henig and Weintraub (2006), for instance, suggest that the emphasis has moved from finding the optimum solution to developing insights into the decision making process, and in particular in understanding the different preferences of stakeholders as well as expanding the range of alternatives considered.

One of the claims made by this process oriented approach is that it might help to resolve conflict between stakeholders. Hostmann et al (2005) suggest that MCA may do this in three ways: by aiming the different positions taken by stakeholders and identifying differences, by improving openness and transparency and by increasing the range of options considered.

One of the issues that has emerged from this transition from an outcome orientation to one of process-facilitation (using Rauschmayer's (2001) terminology, from a consequentialist-utilitarian to deontological model) is the extent to which the rigorous and sometimes onerous methodological requirements of traditional MCA can and should be compromised in the interests of aiding learning and involving stakeholders. Omann (2004: 108) argues that some new MCA developments such as multi-criteria mapping (MCM: Stirling and Mayer 2001) regard the "complicated techniques" of traditional MCA techniques as "superfluous". It is possible that there is a trade-off between methodological robustness on the one hand and ease of use and accessibility (and thus utility for facilitating participation) on the other.

3.3 MCA terminology and mathematical basis

3.3.1 Terminology

Discussions of MCA are sometimes hampered by the plethora of terms used to describe the methods and their technical components. This study uses the term MCA, generically, for the whole family of related Decision Aids, it is often used interchangeably with 'Multi Criteria Decision Making' (MCDM) and 'Multi Criteria Decision Aid' (MCDA), (Omann 2004, Myŝiak 2006). However, these terms are sometimes used to indicate differences between approaches. The following section attempts to clarify some of these nuances.

"***Decision Aid***" and "***Decision Analysis***" are general terms, although "Decision Aid" refers more to facilitative processes, while "Decision Analysis" is associated with a wider approach, including problem solving methods, derived from decision theory by Raiffa and Howard. Roy (1990:324) argues that *"the purpose of decision-aid is, therefore, to help us make our way in the presence of ambiguity [and] uncertainty …".* In contrast, Omann (2004) suggests that "Decision Analysis" can refer to specialist support given to decision makers in preparing for a decision and is therefore a top-down process.

"***Multi Criteria Analysis***" (MCA) - sometimes also referred to as "Multi Criteria Approach" or as "Multi Criteria Assessment" - is a general term for all decision problems with conflicting objectives. It is the preferred term used in this study for the whole family of techniques.

"***Multi Criteria Decision Making***" (MCDM). Omann (2004) suggests that this is the term used in the U.S.A. to refer mainly to additive utility methods, with well-structured mathematical procedures to optimise result and the emphasis placed on the outcome more than on the process. Omann goes on to argue that MCDM is therefore not suitable "in the context of sustainable development", where process is as important as outcome.

"***Multi Criteria Decision Aid***" (or "Multi Criteria Decision Analysis") (MCDA) is sometimes associated with the 'European school' (Omann 2004) and can be seen to differ from MCDM in being less formalised and more concerned with facilitating the decision process than arriving at an optimised solution (that is, in accepting that a single optimal solution may not be available, given the highly subjective and contested nature of some of the variables). However, Rauschmayer and Wittmer (2006) characterize Multi Criteria Decision Aid as essentially non-participatory as it usually involves only one decision maker.

"***Multi Criteria Evaluation***" (MCE) is a term usually used to refer to the decision process proceeding (but not including) the decision itself.

Other important definitions include:

Criteria are factors which should be, as far as possible, taken into account by the outcome of the decision making process. Criteria are sometimes referred to as 'objectives' or 'goals' (Belton and Stewart 2002; Goodwin and Wright 2004), and sometimes confused with attributes (which are measures of the extent to which criteria are met). Omann (2004) uses the term 'objective' to mean a broader value-based 'desirable': something that the decision makes wants to attain; while using the term 'criteria' to mean the measurable aspects of these objectives: "Criteria are used to operationalise the objectives ..." p117. Geneletti (2007: 279) offers a definition of a criterion as a "standard for judging", whereas their evaluation requires "measurable parameters". However, the term 'attribute' is more generally used to refer to a measure of a criterion (see below). The term 'values' is used to describe the more general goals; when these are defined more and more specifically a value tree is created, the final 'twigs' of the tree representing the criteria (Belton and Stewart 2002).

Weights[60]. If all criteria were of equal importance then they would have equal weights. However, in most cases some criteria are judged to be more important than others, so that their relative weights have to be assessed. There are a number of ways in which weights can be elicited, and some controversy as to which methods best represent the views of the decision maker. Choo et al (1999), for instance, argue out that "criteria weights are often misunderstood and misused, and there is no consensus on their meaning" (p 528). They point out that in MCA applications (particularly those that are software based) weights are elicited by asking the participant to give the relative "importance" of each criterion without sufficiently defining what "importance" means. (p538).

Options are also sometimes referred to as 'alternatives' or simply 'choices' (Belton and Stewart 2002; Goodwin and Wright 2004). Either term can be used to refer to the various courses of action that may be taken in the decision problem (including, of course, the decision to defer a decision or not to make a decision at all). As Edwards and Barron (1994) point out, options, or their outcomes, are the objects that are being evaluated.

Attributes refer to some measurable entity which can be taken as representing the degree to which goals / criteria are achieved. Attributes are, therefore, ways in which each option can be associated with a point on a scale value for each criterion. In certain instances, where criteria are stated in a straightforward and objective fashion, attributes represent criteria directly. To give an illustrative example, if one goal, of a specific decision making process involving a National Park, is to maximise the number of visitors, then the attribute could

[60] Criteria weights are sometimes called 'scaling constants' (for example Ananda et al 2003) or 'importance values' (for instance Ferranini et al 2001).

simply be the annual visitor number (insofar as this is an accurate measurement). In other cases, criteria may be stated in a necessarily vaguer or more abstract fashion. For instance, if another criterion in this example were to enhance the landscape attractiveness, then this essentially subjective quality is impossible to measure directly. Instead, some attribute – such as the scores on a questionnaire given to visitors asking them to rate attractiveness – would serve as a proxy for the criterion. Attributes represent the lowest or most distal dimensions of a hierarchical value tree and are sometimes termed 'indicators' (Proctor and Drechsler 2006).

Value function. If attributes are not direct measures of criteria then value functions may have to be determined: that is the relationship between attribute level and perceived value for the corresponding criterion, for instance using the bisection method. In many cases value functions may be non-linear. For many MCA techniques, the calculation of value functions – the basis of the relationship between criteria and attributes – is complex and time consuming.

3.3.2 The sub-families of MCA

The MCA family of procedures can be sub-divided into three sub-families (Roy 1996, Belton and Stewart (2002), Montis et al 2004, Omann 2004, Klauer et al 2006):

1 Additive or Score-based approaches, where each option is given a rating with which it can be compared to all other options, or as Roy (1996, p.241) explains "a single synthesising criterion without incomparabilities" with a complete aggregation method. These are termed value-oriented methods by Myŝiak (2006) insofar as performance is translated into perceived value (or, in conditions of uncertainty, utility). This sub-family includes methods based on Multi Attribute Utility Theory (MAUT) and Multi Attribute Value Theory (MAVT), and also includes the Analytic Hierarchy Process (AHP).[61] The approach is closest to that of Cost Benefit Analysis although CBA cannot be regarded as a Multi-criteria method as it

[61] Hyde et al (2005) use the label Weighted Sum Method (WSM) to refer to the "simple and often used" MCA technique (p282).

considers, by definition, only one criterion. These methods are perhaps the most straightforward in terms of their underlying logic, and thus require less effort for non-expert participants (Konidari and Mavrakis 2006).

2 *Outranking methods* which use pair-wise comparisons (that is, each option is compared with each other option in an iterative process). (Mesner 2006).
Examples include ELECTRE, PROMETHHE, NAIADE and Regime. These are more flexible and qualitative score-based methods, but are generally complex and perhaps harder to use.

3 *Goal based, interactive methods*, where desirable levels are set and options assessed in terms of the extent to which they achieve these levels. Examples include Multi Objective Programming (MOP). Unlike both Additive and Outranking methods, which deal with discrete, discontinuous options, these methods use a continuous set of alternatives (Omann 2004).

3.3.3 The mathematical basis of MCA: the additive approach

The MCA approach is rooted in a formal mathematical treatment. In this section, the basic framework of this mathematics, with respect to the additive MCA approach, will be outlined.

Assume that there is a set of options A (a_1, a_2, …. a_j…. a_m) (for the purpose of this discussion these are discrete and discontinuous, and thus not suitable for Multi Objective Programming: see Banville et al 1998).

Also assume a set of criteria X (x_1, x_2, … x_i,...x_n)
It should be noted that the identification and determination of criteria is a crucially important part of the MCA process, with a number of different methods that can be employed. Criteria should be exhaustive (that is, cover all the relevant goals), monotonic (that is, an increase in value represents a continuous change in desirability) and minimal

(that is, with no superfluous or duplicated criteria). Above all, criteria must be operationable, that is they must be able to be measured (Belton and Stewart 2002).

The performance of each option on each criteria (Hyde et al 2005) can then be identified as :
$P\, x_i\,(a_j)$ which is the performance of the $j^{th.}$ option on the $i^{th.}$ criterion

If this is carried out for every combination of options and criteria it results in an Impact Matrix, in which these performances are presented in a tabular fashion (for instance Banville et al 1998).

Table 3.1 The structure of a simple Impact Matrix with unweighted criteria.

		Options					
		a_1	a_2		a_j	…..	a_m
Criteria	x_1	$P\, x_1\,(a_1)$	$P\, x_1\,(a_2)$		$P\, x_1\,(a_j)$		$P\, x_1\,(a_1)$
	x_2	$P\, x_2\,(a_1)$	$P\, x_2\,(a_2)$		$P\, x_1\,(a_j)$		$P\, x_2\,(a_2)$
	x_i	$P\, x_i\,(a_1)$	$P\, x_i\,(a_2)$		$P\, x_1\,(a_j)$		$P\, x_i\,(a_2)$
	………….						
	x_m	$P\, x_m\,(a_1)$	$P\, x_m\,(a_2)$		$P\, x_1\,(a_j)$		$P\, x_m\,(a_n)$

The entry in each cell represents the impact of each option on each criterion.

This simple impact matrix assumes that each criterion is of equal importance to all other criteria, that is that they have equal weights. If, however, the criteria have different weights such that $w(x_i)$ is the weight of the i^{th} criterion, then the weighted impact matrix may be given as

Table 3.2 Impact matrix with weighted criteria.

			Options					
		Criteria weights	a_1	a_2	…	a_j	….	a_n
Criteria	x_1	$w(x_1)$	$P\,x_1\,(a_1)$	$P\,x_1\,(a_2)$		$P\,x_1\,(a_j)$		$P\,x_1\,(a_1)$
	x_2	$w(x_2)$	$P\,x_2\,(a_1)$	$P\,x_2\,(a_2)$		$P\,x_2\,(a_j)$		$P\,x_2\,(a_2)$
	x_i	$w(x_i)$	$P\,x_i\,(a_1)$	$P\,x_i\,(a_2)$		$P\,x_i\,(a_j)$		$P\,x_i\,(a_2)$
	…							
	x_m	$w(x_m)$	$P\,x_m\,(a_1)$	$P\,x_m\,(a_2)$		$P\,x_m\,(a_j)$		$P\,x_m\,(a_n)$

If certain assumptions are made , then the Value v of the j^{th} option can be calculated as follows in equation 3.1

$$v\left(\mathbf{a_j}\right) = \sum_{i=1}^{n} w\,(x_i) P x_i\left(\mathbf{a_j}\right)$$

(Equation 3.1: the basic multi-criteria calculation of the value of an option).

Where:

$v(a_j)$ is the value of the jth option

$P\,x_i\,(a_j)$ is the performance of the $j^{th.}$ option on the $i^{th.}$ criterion

$w(x_i)$ is the weight of the i^{th} criterion

This then allows a direct comparison of all options to be made.

3.4 How MCA works: SMARTS and SMARTER

3.4.1 SMART (Simple Multi Attribute Rating Technique) and SMARTS (SMART using Swings)

The mathematical explanation given above refers specifically to the additive sub-family of MCA, which includes Attribute Utility Theory (MAUT) and Multi Attribute Value Theory (MAVT). It was Ward Edward's rejection of what he felt was the overly complex nature of the Keeney and Raiffa approach to Multi Attribute Value Theory that led him to develop the SMART (Simple Multi Attribute Rating Technique) family of methods, with ease-of-use as the paramount criterion. The following section gives a step-wise description of SMARTS

(Simple Multi Attribute Rating Technique using Swings), a simplified variation of the original SMART method, developed by Edwards and Barron (1994). SMARTS was followed by a further variation termed SMARTER (SMART Exploiting Ranks: Edwards and Barron 1994), Barron and Barrett 1996a), which is described below. SMARTER formed the basis for the development of the SMARTEST method used in this study (see chapter 5) and is, therefore, discussed in some detail.

SMARTS is a systematic process involving the following stages (Goodwin and Wright 2004, Edwards and Barron 1994):

1. Identifying participants;
2. Identifying alternatives;
3. Identifying criteria;
4. Assigning values for the performance of each alternative on each criterion;
5. Eliminating dominated alternatives;
6. Standardisation;
7. Weighting of criteria;
8. Calculating multiattribute scores;
9. Making a preliminary decision and carrying out a sensitivity analysis.

Each of these steps will be discussed in more detail.

Stage 1. Identification of participants. In traditional MCA applications this is the least problematic part of the process. Edwards and Barron (1994) provide a typical example of the expert based approach in that participants are called "elicitees" (p 307): that is, they are regarded of sources of the information that is used by the MCA expert for the input of information. In its simplest version, participants have no further role in the process until stage 9. However, as MCA began to acknowledge the importance of participation, the question of who to include within the group participants, and how they should engage with the process, became more questionable.

Stage 2. Identification of alternatives. In SMARTS, as in in many variants of MAVT, the identification of alternatives precedes that of criteria. In many situations this is most realistic: the alternative courses of action of already known once the problem is defined. However, in some cases it might be preferable to identify criteria before alternatives. Keeney (1992) advocated this approach within an overall strategy that he termed value-focused thinking, arguing that it encouraged greater creativity. (See also Goodwin and Wright 2004).

Stage 3. Identification of criteria. This may involve the construction of a value tree, a hierarchy which identifies criteria and their related attributes (if criteria are not direct measures). The value tree should show:

1 Completeness – all relevant criteria are identified;

2 Operationality (explicitness, measurability);

3 Decomposability – that is, criteria and their attributes are independent of each other;

4 No redundancy (that is, double counting);

5 With a minimum and maximum size (Edwards and Baron suggest no more than 12).

Omann (2004) argues that completeness (or exhaustiveness as she terms it) is the most important of these, using the rationale supplied by Pomerol and Barba-Romero (2000).

Stage 4. Assignment of values for the performance of each alternative on each criterion. This is often, and more conveniently, termed the creation of an impact matrix. This stage may require the elicitation of expert knowledge, a process that is increasingly recognised as highly complex and indeed problematic (Loveridge 2002). The development of the idea of knowledge engineering, necessary for the development of expert systems, has focused on the importance of such expert knowledge. Such knowledge is often greater than can be obtained from documentary sources but often employs heurists and judgments which are difficult to formally communicate. Furthermore, experts may not be fully aware of their knowledge, making the initial stage of is knowledge elicitation particularly difficult, possibly requiring observations (for instance, of experts carrying out activities with which they are so familiar that they are unable to explain their rationale) or iterative interviews. (Loveridge 2002; Goodwin and Wright 2004).

Step 5. Elimination of dominated alternatives. If there are any two alternatives X and Y where one X has performance in the impact matrix that is at least equal to that of Y on all criteria and has better performance than Y on at least one criterion, then X dominates Y. X, which is termed 'non-dominated', 'efficient' and 'Pareto optimal' is retained but the dominated alternative Y is superfluous and can be eliminated from further consideration. This elimination is not absolutely necessary but may lead to more realistic attribute ranges being employed than would otherwise be the case.

Step 6. Standardisation. This involves reformulation of the impact matrix entries as single-dimension utilities. An important characteristic of SMARTS is that it utilises what Edwards and Barron (1994) termed "the strategy of heroic approximation" (p 310). This is based on the crucial idea that simple methods will be more effective because they are simply easier to use. It implies a trade-off between what they term elicitation-error (that increases as the method becomes more difficult to use) and modelling error (that increases as initial assumptions are violated). The practical implication was that the relationship between attributes and criteria is assumed to be linear. This assumption of linearity means that the derivation of Value Functions is not required, so that attribute performance is measured directly. This strategy involves sacrificing some robustness (by increasing modeling error) to gain ease-of-use (that is, minimising elicitation error). For this assumption to hold a number of conditions must be met, such as the establishment of the existence of monotonic relationships between value and attributes. There are also heuristic methods for determining whether the method is appropriate. The standardisation conducted during this step results in an interval scale of values, that is one in which equal differences in magnitude on the scale represent equal differences of value.

Stage 7. Weighting of criteria. Criteria weighting, that is the measurement of their relative importance, is an essential element of MCA. It has also been at the centre of much controversy (discussed in section 3.4.2). SMARTS is characterised by the use of the Swing method, wherein judgments are made about which of the criteria is most important (and this criterion is then rated at 100), the next most important criterion is rated in comparison to this, and so on, until the least important criterion (rated 0) is identified. The results are then normalised to produce the final criteria weights. Other methods of establishing criteria weights include fixed-point scoring (where a total number of points, usually 100, is allocated among criteria) and paired comparisons, for instance as in AHP (Prato and Herath 2007). More straightforward weighting methods include direct rating and ranking (which is discussed in more detail below).

Stage 8. Calculation of multiattribute scores. This involves the aggregation of results and leads to a single score of the value of each option. This calculation is done by taking the overall performance for each alternative as the sum of the weight of each criterion multiplied by the performance of its attribute on that alternative, that is:

$$v(a) = \sum_{i=1}^{m} w_i \; v_i(a)$$

(Equation 3.2: simplified multi-criteria calculation of the value of an option).

Where

$v(a)$ = the overall value of alternative a

$v_i(a)$ = the performance of alternative a on attribute i, and

w_i = weight of criteria i;

Stage 9. Sensitivity analysis. This involves making a preliminary decision and carrying out a sensitivity analysis: that is, study the effect of changes to weights or performance levels on overall aggregate scores to examine robustness

SMARTS involved two major innovations: the elimination of the distinction between Values and Utilities (for riskless and risky situations respectively), which Edwards and Barron regarded as 'spurious', and the 'heroic approximation' of assuming linearity between criteria and attributes, thus removing the necessity to derive partial value functions. This is justified by suggesting that the selection of any appropriate decision aid involves a trade-off between errors in the model and errors in elicitation.

Barron and Edwards argued that SMARTS involved only a small loss in terms of modelling but a large gain in ease of use: "simpler tools are easier to use and so more likely to be useful" (p310). There is, however, an even simpler version of SMARTS termed SMARTER (SMART exploiting ranks).

3.4.2 SMARTER

In a further development of their stated goal to make these methods easy to use, Edwards and Barron developed an even simpler version, which they termed SMARTER ('SMART exploiting ranks'). SMARTER differs from SMART in that criteria weights are derived from ranking in perceived order of importance. The relatively onerous task of eliciting judgments necessary for the Swing weight computation is thus eliminated.

The case for using ranks to derive criteria weights is extensively argued by Alfares and Duffuaa (2009) on empirical and theoretical grounds. Barron and Barrett (1996a, 1996b) provide further detailed arguments for using ranking as 'surrogate weights' because of its easiness to use.

In SMARTER ranks are then transformed into weights using the Rank Order Centroid (ROC) method. If there are N criteria, ranked in order of perceived importance (i.e. 1 is most important), then the weight of the k^{th} ranked criterion is

$$w_{k\,(ROC)} = \left(\frac{1}{N}\right)\sum_{i=k}^{N}\left(\frac{1}{i}\right)$$ (Equation 3.3: ROC calculation of weight).

Where

$w_{k(ROC)}$ is the weight of kth ranked criterion calculated using ROC

N is the number of criteria

The use of ranks to assess criteria weights is controversial but it is central to the development of simpler, user-friendly MCA techniques proposed in this study.

Furthermore, the exact mechanism by which ranks are transformed into quantities used in the aggregation process has generated further controversy and a number of competing views. These issues will, therefore, be discussed in more detail. Edwards and Barron provide evidence that SMARTER performs at about 98% efficiency compared to SMART.

3.4.3 Ranking and weights

The ability of MCA to incorporate decision makers' judgments on differences in criteria importance into its calculations is essential to the process. Unfortunately it is far from straightforward and is, indeed, often problematic (Roberts and Goodwin 2002). As Belton and Stewart (2002) note, the very notion of criterion weight is not context free: it depends on the specific nature of the decision making process being studied. Furthermore, the weights generated and their interpretation depend greatly on the method used to produce them (Belton 2009). In the absence of consensus on which method to use, there can therefore be no 'true' weights. (Roberts and Goodwin 2002). Choo et al (1999) suggest that the different methods used have "different interpretations and implications which have been misunderstood and neglected by many decision makers and researchers" (p 527) so that weights are "often misused" (p528). The point is reinforced by Omann et al (2008: 1) who argue that the determination of criteria weights represents "the biggest challenge" in MCA. Criteria are the twigs of the value-tree: they represent detailed representations of underlying values. For some authors, especially those concerned with using MCA to enhance democratic, participatory processes, weights therefore attain a special significance.

Some methods for eliciting weights are time consuming, requiring difficult, cognitively complex judgments from the stakeholder (Alfares and Duffuaa 2009). They may also not be transparent – that is, the underlying logic may be unclear to the stakeholder participant. Participants may be uncomfortable being required to carry out such tasks and unable to provide consistent results (Belton 2008). This in turn may lead to further resistance to using the MCA method. One possible solution to this problem is to ask stakeholders to simply put the criteria in order of importance: that is, to rank them. The underlying logic is that the stakeholder usually has an imprecise idea of what the relative weights of the criteria are, and so many methods such as direct rating produce a spurious precision (Roberts and Goodwin 2002). Edwards and Barron (1994) argued that most of the useful information obtained in the

Swing method actually came from the first step: of ranking. Ranking thus provides a way of producing proxy or surrogate weights which approximate closely to the stakeholder's views. Ranking is considerably easier and more acceptable for more participants. Barron and Barrett (1996a, 1996b) provide further evidence to support the argument for ranking, quoting results showing participant preference for ranking over other methods. However, there are a number of different ways ordinal data (that is, ranks) can be translated into weights on a ratio or interval scale, necessary for the calculations involved in aggregation.

3.4.4 Techniques for calculating weights from ranks: The ROC, Rank Sum and Rank Reciprocal methods.

The differences between the various methods of using ranks to create criteria weights has led to some notable debate (Belton and Stewart 2002; Roberts and Goodwin 2002; Alfares and Duffuaa 2009). Three methods that are discussed by Barron and Barrett (1996b) and Roberts and Goodwin (2002) will be considered here: ROC, Rank Sum and Rank Reciprocal.

1 ROC: has been explained above. The method was developed by Edwards and Barron for SMARTER.

2 Rank Sum (RS): weights are ranked following normalisation by dividing by the sum of the ranks, so that the weight of the k^{th} ranked criterion is

$$w_{k(RS)} = \frac{(\mathbf{N+1-k})}{\sum_{\mathbf{i=1}}^{\mathbf{N}} \mathbf{k}} = \frac{\mathbf{2(N-k+1)}}{\mathbf{N(N+1)}}$$ (Equation 3.4: RS calculation of weight).

Where

$w_{k(RS)}$ is the weight of kth ranked criterion calculated using RS

N is the number of criteria

3 Rank Reciprocal (RR) uses reciprocals of ranks, normalised by dividing by the sum of the reciprocals:

$$w_{k(RR)} = \frac{\frac{1}{k}}{\sum_{i=1}^{N}\frac{1}{i}}$$ (Equation 3.5: RR calculation of weight).

Where

$w_{k(RR)}$ is the weight of kth ranked criterion calculated using RR

N is the number of criteria

The debate about which method is best to use assumes that the ranked weights are approximations or proxies of the 'true weights' derived from another method, using the Swing technique. Edwards and Barron (1994) make a strong case for ROC and Barron and Barrett (1996b) reinforced this view with a study (using a Monte Carlo type simulation, over 100 000 trials) to compare 'true', swing derived weights with those from ROC, RS and RR. They found that all three of the ranked weight rules had high levels of agreement with the true weights, with a median value loss of less than 9%, but that ROC outperformed the other two methods. Roberts and Goodwin (2002), however, argued that the ROC method was flawed insofar as the Barron and Barrett (1996b) results were based on a point allocation method, rather than the direct rating method more usually used in SMARTS. From this analysis Roberts and Goodwin recommended a fourth method: Rank Order Distribution (ROD) as a better alternative. However, they also suggested that ROD is difficult to calculate (requiring calculations of probability density functions) and that the easier Rank Sum (RS) procedure is a close approximation. On this basis they recommend that "serious consideration" be given to the use of RS.

An analysis carried out for this study and shown in detail within Appendix 1 provides further support for the use of RS It shows that the ROC method does leave lower ranked criteria with such small weights (when there are more than 8 criteria) that their continued inclusion is of doubtful value. In contract, the RS method, which also has the virtue of simplicity and intuitive attractiveness, has a strong agreement with another method (ROD), which has some theoretical support. Doyle et al 1994 also argue that the RS method is more appropriate.

While there continues to be disagreement concerning the comparative advantages and disadvantages of the three methods, all represent approximations of 'true' values, if indeed such values exist and are not purely contingent artifacts of the original methods used. Furthermore, all three have been shown to have surprisingly good levels of agreement with such 'true' weights. We can conclude that all these methods represent good 'heroic approximations' as intended by the original Edwards and Barron SMART approach, and that the RS method appears to be as robust as any and much easier to use. On this basis, the RS method has been used in this study.

This concludes a brief overview of how the SMART family of methods evolved into SMARTER and how this might be further developed by the use of the RS method of converting ranks to weights. The SMARTEST method, developed in this study and which uses this approach, is discussed in chapter 5. Attention is now turned to how MCA is used in environmental problem contexts.

3.5 Participation and MCA

The aim of this study, as stated in chapter 1, was to evaluate the effectiveness of a new participative MCA technique environmental decision making. In order to do this it was necessary to establish the extent to which current MCA methods and practice facilitate – or hinder – participation. Here participation is defined, as in Reed (2008), as the process wherein individuals and organisation take "an active role in the decisions that affect them" (p.2419). Reed differentiates such stakeholder involvement in the process, where those involved are directly affected by the decision, from broader public participation where effects may be absent (or at least indirect).

3.5.1 Review of a representative sample of MCA studies

In order to investigate the extent to which MCA was being used participatively, a sample of MCA articles was selected for examination in some detail. The aim of this review was not to obtain a comprehensive survey of all applications of MCA to environmental problems, but rather to investigate a representative sample of such studies in some depth, to obtain an overview of how stakeholder participation in MCA worked in practice. The following section provides a summary of the main findings and conclusions.

Four journals, which preliminary searches had shown were those which contained the highest proportion of studies of MCA applied to environmental problems were examined: Journal of Multicriteria Decision Analysis (JMDA), Environment and Planning C: Government and Policy (EPC), Ecological Economics (EE) and the Journal of Environmental Management (JEM). All articles in issues published between 2001 and 2009 were scanned and those in which the use of MCA for an environmental issue was of central concern were selected, resulting in 55 articles in total.

An analysis of these articles showed a wide range of countries of origin, although more than half were European. Of the 55 articles, 37 involved empirical studies (as opposed to theory, reviews or editorials) and were studied in more detail. The environmental questions considered in these articles were also wide ranging, although problems relating to water (fresh and salt) were most common.

A wide range of different MCA techniques were employed, although linear additive techniques, such as those derived from MAVT / MAUT were most common. There was also a great deal of variation in weighting method employed, with ranking, paired comparison, direct rating and equal rating being most common.

Proctor and Drescheler (2006) report a general consensus that there should be between 7 and 12 criteria. Of the 28 articles where the number of criteria was clearly indicated, the minimum number employed was 3 and the maximum 25. Half of these studies examined used less than 7 criteria, and 6 used more than 12. This suggests that MCA users frequently ignore guidelines and may be unaware of the technical requirements.

The 37 empirical studies were further analysed for the degree of participation. First each article was examined to establish who participated in the process, using the following categories:

1 Authors (of the article)

2 Experts (as identified within the article)

3 Stakeholders – those who do not fall within any of the above categories, but were interested parties to the issue. This category includes decision makers – where the course of action to be decided was up to specific individuals (for instance in a private company or central/ local government organisation) as well as others, such as members of NGOs, pressure groups, residents or the public at large.

Table 3.3 below shows the highest level of participation by category[62]. That is, an article was classified as having stakeholder participation even if that was restricted to only one part of the process.

Table 3.3 Analysis of selected articles by highest level of participation

Highest level of participative input into the MCA process	Number of research articles
Author only	5
Expert	10
Stakeholder	22

Of the 37 research articles, five involved input from authors only and ten had some input from experts (but not from stakeholders). The remaining 22 articles had some input from stakeholders. In order to consider this further, a more detailed analysis of these 22 studies that involved some stakeholder participation was carried out, identifying the nature of the participants involved (who, how many and the form of the engagement) and the stages of the MCA process in which they took part[63]. Results are shown in table 3.4. Detailed results are shown in Appendix 2.

[62] Where the term 'highest' is used to denote the most participatory level, as in Arnstein's 'ladder of participation' (see below).

[63] The stages being derived from the SMART method approach, discussed above.

Table 3.4 Selected articles by stages of MCA in which participation occurred (the value function stage is omitted, as only two articles reported stakeholder involvement therein). Greyed out cells indicate participation in that MCA stage.

Author(s)	Number of participants	Identifying alternatives	Identifying Criteria	Criteria Weighting	Impact Matrix	Sensitivity analysis
Ananda and Herath (2003)	36					
Duke and Aull-Hyde (2002)	129					
Gamboa (2006)	45+					
Hajkowicz (2006)	420					
Hermans et al (2007)	121					
Hostmann et al (2005)	26					
Kallis et al (2006)	16					
Kangas et al (2001)	Not stated					
Klauer et al (2006)	Not stated					
Mander (2008)	c. 30					
Marttunen et al (2005)	(a) 36 (b) 2500					
Moran et al (2007)	169					
Munda and Russi (2008)	15					
Paneque Salgado et al (2009)	(a) 16 (b) 425					
Prato and Herath (2007)	20					
Proctor and Drechsler (2006)	6					
Refsgard (2003)	1					
Scolobig et al (2008)	100+					
Sharifi et al (2002)	Not stated					
Stirling and Mayer (2001)	12					
Strager and Rosenberger (2007)	Not stated					
Tzeng et al (2002)	2739					

Table 3.5 below shows a summary of the results of this analysis.

Table 3.5 Selected articles: summary of the stages in which stakeholders were involved

Process stage	Number of articles
Identifying alternatives	10
Identifying Criteria	11
Deciding criteria weightings	15
Contributing to drawing up the impact	2
Sensitivity analysis	3

In some cases stakeholders were directly involved in generating the input, while in others it was reported that input was 'based on' the stakeholder views (although the details of how that was done was often absent). Almost all (15 out of 22) of the studies that had involvement from stakeholders used them to generate (directly or more indirectly) criteria weightings: in nine cases that was the only involvement of stakeholders. Most – nineteen - of the studies had participation in only one (11) or two (8) of the five MCA stages.

A striking result of this analysis was the degree of variation in methods: the range in the number of participants involved (from 1 to over 2000), the nature of the participants (industrialists, central and local government members, representatives of NGOs, residents and citizens) and, above all, the extent of the engagement of the participants in the various stages of the MCA process.

This analysis reveals a surprising lack of stakeholder involvement in most of these studies. Most can hardly be described as fully participative, where so little of the overall process involves engagement with participants. Only three studies - Mander (2006), Proctor and Drechsler (2006) and Stirling and Mayer (2001) - have participant involvement in 4 or 5 of the stages and represent, therefore, a genuinely participative approach. These three studies are considered in more detail below.

3.5.2.Typologies of participation

For the purpose of a further analysis of participation of stakeholders in the MCA process, it will be useful to refer to established typologies of the nature and extent of participation (discussed in chapter 2). These included Arnstein's (1969) 'ladder of participation', Farrington's (1998) tripartite classification of 'consultative', 'functional' and 'empowering' participation and Lawrence's (2006) similar scheme where 'transformative' participation as an alternative top level. Reference will also be made to Rowe and Frewers' (2000) model based on the direction of flow of information where 'communication', which is a one-way process from regulators to the public, 'consultation' as the reverse one-way process and 'participation' itself being a two-way process. Fiorino's (1990) classification of the justifications for participation – substantive, instrumental and normative – will also be used.

Using these typologies to analyse the 22 articles in which some level of stakeholder participation occurred, the following becomes apparent: in most the involvement was either consultative or functional (using Farrington's terms): few were empowering (let alone 'transformative'). Moreover, the flow of communication was most frequently one way and non-iterative.

In those articles which typified the 'consultative' approach, information was often obtained from questionnaires or surveys of residents (for example Tzeng et al 2002, Duke and Aull-Hyde 2002) or even the general public in a street survey[64] (for example Hajkowicz 2006). The numbers involved in such exercises are often large (2739, 129 and 420 respectively in these three examples)[65] but the level of engagement of the participants necessarily low: in many of these articles it is not even always apparent if those participating were informed of how the information elicited from them was going to be used. Furthermore, the

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[64] In using a street survey, where both residents and visitors are included, the boundary is crossed from stakeholder to public participation, as visitors can be seen as to only indirectly affected by the environmental decision being addressed.

[65] Unsurprisingly, more inclusive but shallower methods (in BID terminology: greater *Breadth* but less *Impact*) had larger numbers involved than those techniques involving more in-depth approaches: the six studies that used surveys or questionnaires had an average number of participants of 311 (range 15 to 2739) compared to an average of 25 in the six interview-based studies and 48 for the three articles using group processes such as workshops, focus groups and citizens' jury.

information was used as input into a small number of the MCA stages: in these three examples it was only used to inform criteria weighting. The participation in these studies is generally passive, non-iterative and narrowly applied to the MCA process.

A number of the articles can be classified as 'functional' (using Farrington's terminology), with a greater input from stakeholders and at least some iteration, in a process which enhances the decision making process but falls short of the 'empowering' or 'transformative'. Stakeholders are often members of representative groups, such as NGOs (e.g. Ananda and Herath (2003), Hostmann et al (2005), Kallis et al (2006)) and involvement as often through group or individual interviews, or focus groups (e.g. Moran et al 2007)[66].

Using Fiorino's (1990) terminology, 'functional' participation might be equated with 'substantive' arguments: that is that such decisions may be sounder than those using experts alone (because they draw on a wider knowledge base) while the 'empowering' and 'transformative' can be associated with the 'normative' argument: that participation is a democratic right and that methods that enhance the ability to engage in such activity as desirable in themselves. Within this scheme, the focus moves from optimising the decision making to capacity building of the stakeholders themselves[67].

3.5.3 Three exemplars of highly participative MCA

The review of 55 articles identified only three that could be called properly participative: Mander (2006), Proctor and Drechsler (2006) and Stirling and Mayer (2001). These involved stakeholders in several stages in an iterative, two way process that can be regarded as empowering or even transformative. These three were the only examples, in the sample

[66] A further surprising finding of this analysis was the lack of information on the nature of stakeholder involvement. Strager and Rosenberger (2007), for instance worked with an unspecified number of stakeholders, where identification of criteria and options was "based on input from local stakeholders and technical Experts". No further information on how this process was carried out was supplied. Altogether five of these studies did not specify the number of stakeholders involved, and in others there was considerable lack of detail on how the process was conducted.

[67] At least in some cases, it can be assumed that the 'consultative' approach is used primarily to fulfil the 'instrumental' argument, that is the use of stakeholders in this was enhances the legitimacy of the process.

examined, of stakeholder involvement in Impact Matrix completion and sensitivity analysis and were the only cases in which stakeholders were involved in more than two of the five main stages of the MCA process. These three will, therefore, be examined in some further detail to establish just how empowering or transformative the engagement was.

The Stirling and Mayer (2001) study: Multi Criteria Mapping

The Stirling and Mayer (2001) study commences with the argument that traditional scientific approaches to environmental problem solving are narrow, expert-based procedures which neglect wider social and cultural aspects of the problem context. They argue that, as the understanding of the problematical nature of such exclusiveness has developed, there has arisen an interest in constructing methods that include wider constituencies with greater transparency. There is, therefore, a growing family of deliberative and participative methods, but these methods themselves are contentious; attempts to integrate them into more traditional analytical methods have been incomplete.

Stirling and Mayer use this line of reasoning to justify the development of a new method that they label 'Multi-Criteria Mapping' (MCM), designed to be more overtly transparent and pluralistic. The term 'mapping' in this context refers to the method's focus on examining individual position rather than in combining them during aggregation (Stirling 2006). They argue that while MCA can be used in a prescriptive, overly technical fashion (an 'analytical fix') which may lead to unsuccessful outcomes (as used by the Nuclear Power industry in the UK for selection of sites for radioactive waste disposal) it also has the potential to be used in a more exploratory fashion which lends itself to an open and pluralistic method. Such a heuristic approach can avoid, they argue, the technical complications of some MCA usage, and thus offers "the additional quality of relative simplicity" (p532). The method employed was, accordingly, a 'straightforward' linear additive technique, which can be equated to a SMART type of process.

The mapping method used in this study (of strategies of GM use in agriculture) involved interviews with 12 participants who were representatives of organisations involved or concerned with such policy, in four broad categories: agricultural and food industry, scientists, government advisors and public interest groups. Initially six policy options were designed by the authors, but could be supplemented by the stakeholders. The interviews involved all of the main MCA stages: identification of additional options; identification of criteria, scoring of options against criteria (that is, completing an Impact Matrix, including an indication of degree of uncertainty) and criteria weighting (with considerable flexibility in choice of method). Because stakeholders had so much control over and input into the process the results were individualised and so comparisons between individuals are difficult to make. Thus subsequent grouping of the 117 criteria developed by the stakeholders were conducted 'inductively' by the authors, using intuitive judgments. The authors used these groupings to carry out a sensitivity analysis (by analysing the effects of amending weightings) and these, together with their own results and the anonymised results of all participants, were then sent to each stakeholder, who was then invited to amend their weightings (although none did so) and to provide personal evaluation of the process (which seven did). Although all participants seemed "expressed satisfaction with the exercise as a whole" (p538) and some were "very enthusiastic" (p546), two did not feel sufficiently comfortable with the Impact Matrix to undertake this stage and, of the remaining ten, not all completed scoring for all criterion categories.

In their evaluation of the findings, the authors speculate that the interview duration – considerably shorter than is usual for MCA applications, may have been a disadvantage in some instances (possibly in providing less time to overcome conceptual difficulties in the task itself) but an overall advantage for most, insofar as it reduced the input required from busy participants. The authors also note that "fundamental matters of principle" are raised by the discomfort experienced by one participant in being required to adopt a quantitative approach but contend that the associated anti-utilitarian arguments discussed in chapter 4 are more likely to arise when MCA is used in a prescriptive, results oriented mode rather than in the heuristic fashion that they employed. Overall, they conclude, the MCM method allows for explicit recognition of divergent viewpoints and encourages a thorough deliberative process. Stirling and Mayer conclude that MCM offers a way of combining the rational-technical and subjective factors within a single appraisal process which incorporates flexibility, transparency, verifiability and accessibility to participation.

The optimistic claims made for MCM's potential to bridge the rational- subjective gap in decision making is at least partly supported by the extent to which the method has subsequently been adopted by practitioners. The study has had considerable influence on the subsequent development of deliberative methods, particularly when used to examine contentious issues such as Genetically Modified Organisms (for instance Burgess and Chilvers 2006, Ricroch and Jesus 2008) and nanotechnology (Hansen 2010), as well as in the design of novel and more inclusive forms of Multi-Criteria Assessment (for instance Soma 2010). The Multi Criteria Mapping approach, as deployed in this study, is certainly far more participative than the great majority of articles examined in this review, but is it as iterative and reflexive as the authors assert? With only one round of interviews the process is essentially complete by the time the stakeholders receive the results – and there would be little point in further amendments. This version of MCM can be viewed, perhaps, as a prototype for a new and explicitly participative approach, but not the fully developed technique.

Proctor and Drechsler (2006): deliberative multicriteria evaluation

The Proctor and Dreschler study was an explicit attempt to combine the advantages of formal deliberative approaches – in this case a 'citizens' jury' - with the structured decision support of traditional Multicriteria evaluation. They term this method 'deliberative multicriteria evaluation'.

The authors use MCA in a heuristic fashion, as with Stirling and Mayer:
"… as an aid in the process of decision making and not necessarily as a means of coming to a singular optimal solution." (p172)
However, they also argue that, by itself, multi-criteria methods (which they refer to as Multi Criteria Evaluation or MCE) remain unfriendly towards stakeholder participation:

"In theory and in practice, however, MCE does not adequately address the facilitation issue of interaction between analyst and decision makers to elicit and revise preferences…... With multiple decision makers, MCE does not provide clear guidelines on how to analyse or aggregate multiple weights. Most MCEs provide some sort of average over the various weights provided, and therefore important information concerning the extent of different priorities is lost in the process." (p172) Thus their deliberative method, involving the citizens' jury, necessitates interaction between stakeholders and so, in their view, represents a significant advance in participativeness.

The problem context of this case study was that of natural resource management in a river catchment – popular for recreation and tourism - in Australia, and was part of a larger project ecosystem services. The 'jury' was composed of 6 natural resource managers operating in the area; it was therefore, 'stakeholders' jury rather than a citizens' jury *per se*. Several stages were involved in the overall process:

1. Preliminary one-day workshop with stakeholders, to identify options and criteria;
2. Questionnaire for stakeholders to rank criteria (that is, preliminary weighting);
3. Impact Matrix: carried out by experts, with no input from stakeholders;
4. Aggregation, carried out by the authors;
5. Jury day, which considered results from the above together with expert witness 'testimony, which was set the task of agreeing on criteria weighting, involving a structured and iterative process;
6. Sensitivity analysis, conducted following the jury day.

Although the authors do not seem to have conducted a formal *post-hoc* evaluation of the process itself, they did receive some feedback from the stakeholders, although this concentrated on technical issues such as inputting data into the software. The stakeholders did not, however, identify any conceptual problems with the process and "*found the process interesting, enlightening, and enjoyable*" (p189). The authors did acknowledge that these particular stakeholders were highly informed; they were, in essence, *de facto* fact, experts. The use of the process with a less knowledgeable lay jury might be more problematic. Moreover, the process was time consuming, with two full days attendance required.

The deliberative MCE approach, which can be seen as a separate but parallel development to Stirling and Mayers' Multi Criteria Mapping, has not had the same impact as MCM although it has been used in some environmental problem contexts, especially in Australia (see Herath and Prato 2006). However, although the combined jury-MCA method is undeniably an interesting and novel approach to the problem of how to bridge the gap between rational technique and the participative imperative, it is again noteworthy how far the reality falls short of the rhetoric. Although highly iterative and time consuming, the crucial Impact Matrix stage of the process was conducted without stakeholder involvement and the main jury day was spent entirely on trying to reach agreement of criteria weightings. The extent of stakeholder involvement in sensitivity analysis is unclear. Once again, therefore, we see a process in which stakeholders are invited to engage with selected aspects of the procedure but have little overall control: they do not, essentially, have ownership.

Mander (2008): Discourse coalitions

Mander (2008) did not set out to demonstrate how stakeholders could participate in MCA, but rather intended to explore coalition building among interest groups involved in a highly controversial issue (renewable energy) in England, using Hajer's (1995) discourse analysis framework. Unlike Stirling and Mayer or Proctor and Dreschler, Mander was not primarily interested in either multi criteria analysis nor in participation (the latter term is not mentioned within the article). Instead, MCA was used as a research tool to explore issues raised from initial interviews, which identified two main discourse coalitions (defined as both a set of interconnected narratives and the actors endorsing them). In this respect Mander's study resembles the Social MCE stream of development, which used MCA to investigate inter-actor dynamics. However, rather than use a standard SMCE approach, Mander adopted the Stirling and Mayer (2001) Multicriteria Mapping (MCM) technique.

Despite the fact that enhancing participation was not a stated aim of this study, the process was highly iterative, with four stages involving two sets of interviews with the participants. After each interview the participants were sent a copy of their results (of the MCA analysis) plus the anonymised results of other participants. They also were able to amend their results. In the first interview the policy options developed (by participants) in the previous stage of the study were reviewed and amended, and criteria were identified. The second interview involved completion of an Impact Matrix (termed 'scenario scoring') and criteria weighting (using ranking followed by an interactive process of points allocation). Ten of the 27 individuals undertaking the MCA did not complete the Impact Matrix stage, mainly because of the length of time the process took, rather than because there was "a lack of engagement with the MCA per se" (p591).

The MCA aggregation technique selected was a "simple linear additive model", chosen explicitly because of its "simplicity and transparency" (p593), as opposed to the more technically complex "black box" methods that many stakeholders might regard as impenetrable. The results, including averaged results, were sent to participants who were able to amend their own inputs – essentially a form of sensitivity analysis.

The participants in this study were not the general public but representatives of local government, NGOs and environmental campaigning groups. As such, there was a high level of expertise and local knowledge, illustrating how the boundaries between 'experts', decision makers' and 'citizens' is so often blurred. Thus,
"*whilst respondents were asked to consider uncertainty in the scores that were assigned to criteria, respondents did not consider this to be an issue in the scores that they allocated … many respondents were very sure of their knowledge, so felt that they `knew the score'*." (p591-2)

Mander's study is in many ways a paradox: it represents the most comprehensively participative process of all the 55 articles examined in this review, yet it was not intended as such in that enhanced participation was not its goal. Nevertheless, it provides an elegant, straightforward and relatively time-constrained method that clearly succeeded in facilitating a high level of engagement (although the high failure to complete rate for the Impact Matrix is disconcerting). Mander did, perhaps without meaning to, create a workable approach to participation that outperforms other attempts. The present study aims to re-examine the extent to which this approach can be further developed to facilitate environmental decision making.

3.5.4 Participative MCA: an overview of current practice

From this review of a representative sample of studies using MCA a number of tentative conclusions can be advanced. First, and perhaps most obviously, there is an inverse relationship between the degree of engagement that stakeholders have in the MCA process (that we can term participative *'Impact'* in the BID model) and the number of stakeholders involved (that is, inclusiveness or participative '*Breadth*'). This arises from the fact that facilitating engagement and participation is time consuming and that these articles – most of which were practical field studies – had the usual constraints on resources available. Thus those studies which sought large numbers of participants – such as Tzeng et al (2002) with over 2000 residents completing questionnaires – necessarily involved the most basic information gathering with little or no iteration. In contrast, two of the three most participative studies, discussed in the previous section, are characterised by small numbers: 6 with Proctor and Drechsler (2006), and 12 for Stirling and Mayer (2001). Mander's (2008) study is, however, something of an anomaly, not only in that it was highly participative without intending to be, but also because it involved a relatively large number of participants (27) despite the very high levels of engagement and iteration. This shows – if nothing else – that highly participative methods with relatively large numbers are indeed possible. Perhaps the key aspect that explains Mander's success in this respect is the use of a simple MCA technique that required little explanation or training.

Breadth, *Depth* and *Impact* of participation can be related to underlying purposes of participation as classified by Arnstein, Fiorino and others (see above). For instance, large-scale questionnaire-based studies (high *Breadth*, high *Depth*, low *Impact*) might be seen as being examples of Arnstein's 'manipulation', one-way communication (Rowe and Frewer 2000), 'consultative' (Farrington 1998) and 'instrumental' (Fiorino 1990), while smaller scale highly participative initiatives (low *Breadth*, High *Depth*) could be characterised as 'citizen control', 'two way', 'empowering' and 'normative'[68].

A second conclusion is that many of the studies that employed the rhetoric of participation fell remarkably short of their own stated intentions of involving stakeholders in the decision making process. For instance, although Ananda and Heraths' (2003) study is entitled "Incorporating stakeholder values into regional forest planning", it features stakeholder involvement in only one stage of the MCA process, as does Klauer et al (2006) who unequivocally argue for MCA to be used to include "participatory stakeholder involvement" (p235)[69]. Similarly, Martutunen et al (2005) state that their study is designed to extend participation, yet stakeholders were involved in only two MCA stages and their large scale questionnaire approach was entirely one-way, consultative communication.

This gap between the rhetoric and reality, with regard to the extent of stakeholder participation, is especially noticeable in the group of studies using Social Multi Criteria Evaluation (SMCE) which was developed by Munda (2004), who argued that "a social multi-criteria process must be as participative and as transparent as possible" (p 667). Similarly, Munda and Russi 2008 (p712) assert that SMCE

" *…. can be a useful policy framework to guarantee that decisions …… are made as transparent as possible, and to guarantee that all the involved actors can participate*".

Kallis et al (2006) make even grander claims for SMCE, arguing that it "overcomes the limitations of participatory methods" (p223) by stressing iteration, transparency, reflection and mutual learning. SMCE thus complements traditional MCE with various social science approaches such as institutional analysis, interviews, questionnaires, focus groups and participant observation. However, the five studies in this review that use SMCE seem to fall

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[68] Note that in some of the studies participation can also be extended outside the stakeholder groups to citizens more widely, in forms of deliberative democracy (O'Neill 2001, Rauschmayer and Wittmer 2006) although in the above examples citizen involvement was often very limited and did not amount to participation as such.

[69] However, it should be pointed out that to some extent this was due to circumstances beyond the authors' control, in that there was a dispute within the decision making organisation in which the dominant group, once they realised that the MCA process was favouring an option they did not want, prevented further stakeholder involvement.

significantly short of these aspirations: In Gamboa (2006) stakeholders' comments were mediated by authors and only used for one stage of the MCA process, while in Kallis et al (2006) Mundi and Russi (2008), Paneque Salgado et al (2009) and Scolobig et al (2008) stakeholder involvement was limited to the identification of alternatives and criteria. A *Breadth-Impact-Depth* analysis shows clearly that the Munda and Rossi (2008) and Gamboa (2006) studies score far lower on the *Impact* dimension than the Stirling and Mayer (2001) and Mander (2008) studies. There is, therefore, a paradox here: an explicitly participative method which is, indeed, apparently designed in order to meet the shortfalls in stakeholder engagement in previous MCA applications, which fails to make provision for input into Criteria Weighting, Impact Matrix construction or sensitivity analysis, and which does not contain any significant degree of iteration. Munda and Rossi (2008) themselves admit that participation only provides "an input for analysis" (p713) and contrast this with more participatory methods such as that of Proctor and Dreschler (2006). Kallis et al (2006) provide some justification for limiting stakeholder involvement in that "bottom-up participatory processes … raise issues of democratic legitimacy " (p232) and vested interest groups "seldom possess substantive `knowledge'". There are clear echoes here of the "deficit model" of the Public Understanding of Science, which was based on normative assumptions of the ignorance of the non-scientific public (Irwin and Wynne, 1996; See section 2.2 previously). They conclude that because of the limitations of stakeholder ability to contribute to the process, involvement may need to be limited to consultation. These discussions highlight some of the key problem areas of extending participation using MCA.

From this review it emerges that there is considerable variation in how the term 'stakeholder participation' is interpreted, both in relation to who is involved and in the nature of the participative engagement[70]. Clearly, the ultimate power over the process rests with the authors. There is, however, no widely accepted benchmark or standard as to how participative MCA should be conducted, so that different authors appear to select different techniques and methodologies in a quite unsystematic fashion. Generally, the wider the participation – that is, the more democratic the process (and thus the more inclusive the

[70] There is also considerable variation in the methods used for eliciting information from participating stakeholders, including workshops, interviews, surveys/questionnaires and Delphi panel.

definition of 'stakeholder') the greater are the numbers involved but at the expense of lower *Impact* (that is, less engagement). Moreover, even when participant numbers are small (low *Breadth*), the *Impact* (level of engagement) is often weak and falls far short of the rhetoric. However, there are a few notable exceptions: in this sample three articles exhibit exemplary levels of engagement (that is, *Impact*) and in one - Mander (2008) – there are also reasonable levels of *Depth* and *Breadth*. Mander's study demonstrates that this ideal state of affairs can be achieved under certain circumstances. In particular, the method used is this type of high Impact study is invariably more accessible: a simple linear additive method – very similar to the SMART approach - was used in all three of these high *Impact* studies. There is, furthermore, an explicit intention in these three studies to use a simplified method that facilitates the process rather than complex techniques that may result in more 'correct' outputs. However, even the exemplary Mander study does have its participative flaws: over one third of the participants did not complete the Impact Matrix stage, mainly because of the time involved. The central aim of the present study is to establish if further simplification of the SMART method can improve completion rates: can a practical participative MCA method deliver high *Impact* along with greater both *Breadth* and *Depth* of participation?

Overall, these findings must be seen as disappointing. Participative MCA, as applied to environmental problems, seems still to be at an early, developmental phase where standards, techniques and even terminology has yet to be standardised. Despite promising so much – and already being so widely used – MCA still has not delivered a rigorous, systematic framework for facilitating environmental decision making in a fully participative fashion. From this evidence, participative MCA remains a promise undelivered. There are, nevertheless, some positive developments, such as MCM. The present study attempts to address some of the key tasks that are required for further development of participative MCA.

3.6 Participative MCA and ease-of-use

If participative MCA is to be used by wider, less expert groups of stakeholders then there also needs to be further evidence on how easy it is to use and which variations are most straightforward for employment with non-expert stakeholders. There is already substantial evidence on the importance of ensuring that methods are simple enough to be understood by participants (for instance Myŝiak 2006). The implication is that a method should be no more complex than is capable of being understood by the least experienced or mathematically capable participant. Myŝiak's own review of a number of studies showed that there was a tendency for outranking methods to be significantly harder to understand than simple additive methods (such as MAVT). Bell et al (2001) found similar results: participants found an outranking method (ELECTRE) to be the most difficult method to use, along with goal programming, in an experiment comparing several methods. The different variations of the MCA method seem, therefore, to have very different potentials for being used in a participative, inclusive fashion.

There are also few studies that compare the various methods of criteria weighting with regard to ease of use. Refsgard (2006) reported that participants found ranking of criteria easier than rating. Similarly Hajkowicz (2006) found that participants were most comfortable with ordinal ranking of criteria and had considerable difficulties with more complex techniques. There is, however, not only considerable disagreement about weighting of criteria but also on how to aggregate weights of several individuals. Omann et al (2008) for instance did this through a two stage group based decision making process. In stage one, the group arrived at a ranking through the use of silent negotiating technique; in stage 2 participants could modify this to arrive at individual rankings. They found, perhaps unsurprisingly, that participants varied considerably in the extent that they modified the group ranking: 54% produced rankings that deviated considerably from the group and 18% had ranking that differed greatly. Omann et al (2008) subsequently used derived rankings to obtain criteria weights whereby the ratio between most and least preferred criteria is decided by the participant (the ratio being between 3 and 20). As Hyde et al (2005) suggest, the process of assigning weights to criteria is "often subjective, ambiguous and imprecise" (p279).

MCA methods can be not only difficult but also time consuming, requiring a commitment that participants may be unwilling to make. As already discussed above, Mander (2008) found that 30% of participants were unable to complete the MCA process because of time pressures. Similarly, Stirling and Mayer (2001) found two participants did not complete their multicriteria mapping process "for various reasons, including lack of time, lack of information, and, perhaps, lack of empathy with the approach" (p538). Furthermore, Paneque Salgado et al (2009) found that time, together with friction between participants in highly contested problems, led to interviews being terminated or other failure to participate. They conclude that participatory MCA can be

"*strongly compromised in high conflicting contexts, not only because it makes it difficult to implement dialogue but also discourages social actors' cooperation to make relevant knowledge accessible for the evaluations"*(p1002).

Other than these studies, there is surprisingly little clear evidence on how the selection of methods influences ease of use. One reason for this is lies partly in the paucity of good evaluative data on MCA in any form. As the review of journal articles above , evaluation was rarely carried out and, when it was undertaken, it was often of a cursory or anecdotal nature. The number of studies that conducted systematic evaluation was very small; outside of the sample of articles reviewed there are few other good examples of evaluation. Mustajoki et al (2004) provide one of them, using an on-line survey as part of their method, and were surprised at the highly positive level of responses: 81% of the 52 participants in their study

"at least partly agreed that 'the recommendations for the regulation have been able to combine the different and conflicting interests of both the people living on the Lake Päijänne and the downstream water system'" (p544).

This contrasted with the perceived level of criticism with the recommendations themselves. They concluded that critics may dominate public meetings and not represent a majority view. However, another conclusion could be drawn: that participants may be satisfied that the method was fair and transparent without necessarily being satisfied with the outcome: such an interpretation stresses the ability of participative MCA to increase legitimacy of the process and defuse conflict.

There is, then, a realisation that some MCA methods may be overly time consuming or present too great a cognitive burden (for instance Moran et al 2006, Prato and Herath 2007): these problems are exacerbated when involvement goes beyond experts and becomes truly participative (for instance as with citizens' juries). However, the evidence on differential usability of MCA methods is accruing only slowly. There appears to be a need for a method that is simple and straightforward to use. In other words, there is a growing need for simplicity and ease of use within MCA methodology.

3.7 Participative MCA: a summary

There are, therefore, two converging trends within development of participative MCA: firstly, an increasing emphasis on participation, second a move away from its use as a decision making tool *per se* and towards more heuristic applications, where MCA facilitates the decision making process[71]. However, the discussion in this chapter has also concluded that there is:

1. Confusion about what participation entails;
2. Considerable variation in the nature of participation in published research in terms of who is involved, the processes they are involved in, the degree of control they have over the process and the extent of iteration;
3. Few of studies involve stakeholders in all the stages, which are fully iterative (that is, have high *Impact*);
4. A paucity of studies evaluate the participative nature of the MCA in terms of user views in anything other than a cursory fashion.

[71] Stirling and Mayer (2001) suggest that when used in this heuristic sense MCA should be labelled Multi-Criteria Mapping.

The present study aims to fill some of these gaps in knowledge by carrying out a fully participative study which involves stakeholders in all stages of the MCA process. This is the purpose of the SMARTEST method, described in chapter 5, which attempts to enhance the usability and acceptability of the SMARTER method while retaining relatively high robustness (despite the need for some 'heroic approximations'). Evaluation will consider the extent to which SMARTEST does enhance usability and acceptability.

Chapter 4. Acid Deposition and the acidification of aquatic ecosystems

This study is concerned with the facilitation of environmental decision making, using a case study of policy to expedite recovery from acidification of the river Cree in South West Scotland. In order to provide a clear context for the subject of this case study, this chapter reviews the nature of such acidification and how it affects aquatic ecosystems. It goes on to consider the implications for the design of policy for recovery.[72]

4.1 The importance of acid deposition

Acid Deposition is popularly termed 'Acid Rain' (although there are important differences between the meanings of the two terms) and refers to the emission into the atmosphere of acid compounds (particularly sulphates and nitrates) and their return to the surface (either in the same form or having undergone some transformations in the atmosphere). Acid Rain includes 'wet' deposition, but excludes the important 'dry' and 'occult deposition' processes; the term 'Acid Deposition' is therefore preferred in this paper. The term 'Acidification' is used in this context to denote the processes that occur on the surface because of Acid Deposition (Wellburn 1988; Walker 1995).

Acid Deposition has been called "one of the most widespread pollution problems in the Northern Hemisphere" (Begon et al., 1986: 689) and "one of the main environmental issues of the late twentieth century" (Colls 2002: 402). It has been responsible for widespread damage to forests in Europe ('Waldsterben' or 'forest death') and North America ('tree die-back syndrome') (Wellburn 1988: 205). The consequent acidification of surface waters has had "profound ecological significance" (Weatherley and Ormerod 1987): it is a major threat to aquatic ecosystems causing ecological simplification, the loss of acid-sensitive species and a reduction in biodiversity (UKAWMN 2001). The resulting decline in some species of

[72] Much of this chapter was developed during the M.Res study that preceded and subsequently formed the preliminary year of this Ph.D. See section 1.2 and also Appendix 7 for further information.

invertebrates has reduced numbers of organisms higher in the food chain, including amphibia, fish, birds and mammals (Muniz 1991; Goudie, 1993; Colls, 2002). Effects, such as the local extinction of fish in thousands of Scandinavian lakes, have been found hundreds of miles from sources (Begon et al, 2002: 707).

During the 1970s and 1980s Acid Deposition became a widely reported issue, generating considerable international concern (Elsworth 1984). It was only after several years of considerable controversy that Acid Deposition became the first recognised example of major transboundary pollution (Schindler 1988).

Subsequently, international agreements to limit emissions, such as the 1979 Convention on Long Range Trans Boundary Air Pollution, have resulted in large decreases in emissions of sulphates (Monteith and Evans 2005). For instance, in the UK, Sulphur Dioxide (SO_2) emissions fell by 75% between 1980 and 1998 (UKAWMN 2001). Consequently, interest in Acid Deposition has waned not only because there was a perception that the problem had been dealt with successfully, but also because other environmental issues - especially climate change - took precedence.

The problems arising from Acid Deposition are, however, far from being resolved. While sulphate emissions have declined in Europe, they continue to rise globally, particularly in Asia (Bouwman et al 2002; Monteith and Evans 2005). Matsubara et al (2009) note, for instance, that recent reports of aquatic acidification have resulted in an upsurge of interest in the issue in Japan. Globally, nitrate emissions have become relatively more important: there is, for instance, evidence that nitrate saturation of vegetation and soils may lead to reacidification of some areas (UKAWMN 2001). Furthermore, even where Acid Deposition has clearly decreased, recovery of ecosystems has often been remarkably slow and many may never return to their original state (Schindler 1988). Acid Deposition and consequent Acidification is still a serious environmental problem with many unanswered questions (Gunn and Keller 1998) with “serious gaps” in our knowledge (Lovett et al 2009:99). Research into the conditions affecting recovery from acidification is, therefore, as pertinent as ever.

The rest of this chapter reviews the research evidence on aquatic acidification: its ultimate and proximate causes, biotic effects, mitigation and recovery. It commences with a brief overview of the history of research into acidification has been reported (4.2.1) before summarising the measures taken to reduce its effects and the main areas of current research (4.2.2). The physical and chemical processes underlying Acid Deposition and Acidification have then been outlined in section 4.3, in relation to emissions (4.3.1), deposition (4.3.2), effects on soil (4.3.3) and water (4.3.4). The impact of acidification on aquatic biological systems) has been discussed in section 4.4, including effects on primary producers, Zooplankton (4.4.2), benthic invertebrates (4.4.3), higher trophic levels (4.4.4.), food webs (4.4.5) and overall biodiversity and richness (4.4.6). In section 4.5, the recovery from acidification has been considered, using evidence from field studies and experiments on chemical (4.5.1) and biological recovery (4.5.2), while section 4.5.3 reviews competing explanations for delayed recovery. The influence of two major moderating (independent) variables that impinge on these processes has been considered in section 4.6. The impact of Geology (land-form) is considered in section 4.6.1 and that of and land use – and especially the influence of forestry – is reviewed in 4.6.2. Section 4.7 examines various approaches to the rehabilitation of acidified freshwater and finally section 4.7 provides a brief summary of this chapter.

4.2 Research into acid deposition

4.2.1 Historical context: growth of awareness of the problems of Acid Deposition

Although localised acidic pollutants must have existed as long as fossil fuel has been burned, large-scale acid deposition is essentially a product of the Industrial Revolution. R.A. Smith, the Chief Alkali Inspector of the UK at the time, is attributed with coining the term 'Acid Rain' in 1872 in his *Air and Rain: the Beginning of a Chemical Climatology.* He described the impact of precipitation that contained sulphur compounds from industrial sources around Manchester (Elsworth 1984; Wellburn 1988). There was, however, little scientific interest in the topic until after World War II.

Mason (1991) has pointed out that before 1950 historical records of acidification were often patchy, particularly in upland areas, and analytical techniques had not been refined. The consequence of this was that, when evidence did begin to accumulate, there was difficulty in establishing the historical limits of the problem. This problem was addressed, however, by the use of palaeoecological evidence (from siliceous skeletons of diatoms in lake sediments) which enabled previous communities to be identified. Different assemblages are closely correlated with acidity, so pH histories over long periods could be deduced. The Round Loch of Glenhead in Galloway, for instance, produced evidence of pH having been reduced from more than 5.5 in 1850 to less than 4.6 in the 1960s: a tenfold increase in acidity (Bartarbee et al 1985; Muniz 1991).

Schindler (1988) suggested that widespread damage to ecosystems began in the period 1930-50, when there was a move to a 'dilute and disperse' approach to atmospheric pollution by building taller industrial chimneys and smoke stacks. While this reduced local impact of pollutants, it exported the problem further afield: transboundary (that is, long-range) pollution became more common but (as yet) undetected. The renewal of interest in acid deposition began in Scandinavia, where an accelerating trend of large-scale fish deaths was reported from the 1940s (Elsworth 1984) and links were made with increased acidity by the 1950s (Kahan 1986). Research was hampered, however, by a compartmentalisation (between, for instance, soil and atmospheric scientists) which failed to recognise the interdisciplinary nature of the problem. A unified framework was only developed in the 1960s with research on water acidification that had become widespread in Sweden. It was established that this was caused by the transportation of pollutants over thousands of miles. This was widely reported, and indeed sensationalised in parts of the media, with newspaper headlines such as 'chemical war' (Elsworth 1984: 117).

Subsequently, research findings accumulated rapidly and the full extent and severity of the problem began to be delineated. The topic of Acid Rain was raised at the 1972 UN Conference on the Human Environment and the OECD (Organisation for Economic Co-operation and Development) established the Long Distance Transport of Air Pollutants

(LRTAP) programme. Its 1977 report documented evidence that acid precipitation covered much of Northern Europe. The UN Economic Commission for Europe (UNECE) set up its European Monitoring and Evaluation Programme (EMEP) in 1978 (Elsworth 1984) .

By this time research had begun to establish "irrefutable links" between atmospheric contamination and ecological impacts (Monteith and Evans 2005: 4). This was followed by remarkably rapid international cooperation to find practical measures to mitigate the problem. In 1979, thirty-four countries signed the 'Convention on Long-Range Transboundary Air Pollution' (CLRTAP), which came into force in 1983. This was:
"the first international legally binding instrument to deal with problems of air pollution on a broad regional basis" (UNECE 2011a).

The European Monitoring of Emissions Programme (EMEP) is a key component of CLRTAP and compiles data on atmospheric emissions and measurements of atmospheric pollution, as well as modelling atmospheric transportation and deposition of pollutants (EMEP 2011). The 1979 treaty was followed by eight further specific UNECE protocols, including the 1985 "*Protocol on the Reduction of Sulphur Emissions or their Transboundary Fluxes by at least 30 per cent*" and the 1994 *"Protocol on Further Reduction of Sulphur Emissions"* (UNECE 2011b). These have been instrumental in bringing about large reductions in emissions of sulphur compounds (for instance of 61% in Europe between 1980 and 2001: Monteith and Evans 2005). Similar initiatives have taken place in North America. In Scotland, emissions of SO_2 and NO_x emissions fell between 1996 and 2008 by 62% and 29% respectively (Scottish Government 2009).

An essential element of the international agreements was the need for continued monitoring of Acid Deposition. This has been carried out by bodies such as the UNECE EMEP and, in Britain, the United Kingdom Acid Waters Monitoring Network (UKAWMN 2001; Monteith and Evans 2005). This monitoring established that, despite the reduction in sulphur emissions following the CLRTAP protocols, and the chemical recovery of ecosystems reported in some of the monitoring programmes, there remained serious problems, both at the practical level and in terms of understanding of underlying mechanisms. Some of those issues, which continue to arouse controversy, are discussed in the following section.

4.2.2 Current research issues

The introduction of the EU's Water Framework Directive (2000/60/EC) (WFD) has contributed to renewed attention being paid to the issue of aquatic acidification (Scottish Government 2008). However, there are three more general reasons for further concern: global emission increases, Nitrogen saturation and evidence of slow biological recovery. These are outlined below.

Increasing global Acid Deposition

Although international agreements such as CLRTAP have been effective in reducing Acid Deposition in Europe and North America, global emissions continue to increase (Bouwman et al 2002; Colls 2002). Estimated emissions of Sulphur and NO_x[73] outside Europe and North America are predicted to rise by 31% and 37% respectively by 2015, compared with 1992 levels (Bouwman et al 2002). In particular, Acidification is an emerging problem in rapidly developing countries particularly in Asia. China, whose rapidly developing economy is heavily dependent on energy generated from fossil fuels, has begun to experience a rapid increase in the emission of pollutants. Richter et al (2005) found from satellite data an increase of 50% in tropospheric NO_2 between 1996 and 2004 over industrialized areas of China; they suggested that there was evidence of an accelerating trend in the annual growth rate. China has now, as a consequence, become the third largest region affected by acid deposition after Europe and North America: 2.8 million km^2 were affected in 1993 with significant consequent damage to crops and ecosystem (Feng et al 2002). Acid Deposition has now become recognised as a serious environmental issue in China (Zhao et al 2007), with evidence for substantial soil acidification (Larssen and Carmichael 2000). Yet despite

[73] Nitric Oxide (NO) and Nitrogen Dioxide (NO_2) are collectively termed NO_x gases (Colls 2002).

the fact that in some areas acidification can represent "the most pernicious threat to aquatic ecological health", (Monteith and Evans 2005:3) there is urgent need for further research into the nature and extent of the problem.

The role of nitrogen in Acid Deposition.

Historically, research into Acid Deposition and preventative measures have concentrated on sulphur compounds, as these have made the greatest contribution to Acidification. Now that sulphur emissions in Europe and North America have fallen substantially nitrogen deposition has not only become relatively more important but its absolute impact is now approaching that of sulphur compounds (Schindler 1988; Wright and Hauhs 1991; UKAWMN 2001). Furthermore, there is evidence that long-term build-up of nitrogen compounds in vegetation and water bodies has led to 'nitrogen saturation', where small inputs of nitrogen emissions have disproportionate effects in increasing Nitrate levels in water, so leading to rapid acidification (UKAWMN 2001) . Evidence for these effects include reports that parts of the South Pennines in England have reached an advanced stage of nitrogen saturation (Helliwell et al 2007); computer models suggest that nitrogen emissions need to decrease by 50% in the UK in order to stabilise soil and pH at present levels (Tipping et al 2006). The possibility that nitrogen saturation could lead to the reversal of ecosystem recovery has been cited as a possible reason for the anomalies in recovery, discussed below (Wright and Hauhs 1991).

Slow and uneven recovery of ecosystems from Acidification

As early as the 1980s, when international action limiting emissions had only recently begun, concerns were raised that recovery from Acidification might be much slower than anticipated. Schindler (1988), for instance, argued that some lakes might never recover completely, and that experimental studies indicated that some components of the biota recover much more slowly than others do, while Clair and Hindar (2005) suggested that restored communities were more unstable than those in unaffected areas. A considerable body of evidence began to accumulate that ecosystem recovery did not take place *pro rata* with emissions decline (Colls 2002); it can be much slower than anticipated and show unexplained variation (UKAWMN 2001; Davies et al 2005; Monteith and Evans 2005). It was concluded that recovery from acidification is not simply a reversal of the original process and that biological recovery is less well understood than chemical recuperation (Ledger and Hildrew 2005).

This chapter examines this issue of differential recovery (that is, rapid chemical recovery but slower or absent biological recovery) and the implications for mitigation and rehabilitation of acidified ecosystems. In particular, two factors which have been put forward as explaining differential recovery - variations in land use (especially the degree of forestation) and underlying geology. The research on recovery is considered in some detail in section 4.5 in relation to current theories that have been put forward to explain recovery effects. Before considering recovery from acidification, however, it is necessary to outline the chemical process of initial acid deposition and consequent acidification.

4.3 Processes of acid deposition and acidification

In this section, consideration has been given to the emissions responsible for Acid Deposition (4.3.1), the depositional processes themselves (4.3.2), and the manner in which they affect soils (4.3.3) and water systems (4.3.4). The relationship between chemical and physical process and biological consequences is not a straightforward one, so that the former is dealt with in section 4.3 before the latter is discussed separately in section 4.4.

4.3.1 Emissions

Biogeochemical cycles are the pathways through which atoms and molecules pass through various biotic and abiotic 'reservoirs'. These cycles are, naturally, in equilibrium states, at least on a global scale. However, anthropogenic activities have significantly altered the characteristics of these cycles for Sulphur and Nitrogen (Bouwman et al 2002). Indeed, anthropogenic impacts are so great that some have argued of the term 'nitrogen cycle' to be replaced by the designation 'nitrogen cascade' (Galloway et al 2003, Hooper 2006). The pollutants mainly responsible for Acid Deposition are sulphur and nitrogen oxides from fossil fuel burning, and ammonia released from intensive agriculture (UKAWMN 2001).

Sulphur Dioxide SO_2 is produced mainly from the combustion of fossil fuel, particularly coal (which can contain 0.1-4% sulphur in the form of iron pyrites FeS_2). Seventy-four per cent of atmospheric sulphur is in the form of SO_2 from anthropogenic sources (Colls 2002). Natural sources, for instance from volcanoes, are mainly in reduced form such as Hydrogen Sulphide H_2S. However, about 16% of global sulphur emissions are in the form of Dimethyl Sulphide (DMS: CH_3SCH_3) which is produced by marine plankton and subsequently oxidised to SO_2 in the atmosphere (Colls 2002). Anthropogenic SO_2 emissions are estimated to have increased from 4 Mt in 1860 to 150 Mt in 1990 (Colls 2002); of these more than 60% is produced by the industrial combustion of fossil fuel and 20% from other industrial processes (European Commission for Europe 2007). Since 1990 emissions have been falling in Europe and North America, but larger rises in Asia have resulted in a continued increase in overall global emission levels (Wellburn 1988; Colls 2002). Negligible amounts of sulphur emissions are produced by motor vehicles. In Scotland, overall SO_2 emission levels were reduced by over 50% between 1993 and 2006 (Scottish Executive 2007: 18).

The oxides of nitrogen mainly involved in Acid Deposition are Nitric Oxide (NO) and Nitrogen Dioxide (NO_2), collectively termed NO_x gases. Of the NO_x produced from combustion, 90% is in the form of Nitric Oxide, but this can react with tropospheric ozone to form NO_2 (Colls 2002):

$NO + O_3 \rightarrow NO_2 + O_2$ (Equation 4.1: formation of nitrogen dioxide from tropospheric ozone and nitric oxide)

Approximately 70% of total NO_x emissions are of anthropogenic origin, of which half in the UK is from road transport (Colls 2002). Between 1990 and 2005, however, NO_x emissions in the UK fell by 45%, following the introduction of catalytic converters (Scottish Executive 2007). On a global scale, increased road transport use is leading to increased NO_x emissions (Colls 2002)

Ammonia can also be a major factor in acidification (in certain conditions), as it is transformed into nitrates in the nitrogen cycle (Cresser and Edwards 1987; UKAWMN 2001). Globally, more than half of all ammonia emissions are from livestock farming, by the decomposition of urea from animal wastes (or from uric acids in poultry). In the UK 89% of ammonia is emitted from agricultural sources (Colls 2002). Ammonia is usually, however, only a minor contributor to acid deposition.

4.3.2 Deposition

After emission, acidifying pollutants may remain in the atmosphere for several days and so be carried long distances before being deposited. Accordingly, deposition may be very distant from the emission site, often in different countries: hence their classification as transboundary pollution (EMEP 2011a). Within the atmosphere, SO_2 and NO_x may
(a) react with moisture and are oxidised to form sulphuric and nitric acids or
(b) if the atmosphere is dry, undergo complex photochemical oxidation processes that again results in the formation of sulphuric and nitric acids (Mason 1991). In the former case, the acids will be carried within clouds and then be precipitated as rain, sleet, hail or snow. This is termed Wet Deposition (Wellburn 1988; Mason 1991). Rainwater is 'naturally' acidic; that is, in the absence of anthropogenic influences it would exist in equilibrium with atmospheric Carbon Dioxide at between pH 5 and 5.6 (Wellburn 1988; Schindler 1988; Mason 1991). Anthropogenic emissions, however, reduce this pH significantly: average rainfall in the UK in 1978-1980 had a pH of 4.3, which is an order of magnitude more acidic than the 'natural' level. Rain can, exceptionally, be even more acidic than this; the lowest pH recorded in rain was 2.32 in the USA in 1978 - a hundred times more acidic than normal (Wellburn 1988). However, even during the highest levels of acidifying emissions, rainfall in Europe was only mildly acidified; it was the very high volumes of precipitation on its western seaboard, falling on geologically sensitive areas, that caused such widespread effects (Ormerod and Durance 2009).

Acids formed in the absence of moisture reach the earth in gaseous, aerosol or particulate form, termed Dry Deposition. (Wellburn 1988; Mason 1991). These acidic components are collected from the atmosphere onto vegetation, water or soil by a variety of processes and may subsequently be washed off by precipitation, or be absorbed (Cresser and Edwards 1988).

A third form of Deposition is termed 'Occult' (hidden) Deposition. This occurs when vegetation scavenges acids directly from mist or fog (Wellburn 1988; Mason 1991). This can be particularly important in Scotland, where hills are often shrouded in cloud (SEPA 1996). Mists can also be highly acidic, with pH levels below 2.75, because of physical processes such as evaporation.

4.3.3 Acidification in soil

This study focuses on the recovery of aquatic systems from acidification. However, the impact of acidification on water bodies is mediated by the soil: wet deposition will fall directly onto soil while wet, dry and occult deposition will be intercepted by terrestrial plants before entering the soil. The direct deposition of acids onto water bodies is negligible (Wellburn 1988). It is necessary, therefore, to consider the fate of Acid Deposition components in the soil before examining aquatic acidification in more detail.

Acid Deposition results in hydrogen, sulphate and nitrate ions entering the soil. Cation exchange occurs, with H^+ ions replacing Na^+, K^+ and Mg^{2+} ions from exchange sites on soil particles. The displaced cations may be mobilised if they combine with sulphate ions to produce mobile salts (Wellburn 1988; UKAWMN 2001). Once these natural buffering mechanisms are exhausted, at pH levels between 2.8 and 4.5, then hydrated Aluminium Oxide may be exchanged, leading to the precipitation of mobile Al^{3+} ions (Wellburn 1988; Mason 1991). At this stage, there may also be mobilisation and leaching of elements such as Mercury, Copper and Zinc (Muniz 1991). All of these components will then enter groundwater. It should also be noted that some unpolluted soils might become naturally acidified due to internal processes such as uptake and nitrification by some species of tree

(Johnsson et al 1991). Such naturally acidified soils will be more prone to acidification and have less buffering capacity.

4.3.4 Acidification in water

The mechanisms by which acidified soil drainage water will enter (via stream runoff) and affect aquatic systems are complex and depend on several variables including season, climate, local weather conditions, vegetation and topography (Cresser and Edwards 1987). When soil horizons become saturated, water flows downslope into streams or lakes. It will then influence the chemistry of that body, in up to three stages (Mason 1991). In stage 1, the strong acids are buffered by bicarbonates (from dissolved atmospheric CO_2):

$$H^+ + HCO_3^- \rightarrow H_20 + CO_2$$ (Equation 4.2 Bicarbonate buffering)

In many water bodies the buffering capacity is never exceeded and the pH levels never drop below 6 (Cresser and Edwards 1987; Mason 1991). If, however, the buffering bicarbonate is consumed, then stage 2 of the process is characterised by large pH fluctuations. In the third and final stage, alkalinity is completely lost and the water body has a stable pH level of 5 or below. Typically levels of sulphate, nitrate, and ammonium will all be elevated in such acidified waters, as will Aluminium (Muniz 1991), while Calcium levels will be low (Cresser and Edwards 1987). Trace metals are normally insoluble in circumneutral conditions, but become mobilised with acidification (Schindler 1988); bioavailable Zinc, Copper and Manganese all tend to increase in acidified conditions (Doughty 1990; Muniz 1991).

These processes typically occur under acidification. There is, however, not only considerable complexity, but also a number of factors, which considerably influence the ways in which the processes occur. These can be termed moderating variables.

4.4 The impact of acidification on aquatic ecosystems

From the beginning of research into acidification, it became clear that it had serious implications for aquatic ecosystems (Weatherley and Ormerod 1987). The impact of acidification on different trophic levels is considered in this section, before the overall effects on biodiversity are outlined.

4.4.1 Primary producers

Mason (1991) summarised evidence showing that acidification of lakes led to sharp reductions in the number of species of primary producers such as phytoplankton (that is, a reduction in species richness). Perhaps surprisingly, biomass seemed largely unchanged in acidified lakes while in streams there was evidence that acidified waters had a *greater* overall biomass of primary producers, especially periphytons, probably because of reduced grazing by higher trophic levels. Muniz (1991) also noted substantial evidence that acidification substantially altered the composition of phytoplankton communities, with far fewer species present. There was also evidence of a shift in species dominance, presumably as there was variation between species in terms of acid tolerance. Filamentous algae, for instance, became more common (Muniz 1991).

4.4.2 Zooplankton

Muniz (1991) reported research evidence, which suggested that zooplankton species richness and biomass was reduced in acidic water. Again there was a shift in species dominance, with some species (for instance of *Daphnia*) being far less tolerant of acid conditions than others. However, some species may flourish under acidification, not only through competitive release (fewer competitors within their trophic levels) but also because of a reduction in predation from higher trophic levels (for instance, as a result of a decrease in the abundance of planktivorous fish).

4.4.3 Benthic invertebrates

Substantial research evidence has shown that acidified lakes and streams have reduced diversity of benthic macroinvertebrates, although again there was a less clear-cut impact on abundance and biomass (Harriman and Morison 1982; Mason 1991; Muniz 1991).

For instance Stones et al (1984) found 23-37 invertebrate taxa in Welsh streams with pH greater than 5.5, but over 60 taxa if pH levels were higher, while Simpson et al (1985) found "at least 10% each of midges, mayflies, stoneflies and elmid beetles" in less acidified waters, while more acidic waters contained fewer than half as many taxa. Mackay and Kersey (1985) found 5 species of mayflies in streams with pH 5.3-6.7 but only one in streams with pH levels of 4.3 - 4.8.

Acidification can affect invertebrates through physiological stress (with Hydrogen and Aluminium ions disrupting sodium osmoregulation), changes in food supply and changes in predation (Wellburn 1988; Muniz 1991). For instance, Corrixidae (water boatmen) and Odonata (dragonflies) can become more prolific through a decrease in predation under acidification. Some species appear to be physiologically more tolerant to acidification, while others are much more acid sensitive. Thus, there are differential effects of acidification in different taxa. Those taxa that are dominated by acid sensitive species include mayflies (Ephemeroptera), snails, crayfish and amphipods, while stoneflies (Plecoptera) are generally more acid tolerant and can become dominant in acid waters (Muniz 1991).

As Mayflies (Ephemeroptera) contain many species that are particularly acid sensitive, as well as some that are acid tolerant, they are a good indicator species for acidification (Simpson et al 1985; Mason 1991; Forestry Commission 2003; Monteith and Evans 2005). Accordingly the diversity of Ephemeroptera in acidified waters has been investigated in numerous studies, many of which have also examined the more acid tolerant Plecoptera (such as Mackay and Kersey 1985; Bradley and Ormerod 2002; Lepori et al 2003; Ledger and Hildrew 2005; Kowalik and Ormerod 2006).

4.4.4 Effects on higher trophic levels

Acidification also has direct effects on fish, especially Salmonids, causing developmental deformities and increased mortality (eggs are particularly sensitive to low pH levels) (Mason 1991; Gunn and Mills 1998). Acidity eventually leads to fish becoming absent from some lakes and rivers (Cresser and Edwards 1987). For example, Maitland et al (1987) carried out a detailed study of Scottish lochs and found that many, previously well stocked with Salmonid fish, were fishless. Harriman et al (1987) surveyed fish populations in 22 lochs and 27 streams, finding trout absent in 5 previously fished lochs. They also found evidence for a decline in fish populations over 50 years, with fishless lochs and streams having toxic pH and Aluminium levels. In the U.S.A. acidification has been linked with widespread local extirpation of brook trout (Cai et al 2009).

Wellburn (1988) explained that these adverse effects on fish are related to the associated increases in Aluminium concentration as well as pH decrease. Aluminium disrupts osmotic control mechanisms (the sodium pump), and thus toxicity is enhanced by low pH and low Calcium. Because of the commercial importance of fish and the interests of anglers, the impact of acidification on Salmonids in particular often generates interest. Muniz (1991) and Mason (1991) also report on evidence of adverse effects on other vertebrates, such as amphibians, birds (e.g. the dipper) and otters.

4.4.5 Effects on food webs

Apart from effects on particular groups of organisms, acidification has systematic effects on aquatic food. Generally, food chain length may be reduced by acidification (Ledger and Hildrew 2005). Most studies have also shown that decomposition of allochthonous organic matter is slowed (Mason 1991) and this may result in a high standing stock of detritus (Pretty et al 1995). This may be at least partly explained by the fact that many detritivores (especially grazers that scrape organic material from surfaces) are benthic invertebrates within particularly acid sensitive taxa, such as molluscs, crustacea and mayflies (Muniz (1991).

Mackay and Kersey (1985), for instance, found that more acidic headwater streams were dominated by shredder types of detritivore (that feed on coarse organic matter) such as Plecoptera, and had few grazer or collector species (collectors filter or gather from water or debris) than circumneutral streams, which had balanced detritivore assemblages.

However, Ledger and Hildrew (2005) found that some shredder species might take over the grazer role (and thus fill ecological niches that have become vacated). This process has been cited as one explanation for the apparently slow biological recovery of some systems; it is discussed in more below.

Overall, the effects of acidification on food webs are still little understood, with the possibility of there being unknown multiplicative effects. Lovett et al (2009:99), for instance, argue that these "gaps in knowledge" suggest that impact on biodiversity has been significantly underestimated.

4.4.6 Overall diversity and richness

There is, therefore, substantial evidence from fieldwork and experiments that aquatic ecosystems undergo changes in community composition (Gunn and Mills 1998), with simplification and loss of species biodiversity under acidification (Doughty 1990; Last and Watling 1990; Muniz 1991). While there may be species 'winners' – those that are acid tolerant may benefit from competitive release or reduced predation – overall ecosystem stability is impaired. Species richness may be significantly reduced: Gunn and Mills (1998) reported reductions of 50% in phytoplankton species and 80% in zooplankton as pH reduced from 7.0 to 4.0 in Canadian lakes, for instance. However, most studies show that overall biomass is unchanged (Last and Watling 1990) although some have found significant declines (for instance Okland and Okland 1986).

However, this general pattern does show variation. Doughty (1990) found that his study of waters in South West Scotland showed comparatively rich invertebrate communities where acidification conditions would suggest otherwise. Doughty concludes that "… there was no entirely satisfactory explanation for these apparent anomalies" (Doughty 1990:9). The impact of acidification on ecosystems is, therefore, complex and imperfectly understood. The following sections consider the extent to which knowledge of the moderating variables, such geology and land-use, may help to explain some of these anomalies.

4.5 Recovery from acidification

By the 1970s, SO_2 emissions in Europe began to fall as there was a move away from coal powered electricity generation towards gas (Colls 2002). This decline in sulphur emissions was hastened following the Convention on Long-Range Transboundary Air Pollution of 1979, so that as early as 1988 Schindler reported some initial recovery of lakes from acidification. Early indications were that some fish species returned quite quickly but that zooplankton communities recovered much more slowly (Schindler 1988). In subsequent decades it became clear that recovery was not going to be straightforward, with some processes occurring faster than others, and some ecosystem components not recovering at all. Biological recovery remains much less well understood than the original acidification (Ledger and Hildrew 2005).

This research project is concerned with facilitating decisions on how to encourage the recovery process. In particular, it will contrast strategies that are predicated on the idea that land-use (specifically, some forms of forestation) is a more significant factor in determining recovery than underlying geology. The following sections explore the evidence for these different, competing views, starting with chemical recovery (Section 4.5.1), biological recovery (Section 4.5.2) and competing explanations of differential recovery (4.5.1).

4.5.1 Chemical recovery

The United Kingdom Acid Waters Monitoring Network, which has been carrying out a comprehensive monitoring programme since 1988, reported in 2001 that between 1988 and 1998 there were markedly uneven changes in water sulphate levels: some streams showed substantial improvement while others, especially in remote acid sensitive areas, showed very small changes. They concluded that some catchments might be releasing stored sulphates, thus slowing recovery (UKAWMN 2001).

By 2005, however, some trends were becoming clearer. Davies et al (2005) reported that analysis of water chemistry data over 15 years from 22 acid sensitive sites (lakes and streams) showed general trends in recovery, with sulphate and base cations declining. In some sites, there was also a decline in H^+ and Al^{3+}. Trends in ANC (Acid Neutralising Capacity: a measure of overall buffering capability) were less clear. Nitrate levels showed little overall change, but there was some variation with climate.

Monteith and Evans (2005), in a comprehensive review of UKAWMN results, concluded that trends in chemical recovery had become much clearer since 1998, with widespread increases in pH and alkalinity, and decreases in Al^{3+}. Water sulphate levels had decreased, so that Nitrate levels had become relatively more important. They concluded that the effects of catchment soil and vegetation on recovery were little understood and required more research.

4.5.2 Biological recovery

Some of the earliest evidence on recovery from acidification comes from experimental work, where lakes were first artificially acidified and then acidification was reversed in a controlled manner. Schindler et al (1991) reported on the recovery of an experimental lake ('L223') in Ontario. Chemical indices, such as pH, recovered rapidly but biological recovery was much more uneven. Some groups of organisms (such as phytoplankton) recovered with a time lag of a few years; in other groups, species which had disappeared with

Acidification were replaced by similar species (in terms of ecological function). In yet other groups, no recovery was recorded. Invertebrate taxa richness recovered partially, but not completely. Similarly, Bradley and Ormerod (2002) examined the effects of catchment liming[74] (to reduce acidification) on acidified Welsh streams after ten years. Although there were significant changes in water chemistry the effects on invertebrates were "modest". The number of acid sensitive taxa increased only for 2 years following treatment. Species richness did increase, but added only 2-3 acid-sensitive species, so that overall richness was only about third of than in nearby non-acidified streams. Only one species of Plecoptera and one of Ephemeroptera occurred more often after liming than before.

Clair and Hindar (2005) in a review of results of recovery from acidification by liming concluded that although water chemistry may be restored (albeit only temporarily in some cases), aquatic communities would not return to their "original state" (p91), and restored communities were also more unstable than those in unaffected areas. Gunn and Mills (1998) were more optimistic for the possibility of full recovery of Canadian lakes (especially with respect to trout), but acknowledged that many uncertainties exist.

More recent studies based on fieldwork studies of biological recovery come to broadly similar conclusions: that although recovery was usually occurring, it was slower than might be expected, that it was uneven and that ecosystems were unlikely to return to their pristine conditions. Monteith et al (2005), in their review of the UKAWMN results, concluded that generally biological recovery is "modest" and "very gradual" and that "ecological recovery endpoints are uncertain" (p83).

4.5.3 Explanations for delayed recovery

Monteith et al (2005: 96) put forward four types of hypothesis to explain the lag between chemical recovery and its biotic response:

1. The "linearity" hypothesis: that the relationship between chemical and biological variables is linear, but the former has not yet changed sufficiently to impact on the latter;

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[74] Liming is discussed further in section 2.7

2. The “chemical threshold” hypothesis: that the relationship is non-linear and a threshold must be reached before biological assemblage structure changes;
3. The “dispersal” hypothesis: that AS species disperse slowly back to acidified sites, causing time-lags;
4. The “community closure” hypothesis: that acidified ecosystems change their assemblage structure to a new equilibrium, which presents barriers to returning species.
In addition to these four explanatory frameworks put forward by Monteith et al (2005), it is possible to add another:
5. The “episodicity” hypothesis: that chemical-biological differentials can be explained in terms of infrequent but extreme events, so that sites that are prone to great fluctuations in acid deposition over time may have retarded recovery from acidification (Beverland et al 1997; Jamieson 1998).
Each of these five hypotheses will be discussed in turn.

The “linearity” hypothesis

This hypothesis assumes that biota respond proportionately to changes in water chemistry. Monteith et al (2005) cited some evidence that supports this, particularly for diatoms. The results of this study, however, show that chemical indicators have generally recovered to levels similar to those in waters that have never been acidified. This conforms to the results of recent studies on chemical recovery (Davies et al 2005; Monteith and Evans 2005), providing compelling evidence against the linear hypothesis.

The “Chemical threshold” hypothesis

Monteith et al (2005) suggested that this might be intrinsically more likely than the linearity hypothesis. They proposed that punctuated change would occur, with groups of taxa reappearing once certain chemical thresholds have been achieved. They cited some evidence from studies of macrophytes and fish. With regard to the latter, however, it might be that time lags are more related to trophic level than chemical threshold. That is, organisms higher in trophic level cannot reappear until those in lower trophic levels have become fully established. However, a large range of studies, previously examined, have shown that, even where chemical recovery has proceeded to virtually normal levels for some time, biological recovery may be absent or attenuated. The chemical threshold hypothesis, on its own, seems therefore unlikely to explain differential recovery.

The "Dispersal" hypothesis

The central idea of this hypothesis is that biological recovery will be limited by the maximum dispersal speeds of acid sensitive species returning to previously acidified sites. There is little research data in general concerning the nature of dispersion in many of these species and the ease or otherwise by which they can recolonize areas, from which they have been removed by acidification. Elliot et al (1988) summarised research on the dispersal of Ephemeroptera that showed that in some (but not all) species, adults flew upstream to lay eggs (thus compensating for downstream drift of eggs and larvae), but that this was often dependent on wind direction. In other species, the larvae themselves can move upstream.

Monteith et al (2005) presented evidence for the dispersal hypothesis from the UKAWMN studies. These showed that the two waters that showed greatest divergence between chemical and biological (macroinvertebrate) recovery both lay "in close proximity within the strongly acidified region of Galloway" (p 98). They suggested that it is feasible, therefore, that such areas would apply more "dispersal constraints", as the ecological sources for dispersal would likely to be more distant than in other sites. The two waters in question lie just to the East of the study sites, within the Merrick igneous area, so that their proposal is particularly relevant to this study. On the one hand, the two waters (Round Loch of Glenhead and Dargall Lane) quoted by Monteith et al are close (between 6 and 10 km) to the three granitic sites used in the present study (which showed the least biological recovery), suggesting that dispersal might be a limiting factor throughout this area. On the other hand, the site with greatest biological recovery of the six (Rowantree Burn) is also isolated from other waters, being near the top of the catchment area for the River Cree on the Water of Minnoch tributary. Sites lower down the Water of Minnoch, which would presumably be closer to sources of macroinvertebrate dispersal, showed less biological recovery, with fewer species overall and fewer AS species. It would be difficult to explain this finding using the dispersal hypothesis, unless AS species found at the top of the catchment had 'leapfrogged' other streams.

There is, moreover, further evidence against the dispersal hypothesis. Bradley and Ormerod (2002), in their study of the biological recovery of Welsh streams, which had been limed, found that over a ten-year period many AS species reappeared at least once, but failed to become established. They argued that the results showed that AS species were able to reach previously acidified sites, but other factors were preventing them reoccupying the ecological niches that they had previously held. Masters et al (2007) used malaise traps and benthic samples in Wales to look at limits of dispersal of Ephemeroptera, Plecoptera and Trichoptera. They found that near streams in which larvae had not been caught in 21 years, eight species from all three orders were caught, showing evidence for inter-catchment dispersal. They concluded that the results were sufficient to refute the dispersal hypothesis. Furthermore, Monteith et al (2005) cited evidence from studies using stable isotope and molecular genetic techniques, which suggested that inter-catchment dispersal was much greater than it was hitherto thought to be. Overall, it can be concluded that there is little evidence that dispersal is a limiting factor that can explain differential recovery. The results from Monteith et al (2005) concerning the Round Loch of Glenhead and Dargall Lane do, however, reinforce the findings of this study, namely that the waters arising from the Merrick-Mullwacher granitic intrusion show particularly poor biological recovery, in contrast to good chemical recovery.

The "Community Closure" hypothesis

This approach goes beyond a gross overview of species richness to examine the detailed composition of aquatic ecosystems before and after acidification. Specifically, it proposes that post-acidification ecosystems can achieve a new equilibrium which is resistant to the re-entry of Acid Sensitive species which were absent during the readjustment process. As proposed by Ledger and Hildrew (2005), shredder species (which feed on coarse organic matter) can take over the niches previously occupied by grazers (which consume finer material, and tend to be more Acid Sensitive) (see section 1.4.5). Supporting evidence includes the findings of Mackay and Kersey (1985) that acidic upland waters were dominated by shredders such as Plecoptera and had fewer grazers than circumneutral streams. Pretty et al (2005) found that species-specific production of four species of shredder Plecoptera in an acid stream was high, and suggested that this could be explained by competitor release (that is, niche expansion in the absence of a competitor: Begon et al 1987). The community closure model would also explain the findings of Bradley and Ormerod (2002), that Acid Sensitive species were found near previously acidified streams but failed to become established.

Ledger and Hildrew (2005) suggested that Nemourid and Leuctrid Plecoptera, in particular, might be able to adapt to a grazing mode, while in normal (non-acidic) conditions all Plecoptera except *Amphinemoua sulciolis* and *Brachyptera risi* can be categorised as shredders. In contrast, all Ephemeroptera are grazers.

There are other variations of this model, which consider various ecosystem parameters. For instance, Arnott et al (2006) suggested that acidification changes the nature of predator assemblages high in the food chain, thus providing predator release for organisms lower at lower trophic levels.

This community closure hypothesis is of recent origin and illustrates the increasing complexity of explanatory models of recovery from acidification. However, community closure by itself cannot explain the substantial differential between chemical and biological recovery, nor can it explain the results of this study, showing that recovery was inhibited in granitic and highly forested sites.

The "episodicity" hypothesis

This hypothesis does explain, however, the chemical-biological recovery differential. The central focus of this proposal is that fluctuations in upland stream conditions can be very large, with low-frequency but high-impact events (such as storms or rapid snow melt) having a disproportional impact on biological recovery, preventing recolonisation of AS species, while having less effect on mean chemical indicators (Kowalik and Ormerod 2006) .

The importance of rapid fluctuations in precipitation in aquatic acidification has long been recognised. Cresser and Edwards (1987), for instance, explain in detail how upland catchments are often steep with shallow soils, so that heavy rain, that quickly saturates the soil, would soon result in rapid lateral flow into watercourses, so that stream discharge would rise very rapidly. Under such conditions, common in mountain storms, water will have little time (a few hours) to be buffered within the soil; accordingly, stream acidity can increase markedly. SEPA (1996) reports that pH levels can change by a level of 2 over a matter of a few hours: that represents a hundred-fold increase in acidity. Accordingly, while some streams may show that overall, mean levels of acidification have fallen to normal, pristine conditions, there may be infrequent but extreme events, which are preventing biological recovery. Hall et al (1980) reported evidence from studies of experimentally acidified waters that showed that the drift rates (that is, number of invertebrates moving from their usual benthic locations and into the water column, thus drifting downstream) increased markedly in AS species during high acidification. Furthermore, high flow rates (such as floods) will tend to flush out many benthic invertebrates, whether the conditions are acidic or not (Dobson and Frid 1998).

A number of recent studies have provided evidence for the importance of such extreme events. Helliwell et al (2007) found marked seasonality in their survey of nitrate levels and acidity in four upland areas of UK, including Galloway. Lepori and Ormerod (2005) reported that in episodically acidified streams survival (of species of Acid Sensitive Ephemeroptera) was the same as with matched circumneutral streams during periods of low flow, but substantially lower during episodes of high flow (during Alpine spring floods), when acidity increased significantly. Kowalik and Ormerod (2006) tested this idea experimentally, exposing one AS species of Ephemeroptera (*Baetis rhodani*) to either chronic exposure to acidification or repeated short-term (episodic) doses. Mortality was high under chronic exposure conditions (>80%), as compared to less than 10% mortality in a control group, maintained in circumneutral conditions. Those exposed to short-term episodes (2 x 4 days, interspersed with 4 day recovery periods), however, also showed higher mortality (>40%) than the controls. The authors further argue that many AS species have life cycles that render them particularly vulnerable to acidic episodes that would occur during high flow conditions in autumn and winter. They conclude by arguing that this evidence further supports the importance of episodic acidification. Kowalik et al (2007) provided further evidence, showing that invertebrate assemblages were significantly different in sites that showed evidence of different types of episodic events. Matsubara et al (2009) short term changes in acidification associated with high hydrological loading e.g. during snowmelt, while Cai et al (2009) concluded that recovery from acidification in high-elevation streams depended on the interrelationship of biogeochemical processes and precipitation patterns. There is, therefore, accumulating evidence for the significance of acidic episodes. In particular, streams may differ in the extent to which they are prone to high-flow acidic incidents[75]. Factors involved in such differentiation may include aspect, slope, catchment size and altitude.

Summary: hypotheses of delayed recovery.

From the above summary of the literature and the evidence from this study, the "linearity" and "chemical threshold" explanations can be discounted: chemical recovery has proceeded too far for these to be important. The remaining hypotheses all have some supporting evidence, and it can be proposed that they may be acting together, in a complex fashion, to influence differentials in recovery. For instance, acidic episodes (which may be more common in some streams because of specific topographic features) may remove certain AS species during high flow events; some of these species may later recolonise those streams more slowly than others, because of differential dispersal methods and on arrival at their previous locations may not be able to re-establish because of community closure. Moreover, these factors may interact with geology and land-use. For instance, the acidifying effects of

[75] In this context, episodicity has referred to the infrequent occurrence of high-flow events. However, in North America, and at a slightly different time-scale, it might also relate to periods of low-flow (drought conditions) that may become more frequent with climate change (Aherne et al 2008). Such droughts may lead to oxidation of previously stored Sulphur compounds, further offsetting reductions in emissions.

high-flow episodes may be considerably mitigated in sedimentary catchments if they are large enough; Adult Ephemeroptera may disperse shorter distances in forested areas. It seems, therefore, that recovery from acidification, particularly with respect to biota, is considerably more complex than hitherto thought. The present study has attempted to conduct a controlled experiment of two of the contributory factors. The following section will examine some of the drawbacks in the methods employed and make some proposals for future research on the topic.

4.5.4 Overview of recovery

To summarise the foregoing, acid emissions in Europe have fallen considerably and many water bodies show significant chemical recovery, but biological recovery has been significantly slower and more uneven. Moreover, ecosystems may takes fifty years or more to recover to previous, uncontaminated states (Jenkins et al 1998; Colls 2002), and some may never do so.

As Wright and Hauhs (1991) observed, decreases in acid deposition and ecosystem recovery have been characterised by discrepancies between observed and predicted effects. There is, therefore, "much interest in the extent and rate of recovery of affected soil and water ecosystems" (Colls 2002: 423). Furthermore, there is continuing lack of understanding concerning the comparative influences of the moderating variables (geology and land-use) on the recovery processes and the extent to which they explain its patchy and uneven nature. It seems probable from previous research, for instance, that there are non-linear interactions between the effects of base-poor bedrock and mature forestation that present particular barriers to recovery. The precise nature of those relationships have important implications for how rehabilitation methods can best facilitate recovery, and so these moderating factors will now be considered in some detail.

4.6 Moderating effects of land-form and land-use

From the early studies of fish mortality in Scandinavia, it became clear that there was not a simple linear relationship between acid emissions and chemical changes in water systems. The nature of the underlying bedrock (i.e. the geology of catchments), soil types (edaphic factors) and land usage have been identified as having significant qualitative and quantitative influences on the chemical processes of acidification (Last and Watling 1990).

4.6.1. Effects of Geology and soil types

Effects on water chemistry

It is generally accepted that sensitivity to acidification is largely based on bedrock geology, reflecting differences in buffering capacity and ability to replace lost base cations by weathering (Last and Watling 1990; Cai et al 2009). Matsubara et al (2009), for instance, found a clear relationship in one river catchment between the prevalence of granitic rocks and increased acidification. It has been noted (section 4.3.3) that cation exchange in the soil (involving Na^+, K^+ and Mg^{2+} ions) serves to buffer acidification. Once these base cations are exhausted acidification proceeds with H^+ and Al^{3+} ions being leached into groundwater[76]. In many areas, underlying bedrock is sufficiently rich in these base cations that the process of weathering replenishes those lost in soil acidification. Base poor bedrock, however, will not weather at the necessary rate to replace lost cations, and thus soils (and therefore waters) in these areas are particularly sensitive to acidification (UKAWMN 2001). Igneous rocks such as granite are especially low in these base cations, and so those areas of Scotland with a predominantly granitic solid geology are more prone to acidification, even at relatively low atmospheric levels of sulphur and Nitrate pollutants. It is because of these geological factors that one area of South West Scotland, the Galloway Hills formed from a large granite batholith, shows some of the greatest effects of acidification in the U.K., despite having lower sulphur fallout and higher rain pH than many other areas (Whitlow 1977; Mason 1991). The River Cree, which is situated within this catchment, provides the location for this study.

[76] Alewell et al (2000) argue that because of this increases in cation concentrations in streams, often taken as an indicator of recovery from acidification, can actually indicate continued increasing soil acidification.

It should be noted that underlying geology varies on a continuum from base poor to base rich, with granite at one end of the continuum. Metasediments, grits and quartz sandstones are also more acidifying than base-rich rocks such as limestones (Cresser and Edwards 1987). In a study for the Scottish River Purification Boards Doughty (1990) examined 145 streams selected using geological factors. He found that the most acidified sites occurred in areas with susceptible geology, although some granitic areas were not acidified. The mean pH level for each of the six geological types were Granites 6.22; Moine schists 6.49; Dalradian schists, slates 6.83; Ordovician and Silurian shales 6.85; Basaltic and andesitic lavas 7.51; Limestones and sandstones 7.55

Soil types can also influence the acidification process. Geological sensitivity is exacerbated by thin soils, as weathering will deplete available base cations faster than thicker soils, and thus the buffering capacity is reduced (Cresser and Edwards 1987; Mason 1991). Furthermore, soils may become naturally acidified, due to internal processes such as uptake and nitrification by some plant species, such as alders (Johnsson et al 1991)

Effects on ecosystems

It has been established, therefore, that in base-poor bedrock weathering cannot keep pace with the uptake of cations from the soil following acid deposition, so that such geology exacerbates acidification. Research confirms that these effects are also present in terms of impact on ecosystems. For instance, Doughty's (1990) study of 145 sites selected on basis of geological factors (previously described in section 4.6.1) found that taxon richness (number of species) for Ephemeroptera (mayflies) was significantly positively correlated with pH and calcium concentration, and negatively correlated with aluminium concentration. Coleoptera (beetle) and Trichoptera (caddis fly) richness was positively correlated with pH, calcium and sulphate. Plecoptera (stonefly) richness showed a completely different pattern, with no significant correlation with any of these variables, leading to the conclusion that this order may be benefiting from competitive release[77] as other species decline.

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[77] This refers to the process whereby one species, hitherto subject to reduced fitness from inter-species

These and other similar findings have informed the development of various Critical Load (CL) models. Critical Loads are frequently used in the area of atmospheric pollution as a measure of environmental sensitivity. If the actual level of a specific measured CL is more than the appropriate CL, then the CL is exceeded. Maps may be generated showing the levels of exceedance. The CL approach was used for second UNECE sulphur protocol of 1994 (Bartabee et al 1995), has been widely adopted by members of the European Union. (Defra 2011) and is now being used in revisions of new protocols to limit emissions in Europe (Larssen et al 2010).

The critical load for acid deposition can be defined as the "highest deposition of acidifying compounds that will not cause chemical changes leading to long-term harmful effects on ecosystem structure and function" (SEPA 1996 p 14). There are a number of different ways in which the CL for aquatic acidification can be calculated, including

1 The diatom CL model: using paleolimnological data to determine the point at which changes in the diatom composition towards a more acidophilic assemblage are first identified (Bartabee et al 1995);

2 The Steady-state water chemistry (SSWC) model, using Acid Neutralising Capacity (ANC) which measures the buffering capacity of a particular area. The CL for ANC is selected using sensitivity of a specific organism to acidification. For instance, 0 μeq ANC L^{-1} is the level at which 50% of brown trout (*Salmo trutta*) populations are seen to suffer damage, derived from empirical dose-response relationships (Defra 2011).

Nisbet et al (2007), for instance, argues that the SSWC Critical Load approach is especially useful to quantify site sensitivity to surface water acidification, in that Acid Neutralising Capacity (ANC) is "the best chemical indicator of a biological response to water acidification".

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competition, is found to have an increased realised niche following the removal of one or more of the competing species (see Begon et al 2006).

ANC is calculated:

$$ANC = Ca^{2+} + Mg^{2+} + Na^{+} + K^{+} - SO_4^{2-} - Cl^{-} - NO_3^{-}$$ (Equation 4.3: calculation of Acid Neutralising Capacity ANC)

and is thus a measure of the supply of base cations from the weathering of underlying bedrock. Critical ANC values for particular species (such as fish) can be calculated from dose response. However, there are some criticisms of this CL approach as being too crude to assess adequately the risk to ecosystems. The Galloway Fisheries Trust, for instance, believes Critical Load assessment is not sensitive enough as it only applies above 300 m (Galloway Fisheries Trust 2006).

In Dumfries and Galloway, for instance, exceedance in some granitic areas is over 1 kg acid equiv hectare^{-1} y^{-1}. (SNH 2002). Critical Load calculations have been used in Forestry Commission planning to avoid new planting in areas with high exceedance. This approach implicitly recognises the strong link between forestation and ecosystem degradation under acidification (discussed in the next section).

The importance of solid Geology on the impact of acidification on ecosystems is thus widely recognised, but it remains unclear as to how its effects interact with other variables, such as land-use.

4.6.2 Effects of land use

Effects on water chemistry: forestation[78]

Considerable research has addressed the extent to which forestation affects acidification. Indeed, some early work suggested that forestation alone, even in the absence of acidic emissions, was responsible for significant water acidification (for instance Johnson et al 1991). On the other hand, it was claimed by some writers that there was no proven relationship between forestation and acidification. As this issue - that is, the degree of impact that forestry has on acidification and its recovery - is central to the present study, this section will consider the research evidence in some detail.

A frequently cited early study by Harriman and Morrison (1982) examined 12 streams in forested (mainly Sitka spruce) and non-forested areas where slow-weathering bedrock was mainly quartzite, schists and slates. Precipitation had a mean pH of 4.3-4.5. Streams in forested areas were always more acidic and had higher Al^{3+} levels. Generally forest age was associated with lower pH (that is, older forests had more acidic streams). They concluded that forests increased cation leaching and uptake by trees, so reducing base-cation levels in soils. They also suggested that ploughing methods before planting might reduce drainage time, therefore increasing acidification, as there was less opportunity for buffering.

Harriman et al (1987) provided further evidence that forested catchments have lower pH and higher Al^{3+} levels. They found that semi-mature forested catchments had lower pH and higher levels of sulphate than moorland. They concluded that the evidence suggested that forestation (particularly coniferous) enhanced acidification by increased filtering of pollutants from the atmosphere, but there was no direct evidence that forestation without atmospheric pollution caused acidification.

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[78] A distinction should be made between the terms 'forestation' – the extent of forest cover – and 'afforestation', which is the establishment of new forest from seeding and/ or from deliberate planting of areas that not previously been forested . A 'forest' is here defined as canopy cover of at least 20% over a minimum area of 0.1 ha. (Forestry Department FAO 2010**).**

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Two further well reported studies are those of Doughty (1990) and Ormerod et al (1989). The latter collected data on Al^{3+} levels and pH from 113 Welsh catchments of contrasting land use, with three ranges of acid sensitivity (in terms of water hardness, that is concentration of $CaCO_3$). In each range, pH decreased and Aluminium increased significantly with increasing forest cover. Doughty (1990) reported on sulphate levels and acidity in three categories of site forestation (<20%, 20-40% and > 40%). He found that sulphate and acidity were both correlated positively with forestation level.

Although these and other studies provided strong evidence for the role of forestation, other authors were more sceptical. For instance, Schindler (1988) argued that there was research contradicting this land-use hypothesis, including findings that in Norway acidification occurred in pristine areas as much as those subject to afforestation. He also cited the paleoecological studies of Bartarbee et al (1985) (see section 1.2.1 above), which showed that historical acidification events in Galloway occurred before afforestation of this area.

Similarly, Nisbet (1990:1) stated that the role of forestation as a direct cause of surface water acidification was "by no means as clear and conclusive" as some had suggested. He argued that susceptibility to acidification was mainly governed by underlying rocks and soil. He suggested that the evidence was mixed: some studies showed streams with older forested catchments (more than fifteen years old) were more acidic, while others showed no such relationship. Nisbet also made a number of technical criticisms of the methodology employed by many of these studies. Paired comparison studies assume geology to be the same, although there might be important variability in soils, bedrock and topography. He further contended that the use of water hardness as a measure of geology was questionable. Nisbet did concede, however, that there were a number of plausible mechanisms for the postulated forestation effect:

1. Scavenging by tree crowns;
2. Increased solute concentration from tree evapotranspiration;
3. Trees uptake of base cations, making them unavailable for buffering;
4. Modified (increased) drainage, reducing the time for buffering;

5. Drying effects, increasing oxidation.

Nevertheless, Nisbet claimed that forests cannot be shown to be causative agents, and that long-term studies would be needed to establish this.

This view was partially supported by Cresser and Edwards (1987) who suggested that research evidence for the forestation effect was confined largely to Britain, where coniferous forests have been usually planted on marginal upland areas with steep slopes and thin, poor soils; these would naturally be prone to acidification, especially during storms.

Nevertheless, evidence continued to accumulate during the 1990's for a significant role for forestation in enhancing acidification. Mason (1991) concluded that research showed that vegetation scavenged dry and occult deposition, and that conifers appeared to be especially effective in doing so. He cited research, which showed that coniferous forest cover was correlated with lower pH levels and higher sulphate and aluminium levels.

Moreover, further evidence emerged that the age of the coniferous forest was the most critical factor. Reynolds et al (1994) collected data on nitrate levels from 136 streams in upland Wales. Mean nitrate concentrations increased significantly with average age of conifers and with increased areal cover. Malik (2009) found evidence that N and S deposition levels were both associated with tree age for Norway spruce in Silesia

Research methodology has also became more sophisticated, and served to answer some of Nisbet's earlier criticisms. Jenkins et al (1998) used the MAGIC model (Model of Acidification of Groundwater in Catchments), applied to 21 upland sites in UK. There was evidence that land use scenarios indicated that replanting felled forests would lead to further increase in acidification. Puhr et al (2000) carried out a survey of water chemistry in 95 streams in Galloway, using much more detailed data on land use, geology and topography than hitherto. Results showed that pH levels were lower and aluminium levels were higher with increasing coniferous forestation. SEPA (1996) suggested that in coniferous forests over twenty-five years old branches intermingle, forming a closed canopy which renders the needles as particularly effective filters of air borne pollutants; closed canopies not only have higher surface areas but also greater "aerodynamic roughness" (SEPA 2006: 110). Gagkas et al (2008), however, found evidence that broadleaf (deciduous) woodland cover was also correlated with higher nitrate and aluminium levels in 14 catchments in acid sensitive areas. They concluded that the forestation effect was not restricted to conifers.

Overall the evidence points towards forestation being neither a necessary nor sufficient condition for acidification on its own, but that it can significantly enhance the acidification process in certain circumstances (such as in the presence of base poor geology). Although the exact nature of the process is far from understood, forest age (and thus degree of canopy cover) is possibly an important factor. Whether the same processes are equally applicable in recovery from acidification is far from clear, but the evidence is reviewed in section 2.5 below.

Effects of land use: felling / harvesting

If the effects of forestation were primarily due to increased scavenging of pollutants together with increased take up of cations, then one might predict that forest harvesting (that is, felling) would reverse these effects and that acidification would decrease. The evidence for this is, however, ambiguous. Cresser and Edwards (1987) discussed how those tree-felling effects that increased acidification (by increased water flow, mineralisation of degradable material) might outweigh those factors decreasing acidification (such as reduced cation uptake). They concluded that harvesting would (overall) be likely to result in increased acidification, especially during high water flow. Nisbet (1990), however, argued that studies of the effect of clear felling failed to show these reversal effects. Nevertheless, the Forestry Commission (FC) 'Forests and Water Guidelines' (Forestry Commission 2003) state that harvesting operations may also result in nitrate leakage, from increased mineralization and nitrification, and that this may last 2 to 5 years. Because of this, the FC recommended avoidance of large scale clear felling. They also advise forest restructuring to promote biological recovery such as opening up stream sides to sunlight. Research by Gagkas et al (2008) provides some evidence that base cations that are accumulated in trees are removed from availability on harvesting, thus increasing acidification. Clearly, the effects of felling are complex and not well understood.

Effects on ecosystems

If forested areas were more prone to acidification than non-forested, one would expect that tree planting would be associated with ecosystem degradation. Some evidence to support this view is provided by Harriman and Morrison (1982 who found that that planted zones were virtually fishless with high fish egg mortality rates, whereas in non-forested areas mortality was low. Ephemeroptera were noticeably species poor in forested areas. Clenaghan et al (1998), however, found that in a conifer forested area of Ireland, which was subject to very low levels of acid deposition, invertebrate taxon richness was not impoverished although assemblages differed above and below planting. They suggested that these results show that local ecological factors and distance from stream origin may explain the variation in community composition, rather than planting itself. This interpretation would agree with the idea that forests only exacerbate acidification in areas with high acid deposition.

In fact, few studies directly compare the biological impact of forested and non-forested areas. Among the most relevant are the egg-box experiments of the Galloway Fisheries Trust (2007). Salmon eggs were placed in containers and sited within streams of the River Bladnoch catchment in Galloway. Survival rates varied from 96.3% to 0%. On one stream, the Polbae Burn, the survival rate was 86% for the Upper Burn, above coniferous plantation, and 0% in the lower Burn, which was forested. These results were recorded in three consecutive years, and the GFT suggest that these results are "fairly conclusive" (Galloway Fisheries Trust 2007: 5) in showing the impact of coniferous plantation on water quality, in that it exacerbates scavenging. However, although these results do lend powerful argument for the role of coniferous forest, there was no replication of this result in other sites. Moreover, it is unclear whether harvesting itself may contribute to the problem.

This section has discussed some of the complexities surrounding this issue, and suggested that there are a number of processes involved in felling which may exacerbate acidification, while others may mitigate it (Cresser and Edwards 1987). Furthermore, Johnsson et al (1991) argued that harvesting might deplete the pool of "potentially limiting cations" more than leaching, thus increasing acidification. Because of these factors, the Forestry Commission 'Forests and Water Guidelines' (FWG) document (2003) recommended the avoidance of large-scale clear felling. It seems, therefore, that there is still considerable uncertainty about the role played by forests in aquatic acidification. Furthermore, much of the research work that was carried out when acid deposition was increasing; it is uncertain whether the same processes will operate in reverse when emissions are falling. The next section will consider this issue of recovery from acidification.

Summary of effects of moderating variables on process

The processes by which acid deposition induces chemical changes in soil and water is influenced by other factors, such as seasonality (Helliwell et al 2007), animal grazing, ploughing and drainage (Cresser and Edwards 1987) and topography (Doughty 1990; Puhr et al 2000). However, forestation and geology appear to be the most significant factors. Specifically, areas with mature coniferous forests planted on thin soils in granitic regions appear most susceptible. However, the relative contributions of these two factors to the acidification – and more importantly in this context, the role they play in hindering recovery – have not been fully delineated. Clearly, this means that decisions that are made concerning rehabilitation methods lack the full range of evidence. However, such decisions can also be informed by explanatory frameworks that have been put forward to explain differential recovery; these are discussed in the following section.

4.7 Approaches to the rehabilitation of acidified freshwater

While international treaties to limit acidifying emissions were agreed from 1979, there were also, from the middle of the 1970s, attempts made to facilitate or accelerate recovery (Gunn and Mills 1998). These can be broadly classified into three different types of intervention:

1. Liming
2. Measures to facilitate the recovery of specific species
3. Changes in land-use.

4.7.1 Liming

Liming, which is a broad term used to refer to the application of lime (calcium carbonate $CaCO_3$) and other base neutralizing substances to acidic soils and surface waters (Gunn and Keller 1998; Clair and Hindley 2005) , has been the most widely used method in many areas. Large scale studies of liming have been carried out in Canada (particularly in Sudbury, Ontario (Gunn and Miller 1998) and in Sweden (Appleberg 1998) , in 1998 7500, lakes and 110000 km water courses were regularly limed. Smaller scale liming has been carried out in Wales (Ormerod and Durance 2009), but no significant use of liming for recovery from acidification has been reported in Scotland.

Evidence of the long-term effects on biological recovery has been inconclusive, as outlined in section 4.5.2 above. Appleberg (1998) showed that fish species richness increased after liming in Swedish lakes and that after 10-20 years was comparable to that in circumneutral lakes (which were never acidified). However the differences between limed and unlimed acidified lakes in term of species richness for some pelagic fish and for cyprinids were less marked. Appleberg concluded that colonisation was a crucial factor: in some lakes reintroduction had been carried out alongside liming and biological recovery was enhanced. McKie et al (2006), however, examined invertebrate assemblages after liming in Swedish streams and concluded that acidification results in considerable ecosystem perturbation, with species richness and abundance in some groups of invertebrate declining. Similarly, Keene and Sharpe (2005) found in in streams applied with limestone sand in Pennsylvania, a negative relationship between the amount of sand deposited and the abundance of macroinvertabrates. They concluded that such results call into question the use of limestone sand in such chronically acidified waters Furthermore Bishop et al (2001) argue that much liming policy has not been research led. They cite the example of many streams in Northern Sweden, where deposition has been low, but periods of flooding led to sharp reductions in pH, resulting in liming being carried out as mitigation. They contest that recent research has indicated that much of the episodic decrease in pH was due to natural acidity and conclude that liming policy now needs to be reviewed in the light of such research advances.

Ormerod and Durance (2009) report long term data (over 25 years) on the Llyn Brianne experimental catchment in Wales. During the early part of the period limed streams had higher pH than unlimed, but this difference diminished over time. In both limed and unlimed streams some recovery in invertebrate assemblages were seen in terms of the return of some acid sensitive (AS) species, but there were still far fewer AS species than in reference streams that had never been acidified. There was no significant difference between limed and unlimed streams in terms of biological recovery.

Clair and Hindar (2005) carried out a comprehensive review of the literature on liming and concluded that although water chemistry may be restored by liming to pre-acidified levels, aquatic ecosystems will probably not be restored. However, some targeted fish species may recover through a combination of liming and other active management techniques, although the subsequent assemblages will not be as stable as those in non-acidified ecosystems. They also suggest that in some locations liming, if it is to be effective, may be required for more than 50 years.

4.7.2 Measures to facilitate the recovery of specific species

Although acidification affects entire ecosystems, it is the impact of sport fishing that has often attracted the greatest attention (Gunn and Mills 1998). Accordingly, there have been a number of measures to enhance the recovery of salmonids (such as trout and salmon). In some cases this has been carried out in conjunction with liming (as in Appleberg (1998), while in others it has been a stand-alone policy. Gunn and Mills (1998) review management options for this form of recovery, including hatchery stocking and harvesting controls.

4.7.3 Changes in land-use

With some evidence that levels of coniferous forestation were the critical determining factor in delayed biological factors, some proposals for enhanced recovery have focused on reducing forest cover through clearance and restricted replanting. For instance, Galloway Fisheries Trust reports (GFT2006, 2007) support the view that forestation was more significant than geology in exacerbating the effects of Acidification. Accordingly, the GFT has become strong advocates of changes in forestry management. Such lobbying has met with some success, as the fourth edition of the Forestry Commission's *'Forests and Water Guidelines'* (Forestry Commission 2003) recommends forest restructuring to promote biological recovery . There are, however, little evidence of how effective such changes would be, although Zirlewagen and von Wilpert (2004) provide some modelling for the effects of forest restructuring (such as the replacement of coniferous forests with mixed broad-leaved strands.

4.8Acidification: Summary

This chapter has outlined the main features of aquatic acidification arising from transboundary pollution. The scientific understanding of how these emissions can result in acidification of freshwater bodies, and how such acidification impacts on ecosystems, became well developed in the 1970's and was instrumental in securing a number of effective international treaties which reduced emissions significantly in much of the developed world. However, global emissions are again increasing and many soils are prone to Nitrogen saturation. In addition, biological recovery has, in some instances, lagged far behind chemical recovery. Aquatic acidification is, therefore, a continuing and significant environmental problem that requires serious attention. This is particularly the case where catchment soils are base poor and where there is significant coniferous forestation. Both of these conditions occur in the Galloway Forest Park in South West Scotland. This area was, therefore, selected as the location for this research.

Chapter 5.

Development of the SMARTEST method

5.1 Introduction

This chapter reports the methods used in the main study. It aims to explain what was done in sufficient detail to allow for replication of the method in other settings , bearing in mind the context-specific nature of the case study. It also outlines the rational for the selection of methods, their assumptions and drawbacks.

This chapter is organised as follows. Section 5.1.1 introduces the methodological approach taken, while section 5.1.2 explains the design of SMARTEST, the MCA process that was developed for this study. Section 5.2 describes the study area used in the case study: the River Cree. The rest of the chapter is devoted to a systematic and sequential explanation of the procedures used in the study. Section 5.3 gives further details of Problem Identification stage and is followed by section 5.4 on Problem Structuring (identification of stakeholders, criteria and options) and 5.5 on Model Building (identifying attributes, establishing criteria weights and the development of the Impact Matrix, followed by aggregation and sensitivity analysis). Section 5.6 reports on the results of the PMCA process itself (development of action plans) and how the results were presented to stakeholders (note that the results of the use of the method are discussed in chapter 6).

5.1.1 Methodological approach

Much of the standard approach to research methodology postulates a straightforward dichotomy between positivist and subjectivist/ interpretivist approaches to research, with science adopting the former and most (not all) of the social sciences the latter. The polarised nature of this oppositional, illustrated by table 5.1 which contrasts the two positions, and is typical of those found in many texts (for instance Yates 2004, Palmer 2006).

Table 5.1 Comparison of the positivist and subjectivist approaches to research

Overall perspective	Modernist	Post-modernist / phenomenological
Ontology	Realism: A real world exists irrespective of human perception of it	Idealism Anti-realism
Epistemology	Objectivism Positivism	Constructivism Subjectivism
Methodological approach	Scientific method	Interpretivist
Typical data	Quantitative	Qualitative
Typical research techniques	Observation Measurement Experimentation	Ethnography Grounded theory Participant observation Discourse analysis

It has been argued in earlier chapters that such polarisation is unhelpful and that integrative approaches, which attempt a synthesis, may have greater ultimate utility. This study, therefore, adopts a mixed methods approach, within what Guba and Lincoln (2005) term the participative / cooperative paradigm, using an integrative approach derived from co-constructionism[79] and critical realism. Such an integrative strategy acknowledges that a realist ontology may be an appropriate view with which to explore the nature of environmental problems, but that research concerning human activities in response to such environmental problems may require the use of interpretivist, constructionist explanations and methods. That is, environmental problems have an objective reality but our (human) understanding – or construction - of that reality is moulded by the particular societal context in which it is encountered. Moreover, that construction is often contested and there are, therefore, multiple constructions[80]. However, not all those constructions are equally valid or useful. Furthermore, these constructions are dynamic: some may become closer (or further) from the underlying reality. This position rejects the extreme post-modern, subjectivist view

[79] Co-constructionism is especially relevant to this study in that it is concerned with the relationship between expert and lay knowledge (Cudworth 2003).

[80] Whatever construction is dominant at any one time may have less to do with the nature of the reality it seeks to explain and more to do with the social power wielded by the groups that promote it.

that all viewpoints – or constructions – are equally valid and instead promotes the position that the purpose of research is to close the gap between the underlying reality and our collective understanding of it. As such, research methods should be chosen for fitness-for-purpose: that is, for their appropriateness to the specific problem. Furthermore, environmental problems, which so often have both scientific and social elements, may require interdisciplinary approaches which in turn may call for a multi-method – or Mixed Method - approach.

Mixed Methods research is an eclectic strategy towards methodology that takes a pragmatic 'whatever works' approach and is, moreover, comfortable with the use of both positivist and interpretivist methods within the same study (Howe 1988). Burke Johnson et al (2007) regard Mixed Methods as the third major research paradigm (following the qualitative and quantitative) and define it as

"… the class of research where the researcher mixes or combines quantitative and qualitative research techniques, methods, approaches, concepts or language into a single study or set of related studies" (p120).[81]

In relation specifically to the present study, chapter 4 outlines the scientific basis of acidification and the evidence concerning recovery. The study reported in this chapter, however, which was concerned with the decision making process of how to manage recovery from this acidification, necessitated more interpretivist methods. Moreover, this is in itself Mixed Method research, in that it employs a variety of methods for data gathering and analysis, including both qualitative and quantitative approaches.

For this study, Participative Action Research (PAR) was selected as the main research framework, given that one of the key research aims was to evaluate the use of participative decision making. PAR attempts to carry out research at the same time as influencing some

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[81] Mixed methods research has been criticised, mainly from the post-modern perspective by advocates of the 'incompatibility thesis' who argue that it fails to address the conceptual background underpinning the research (for instance Yanchar and Williams 2006)

form of outcome (Learning for Sustainability 2011). It therefore differs from pure research which, ideally, is completely removed from the object of study. In PAR the researcher is also a practitioner, attempting to intervene in a problem situation in order to facilitate improvement. However, PAR can also aim to change the nature of the problem context itself by "helping clients change themselves" (Learning for Sustainability 2011). PAR also embraces the idea of experiential learning (that is, learning by doing), driven by the idea attributed to Kurt Lewin that "you cannot understand a system until you try to change it" (Schein 1996). PAR also has roots in the critical pedagogy of Paulo Freire and has frequently been used to enhance social learning or otherwise support disadvantaged groups faced with 'wicked' environmental problems (Ballard and Belsky 2010; Blythe et al 2008). PAR is, therefore, closed aligned with the ideas of co-constructionism and Post-Normal Science.

PAR is itself derived from the broader category of Action Research, which is an inherently cyclic process of planning, action, observation, evaluation and reflection (Learning for Sustainability 2011). In PAR, stakeholders work with the Action Researcher to examine current activities and seek ways for improvement. PAR can thus be contrasted with traditional 'extractive' research where the results of research are usually unavailable to stakeholders. As Helmfrid et al (2008) point out:

"in practice, much of the new knowledge generated by scientific inquiry ends up adding to the collective databank of facts that point out what is going wrong. It often takes many decades for the results of science to lead to action in the area of concern" (p106).

With PAR, in contrast to such traditional extractive processes, there are several simultaneous goals: to generate scientific knowledge, to enable participants to internalise such knowledge and to implement change in the system being researched. PAR was selected for this study, therefore, as being particularly appropriate for the evaluation of new participative MCA technique within an environmental problem that had contested views.

5.1.2 The structure of the Multi Criteria Analysis: SMARTEST

The use of MCA to facilitate decision making in this case study used a new technique: SMARTEST (SMART for Enhanced Stakeholder Take-up). This was derived from earlier versions of the SMART method (Simple Multi Attribute Rating Technique) (Edwards and Barron 1994), which were described in section 3.4, and in particular from SMARTER (SMART exploiting ranks).

SMARTER is an intuitively attractive but little used method. A persuasive argument can be made for the establishment of a standard PMCA method, which can be widely used with straightforward training. At present, it appears that those wishing to use MCA methods for environmental decision making often 'reinvent the wheel' or else select an existing method with considerable disadvantages (methods involving pairwise comparisons, for instance, can be time consuming and tedious). The finding, reported in section 4.5, that over half the research papers using MCA employed an inappropriate number of criteria, also suggests that many users fail to understand the technical requirements of the method.

The development of SMARTEST also drew on a number of more recent studies, which have described the use of MCA with particular reference to environmental problems, such as Munda and Russi (2008), Mustajoki et al (2004), Omann (2000, 2004). In her Ph.D. thesis Omann (2004), for instance, evaluated the use of MCA in decision processes promoting sustainability, using two case studies (one at the company level while the other involved public policy development. One of her four main recommendations was that "both the persons affected and the decision makers are involved in the process" (Omann 2004 page xiv).

However, in common with the other studies – and with most of those reviewed in chapter 3 (section 3.5) – facilitating participation was not an explicit objective of her study, not was the MCA method designed with it in mind.

The development of SMARTEST as a more participative form of MCA followed the consideration of those studies analysed in chapter 3 that had, according to the BID model, the highest levels of *Breadth*, *Depth* and *Impact*: Stirling and Mayer (2001), Proctor and Dreschler (2006) and Mander (2008). SMARTEST aspired to surpass these studies in the extent to which it enabled participation in that it was designed to have the maximum level of Impact. Necessarily in this case study, resource limitations necessitated that both Breadth and Depth were not as great as would be desired, however. The intention was to test the new technique in the case study before making it more widely available for use in high Breadth, high Depth contexts.

The general methodology follows, therefore, well established procedures, together with new developments which have evolved in the early 21st century, to use MCA in an essentially participatory fashion. The design principles for SMARTEST were, therefore, that the method should meet the following criteria:

1. Maximise ease-of-use (provided that the overall technical robustness was retained), that is, to eliminate factors leading to elicitation-error (Edwards and Barron (1994) while keeping modelling-error acceptably low. In this context, ease-of-use refers not only to the ease with which stakeholder participants can engage with the process (that is, that the method is clear, transparent and comprehensible) but also the extent to which it can be replicated by other users without substantial training.
2. That participants should have as much say as possible over the process in as many stages as possible. Stirling and Mayer (2001) and Mander (2008) had significant stakeholder engagement in five stages (identifying alternatives and criteria, criteria weighting, Impact Matrix and sensitivity analysis) and Proctor and Drechsler (2006) in four. SMARTEST was designed to equal and surpass this level of engagement.
3. To be iterative and stepwise throughout. The term 'iterative' is used here to denote a process in which the researchers return to stakeholders for review or clarification of earlier input. In a typically non-iterative process the information flow is purely one-way: from the stakeholders to the researchers, with the overall control on how the information is used remaining firmly with the latter. In SMARTEST, each step required discussion with stakeholders, the outcomes of which would influence the precise nature of the next step. It was made a condition of the process that all stakeholders would agree that they were content with the author's interpretation of their input before proceeding to the next step. In

steps 1-5 of the process (see table 5.2) this involved agreement from all stakeholders collectively. That is, all stakeholders were asked to agree with the author's summary of their aggregated inputs. In steps 6-10 iteration involved each stakeholder agreeing that the author's interpretation of their own inputs, and the implications for the model, were a true reflection of their opinions[82]. Such iteration will not only increase participants' sense of ownership of the process (and thus increase their input into the process n (point 2 above) but will also contribute to the social learning process (for both participants and facilitator).

4. That the outcomes of each participants input should, with their agreement, be available to other participants. Unlike Stirling and Mayers' (2001) Multi Criteria Mapping, comparability between stakeholders is available and was, indeed, regarded as an essential part of the process.

5. That the process should not be excessively onerous on participants in terms of the time required. (The two full days group work required by Proctor and Drechslers' (2006) deliberative multicriteria evaluation could be regarded as excessive).

6. Rankings were converted into weightings using the Rank Sum method (explained in section 3.4.4) which is intended to be clearer and more intuitive to participants than the more complex Rank Order Centroid method used in SMARTER (see section 3.4.2).

It should be noted that the intention of this study was to trial the new SMARTEST method to ascertain if it would facilitate greater *Impact* of participation; the trial took place with low *Breadth* and *Depth* conditions. The extent to which findings can be extrapolated to greater *Breadth* and *Depth* conditions (that is, with more participants including those with less specialist knowledge) is discussed in chapter 7.

The use of SMARTEST involved, as is usual in MCA, three main stages (Belton and Stewart 2002: 14):

A. Problem identification and structuring;

B. Model Building and use;

[82] Because SMARTEST did not attempt to arrive at collective aggregate scores it was unnecessary for all stakeholders to collectively agree with stages 6-10.

C. Development of action plans[83].

These three stages can be further broken down into ten steps, as shown in table 5.2 and diagrammatically in figure 5.1.

Table 5.2 The ten steps of the full SMARTEST process (developed from Omann 2004 and Munda 1995)

Stage	**Step**
A. Problem identification and structuring	1 Problem identification (step 1)
	2 Problem structuring: 2.1 Identification of stakeholders (step 2)
	2.2 Identification of stakeholder values, objectives and hence criteria (step 3)
	2.3 identification of options (alternatives) (step 4)
B. Model Building and use	3 Model building: 3.1 Identifying attributes (i.e. variables associated with criteria according to which option performance is evaluated) (step 5)
	3.2 Establish weights for criteria (step 6)
	3.3 Developing impact matrix (step 7)
	4 Model use: 4.1 Aggregation. (step 8)
	4.2 Sensitivity analysis (step 9)
C. Development of Action Plans[84]	5. Feedback of results to stakeholders (step 10)

[83] Note that Omann (2004) terms the three stages as preparation, modelling and calculating, and dissemination.

[84] In participative MCA, Action Plans are not required, as the emphasis is on process not outcome. Nevertheless some form of final feedback is necessary.

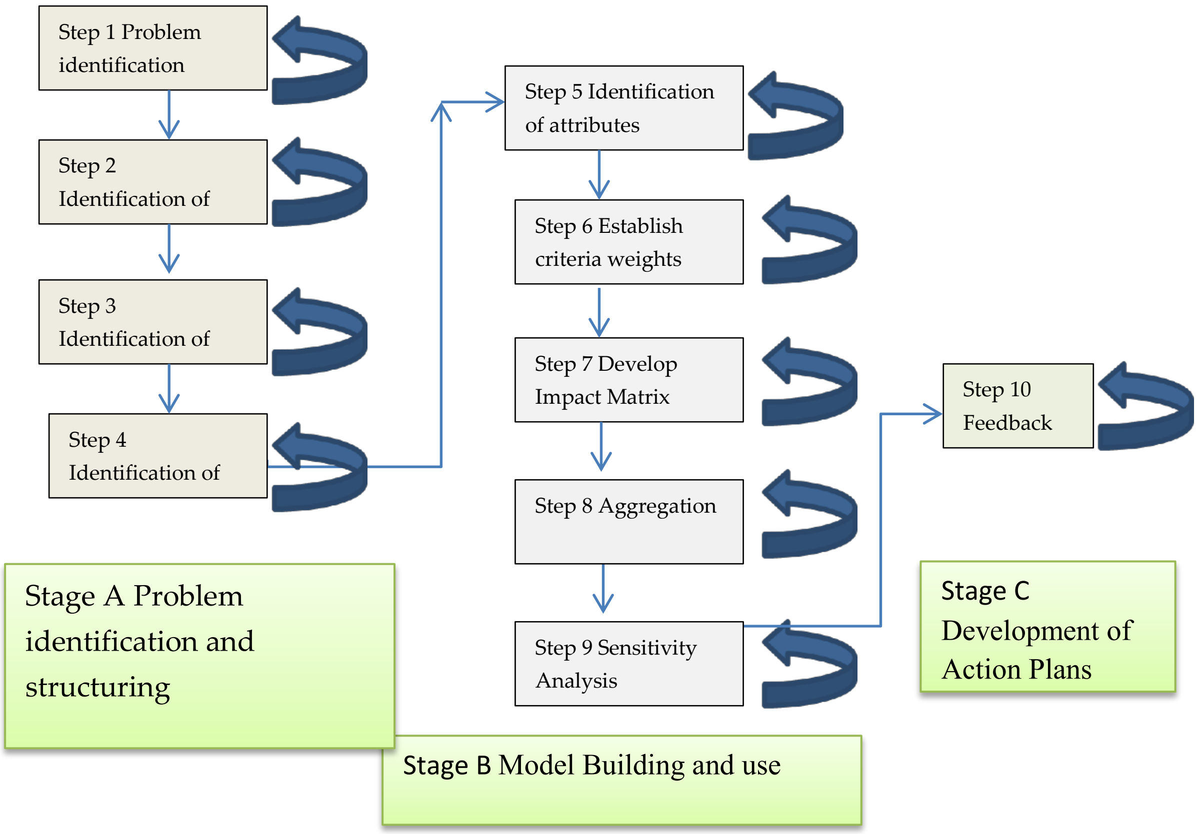


Figure 5.1. Flow diagram of SMARTEST stages and steps showing their iterative characteristics

Because the SMARTEST method is so iterative, some of the results of early elements of the procedure are included here within the methodology, in order to explain how that process developed. This chapter is therefore confined to a consideration of the main outcomes of the MCA process. However, the interim 'results' are also significant in their own right (and not merely as necessary parts of the process), and accordingly some are also considered within chapter 7.

5.2 Case study location

This study arose from an observation made in the SEPA annual report 'The State of Scotland's Environment' of 2006.[85] This noted that there may be significant variations in the extent of ecosystem recovery from acidification, and gave an illustrative example in South

West Scotland: Pulnagashel Burn, within the River Cree catchment area in the Galloway hills areas of South West Scotland, showed evidence of steady recovery, with the number of acid-sensitive species increasing significantly from 1996 to 2004. In contrast, Cairnfore Burn, a nearby and similar stream within the same river system, had shown no such recovery. The report commented that the reasons for such differences remained unclear, but SEPA suggested that interactions between the following three factors were most likely to be primarily responsible:

1. Differences in land use: particularly degree of forestation;
2. Underlying geology: proportion of catchments with underlying silica-rich and base-poor rocks;
3. Land Management, in particular the impact of clear-felling of forests and improved planting regimes (SEPA 2006: 108).

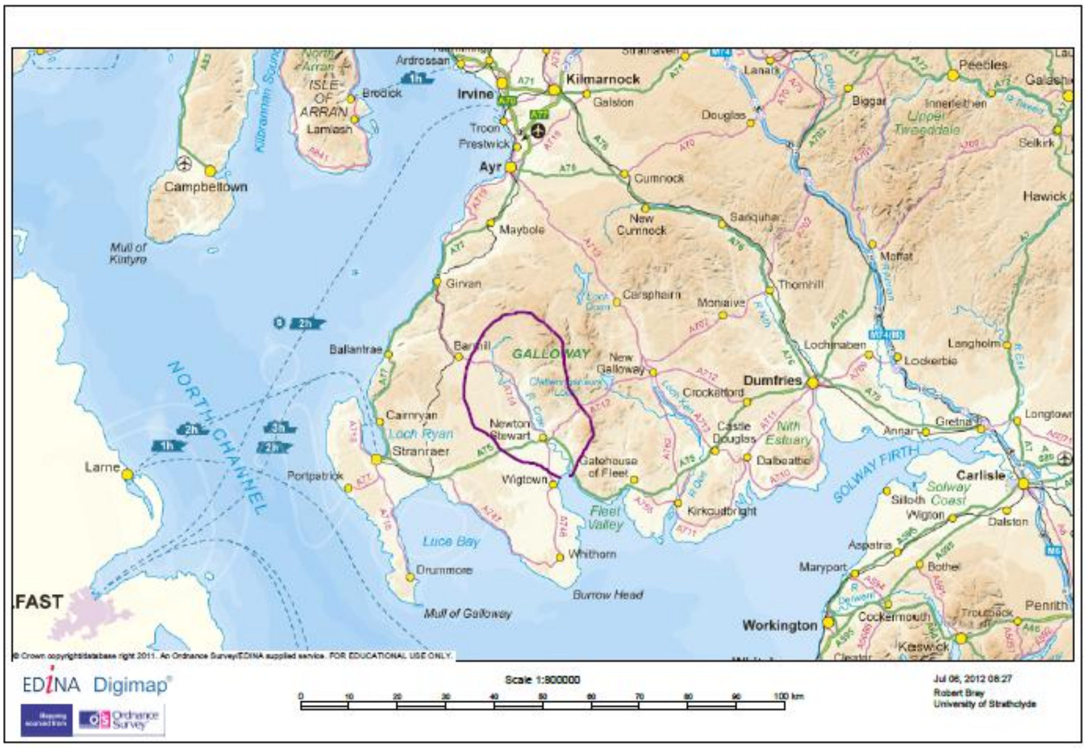
The River Cree

The River Cree flows into Solway Firth, one of five large Scottish estuaries, and has a catchment area of 368 km^2 (Lyle and Maitland 1997). It was selected for this study for the following reasons:

1. It lies within the area of the Galloway hills in South West Scotland identified as being particularly vulnerable to acidification, and which has therefore been the setting for many previous studies (Rendall and Bell 2008);
2. The SEPA 2006 report identified two of the Cree tributary waters (the Pulnagashel Burn and the Minnoch Tributary: see section 1.6 above) as being especially worthy of further attention because of differential biological recovery. Helliwell et al (2001) had previously identified the Cree catchment as not showing the expected level of chemical recovery, following emissions reductions;
3. There is significant variation in underlying geology and degree of forestation and shows an unusual combination of underlying highly siliceous igneous bedrock (covered with a thin, acidic soil) and coniferous forestation over much of the catchment (Helliwell et al 2001). (See figure 5.4). Geologically, the eastern part of the catchment is dominated by the igneous mass south of Loch Doon, featuring the Mullwachar (692 m) and Merrick (843 m)

tops (Greig 1971). With regard to land-use, Dumfries and Galloway is one of the most forested in the country, with approximately 25% tree covered, of which 93% is coniferous. Virtually all of this has been planted in the last century, with the peaks in the 1970s and 1980s; much of the coniferous forest is, therefore, now mature (thirty-five years or older). The dominant species is Sitka spruce (*Picea sitchensis*), with smaller amounts of Lodgepole pine (*Pinus contorta*), Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*) and European Larch (*Larix decidua*).The river Cree is a designated salmonid fishery under the EC Freshwater Fisheries Directive (Environment Resources Management 2000). Figure 5.3 is a map of the River Cree area, showing the location of the six study sites. The sites on sedimentary bedrock are in the North West part of the catchment, while the three streams rising on the flanks of the Merrick have granitic solid geology. The river catchment has no urban development north of Newton Stewart (at its mouth) and is regarded as a relatively unspoiled and pristine environment (see Figures 5.2 and 5.5).

Figure 5.2 Loch Moan feeds into the River Cree. The significant level of coniferous afforestation (mainly Sitka Spruce) is evident.



5.3

Map showing location of the River Cree catchment area in South West Scotland.

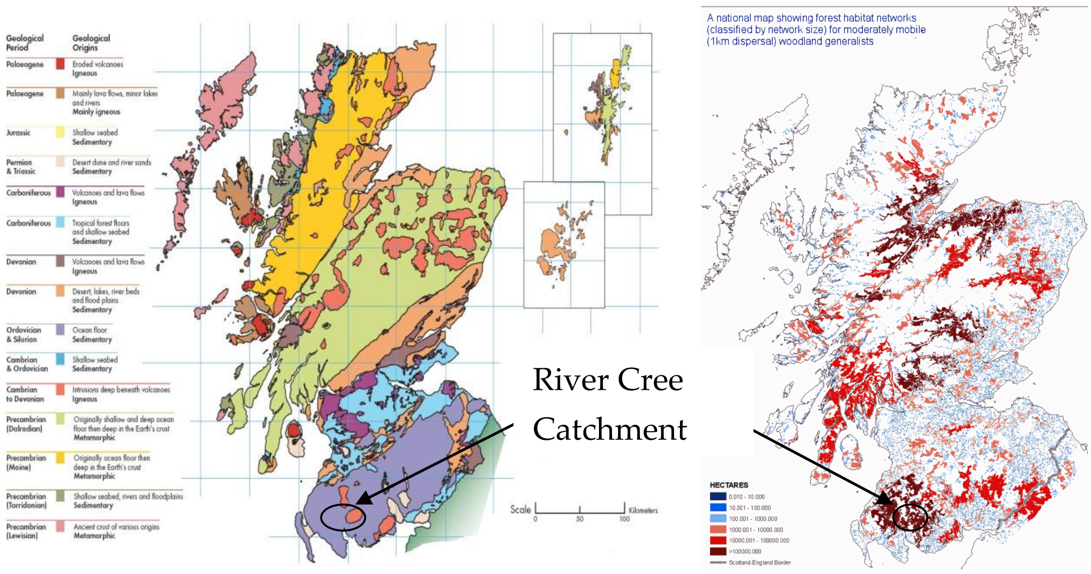


Figure **5.4 River Cree geology and forestation.** The map on the left shows the River Cree catchment lying partly (especially in the east) on igneous rock in an area dominated by Ordivician and Silurian sedimentary rocks (Scottish Geology (2011) while the map on the right shows that it lies in one of the largest areas of forest in Scotland (with over 10^6 ha of forest habitat as measured for moderately mobile woodland generalists) (Forest Research 2011).

Figure 5.5 The River Cree catchment with Merrick in the background, showing natural regeneration of Sitka Spruce after clear felling

Designated areas

There are several areas within the River Cree catchment that are designated as environmentally significant by National, European or International bodies. Much of the east of the Cree catchment lies within the 96,600 hectare Galloway Forest Park, established in 1947 and managed by the Forestry Commission Scotland. Forest parks are extensive areas of forest managed for multiple benefits with particular emphasis on recreation (Galloway Forest Park 2011). Three SSSIs and two Special Areas of Conservation lie wholly or partly within the catchment, as shown in table 5.3 (SNH 2011). A Special Area of Conservation (SAC) is a site designated under the Habitats Directive (European Union Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora). Together with Special Protection Areas (SPAs), SACs form the 'Natura' network of sites of international importance to threatened habitats and species. A Site of Special Scientific Interest (SSSI) is a protected area designated within the UK: in Scotland SSSIs are designated by the Nature Conservation (Scotland) Act 2004 (SNH 2011). Much of the eastern part of the catchment is also within the Merrick Kells and Silver Flowe Moss Biosphere Reserve, designated in 1976. Biosphere reserves are a non-statutory designation made by the United Nations Education, Science and Culture Organisation (UNESCO) within the 'Man and the Biosphere' ecological programme launched in 1970. Currently there are 531 Biospheres world-wide, spread across 105 countries, with eight in UK, of which four are in Scotland. In

2011 consultation began to develop an expanded 'new style' biosphere incorporating the existing biosphere within a much larger area (Proposed Galloway and Southern Ayrshire Biosphere 2011). These designations suggest that the River Cree is, in a number of respects, an ecologically significant site.

Table 5.3. Sites designated by the habitats directive lying wholly or partly within the River Cree catchment

Site	Type	Area ha	Notable characteristics
Glentrool	SSSI	71.2	Three relict sessile oak woods
Galloway	SAC	355.1	Western acidic oak woodland
Merrick Kells	SSSI	8767.6	An important system of patterned blanket bog.
Merrick Kells	SAC	8767.6	Blanket bog, dry heaths, acid peat-stained lakes and ponds, clear-water lakes or lochs with aquatic vegetation and poor to moderate nutrient levels, montane acid grasslands
Wood of Cree	SSSI	142.9	Ancient coppice woodland; oligotrophic pools

5.3 Using SMARTEST to facilitate recovery from acidification in the River Cree: Problem identification

The detailed structure of the study, using the format outlined in section 5.1.2 (table 5.2), is shown in table 5.4

Table 5.4 Stages and steps of the study as outlined in this chapter.

Stage	Step	See section(s)
A. Problem identification and structuring	1 Problem identification (step 1)	5.3
	2 Problem structuring: 2.1 Identification of stakeholders (step 2)	5.4.1
	2.2 Identification of stakeholder values, objectives and hence criteria (step 3)	5.4.2
	2.3 Identification of options (alternatives) (step 4)	5.4.3
B. Model Building	3 Model building:	5.5

and use	3.1 Identifying attributes (i.e. variables associated with criteria according to which option performance is evaluated) (step 5)	5.5.1
	3.2 Establishing weights for criteria (step 6)	5.5.2
	3.3 Developing impact matrix (step 7)	5.5.3
	4 Model use: 4.1 Aggregation. (step 8)	5.5.4
	4.2 Sensitivity analysis (step 9)	5.5.4
C. Development of Action Plans	5. Feedback of results to stakeholders (step 10)	5.6.1

The initial task was that of *problem identification and structuring*, that is of establishing the nature of the problem (Belton and Stewart 2002:14). *Problem identification – step 1* - involved defining, as closely as possible, the nature of the problem, its parameters and limits. This is especially important in environmental problems of this nature where there is substantial interconnectedness (ecological, political, and geographical) and thus a danger that a research plan expands beyond its original objectives into a much larger, unmanageable project.

As described above at the start of this chapter, the *problem identification* stage arose in the study conducted by the author of the chemical and biological recovery from acidification of the River Cree (see chapter 1). That research, conducted as part of the M.Res. in Integrated Pollution Prevention and Control qualification at the University of Strathclyde, aimed to investigate the reasons underlying differential chemical and biological recovery from acidification in upland waters of the River Cree catchment area. As such, it limited its field of reference in the following respects:

1. Focus of study: aquatic acidification. Although this is clearly linked in complex and sometimes important aspects to acidification in soils, only acidification in water bodies was considered. Moreover, in order to design a manageable project, lentic ecosystems were also excluded, so that only flowing water bodies were considered. Furthermore, although the observed chemical and biological variables were influenced by many factors (including environmental factors such as climate change), the focus was on changes brought about by acidification.
2. Location: The Cree Valley was selected as the locus for this study for reasons outlined above. In brief, the Cree catchment has had historically very high levels of acidification

which have probably been brought about by a unique (in the UK) combination of high levels of coniferous forestation and particular geological features. Moreover, the Cree has been subject to much study in relation to the effects of acidification, particularly on fish. Nevertheless, the underlying processes in the Cree remain little understood and anomalous results concerning recovery from acidification have been a continuing cause of concern (SEPA 2006).

In this earlier M.Res study, water samples were collected from six streams within the Cree catchment area (see figure 5.3) for chemical and biological testing. The results suggested that while there was substantial chemical recovery in all six streams, there was much more limited and uneven biological recovery. Some streams remained devoid of acid sensitive macroinvertebrates, as well as having overall low invertebrate abundance. Statistical analysis suggested that both forestation and geology were implicated in this retarded recovery. This study confirmed uneven, and in some instances very slow, biological recovery in the Cree. It also established that there were a number of alternative courses of action that had been proposed by various stakeholders to tackle the problem, but that there was a lack of agreement as to the best option. This led to the primary problem focus for the present study: "what courses of action should be undertaken to improve recovery from aquatic acidification in the Cree catchment". This became the ***problem definition*** for consideration within the MCA framework.

The choice of this problem definition specified that it was a *choice problematique* (Shmelev and Rodríguez-Labajos 2009), that is one aimed to select a small number of desirable outcomes so that a single option may then be chosen. This can be contrasted to other types, such as sorting, ranking and description problematiques. It furthermore suggested that this was a *discrete choice problem* as opposed to a *multiobjective design problem*. This analysis suggests that the use of a linear MAVT type of MCA, such as SMARTEST, would be appropriate.

5.4 Problem Structuring

Once p*roblem identification* (step 1) was complete, problem *structuring* was undertaken. This is the delineation of the parameters for consideration, or as Belton and Stewart (2002; 35-36) characterise it:

"making sense of an issue; identifying key concerns, goals, stakeholders, actions, uncertainties, and so on".

This involves steps 2-4 of the MCA process:

Step 2: The identification of relevant stakeholders (section 5.4.1);

Step 3: The identification of stakeholder values, objectives and hence criteria (section 5.4.2)

Step 4: The identification of possible courses of action ('options', 'alternatives' (section 5.4.3).

5.4.1 Stakeholder identification

The first stage in problem structuring was necessarily the identification of "relevant social actors" (Munda and Russi 2008: 713)[86]. It should be noted that the literature on MCA methods often uses the term stakeholder interchangeably with that of 'social actor'. While the former term came into use in relation to business modelling, it has now become more widely applied as referring to any individual or organisation concerned with a specified activity (Belton and Stewart 2002: 59). Although it continues to have some restrictive resonances, the term *stakeholder* will be used here in preference to the more technically precise term *social actors*. Some of the interrelated problems concerned with stakeholder identification are considered in the section on participation above. It should be noted here, however, that by using the term stakeholder in the inclusive sense suggested by its alternative of 'social actor', one is including all organisations and bodies that might be concerned with the issue, whether they are part of the formal decision making process or not. This conforms with Banville et al (1998) who used the term to include everyone with a vested interest in a common problem. This is an essential element of participative MCA

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[86] Omann (2004) notes that while stakeholder participation has long been recognised as essential, "it remains on a fairly theoretical level and hardly any experience with participation or advice on its accomplishment is given in the literature or included in the methods described" (p 123).

and can be starkly contrasted with those methods which restrict involvement to the actual Decision Makers only (see for instance Goodwin and Wright 2004).

Stakeholder identification was carried out here in two ways. Firstly, the study employed an institutional analysis. Secondly a co-nomination process was used (Loveridge 2002).

The first institutional analysis, conducted as part of the earlier M.Res. study, established the overall development of decision making with regard to acidification within the UK. Following methods outlined by Munda and Russi (2008) and Paneque et al (2009), further institutional analysis involved the analysis of relevant structures using publically available documents to study the economic and political processes. From this an analysis of the role of each of the main institutional stakeholders was developed: these were termed the ***Stakeholders A*** group. This is summarised in table 5.5. In each case, the organisation identified a named individual to represent it in this project. These six individuals therefore represented the stakeholder organisations throughout. Further details of these individuals are provided in Appendix 8.

Table 5.5. The main stakeholders (group A), identified from institutional analysis.

Organisation and abbreviation	Status	Statutory responsibilities / Objectives	Main contact
Dumfries and Galloway Council (D&G)	Local Government	Dumfries and Galloway Council is one of 32 council areas in Scotland. The River Cree catchment lies only within the county. The County Biodiversity Officer services the Dumfries and Galloway Biodiversity Partnership which produces the Local Biodiversity Action Plan[87] (Dumfries and Galloway Council 2009)	Council Biodiversity Officer
Forestry Commission Scotland, Galloway District (FCS)	Public body	FCS was set up in 2003 following devolution of the Forestry Commission. Its mission statement is "to protect and expand Scotland's forests and woodlands and increase their value to society and the environment" FCS serves as the forestry directorate of the Scottish Government	Forest District Manager, Galloway Forest District.
Galloway Fisheries Trust (GFT)	Voluntary organisation	The Galloway Fisheries Trust is an environmental charity which was set up in 1988 by four local District Salmon Fisheries Boards. The GFT carries out research, conservation work and lobbying.	Senior Biologist
Scottish Environment Protection Agency (SEPA)	Executive non-departmental public body of the Scottish Government	Scotland's environmental regulator Its main role is to protect Scotland's environment through implementing regulations and monitoring the quality of the environment.	Senior Environment Protection Officer, Newton Stewart
Scottish Natural Heritage (SNH)	Executive non-departmental public body of the Scottish Government	Responsible for promoting care and improvement of the natural heritage including its wildlife, habitats and landscapes. Also acts as the agent responsible for conservation designations	Area Officer, Newton Stewart
The Cree Valley Community Woodlands Trust (CVCWT)	Voluntary organization (charity)	"CVCWT enters into long term management agreements with landowners to enhance biodiversity and provide public access, especially in broadleaf woodlands habitats. " http://www.creevalley.com/who_are_we.htm	Ecologist

The present study commenced with a letter being sent to each of the six identified Stakeholder A organisations. Fortunately, one of these - The Cree Valley Community Woodlands Trust (CVCWT) – holds monthly meetings at which representatives of a number

[87] Local Biodiversity Action Plans form part the internationally recognised Biodiversity Action Plan programme of conservation.

of stakeholder groups (and others) attend. The author was invited to attend one of these meetings (in May 2009) where he outlined the proposed nature of this study. The other Stakeholder groups that were attending all expressed their willingness to be involved in the research and identified representatives to be contacted.

This meeting also identified other organisations – in a co-nomination process [88] – that had an interest in the environmental condition of the River Cree. However, these organisations were more peripherally involved in recovery from acidification and so were labeled the 'Stakeholders B' group. The distinction between the A and B groups was that:
Stakeholders A had as one of their central institutional objectives an activity that was affected by the acidification of the Cree and the responses to it. Each member of this group had been identified in the original institutional analysis;
Stakeholders B, in contrast, had no such central objectives, but were none the less influenced in more peripheral ways. The members of this group were identified by co-nomination. Information on the stakeholders B group is given in Appendix 6.

The distinction between the two stakeholder groups – and their differential roles – is an important feature of the method used here and reflects the aim to maximise participation in the most time -efficient process. Because all the Stakeholders A group were far more centrally involved in problem of acidification than those in Group B, the decision was made to use only the A group for the MCA analysis, and contact Group B members for consultation and background information only[89]. This meant that the number of participants in the MCA process was small – six organisations only – which was manageable given the resources available. (As mentioned, for the purpose of trialling the use of SMARTEST to evaluate its participative impact, a larger number of participants was unnecessary). Necessarily, this reduced the *Breadth* and *Depth* of this study in terms of the BIB model outlined in section 2.4.1.

[88] This sort of iterative process for the identification of potential participants is sometimes termed 'snowball' or 'referral' sampling (Ananda and Herath 2003).
[89] Originally it had been the intention to invite the Stakeholders B group to engage with some parts of the MCA process. However, it became clear during this stage in the research that this would create an unfortunate two-tier approach and also that, because many of the B group were voluntary organisations, securing participation would be especially difficult.

Following Belton and Stewart (2002) attention was paid to the need to identify the relationships between stakeholders, as summarized in table 5.6, by an institutional analysis that identifies:

1. The degree of formal power/ control they had over the decision;
2. Their interest in the issue (that is, the centrality of the issue to their core values and goals);
3. Their ability to influence other stakeholders.

Table 5.6 Institutional analysis of Stakeholder characteristics: power, interest and influence.

Organisation and abbreviation	Power / control	Centrality of interest	Influence
Dumfries and Galloway Council (D&G)	**Low** (issue does not impinge greatly on statutory responsibilities)	**Moderate** (as acidification effects biodiversity)	**Moderate** (Council covers a large area and there are many other biodiversity priorities)
Forestry Commission Scotland, Galloway District (FCS)	**High** (responsibility for activities within public forests, which dominate Cree catchment	**Moderately high (as part of the FCS overall biodiversity and conservation policy)**	**High (as owners of most of the Cree catchment FCS has ultimate control over the issue**
Galloway Fisheries Trust (GFT)	**Low** formal power	**Very high**: GFT have lobbied on this issue for many years	**High:** GFT have established a strong reputation among other stakeholders
Scottish Environment Protection Agency (SEPA)	**Moderately high** insofar as they are responsible for implementing regulations	**High (as indicated in their** 'State *of Scotland's Environment* 2006 (SEPA 2006).	**High (as Scotland's environmental regulator)**
Scottish Natural Heritage (SNH)	**Moderately high** insofar as they are responsible for implementing regulations concerning designated areas	**Moderately high (with regard to their responsibility for biodiversity)**	**High (particularly with regard to any action taken in designated protected areas, for which SNH has certain statutory responsibilities)**
The Cree Valley Community Woodlands Trust (CVCWT)	**Low** (as a voluntary organisation)	**Low** (concerned more with terrestrial ecosystems)	**Moderate** (provides forum for many local organisations)

The co-nomination process was also used to identify a number of experts who had acknowledged specialist knowledge pertinent to the problem:

- John Dougan, Conservator, South of Scotland FCS;
- Dr. Joan Mitchell, member of the board of SNH;
- Dr. Tom Nisbet; Programme Manager: Changing Physical Environment; Centre for Forestry and Climate Change; Forest Research;
- Professor Steve Ormerod, Professor of Ecology, Cardiff School of Biosciences, Cardiff University;
- Dr Chris Spray, Director of Environmental Science, Scottish Environment Protection Agency.

As can be seen, some of these experts were part of the organisations that were members of the Stakeholders A group. However, that group was essentially made up of nominated representatives of the local branches of those organisations, who had agreed to participate in the MCA study, while the experts were contacted only for background information, and took no part in the MCA.

At the end of this stage the six Stakeholder A organisations had been identified and had agreed to participate. It was then planned that their involvement would be as shown in table 5.7, which is organised by MCA step.

Table 5.7 Involvement of the stakeholders in MCA steps

Step	Involvement of Stakeholders A
Identification of stakeholders (step 2)	Co-nomination (from initial meeting at CVCWT May 2009)
Identification of stakeholder values, objectives and hence criteria (step 3)	from 1st round interviews
Identification of options (alternatives) (step 4)	from 1st round interviews
Identifying attributes (step 5)	from 1st round interviews
Establish weights for criteria (step 6)	Questionnaire 2nd round interviews
Developing impact matrix (step 7)	Questionnaire 2nd round interviews
Aggregation (step 8)	Carried out by author and discussed with stakeholders in final interviews
Sensitivity analysis (step 9)	Final (3rd) round of interviews
Feedback of results to stakeholders (step 10)	Final (3rd) round of interviews; plenary meeting of stakeholders

As can be seen, stakeholders were involved in 9 of the 10 steps. In six of these, the process was essentially dependent on the input of the stakeholders. That is, the author structured the task but otherwise only facilitated the process. Moreover, in these steps the process was highly iterative: the author would use the data supplied by each stakeholder (and, if necessary, convert it into the required MCA format) but then return it to that stakeholder for agreement. As mentioned above, it was a condition of the process that all stakeholders would agree that they were content with the author's interpretation of their input before proceeding to the next step. The process was, therefore, highly iterative and designed to maximize participation.

Table 5.8 shows the process chronologically in terms of the main research activities, with reference to the documents presented in the appendices.

Table 5.8 The MCA schedule of activities

Activity	Documents	Period	Notes	MCA step
Sending out initial letter to contacts from Phase I		April 2009	To prospective stakeholders	2
Meeting at CVCWT		19 May 2009	Initial dissemination of research project aims to prospective stakeholders	(1), 2
First round (preliminary) interviews		May-June 2009	Initial identification of criteria attributes and options	(2),3,4,5
Questionnaire A: sent for comments	Appendix 3	Aug 2009	Draft criteria and attributes	3,5
Questionnaire A returned		August – October 2009	Comments on draft criteria and attributes	3,5
Draft options sent out for comments		August 2009		4
Feedback received from options draft		Aug – Sept 2009	Options, Criteria and attributes amended	3,4,5
Options, Criteria and attributes amended and finalised	Tables 5.10,5.11,5.12, 5.13	September 2009		
Questionnaire B: sent out and returned	Appendix 4	Nov 2009	Weighting of criteria	6
2nd round interviews		Nov- Dec 2009	Weighting of criteria and Impact Matrix	6
Questionnaire C: Impact Matrix given out	Appendix 5	Nov- Dec 2009	Impact Matrix	7
Questionnaire C: Impact Matrix returned		Jan – Mar 2010	Impact Matrix	7
3rd round interviews		Feb- Mar 2010	Impact Matrix	7
Aggregation	See chapter 6	Feb- April 2010		8
Sensitivity analysis	See chapter 6	April- May 2010		9
Presentation of results		June 2010	Meeting of stakeholders June 21 2010	10
Follow up interviews		May- June 2011		

The stakeholders B group were also contacted during the first five months of the project. They were informed about this project and asked for their opinions. These were incorporated into the background information that informed the project activities but not used for the formal MCA process.

5.4.2 Identification of stakeholder values and objectives (criteria)

This was initiated during the first round of interviews; held in May-June 2009. Eight individuals from the six Stakeholder A groups were interviewed (the Forestry Commission requested that three of their staff were involved, representing different aspects of their work: two of these were identified as belonging to the 'Expert' group and did not take part in the remainder of the MCA process). Interviews were conducted face to face, with the exception of one carried out by telephone[90]. Each interview lasted between 1 and 2 hours. Interviews commenced with the author restating the aims and objectives of the project and the purpose of the interview. Given the emphasis on participation, it was seen as important that stakeholders gave informed consent: that is that there was an open relationship between the interviewer and the stakeholders as was feasible (see Yates 1998. p 162). The interview then proceeded in a semi-structured format. Pre-arranged questions were used as prompts to discussion, but the interviewee was given the opportunity to raise other issues as they felt appropriate. Initial interviews were not tape-recorded. It was seen as important to build relationships and establish trust between the researcher and the participants: recording might be seen as intrusive and endanger this process. Detailed notes were, however, taken during the interview, written up immediately afterwards and then sent to the interviewee, who were invited to comment on them and amend as they wished. The interview notes represent, therefore, an agreed record. Interviewees consented (by email) that they could be quoted from the agreed notes. [91]

From these interviews, criteria (initially termed 'objectives'), attributes and options were identified, using the standard MCA requirements (for instance see Belton and Stewart (2002) and Goodwin and Wright (2004)[92].

[90] It is generally accepted that face-to-face interviews are preferable to those carried out by telephone. For instance Sappsford (2007) states that face-to-face interviews establish greater rapport and encourage a more relaxed and cooperative attitude from interviewees, compared to more formal telephone interviews.

[91] The appropriate ethical procedures of the University were completed.

[92] For instance, criteria were defined so that they should demonstrate completeness, operationality, decomposability, absence of redundancy, and a minimum size.

For criteria and attributes, a questionnaire (See Appendix 3: Questionnaire A) was sent to all eight interviewees for their comments. From comments from five of the interviewees a revised set of criteria was established. However, not all comments could be incorporated: it was important to limit the overall number of secondary criteria and to resist the possibility of 'criteria inflation', which can lead to splitting bias (where one criterion is split into several and thus attracts a higher total weighting than it would otherwise: see Hämäläinen and Alaja 2008). The final list of criteria and attributes was therefore developed by the author, using his judgment in attempting to reflect the views of the stakeholders as accurately as possible. They were sent to each of the participants for their agreement before the next stage of the process was started. The process was, therefore, participative and iterative, but with some limitations that are discussed in chapter 7.

The criteria that resulted from this process were organised in a hierarchical fashion (a 'value tree') at three levels:

1. Overall objective: recovery from acidification of the River Cree;
2. Main Objectives: Improving Ecology; Supporting the Local Economy; Supporting Social, Recreational and Amenity uses; Meeting Environmental Objectives;
3. Secondary Objectives: 12 identified[93] (see table 5.9).

[93]Note that there is a consensus that there should be between 7 and 12 criteria (Proctor and Drescheler 2006).

Table 5.9 Final Objectives (Criteria) Note that Criteria are termed Objectives in subsequent documents used with stakeholders. See questionnaire in Appendix 3.

Main objectives	*Secondary Objectives*
Improving ecology	Improving **fish species richness and abundance**
	Improving **mammal species richness and abundance**
	Improving aquatic **bird species richness and abundance**
	Improving aquatic **invertebrate species richness and abundance**
	Improving **plant species richness** and abundance (in keeping with unmodified channel processes)
Supporting the local economy	Maintaining / increasing **private forest income**
	Maintaining/ increasing **Forestry Enterprise asset value**
Supporting social recreational and amenities uses	Development of **Community involvement**
	Maintaining / increasing Recreational **access** (walkers, cyclists, visitors, local people, birdwatchers, anglers etc.)
	Maintaining/ Enhancing **Landscape features**
Meeting environmental objectives	Contributing to **Carbon sequestration**
	Maintaining/ improving **water chemistry**

It should also be noted that the 'standard' MAVT procedure involves the identification of options (alternatives) before that of criteria. However, as discussed in the previous chapter, this study favours the Value-focused thinking approach, and thus criteria have been identified by stakeholders at the same time as they discuss possible options.

5.4.3 Identification of options (alternatives)

From the first round of interviews a number of possible options were identified, as shown in table 5.10. Note that these options are mutually exclusive as is required in additive MCA methods such as SMARTER.

Table 5.10 Initial options (alternatives) identified from first round of interviews.
✓ = proposed as a possibly desirable way * = has mentioned as possible development without suggesting that it is desirable

Options	SEPA	GFT	CVCWT
Status quo	Included as standard		
'Status Quo plus': minor adjustments to FWG, CL model (evolutionary)	*		
Change riparian management – extend streamside buffer zones	✓	✓	
Large scale clearance with no replanting		✓	
Reintroduction of species	✓		
Liming (shells)		✓	
Change CL to the tripartite 'traffic lights' model	✓	✓	
Privitisation	*		
Continuous Cover Forestry			✓

Each option was identified by at least one stakeholder. In some cases, the details of what an option entailed were clarified by further communication with the stakeholder. Two potential options which were identified at this initial stage were subsequently discarded by agreement with the stakeholder participants:

1. Reintroduction of species: this was raised as a possibility by one stakeholder, but subsequent discussion clarified that this was regarded as a possible pilot study and not as a fully-fledged alternative course of action;

2. Forestry privitisation: this was mentioned by two of the stakeholders as a possibility, given that it had recently been discussed in the Scottish Parliament by a government minister previously. However, it was judged by the stakeholders that it was not a likely development; furthermore it had no support among any of the stakeholders.

The final list of six options that emerged from this process is shown in table 5.11.

Table 5.11 Final list of options (alternatives) following iterations in MCA step 4 and agreed consensus

Option and abbreviation	Explanation
Status quo ('SQ')	The existing situation: this is used as a baseline measure
'Status Quo plus' ('SQ+')	The situation as it is likely to develop without any significant changes in environmental management strategy
Large scale clearance with no replanting ('Clearance')	An overall reduction of the coniferous forest cover of approximately 40% by 2015, by means of felling without coniferous replanting.
Liming (liming)	Introduction of lime (calcium carbonate) using targeted silos in particular critical watercourses
Change CL to the tripartite 'traffic lights' model ('Change CL')	Replacing current Critical Load method with one with two thresholds: the current CL level ('red') and another higher threshold ('amber') derived for instance from biological monitoring data, indicating potential concern, need to look at further data to see if there are signs of recovery before proceeding
Continuous cover forestry ('CCF')	Selective harvesting as opposed to clear felling, thinning trees but maintaining canopy cover; to replace clear felling.

5.5 Model Building:

5.5.1 Identifying attributes

The process by which criteria (objectives) were identified (interviews, Questionnaire A) was also used (at the same time) to derive the attributes associated with the secondary objectives. As discussed in chapter 3, attributes are quantifiable variables that can be used to measure performance of options. The agreed attributes, derived from this iterative process, are shown in table 5.12.

Table 5.12 Attributes associated with secondary objectives, as finally agreed following iterations in MCA step 5.

Secondary Objectives	***Attributes*: measures of the extent to which criteria can be achieved by 2015**
Improving **fish species richness and abundance**	Change in overall fish biodiversity index (incorporating richness and abundance)
Improving **mammal species richness and abundance**	Change in overall biodiversity index for mammals
Improving aquatic **bird species richness and abundance**	Change in overall biodiversity index for aquatic birds
Improving aquatic **invertebrate species richness and abundance**	Change in overall biodiversity index for aquatic invertebrates
Improving **plant species richness** and abundance (in keeping with unmodified channel processes)	Change in overall biodiversity index for plants (macrophytes and phytobenthos)
Maintaining / increasing **private forest income**	Change in overall private forest income from the Cree catchment
Maintaining/ increasing **Forestry Enterprise asset value**	Change in overall Forest Enterprise Income from the Cree catchment
Development of **Community involvement**	Overall development of community activities, events and projects in the Cree
Maintaining / increasing Recreational **access** (walkers, cyclists, visitors, local people, birdwatchers, anglers etc.)	Change in number of visitors using amenities on the Cree catchment
Maintaining/ Enhancing **Landscape features**	Valuation of the attractiveness of the overall landscape
Contributing to **Carbon sequestration**	Change in the estimated amount of Carbon stored in the Cree catchment
Maintaining/ improving **water chemistry**	Meeting Water Framework Directive (WFD) 'Good Surface Water Chemical Status' targets

5.5.2 Establishing weights for criteria

Questionnaire B, shown in Appendix 4 was developed from the agreed objectives and attributes shown in tables 5.10 and 5.13. It was sent to members of the Stakeholder A group in November 2009 and asked respondents to rank the four main criteria (termed objectives in the questionnaires) and then the twelve secondary criteria.

Finally it asked respondents to give a ratio value for the comparative importance of the most to the least important criteria (in order to ascertain whether the weights derived ranks using the Rank Sum method showed a good correspondence with the weights implicit in stakeholder's responses). The results for this were: 2,3,10,12, 20 (one participant did not respond) with a mean value of 9.4.

As explained above, it was decided that SMARTEST would use the rank sum (RS) method of converting ranks to weightings, as opposed to the ROC (Rank Order Centroid) method used in SMARTER. As discussed above, and shown in Appendix 1, the RS method gives a far lower ratio between the highest and lowest weights derived from ranking than does ROC. Table 5 in Appendix 1 compares the weights derived from the RS, RR and ROC methods when N=12 (where N is the number of criteria), that is, the number of criteria used in this study. The ratio between the highest and lowest weights were 37:1 for ROC, 11.9:1 for RR and 11.8 for RS. The RS ratio is therefore far nearer the ratio reported by the stakeholder participants than was the ROC ratio, suggesting that, in this respect at least, the RS method was better at reflecting the participant's preferences.

Questionnaire B was returned in November 2009 and the results analysed. The results for each stakeholder was presented during the 2nd round of interviews (Nov-Dec 2009) with the opportunity for stakeholders to amend their rankings, thus again ensuring that participants were content with their input before proceeding to the next step.

5.5.3. Development of the Impact Matrix

The Impact Matrix, termed the Evaluation Matrix by Omann (2004), is essentially a grid for recording the impact (or performance) of each option with respect to each criterion, as shown in table 5.13.

Table 5.13 The Impact Matrix (see Questionnaire C, Appendix 5)

	Options					
***Attributes*: measures of the extent to which criteria can be achieved by 2015**	Status quo	'Status Quo plus'	Large scale clearance	Liming	Change CL to the tripartite 'traffic lights' model	Continuous cover forestry
1. Change in overall fish biodiversity index (incorporating richness and abundance)						
2. Change in overall biodiversity index for mammals						
3. Change in overall biodiversity index for aquatic birds						
4. Change in overall biodiversity index for aquatic invertebrates						
5. Change in overall biodiversity index for plants (macrophytes and phytobenthos)						
6. Change in overall private forest income from the Cree catchment						
7. Change in overall Forest Enterprise Income from the Cree catchment						
8. Overall development of community activities, events and projects in the Cree						
9. Change in number of visitors using amenities on the Cree catchment						
10. Valuation of the attractiveness of the overall landscape						
11. Change in the estimated amount of Carbon stored in the Cree catchment						
12. Meeting Water Framework Directive (WFD) 'Good Surface Water Chemical Status' targets						

The Impact Matrix was distributed to stakeholders, as Questionnaire C, in November-December 2009 (see Appendix 5). The Impact Matrix was initially introduced during the second round of interviews, and additional electronic copies were subsequently emailed. Questionnaire C responses were returned between January and March 2010 and the results discussed (and amended, if appropriate during the third round of interviews in February –

March 2010). The responses from stakeholders to Questionnaire C required considerable interpretation in order to be converted into a standard format, so the iterative step of discussing and amending results in the 3rd round of interviews was essential. This 3rd round of interviews was carried out in February and March 2010. A set of rules were developed to translate the responses into a standardised quantitative form for input into the Impact Matrix. In the example below (table 5.14), for instance: +1 ⇨ +10; +2 ⇨ +20; -1 ⇨ -20;

Table 5.14 Example of use of raw Impact Matrix input into standardized scores.

D&G	**Responses (raw)**						***Impact Matrix input***					
Attributes	**SQ**	**SQ+**	**clearance**	**Liming**	**Change CL**	***CCF***	**SQ**	**SQ+**	**clearance**	**Liming**	**Change CL**	***CCF***
Fish	0	+1	+2	*+1*	+2	*+1*	*0.00*	*0.10*	*0.20*	*0.10*	*0.20*	*0.10*
Mammals	0	+1	+1	0	0	+2	*0.00*	*0.10*	*0.10*	*0.00*	*0.00*	*0.20*
Birds	0	+1	0	0	0	+1	*0.00*	*0.10*	*0.00*	*0.00*	*0.00*	*0.10*
Invertebrates	0	+1	+1	+1	+2	+1	*0.00*	*0.10*	*0.10*	*0.10*	*0.20*	*0.10*
Plants	0	0	0	0	0	0	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
Private Forest	DK	DK	DK	DK	DK	DK						
Forest Enterprise	DK	DK	DK	DK	DK	DK						
Community	0	+1	0	0	0	+1	*0.00*	*0.10*	*0.00*	*0.00*	*0.00*	*0.10*
Recreational	0	+1	-1	0	0	0	*0.00*	*0.10*	*-0.10*	*0.00*	*0.00*	*0.00*
Landscape	0	0	-2	0	0	+1	*0.00*	*0.00*	*-0.20*	*0.00*	*0.00*	*0.10*
Carbon sequestration	0	0	-1	0	0	0	*0.00*	*0.00*	*-0.10*	*0.00*	*0.00*	*0.00*
Water chemistry	DK	DK	DK	DK	DK	DK				*0.00*		

Note: The columns on the left show the raw data supplied by the stakeholder while those on the right show the values derived from these, using the scoring rules, that were subsequently used for calculating overall option values. DK = Don't know

5.5.4 Using the model: Aggregation

Aggregation was carried out using excel spreadsheet employing the following:
Aggregate scores for each option were arrived at by taking the overall performance for each alternative as the sum of the weight of each criterion multiplied by the performance of its attribute on that alternative, that is using the simplified basic multi-criteria calculation of the value of an option (equation 3.2):

$$v(a) = \sum_{i=1}^{m} w_i \ v_i(a)$$

Equation 3.2: simplified multi-criteria calculation of the value of an option.

Where

$v\ (a)$ = the overall value of alternative a

$v_i\,(a)$ = the performance of alternative a on attribute i, and

w_i = weight of criteria i;

It should be noted that aggregation was carried out at the individual level: that is, there was no attempt made to calculate aggregate group results by, for instance, averaging criteria weights.

5.5.5 Using the model: Sensitivity analysis

In the context of MCA use, sensitivity analysis usually refers to testing the robustness of a model: how do outputs vary if initial inputs change[94]. As such it can be termed a 'what if' analysis (Goodwin and Wright 2004: p47). Usual practice in MCA use is for sensitivity analysis to be restricted to examining the effect of changing criteria weightings (Dyer et al 1992; Edwards and Barron 1994). Thus Stirling and Mayer (2001), in their paper on Multi-Criteria Mapping (discussed in section 3.5.3 above) examined the effects of increasing and decreasing participants'

[94] As opposed to the narrower statistical meaning of the term: see Dyer et al 1992.

criteria-weighting values and then subsequently asking them "whether, in the light of the results of the sensitivity analysis, their weightings still reflected their opinions" (p539).

As Proctor and Drechsler (2006) suggest in their paper (also discussed in section 3.5.3)

"The use of sensitivity analysis in the way described above considerably differs from conventional sensitivity analysis in that the analyst is not performing the calculations alone in his or her laboratory, but in a situation where close and real-time interaction with the decision makers is crucial" p176.

Following SMARTEST's design principles of maximising transparency and engagement, this latter approach was adopted in the current study. It was, moreover, extended from looking only at participants' weighting (carried out during iterative process of step 3) to also examining their impact matrix inputs and how changes in these can influence their overall preference profiles (at stage 9). At each of the final interviews at this stage (see tables 5.7 and 5.8) participants were shown the Excel spreadsheets and the underlying calculations of how their inputs resulted in overall values were explained. It was then demonstrated how changes in inputs into specific impact matrix cells would influence the overall preference scores. If stakeholders were content with the results as they stood, no further amendments were made, but there was the opportunity for input scores to be altered and new aggregate scores to be calculated. As with the entire SMARTEST process, this iteration would continue until the stakeholder was satisfied with the result.

5.6 Development of Action Plans

5.6.1 Model Use: Feedback of results to stakeholders

Feedback of results was performed in two stages:

1. In the first stage, results for each individual stakeholder was discussed with them during the third round of interviews (when sensitivity analysis was also performed). From each interview the Impact Matrix scores were amended if necessary, following sensitivity analysis, for presentation in stage 2;
2. In the second and final stage, members of the Stakeholder A group were invited to a meeting on June 21st 2010, at the SEPA offices in Newton Stewart, at which the results were presented and discussed. (One of the stakeholders – D & G – was unable to attend). The meeting commenced with a PowerPoint presentation by the author, recapitulating the aims of the study, followed by a resume of the project activities. The results were then presented in detail via a further PowerPoint presentation and a printed pack. The presentation was followed by a discussion of the results and their implications. Detailed notes were taken during the meeting.

5.6.2 Follow-up activities

A final round of interviews, to establish what developments had occurred after the presentation of results meeting of 2010, was held in May – June 2011. This is discussed further in the following chapter.

Chapter 6. A Critical Analysis of the implementation of SMARTEST

6.1 Introduction

In this chapter, the key results are presented and analysed. However, as Stirling and Mayer (2001: 538) argue in their report on the use of Multi-Criteria Mapping (see section 3.5.3): *"In a heuristic exercise such as this, the scope of what constitutes a `finding' extends beyond the normal domain of discrete quantitative results or prescriptive narrative conclusions. The mode of engagement of participants, the ways in which they defined the various options and thought about the business of appraisal itself are just as important as the values of `outputs' such as scores, weightings, and consequent rankings. Each will therefore be discussed in turn, and particular attention paid to the associated uncertainties and sensitivities …"*

Accordingly, the results will be accompanied by a commentary on the nature of the stakeholder engagement with each step of the process, including an assessment of how the process facilitated or impeded their inputs. This commentary will attempt to be essentially critical; that is, it will identify the extent to which the method was effective in producing useful outputs and where it failed to do so. The chapter will be organised around the ten MCA steps (see table 5.2 of the preceding chapter), as shown in table 6.1

Table 6.1 Results of the MCA process related to sections of this chapter

MCA Step	See section:
1 Problem identification	6.2
2 Identification of stakeholders	6.3
3 Identification of stakeholder values, objectives and hence criteria	6.4
4 Identification of options (alternatives)	6.5
5 Identifying attributes	6.6
6 Establishing weights for criteria	6.7
7 Developing the impact matrix	6.8

8 Aggregation	6.9
9 Sensitivity analysis	6.10
10 Feedback of results to stakeholders	6.11

The chapter will end (section 6.12) with an overall review of the involvement of stakeholders in the MCA process together with feedback.

6.2 Problem Identification (Step 1).

The process by which the problem identification step was carried out is described in section 5.3. It culminated in the problem definition: "what courses of action should be undertaken to improve recovery from aquatic acidification in the Cree catchment?" As the study progressed it became clear that this definition was questionable in a number of respects:
1. Was it too narrow? The problem of recovery from acidification was intimately related to a number of other problem issues from which it was often difficult to disentangle. However, this is the case with many – probably most – environmental questions and is, to some extent, unavoidable;
2. Geographically, was it specific enough? It became clear that the problems of the Upper - or High – Cree were rather different to those in the Water of Minnoch tributaries (which included the sites used in the M.Res study outlined in chapter 5). Moreover, stakeholders were not always consistent in their terminology, so that some confusion as to which waters were being discussed arose on occasion. On the other hand, it could also be argued that the study should also have included other nearby rivers, such as the Bladnoch and Fleet. Overall, however, it was probably appropriate to use a single whole river catchment as the locus of this study.

Neither of these issues proved to be problematic during the course of the study and none of the stakeholders suggested that that the problem identification was inappropriate.

6.3 Identification of stakeholders (Step 2).

The co-nomination process used proved to be effective: it identified a number of experts and all of the Stakeholders B group. It also identified two further members of the Stakeholders A group (CVCWT and D & G), who were added to the original core group of four organisations. Co-nomination was also effective in ensuring participant engagement from the very beginning of the process, creating a context in which participants could feel enabled to direct the shape of the study

The status of this research provided a significant limitation on the nature of the interactions with the Stakeholder A group. This research project was unfunded and had no 'official' standing other than it was conducted as part of a doctoral study. There were, therefore, no financial or commercial interests involved. This provided both advantages and disadvantages: on the one hand it provided reassurance that the researcher did not represent any particular vested interest[96]. In one case the author was asked directly by a stakeholder, before the first round of interviews, who was financially backing the project, with the clear implication that they would be less inclined to co-operate with research that was sponsored by a stakeholder that held interests opposed to their own. On the other hand, the lack of any official status meant that this project relied entirely on the goodwill of the stakeholders, all of whom provided considerable time: participation in three interviews of between one and two hours each, completion of three questionnaires and attendance at the final project meeting in June 2010. In the event, all of the stakeholders participated willingly and helpfully. To some extent this was facilitated by the fact that all the stakeholders A group had good pre-existing working relationships. Nevertheless, there were sharp divisions of opinion between some of this group, with the Forestry Commission and Galloway Fisheries Trust taking diametrically opposed positions on the nature, extent and possible solution to the problem of acidification on the Cree, with the other stakeholders taking a variety of intermediate positions. These differences appeared to be longstanding and, to some extent, irreconcilable: there seemed to be, therefore, a block to any progress in deciding

[96] Note the concerns that the objectivity of scientific research can be compromised by the nature of its financial support, as discussed in chapter 2.

consensually on the way forward. One of the purposes of the use of PMCA in this project was to access the extent to which it would facilitate some reconciliation of views and thus move the decision making process forward.

Finally, in relation to Stakeholder Identification, it should be noted that the six stakeholder groups were represented by a single named individual in each case. To some extent, those individuals became the stakeholders, while at the same time they represented their organisation. On some occasions this led to an ambiguity of role. For instance, one said "this is only my view, not [the organisation he represented]": this was a typical statement. This is a recurrent difficulty in studies of this nature that deal with environmental problems of emergent complexity: individuals may represent corporate entities but often have to rely on their own knowledge, understanding and opinions, which may be at variance with those of their organisation. Wherever possible a differentiation was made between a clear organisational position and that adopted by individuals (typically with regard to particularly detailed and complex questions).

6.4 Identification of values, objectives and hence criteria (Step 3).

SMARTEST was designed to be highly iterative to ensure that all stakeholders felt fully engaged; this was particularly important in this stage, which framed the entire subsequent process. Inevitably there was a large range of potential criteria initially identified and some effort was required to reduce these to a maximum of twelve (as recommended). Considerable time was devoted to this stage to ensure that stakeholders had confidence that their opinions were being taken into account from the onset (the process lasted from May to September 2009), thus ensuring that all stakeholders had such an input that they felt a degree of ownership over the procedure The final criteria have been shown in table 5.10.

6.5 Identification of options (alternatives) (Step 4).

This process was carried out at the same time as criteria identification (May to September 2009). The final, agreed options were presented in table 5.12. There is some question as to whether these options are truly mutually exclusive as is required by additive MCA methods such as SMARTER. For instance, would it be possible to develop a policy that incorporated both a change to the Critical Load model, as proposed, *and* limited liming? However, it can be argued that by treating the options as mutually exclusive for the purposes of the MCA activity, it enabled participants to see the advantages and disadvantages of each clearly. None of the stakeholders raised the question of using multiple options simultaneously during the interviews.

Another question pertaining to the options was whether they were sufficiently well defined. In particular, there may have been a lack of clarity between the 'Status Quo' and Status Quo plus' options: the former is in fact merely included as a base line and should not be regarded as a realistic option as the environment is constantly changing and evolving.

During the first and second round of interviews it became clear that some stakeholders had clear preferences for some options (and equally, a clear aversion to others). One of the purposes of using the PMCA method was to analyse the underlying reasons for such preferences in a way that was transparent and aided further dialogue between stakeholders.

Again the requirement for systematic iteration, ensuring agreement form all stakeholders before proceeding to the next step of the process, ensured ownership and engagement.

6.6 Identification of attributes (Step 5).

This step was carried out immediately after the criteria was agreed and emerged from the first round of interviews. It appeared to be unproblematic.

6.7 Establishing weights for criteria (Step 6).

Note that it was the initial intention to use both the ranking of main objectives and secondary objectives in the final analysis. However, following receipt of the weightings (Questionnaire B) it became apparent that the main criteria weightings added little to the final analysis; it was therefore not used subsequently. The raw rankings for the twelve secondary criteria, by each of the stakeholder A group, is shown in table 6.2 (from questionnaire B, Appendix 4).

Table 6.2 Raw ranks given to the secondary criteria by stakeholders (from questionnaire B, Appendix 4)

	Criteria	SEPA	SNH	D&G	FCS	CVCWT	GFT
1	Improving **fish species richness and abundance**	1	6	7	1	1	2
2	Improving **mammal species richness and abundance**	1	3=	9	1	3	4
3	Improving aquatic **bird species richness and abundance**	1	3=	8	1	3	10
4	Improving aquatic **invertebrate species richness and abundance**	1	3=	2	1	1	3
5	Improving **plant species richness** and abundance (in keeping with unmodified channel processes)	1	2	1	1	3	9
6	Maintaining / increasing **private forest income**	12	12	12	11	12	12
7	Maintaining/ increasing **Forestry Enterprise asset value**	12	11	11	1	11	11
8	Development of **Community involvement**	8	10	3	11	8	5
9	Maintaining / increasing Recreational **access** (walkers, cyclists, visitors, local people, birdwatchers, anglers etc.)	9	7	10	9	8	6
10	Maintaining/ Enhancing **Landscape features**	9	7	6	1	7	8
11	Contributing to **Carbon sequestration**	11	7	5	9	10	7
12	Maintaining/ improving **water chemistry**	1	1	4	1	6	1

These results were then converted to weightings using the Rank Sum method and are shown in table 6.3 and diagrammatically in figure 6.1.

Table 6.3 Weightings for secondary criteria, derived from rankings using the Rank Sum method.

Criteria	SEPA	SNH	D&G	FCS	CVCWT	GFT	Average
Fish	0.122	0.090	0.077	0.109	0.147	0.141	0.114
Mammals	0.122	0.115	0.051	0.109	0.115	0.115	0.105
Birds	0.122	0.115	0.064	0.109	0.115	0.038	0.094
Invertebrates	0.122	0.115	0.141	0.109	0.147	0.128	0.127
Plants	0.122	0.141	0.154	0.109	0.115	0.051	0.115
Private forestry	0.019	0.013	0.013	0.019	0.013	0.013	0.015
Forest Enterprise	0.019	0.026	0.026	0.109	0.026	0.026	0.038
Community	0.077	0.038	0.128	0.019	0.058	0.103	0.071
Recreational	0.058	0.064	0.038	0.045	0.058	0.090	0.059
Landscape	0.058	0.064	0.090	0.109	0.077	0.064	0.077
Carbon sequestration	0.038	0.064	0.103	0.045	0.038	0.077	0.061
Water chemistry	0.122	0.154	0.115	0.109	0.090	0.154	0.124

Note: **The raw data of table 6.2 was converted to weightings using equation 3.4. All weightings lie within the range 0-1.**

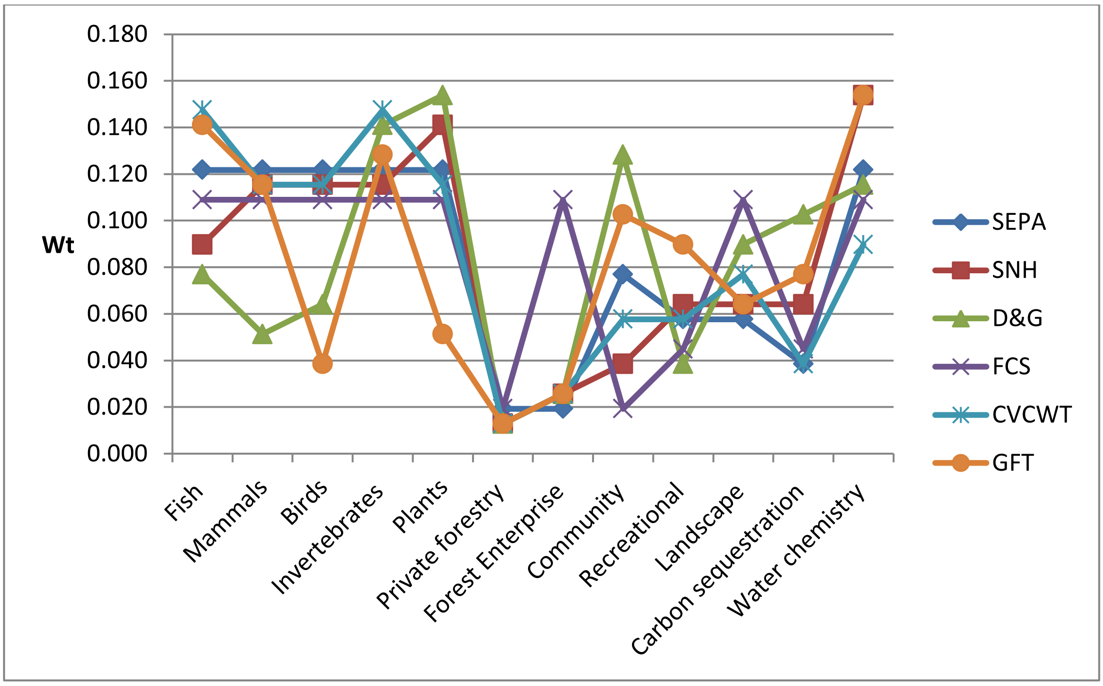

Figure 6.1 Stakeholder Weightings of secondary criteria, derived from rankings using the Rank Sum method. The figure shows the weightings given by each stakeholder to each criterion.

Correlations between stakeholders with respected to derived criteria weightings are shown in table 6.4.

Table 6.4 Correlations between stakeholders A with respect to derived criteria weightings of table 6.3.

SEPA	SNH	D&G	FCS	CVCWT	GFT
SEPA	0.89	0.55	0.59	0.93	0.62
SNH		0.57	0.67	0.84	0.56
D&G			0.28	0.68	0.61
FC				0.61	0.20
CVCWT					0.50

These results shown in figure 6.1 and table 6.4 suggest a surprisingly high degree of agreement between the stakeholders with respect to the relative importance of the criteria; the results also identify specific criteria where there are differences in weightings. Thus invertebrates are unanimously regarded as important (ranked between 1 and 3) while private forestry interests are regarded as much less important (ranked 11 or 12). However, some criteria received a wide variety of weightings: Criteria 8 "Development of Community involvement" received a highest rank of 3 and a lowest of 11. Nevertheless, the overall agreement between stakeholder weightings is striking and is further reflected in table 6.4, showing correlations between stakeholders. The average correlation is 0.61 and only one is less than 0.50: that between FCS and GFT.

These results can also be used to derive a dendrogram from cluster analysis. Paneque Salgado et al (2009) used this approach to examine potential 'coalitions' between various social actors and the relationships between them. The dendrogram shows the degree of similarity between the stakeholders according to their criteria weightings. As shown in figure 6.2, the suggests that the FCS were not as greatly diverged from the GFT view – with regards to criteria weighting at least – as previously was thought on the basis of the first interviews.

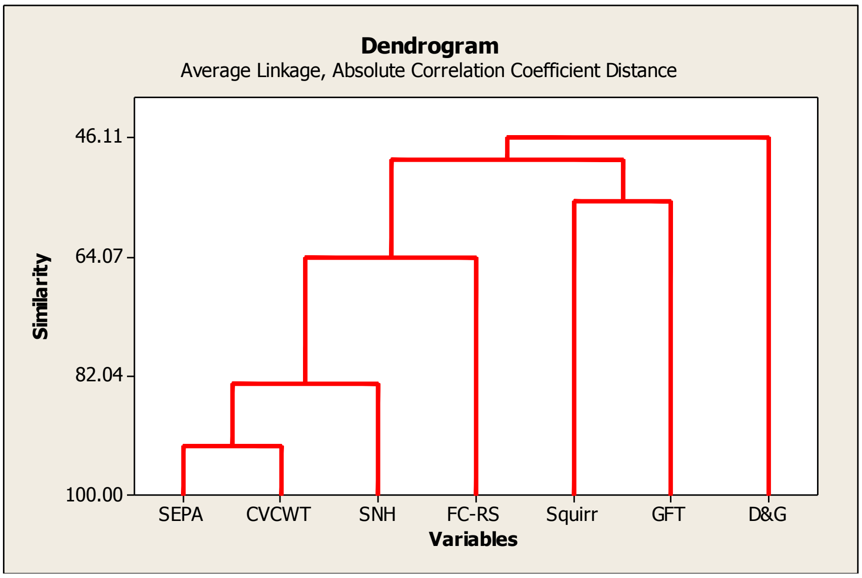

Figure 6.2 Dendrogram using cluster variables (an agglomerative hierarchical method) from criteria weightings. This shows the degree of similarity between the results from each of the stakeholders and groups them together according to the similarities between each. (Note that one member of the Stakeholder B group was included in this analysis).

Overall, the results of the criteria weightings by themselves suggest that the differences between stakeholders may not lie in their perceptions of the objectives, but rather in how those objectives are to be achieved. This in itself is a significant finding, although the criteria weightings are primarily developed as an integral part of the overall MCA process.

There was a degree of reluctance on behalf of some of the stakeholders to use the ranking method of weighting. One (FCS) stated in the second round interview that it (the ranking of criteria) was

"not the way that [name of organisation] thinks: all [criteria] are important because of their wide brief, including social and environmental issues."

He went on to indicate that he would rather rate the criteria, or identify High, Medium, Low priorities. A second stakeholder (D&G) indicated that the ranking method was 'difficult' while a third (GFT) suggested that some of the criteria were inter-related. Despite these comments there was a general acceptance of the method and willingness to accept the results. The acceptability of the rating method employed is discussed further in chapter 7.

6.8 Developing the Impact Matrix (Step 7).

The completion of the Impact Matrix was clearly the most difficult task that the stakeholders were required to undertake. One stakeholder commented on how difficult it was to be consistent in their scoring. Another pointed out that the scoring the Impact Matrix was dependent on limitations of scale (which part of the catchment one was focusing on or had the greatest knowledge of) and time (the Impact Matrix specified that impacts were to be based on the target dates of 2015, but some might be working on much shorter – or longer – timescales. However, the greatest difficulty confronting the stakeholders (as reported to the author) appeared to be the range of knowledge that the Impact Matrix required of them. That is, to complete the Impact Matrix required them to feel confident that they could quantify the impact of six different future scenarios on twelve attributes, which ranged from ecological to economic and amenity based factors. Clearly, none of the stakeholders felt entirely confident in this task and one felt that they could only complete the Impact Matrix for two of the criteria out of 12: this was insufficient for the aggregating to proceed and the final scores for this stakeholder were not calculated. Of the remaining five stakeholders none completed the Impact Matrix for all 12 criteria; the range of criteria completed was 6 to 11. However, this was judged to be sufficient for the aggregation stage to be completed for each of the five and thus for final scores to be computed. Appendix 6 shows the completed Impact Matrices for the five stakeholders remaining at this stage.

Again the process was designed to be highly iterative: the Impact Matrix was introduced and given to the stakeholders during the second round of interviews in November – December 2009, received back (electronically or in paper versions) between January and March 2010 and then discussed with each stakeholder during the third round of interviews in February – March so that each participant was content for the author to use their IM input in the model.

6.9 Aggregation (Step 8).

Following agreement on individual Impact Matrix scores, an overall values for each of the options was calculated using

$$v(a) = \sum_{i=1}^{m} w_i \; v_i(a)$$

Equation 3.2: simplified multi-criteria calculation of the value of an option.

Where

v (a) = the overall value of alternative a

$v_i(a)$ = the performance of alternative a on attribute i, and

w_i = weight of criteria i.

These results are shown in tables 6.5 and figures 6.3-6.4

Table 6.5: Overall option values for each stakeholder. This shows the v (a) score as calculated by equation 3.2

	SQ	**SQ+**	**clearance**	**Liming**	**Change CL**	***CCF***
GFT	0.036	0.116	0.190	0.356	0.140	0.101
FCS	0.033	0.076	0.029	0.056	0.000	0.000
SEPA	0.000	0.073	0.146	0.000	0.037	0.022
SNH	0.000	0.021	-0.063	0.000	0.083	0.042
D&G	0.000	0.050	0.003	0.022	0.044	0.060
SUM	**0.069**	**0.336**	**0.306**	**0.435**	**0.304**	**0.225**

Figure 6.3 shows the overall option values for each stakeholder, while figure 6.4 compiles this information into one chart so that scores for each option can be compared across stakeholders. The lack of agreement between stakeholders becomes evident from these figures.

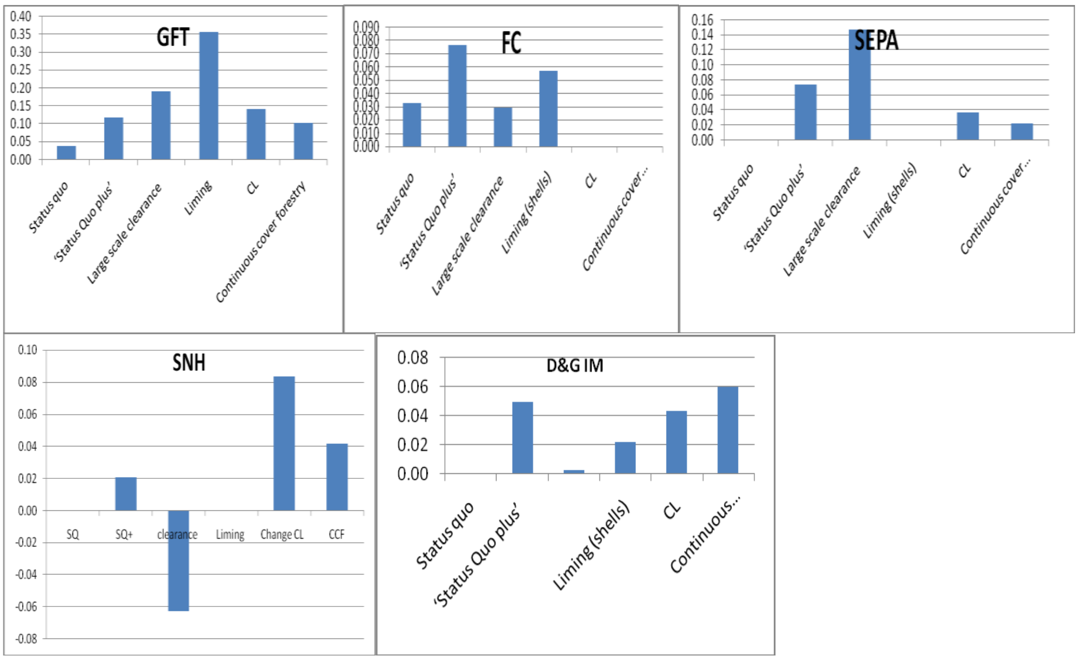

Figure 6.3 Charts showing option value *v (a)* scores for each of five stakeholders

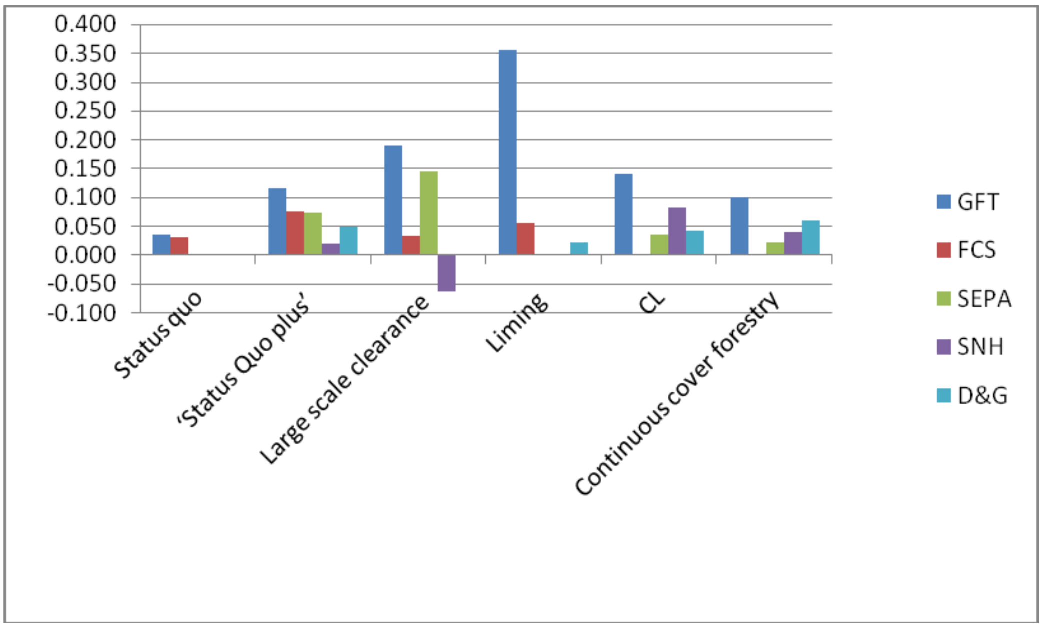

Figure 6.4 Chart of value *v (a)* scores for all stakeholders

However, it was considered that standardized scores might be more useful (that is, where the overall total score for the option values for each stakeholder summed to 100), and these were as follows in tables 6.6 and figures 6.5-6.6.

Table 6.6 Standardised option values

	SQ	SQ+	clearance	Liming	Change CL	CCF
GFT	3.82	12.34	20.25	37.90	14.93	10.77
FCS	16.80	39.20	14.99	29.02	0.00	0.00
SEPA	0.00	26.32	52.63	0.00	13.16	7.89
SNH	0.00	25.00	-75.00	0.00	100.00	50.00
D&G	0.00	28.06	1.44	12.23	24.46	33.81
SUM	**20.62**	**130.91**	**14.30**	**79.15**	**152.55**	**102.48**

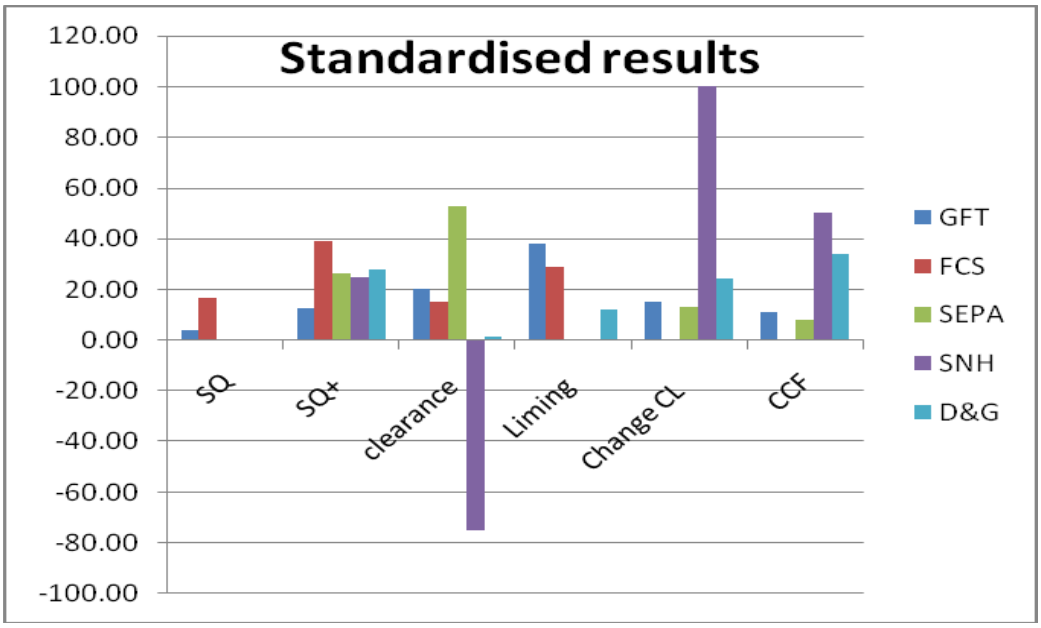

Figure 6.5 Chart of standardised value scores for all stakeholders

Figure 6.6 shows the standardized scores without SNH, as the large positive value they assign to the CCF option skews the overall results and make the detail more difficult to evaluate.

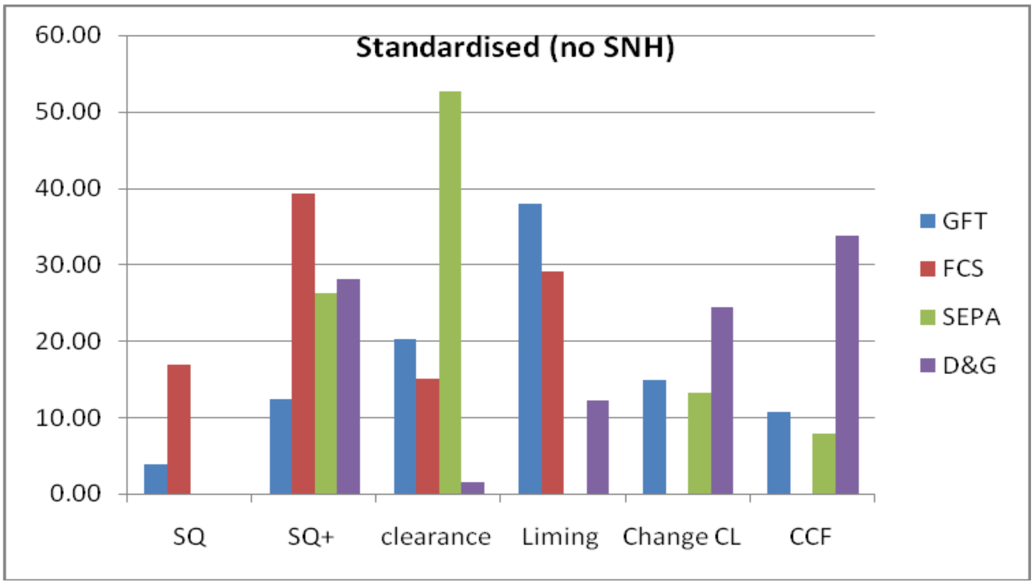

Figure 6.6 Chart of standardized value scores for all stakeholders (omitting SNH)

6.10 Sensitivity analysis (Step 9).

Sensitivity analysis was carried out during the third round of interviews to illustrate the changes in overall value scores that would result from changes in weights or Impact Matrix scores. It complemented the iterations that had already taken place. During this process one of the stakeholders made some modifications from the original Impact Matrix inputs to better represent his views: Liming was reduced to 0 and Status Quo plus increased (a little) from 0 to indicate that some (limited) progress was likely.

The other stakeholders expressed their contentment with the results as they stood.

Comments from two are illustrative:

"I am happy with results – there are no surprises but they validate my views"

"There is a mismatch between language and numbers, but this interpretation above seems a reasonable reflection of my views, provided we don't interrogate individual input too closely, but look at the overall pattern of results"

6.11 Feedback of results to stakeholders (Step 10).

The results were presented to the stakeholders at a meeting called specifically for that purpose on June 21 2010. The main conclusions drawn by the author from these results, as stated to the stakeholders, are as follows:

SQ: Status quo is the current baseline. Most of the options are scored significantly higher than this by most stakeholders, so the implication is that the current situation is unsatisfactory. SQ had the lowest overall standardised score (20.6)

Sq+: Status Quo Plus is how the situation is likely to develop with current policy directions. It had the second highest overall Impact score (standardised 130.9 and unstandardised 0.34) and scored most consistently among all 5 stakeholders (range 12.3 – 39.2 Standardised; low Standard Deviation of 9.6). The lowest overall score for SQ+ was 12.3 by GFT. SQ+ was rated as the best option by FC and second highest by SEPA and D&G

Clearance: "Large scale clearance with no replanting - An overall reduction of the coniferous forest cover of approximately 40% by 2015, by means of felling without coniferous replanting." Overall Impact scores were 0.31 (unstandardised) (3rd overall) and 14.3 (standardised) (6th). This option shows a high level of disagreement between stakeholders (high Standard Deviation of 47.4), with high scores from SEPA (highest ranked option) and GFT (2nd highest) but low ranks by D&G and negative rating by SNH (the only option to be rated negatively by any stakeholder). This was due to SNH's view that clearance "*May have negative impacts in short term, depending on scale and potential for excessive siltation loads*" for fish, invert and plant biodiversity and was "*Likely to be the most negatively viewed option, given the public's general view of clearfell*" for amenity use and landscape value.

Liming: Results for this option also showed significant levels of disagreement (Standard Deviation = 17) with high scores from GFT (highest ranked option) but very low scores by SNH and SEPA. However, this option had the highest average Impact score (unstandardised of 0.435) but the fourth highest (79.2) standardised.

Change CL: *"Replacing current Critical Load method with one with two thresholds: the current CL level ('red') and another higher threshold ('amber') derived for instance from biological monitoring data, indicating potential concern, need to look at further data to see if there are signs of recovery before proceeding"*. High levels of disagreement (Standard Deviation = 39.8). This option was 3rd highest for GFT, SEPA and D&G, but highest for SNH and lowest by FC. Overall this option had the 4th highest score (0.30 unstandardised). Its standardised score was the highest of all the options but this result is skewed by the very high score from SNH (and the fact that SNH gave liming a negative score disproportionately inflated the standardised Change CL score).

CCF: Continuous cover forestry is the *"Selective harvesting as opposed to clear felling, thinning trees but maintaining canopy cover; to replace clear felling"*. This had the lowest unstandardised score (0.22) and the third highest standardised score of 12.5 (again this was disproportionately inflated by the high SNH score). It was the highest rated option by D&G and second highest of SNH, but the lowest rated option of GFT, FCS and SEPA.

Table 6.7 Standardised value scores for each option and each stakeholder, showing most and least preferred options. The highest ranked option of each stakeholder is in bold and highlighted; the lowest two options (one for SNH) for each stakeholder is shown in *italics* in a shaded box.

	SQ	SQ+	clearance	Liming	Change CL	*CCF*
GFT	3.82	*12.34*	20.25	**37.90**	14.93	*10.77*
FCS	16.80	**39.20**	14.99	29.02	*0.00*	*0.00*
SEPA	0.00	26.32	**52.63**	*0.00*	13.16	*7.89*
SNH	0.00	25.00	*-75.00*	*0.00*	**100.00**	50.00
D&G	*0.00*	28.06	*1.44*	12.23	24.46	**33.81**

To summarise: as table 6.7 clearly illustrates, no option commands general approval and there was a high level of disagreement within most options. Each option was selected as the highest rank by one stakeholder only but also rated at the as the lowest ranked by at least one other stakeholder. These results reinforce the point made in section 6.6: differences between stakeholders have arisen not because they wish to achieve different objectives so much as they have very different views on how agreed objectives can be achieved.

Table 6.8 highlights those cells of the Impact Matrix with the greatest disagreement: if there was greater agreement on any of these there would be substantially greater consensus overall. As can be seen, there are some specific areas with very considerable disagreement, for example the predicted impact of liming on the biodiversity of fish varied from 0 (SEPA, SNH) to a 50% increase (GFT); the predictions for the impact of liming on wearter chemistry varied from 0 (SEPA) to 100% increase (GFT).

Table 6.8 Summary of Impact Matrix raw scores (questionnaire C, Appendix C) , showing the origins of the differences between stakeholders (shaded cells show greatest divergence in scores). (X= no response; ? = no clear response)

		Options					
Attributes	*Stake-holders*	Status quo	'Status Quo plus'	Large scale clearance	Liming (shells)	Change CL	Continuous cover forestry
Fish	GFT FC SEPA SNH D&G	+5 +10 0 0 0	+15 +20 +10 0 +10	+30 +10 (?) +20 -5 +20	+50 +20 0 0 +10	+15 0 +5 +30 +20	+10 X +3 +10 +10
Mammals	GFT FC SEPA SNH D&G CVCW	+0 +5 0 0 0 0	+10 +10 +10 0 +10 -2	+25 -10 +20 0 +10 +7	+10 0 0 0 0 2	+20 0 +5 +5 0 +3	0 X +3 +10 +20 +4.5
Birds	FC SEPA SNH D&G CVCW	+5 0 0 0 0	+10 +10 0 +10 -4.5	+10 +20 0 0 +9.5	0 0 0 0 +6	0 +5 +5 0 +5	X +3 +10 +10 +1
Invertebrates	GFT FC SEPA SNH D&G	+5 +5 0 0 0	+15 +10 +10 0 +10	+30 +10 +20 -5 +10	+50 +10 0 0 +10	+15 0 +5 +30 +20	+10 X +3 +10 +10
Plants	FC SEPA SNH D&G	+5 0 0 0	+10 +10 0 0	+10 +20 -5 0	+20 +0 0 0	0 +5 +30 0	X +3 +10 0
Private forestry	FC	?	?	?	?	0	X
Forest Enterprise	FC	0	-10	+5	0	0	X
Community	GFT FC D&G	+10 0 +10	+10 0 0	+15 0 0	+20 0 0	+15 0 0	+10 X 0
Recreational	GFT FC SNH D&G	+5 0 X +10	+15 +10 X +10	0 ? -30 -10	+40 +5 X 0	+20 0 X 0	+40 X X 0
Landscape	GFT FC SNH D&G	0 0 X 0	+15 +10 X 0	+30 ? -30 -20	0 0 0 X	+20 0 0 X	+20 X +10 X
Carbon sequestration	FC D&G	0 0	-10 0	-20 -10	-3 0	0 0	X 0
Water chemistry	GFT FC SEPA	+5 0 0	+20 +10 +10	+30 ? +20	+100 +1 0	+20 0 +5	+10 X +3

The presentation posed the question to stakeholders: was there an opportunity to review the inputs on some of the options so as to arrive at greater consenus? In the absence of consensus – and bearing in mind the precautionary principle – is the 'Status Quo plus' option the only one commanding sufficient agreement?

This presentation led to a detailed and considered discussion, focusing particularly on the differences in Impact Matrix inputs identified in table 6.8.

6.12 Overall engagement of stakeholders: impact and evaluation

During the third round of interviews stakeholders made a number of comments concerning the value of the process. These included:
"This project will be helpful if it does shed more light on the problem, encourages further discussion. If it results in some novel ideas that will be especially attractive to those working on the Biosphere."(SNH)

"[I am] happy with the results – no surprises but validates. ….. [This MCA] model will be useful if it results in harmony or if it helps stakeholders to be more specific about their differences – i.e. to clarify. [It] needs input from private forestry and local community." (SEPA)

"*There is a mismatch between language and numbers, but this interpretation above [the Impact Matrix] seems a reasonable reflection of views, provided we don't interrogate individual input too closely, but look at overall pattern of results*." (FCS)

A final round of follow-up interviews was held with four of the stakeholders in May – June 2011, to examine developments that had occurred since the June 21 2010 meeting. This established that there had been considerable progress, with the start of a trial, carried out by GFT but with agreement from the other stakeholders, using limestone gravel in one location on the Upper Cree. This trial arose from a visit made by several of the stakeholders to the

River Wye in Wales, where liming had been in operation for some time. It appeared that from this visit a consensus emerged that liming could be done at a very localized scale with little ecosystem damage. However, it was also agreed that constant monitoring was essential and that any larger scale liming could only be justified by properly scientific evidence that emerged.

A further comment emerged from these interviews concerning the use of MCA in this project:

"It's all helpful - information is helpful to see different people's perspectives that you may not have been aware of" (CVCWT).

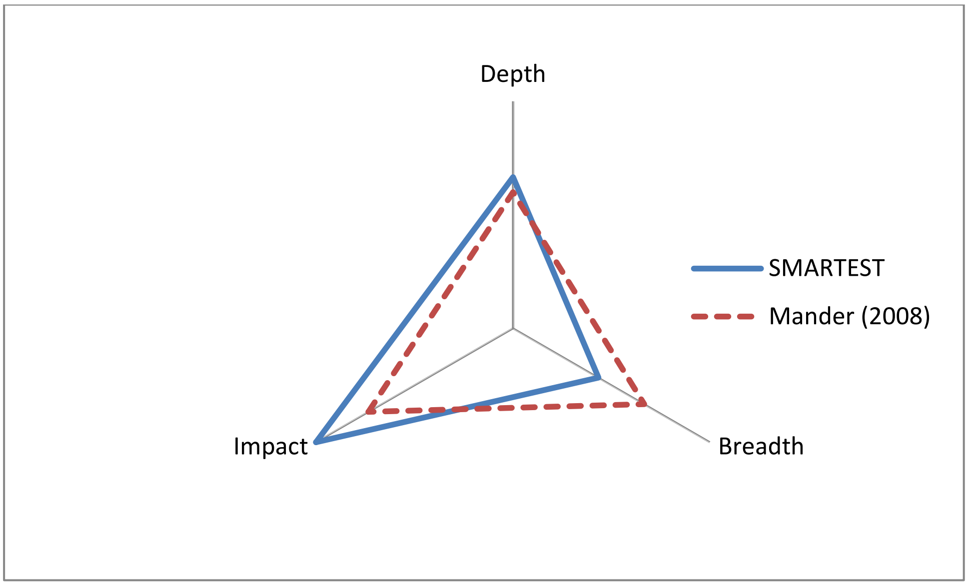

Figure 6.7 *Breadth-Impact-Depth* analysis of SMARTEST as used in this case study, with that of Mander (2008) for comparison. SMARTEST exceeds Mander's method in terms of Impact but had less breadth of participation.

Finally, these results suggest that one of the original project aims – to design SMARTEST to optimise the level of *Impact*, as defined within the BID model, was successful. As discussed in chapter 5, the limitations of this case study meant that neither *Breadth* nor *Depth* could be as great as would be desired. Further testing of the method, to investigate the extent to which these can be attained, would be necessary if the technique is to fulfill its design objectives. Figure 6.7 shows a BID analysis of the technique as used in this project, with that for Mander (2008) for comparison.

Chapter 7. Discussion and Conclusions

7.1 Introduction

This study has explored the extent that environmental decision making can move to greater rationality while extending participation through the use of MCA methodologies, specifically the SMARTEST method. It has adopted the position of Glasser (1998) in arguing for a procedural rationality, which is deliberative and deontological rather than teleological. That is, such an approach (similar to that of the co-constructionists) emphasises the value of developing the decision making process, not merely focusing on the outcomes. As such it recognises the important of iterative reflection, transparency and participation in seeking a 'best compromise': the best feasible outcome if not the best imaginable.

This final chapter attempts two main tasks: to analyse the implications of this research and also to critically examine the methodology employed. Section 7.2 asks what contribution participative MCA can make to environmental decision making. This is examined in the specific context of the River Cree case study and, by extrapolation, in the lessons that can be learned for the process more generally. Section 7.3 examines the extent to which the SMARTEST method is an appropriate and fitting methodology for participative MCA: did it achieve the design aims set out in chapter 5 and was it effective in enhancing participative engagement in the decision making process. Section 7.4 is concerned with Post-Normal Science (PNS): how useful is the PNS paradigm as a framing device for participative methods? This section returns to the questions raised in Chapter 2 and examines the extent to which PNS has succeeded in bridging the gap between traditional Rational-technical methods and its post-modern, constructivist alternatives. Section 7.5 considers the *Breadth-Impact-Depth* model, which has been introduced in this study. How valuable might it be as a means of analysing and comparing participatory methods? Section 7.6 moves on to a reflection on the methodology employed in this study and examines ways in which it could have been enhanced. This section includes a discussion of the importance of the facilitator's role and, more generally, a reflection of the author's own position with regard to the research. Section 7.7 follows on from this to suggest future lines of research, at various scales: at the local level, for research on the Cree, and at a more global level concerning the use of MCA and other participative methods in environmental decision making. Finally, section 7.8 moves the focus further back to discuss some of the larger issues that have arisen from this study, and to offer final thoughts and reflections.

7.2 The contribution of participative MCA to the environmental decision making process.

The question of the potential contribution of PMCA to environmental decision making is twofold: firstly, how effective was this action research in the specific case study of recovery of the River Cree from acidification; secondly, what can be extrapolated from this example to provide more general conclusions on the use of how this type of participative MCA may be used in environmental decision making?

7.2.1 The River Cree and recovery from acidification.

There is evidence that this study provided significant facilitation of the decision making process. The stakeholders made available a substantial amount of time to the research over a period of more than two years. The willingness of all the stakeholders to participate in this way suggests that the highly iterative nature of the process, in which each step was fully discussed until consensus had emerged, was effective in enabling participants to feel fully engaged with the process. It was important, in this sense, that the researcher maintained a neutral and objective position, avoiding being seen as partisan. The role of the facilitator was, therefore, crucial, not merely in a technical sense (in terms of the ability to carry out the technique) but also in the fashion in which relationships with stakeholders were built and maintained. The important but intangible nature of the interpersonal skills necessary to build and maintain relationships in such action research contexts became apparent during this process. For instance, sensitivity to the power dynamics – within the stakeholder group and also between stakeholders and the facilitator - was also required. As Eden (1999) argues, the position of the 'expert' automatically confers some level of power, in terms of control over the process. However, in this case this was attenuated by the nature of the research project. Further discussion on this point is provided in section 7.6 below.

From the point of view of the stakeholders, the potential benefits that they might derive from participation in the research can be divided into several component parts. Firstly, the research process provided an opportunity to discuss, with a neutral 'outsider' (with no vested interests but who had a good level of understanding of the nature of the problem) their own perspective of that problem and the social and political complexities involved in finding a solution. While any structured interview process would have been effective in providing stakeholders with an opportunity to restate and review their ideas in a non-confrontational environment, the fact that the interviews used the MCA format allowed them to go significantly beyond this simple reflection process, in that it required participants to disaggregate the various elements of the problem and examine each separately.

This separation of the problem elements was a crucial part of the process, as it enabled stakeholders to review previously established positions and reexamine the nature of their preconceived views. The identification of criteria and options, the weighting of criteria and the making of judgments on the likely effect of options on criteria were all essential steps. This process was, in some cases, uncomfortable, perhaps as with any 'troublesome knowledge', but nevertheless necessary if new forms of understanding were to be achieved. Thus the MCA process, which requires this rational and stepwise decomposition of the problem into a number of separate elements, provided new and unique ways of perceiving the problem.

Finally, as well as providing opportunities (in the interviews) for stakeholders to discuss their views and (in the MCA process) for them to interrogate specific elements of the problem, the MCA process also enabled them to compare their opinions, beliefs and ideas with those of the other stakeholders. This was particularly revealing, enabling original perspectives to be gained.

These outcomes can be compared with the analysis, outlined in chapter 3, of the potential for MCA to help to resolve environmental conflicts, particularly as proposed by Hostmann et al (2005), who argue that MCA may help reduce conflicts between stakeholders in three ways: by clarifying the different positions taken by stakeholders, identifying differences, by improving openness and transparency and by increasing the range of options considered. The analysis above suggests that this research process helped clarify the various positions, identifying not only the important differences identified in table 6.8 but also some unexpected similarities, such as those concerning criteria priorities. These similarities provided an important insight: that stakeholders were essentially trying to achieve the same ends but only had contested views as to how different means might achieve them. This led, in turn, to greater transparency and openness in that stakeholders became more aware of the origins of other's views. For instance, the final meeting, in June 2010, clarified several misconceptions regarding the Continuous Cover Forestry (CCF). However, the process did not so much increase the range of options under consideration as clarify exactly what was meant by each option. Most importantly, liming was perceived in diverse ways by the various stakeholders: it was only after several had visited Wales, to see a site where it was being used, that consensus began to emerge. The MCA process appeared, therefore, to reduce conflict through clarification and enhanced transparency, but not necessarily through the identification of new options. However, the imperative to generate such new options, as suggested by Hostmann et al (2005), can perhaps be challenged by the model put forward by Stirling (2006).

Stirling (2006) introduces an important distinction between the 'closing-down' and 'opening-up' of policy options (discussed in section 3.5 above). Stirling argued that traditional rational methods (such as non-participative versions of MCA) have been seen as 'closing-down' the policy debate by narrowing the range being consider to a single 'best' option, while on the other hand post-modern and constructivist approaches 'open-up' the debate by encouraging pluralism of opinion and, therefore, more options. Stirling suggests that this may have given rise to a false dichotomy (termed the 'efficacy paradox' by Voss and Kemp 2005), in that both 'opening-up' and 'closing-down' may be legitimate at different stages of the decision making process.

In the context of this research there appeared to be both 'opening-up' and 'closing-down': at the beginning of the process a wider range of options was being considered than had been advanced by any one stakeholder; at the end several of these options were being generally discarded and the range of possible solutions had narrowed considerably. Thus CCF was discarded as being inappropriate for local climatic and pedalogical reasons, while there was also a realisation that large scale clearance was infeasible (not least because of increasing attention being paid to the need for Carbon Sequestration because of Climate Change). With the realisation that changing the details of the Critical Load model (which was being discussed in the preparation of the new edition of the Forest Water Guidelines) might not lead to any radical changes in forestry practice, this left only the liming option as a viable alternative to the 'Status Quo Plus' (or 'Business as Usual') model. This analysis was borne out by subsequent events, where renewed interest in liming, spurred by the realisation perhaps that it was the only achievable way forward, led several stakeholders to reconsider the evidence and develop new approaches. With this perspective, the MCA process was effective in enabling stakeholders to identify an achievable compromise. It was, moreover, probably successful not only at the process level (which enabled some initial opening-up) but also in terms of facilitating outcomes in terms of 'closing-down' of options at the end of the process.

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7.2.2 What is the potential for participative MCA in enhancing environmental decision making?

The research reported here adds further evidence that participative MCA has significant potential to play an important role in environmental decision making. In particular, the emphasis on iteration and on involving the stakeholders in as many of the steps as possible appears to have contributed greatly to benefits that stakeholders gained in terms of insights, analysis, comparison and transparency that have been discussed in the previous section.

This use of participative MCA is similar to that of Multi Criteria Mapping (MCM) in that the emphasis was on working with each individual rather than developing a total aggregated value score for the whole group, although it also employed comparison and some group work, as discussed above. It has been emphasised throughout this study that one important implication of the type of MCA typified by MCM is that, because the focus moves from outcome to process, some technical robustness can be sacrificed in the interests of usability, so that the 'heroic approximations' involved in SMARTEST, are justifiable. Using the

Edwards and Barron (1994) terminology, some degree of modelling error is allowed if it is compensated for by minimising elicitation error. As Omann (2004: 108) puts it "*Complicated techniques commonly used in MCDA methods become superfluous in MCM*" with the ultimate aim being to promote understanding rather than trying to identify the 'perfect solution'. Omann goes on to argue that

"*correct framing of the problem and understanding the differences of the stakeholders' perceptions and preferences is more important than aggregation*" (Omann 2004:108).

However, the preceding comments should not be taken to suggest that an uncritical view has been taken with the regard to the effectiveness of PMCA. On the contrary there are a number of questions, problems and difficulties with this approach in general (quite apart from the specific failings of the approach taken in this study, which are considered below).

Firstly, there are a number of context-specific factors which seem to be required for this approach to be effective. As discussed above, this method was highly dependent on the creation and maintenance of a network of relationships between the researcher and stakeholders (over which the researcher may have a degree of control), which in turn were contingent on the history local social/ political framework (over which the researcher has no control). However participative the action researcher is, he or she is essentially an outsider, who engages with the stakeholders for a limited period and then leaves. For stakeholders, in contrast, there is a pre-existing history and a continuing future, in which the researcher plays no part. The temporary and detached nature of the researcher's involvement is, of course, an advantage in some respects, allowing for a perceived neutrality and objectivity that would otherwise be difficult if not impossible; nevertheless it means that the researcher cannot be fully participative or engage with the process on the same footing as the participants themselves. Participative MCA has, therefore, clear limitations.

Secondly, this type of highly iterative PMCA is time-intensive in two senses: it requires a great deal of input from each stakeholder and the process will extend over a considerable duration (in this case, over two years). The willingness of stakeholders to engage on this basis is dependent on the type of relationship building and maintenance discussed above.

In this case, the goodwill and cooperation shown by all the stakeholders has enabled the process to be completed successfully, but this may not always be the case. The review of MCA studies in chapter 3 found several examples of the process being curtailed because of a lack of cooperation; Kallis et al (2006: 225), for instance, some stakeholders refused to participate "despite repeated invitations".

Both the above (relationships and time) are influenced in turn by the status and role of the researcher. In this research that role had no formal standing: the researcher was not employed or otherwise sponsored by any of the stakeholders or indeed any other organisation. As indicated above, this lack of vested interest had some advantages in that it reassured stakeholders as to the impartiality and neutrality of the researcher. On the other hand, it also presented some disadvantages in that relationships and standing had to be built from the ground up, rather than being ascribed from a formal role.

The fourth problematic factor that this research highlights concerns the nature of the stakeholders themselves. As discussed in section 2.4, the stakeholder concept is central to the idea of participation, yet it remains curiously elusive. On the one hand it appears straightforward to carry out an institutional analysis, as in chapter 5, to identify those organisations that have a strong interest or stake in the problem of acidification in this river and to invite each to nominate a representative to act on their behalf in the project. On the other hand, this process itself identified disparities in the nature of the organisations involved, their formal power and informal influence (as in table 5.6). As Banville et al (1998) point out, much of the previous work in this area defined stakeholders as those with a vested interest, where such interest implied a significant capacity for influencing outcomes. Such a definition excludes those affected by but unable to effect events, in other words a 'catch 22' whereby one must already have power in order to be admitted to the 'stakeholder club' – and thus be afforded further power. The movement towards participation seeks to break out of this closed circle and empower the powerless.

However, an immediate problem is the representativeness of stakeholder groups. The definition of stakeholder adopted in this study was "any group of people, organized or unorganized, who share a common interest or stake in a particular issue or system" (Ananda and Herath (2003: p82). However, unorganized groups by definition cannot have representatives. Unless large numbers are to be involved in the decision making process – which in itself precludes the use of the sort of highly iterative, individualised participation used in this study, then representatives of organised groups must the participants. The nature of this representativeness is, however, problematic: to what extent can individuals be required to speak for an entire organisation. As outlined in chapter, Rowe and Frewer (2000) identified the representativeness *and* independence of the participants as among the criteria for evaluating participation: the paradox apparent in this proposal is apparent. As reported in chapter 6, some of the participants in this study articulated their unease with this ambiguity.

The precise status of the individual stakeholder representatives is also an important but under-researched factor. Much of the literature on participation, such as that reviewed in chapter 2, depends on rather simplistic distinctions between 'decision maker', 'experts' and 'citizens/ the public'. The implied assumption is that each individual can be classified in one or other of such mutually exclusive categories. Yet an individual can be a decision maker in one context and an expert in another, while all of us can be regarded as 'citizens'. Indeed, the assumption that scientists are qualified to pronounce authoritatively on subjects outside their immediate discipline has fuelled many of the criticisms of elitism that have promoted movements such as Post-Normal Science (see the discussion of Weinburg's (1972) concept of trans-science in section 2.6). Within the multidisciplinary area of environmental policy the essentially ambiguous yet crucial role of the expert becomes especially acute: would, for instance, an eminent, internationally respected scientist in the field of nuclear waste recycling be qualified to speak as an 'expert' on biodiversity loss, climate change or policy to reduce acidification?

There is a need for greater clarity in distinguishing different degrees of 'expertness' if the trend towards great participation in decision making is to be maintained. Much of the discussion within this study has been based on normative assumptions about the desirability of extending decision making beyond traditional, narrow elites. Yet this study itself has involved stakeholders who are, in essence, experts: all had expert knowledge and professional qualifications: they could certainly not be regarded as being 'non-expert citizens'. It is nevertheless reasonable to maintain that the methods used here can, in principle, be extended to much wider groups.

Overall, therefore, this study adds to the growing evidence of the efficacy of participative MCA to facilitate environmental decision making. There are, however, a number of important conditions and provisos: it should be clear from the outset that the aim of the deliberative process is to promote understanding, not to provide a justification for one 'best solution'; ample time should be available for the amount of iteration required; a basic degree of trust and co-operation needs to exist (or be created) between the participants and with the researcher. If these conditions exist then participative MCA may have much to contribute.

7.3. Is the SMARTEST method an appropriate and fitting methodology for participative MCA?

The previous section examined the insights this study has afforded for understanding of the impact that MCA in general can have on participative decision making; this section examines the specific case of SMARTEST. SMARTEST has been introduced here as a development of the SMARTER technique of Edwards and Barrons' (1994), with specific innovations designed to facilitate participant engagement with the process.

As explained in chapter 5 (section 5.1.2), the design principles for SMARTEST were that it should meet the following criteria:

1. To maximise ease-of-use.
2. That participants should have as much say as possible over the process in as many stages as possible.
3. To be iterative and stepwise throughout.
4. That the outcomes of each participants input should, with their agreement, be available to other participants.

5. That the process should not be excessively onerous on participants in terms of the time required.
6. Rankings were converted into weightings using the Rank Sum method.

The results reported above suggest that SMARTEST meets all of these criteria. Stakeholders participated in all of the ten stages of the process (see table 5.8) and in most of those stages they had considerable control over the process. This was a significant improvement in participatory *Impact* (using the BID model) on any of the research studies reviewed in chapter 3. The iterative nature of SMARTEST – with the condition that each stakeholder should be content with a stage (whether in terms of their own input or in the design of the process itself) before the process moved on – was viewed as being crucial in securing the continued engagement of all of the stakeholders. The requirement for iterativity was met without any problems being encountered. However, these iterations were time-consuming in two ways: they required considerable input from each stakeholder and extended the period over which the process took place.

Participants reported, in general, few difficulties in understanding the process or inputting data. However, the Impact Matrix clearly presented some difficulties, with one of the stakeholders feeling unable to complete it for more than two of the criteria. Others reported some difficulty with using numerical inputs. These results can be compared favourably with those of those otherwise exemplary examples of participative MCA discussed in section 3.5.3. Stirling and Mayer (2001), for instance, reported that two (out of twelve) did not feel sufficiently comfortable with the Impact Matrix to undertake this stage while Mander (2008) found that ten of the twenty-seven individuals undertaking the MCA did not complete that stage. However, further development and evaluation is clearly required in this respect if SMARTEST is to be a successful technique with which a wide range of stakeholders are happy to engage with.

The ranking method (for deriving criteria weights) was also not universally popular with stakeholders, with some stating a preference for a rating method. However, despite these difficulties, the interactions with participants during interviews, and their responses to the three questionnaires, indicated that they were generally able to engage fully with the process, and that the time requirements were not excessive. Stakeholders were also especially appreciative of SMARTEST's facility for comparing their results with those of others: this generated useful discussion in the plenary meeting.

With regard to technical robustness (that is, the capacity of a method to minimise modelling error), there were no apparent problems with the ability of SMARTEST to generate meaningful results which reflected the participants input. Stakeholders indicated in most instances that they were content with the results that were fed back to them; where there were problems the iterative nature of the process allowed for corrections to be made. The transparency and ease-of-use of SMARTEST overcomes, therefore, much of the concern about potential loss of robustness inherent in its 'heroic approximations'.

It should also be reiterated, moreover, that in this type of use of participative MCA there is less onus to deliver a technically robust solution: the onus is on the process more than the outcome. As Banville et al (1998) argue, it is the MCA expert who is most aware of the mathematical rigour of the model, while they may be less aware of organisational relevance and its socio-political aspects. Edwards and Barron (1994: 321) put it most succinctly: "The most important goal of decision analysis is insight, not numerical treatment". Nevertheless, it is necessary that any model has good face validity: SMARTEST appears to meet this requirement and its 'heroic approximations' seem to be justified.

SMARTEST seems, therefore, to have achieved the goals it was set. However, further development work is necessary, in particular to simplify the Impact Matrix stage. It should be noted that, because the intention of this study was to trial the new SMARTEST method to ascertain if it would facilitate greater *Impact* of participation, the trial took place with low *Breadth* and *Depth* conditions: there was a small number of participants, all drawn from the usual stakeholder groups, and all of whom could be regarded as having 'expert' status. The extent to which findings can be extrapolated to more challenging conditions, with greater *Breadth* and *Depth* conditions (that is, with more participants including those with less specialist knowledge) is, as yet, untested.

7.4. How useful is the Post-Normal Science paradigm as a framing device[97] for participative methods?

It has been argued in chapters 2 and 3 that there has been a gap in approaches to environmental problems between overtly rational paradigms and more deliberative, post-modern and constructionist views which do not , however, supply practical methods. Furthermore, it was proposed that Post Normal Science offers some way forward, in framing the conditions in which integrated methods, which bridge this gap, can be developed. It was suggested that PNS, with its emphasis on deliberation involving the extended peer community, might provide a unifying conceptual framework for bridging that gap. Does the output from this project suggest that such propositions were justified?

The diagnostic elements of PNS appear to be useful: Ravetz's often quoted characterization of complex problems where "facts are uncertain, values in dispute, stakes high and decisions urgent" (Ravetz 2004 p. 349) applies to many environmental problems. Increasingly, it can be applied to the question of recovery from acidification of aquatic ecosystems, as chapter 4 outlines. Many of the pertinent issues of acidification contain significant *uncertainties* (recovery rates, ecosystem response, influence of land-use and geology, the role of episodicity, critical loads, the future impact of climate change, soil saturation, etc.). Insofar as some ecosystems may never return to their pre-acidification state, the *stakes* seem high, although they are sometimes overshadowed by the potential effects of climate change. Nevertheless, at the local level, the return of fish to levels of abundance that were witnessed a generation ago, with its attendant economic benefits, is certainly perceived by many, such as GFT and its supporters, as being a high *stake* as well being *urgent*. The contestation of *values*, it has been assumed, also underpinned disagreements about policy for recovery from acidification. However, this study suggests

[97] The concepts of frames and framing have become increasingly useful in discussions on environmental problem solving (Brugnach et al 2008). Frames are "sense-making devices" (p3), representations of the real world, which are heuristic but biased". There are, therefore, multiple frames, each a different way of viewing the situation. The framing concept is thus quintessentially constructivist, and provides an important justification for participatory methods such as those used here.

otherwise: that the general homogeneity of weightings indicates a surprising degree of agreement about values and the prioritization of objectives that they give rise to. Nevertheless, the PNS approach does seem a useful framing device for identifying emergent complexity in environmental problems.

PNS also contributes cogent arguments to the critique of the traditional rationalist approach, as characterised by Funtowicz and Ravetz (1994a: 577):
"Traditional science assumed nature to be simple, and capable of reductionist mathematical explanations, themselves based on observations by a detached observer".
Bidwell (2009) summaries the contemporary PNS objections to such traditional science: that in relying exclusively on supposedly neutral experts to carry out allegedly objective research the myth of scientific objectivity is perpetuated, aiming at a "mirror-like" reflection of reality (p733). For PNS advocates, this formulation neglects that centrality of subjectivity: in his view, all research is 'inherently value-laden' (p734) and so science cannot be neutral. This rendering of the PNS epistemology places it firmly within the post-modern, constructivist camp. However, this is a considerable deviation from Funtowicz and Ravetzs' original formulation, as for instance "Post-normal science enables us to avert the nihilistic implication of post-modernism …" (p579) by admitting the existence of objective reality while accepting that such reality will also generate different perceptions. The epistemology of PNS seems confused, therefore, claimed both by post-modernists and by critical rationalists.

Furthermore, while PNS may offer useful diagnosis and analysis of the nature of the problems facing environmental decision making, it fails to advance many practical proposals for their solution, other than the call for using an 'extended peer community' and for a consideration of 'extended facts'. The 'extended peer community' is intended to include all those with a perceived stake in an issue, such as interest groups and individual citizens. It seeks to expand the scope of the traditional peer review and instead of concentrating on methodological procedures will examine the nature of the research question, problem framing, risk and trade-offs. However, this is essentially a restatement of the now standard argument for increased participation; it is not clear what new perspective

PNS brings to the 'participative turn' other than the phrase 'extended peer community' itself. The other major practical proposal of PNS is its call for a consideration of 'extended facts': values, personal experiences, beliefs and feelings and other types of information not traditionally acceptable within the framework of normal science. Extended facts therefore "expand the bandwidth of validity" (Bradbury and Reason 2003, 344). This again appears to be a reiteration of the typical post-modern approach (see the parallels, for instance, with Integral Theory, discussed in section 2.3). So while Bidwell (2009) argues that PNS integrates facts and values, enabling dialogue between all stakeholders, regardless of position or status, this seems to be a statement of aspiration rather than description or explanation of how such a state of affairs is to be achieved. PNS is, therefore, a set of values – essentially constructivist and post-modern - rather than a methodology.

Furthermore, PNS offers no solutions to the key normative problem of participation: what are the limits of the PNS approach: does 'anything go' in terms of anecdotal reports, feelings and beliefs? According to the more extreme versions of the post-modern, constructivist position, all voices should be heard – in which case expert knowledge loses all currency. Durrant (2010) provides an useful analysis of the limitations on participation within the context of Science and Technology Studies (STS), suggesting a tension between those, on the one hand, who seek to identify the limits of participation (and thus when and where expert advice should be used) and on the other hand theorists who see no need for such limits and so criticise the very notion of expert autonomy. This issue seems to be of central importance in the movement to extend participation in decision making, but PNS appears to bring few new insights or ideas of how the question may be resolved.

This analysis extends the criticisms, outlined in chapter 2 above, into new spheres and suggests that PNS has failed as a compromise, synthesis or solution to the conflict between scientific rationality and post-modern interpretivism. While on the one hand Rauschmayer et al (2009) argue that PNS overtly challenges "the legitimacy of science itself", Wesselink and Hoppe (2011) suggest, on the other, that PNS is merely a different way of doing science that still relies of the myth of ratiocination. They further argue that, although PNS arose from the democratising, green political agenda of Funtowicz and Ravetz, it has subsequently failed to address issues of governance, and conclude with a plea for greater consideration of the political dimension of environmental decision making. While Wesselink and Hoppe argue an extreme position for the degree to which PNS remains within the scientific tradition, it does appear that PNS fails to examine issues of power and control that are central to the intractability of many environmental problems.

Some of the insights into power and social control that are absent in PNS may come from the field of Environmental Sociology, within which there are several ongoing debates relevant to these issues. In particular, there is a sharp contestation between the Ecological Modernisation (EM) (Mol and Spaargaren 2005) and political economy models, such as Schnaiberg's 'Treadmill of Production' and Wallerstein's World Systems Theory (Buttell 2004). The 'Treadmill of Production' theory is a neo-Marxist view, taking a more rationalist, epistemologically realist position than that of the post-modern interpretivists, that sees powerful forces that drive continuous capitalist expansion as primarily responsible for the inevitable destruction of a finite environment. Ecological modernization, in contrast, sees the global capitalist economic system as the solution to environmental problems rather than the source. Ecological Modernisation, which has increasingly won approval from the higher echelons of government and business, also favours increased participation, which critics regard as failing to address the underlying mechanisms that drive environmental problems (Hajer 1995)[98]. The debate between these sharply contrasting positions focuses on the nature of the locus of decision making and addresses the problem of power in a manner that is conspicuously absent within Post Normal Science[99].

Environmental Sociology is also one of the fields within which the contest between rationality and constructivism has been most keen, and where perhaps the integration of both into co-constructionism is most developed (Hannigan 2006). It provides, therefore, a

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98 Hajer's 1995 widely cited 'The Politics of Environmental Discourse' used a detailed and elegant constructivist approach to analyse the regulation of acid deposition in Europe, which provides an illustration of how such a method may provide compelling post-hoc explanations while failing to offer practical ideas for the future.

99 For example, PNS fails to address concerns that deliberation may subvert the democratic process (Stirling and Mayer 2001) or Levidow's (1999) assertion that it may entrench privileged positions and suppress dissent.

theoretical basis for the rehabilitation of rationality while recognizing the domination of social perceptions in how environmental problems are framed.

This analysis suggests, therefore, that PNS has failed to provide any enduring answers to the problems of participation in environmental decision making. While its identification of many environmental problems as being examples of emergent complexity has been useful, its epistemological basis appears to be unclear, it fails to offer any new practical methods or to answer questions about the how far participation should extend and it undermines the perceived legitimacy of the science that it sought to reform, while neglecting essential questions about the role of economic power in environmental policy making. Perhaps PNS provided, for a while, a useful framework for the examination of these issues – but those debates have now moved on. PNS may be about to become part of the history of environmental decision making, and will be superseded by newer, more innovative and comprehensive approaches[100].

7.5 The B*readth-Impact-Depth* model

The B*readth-Impact-Depth* model, which was developed during this study, was introduced in chapter 2. It provides an innovative method of summarizing the nature and extent of participation in an activity or process by the use of three dimensions.
The model has been useful for this study in that it not only provides a multi-dimensional approach to participation (most previous models having utilised only one dimension) but also because it provides a means of graphically illustrating participation in the 'BID diagrams'.

However, further development is needed before the model can be more widely used. The definitions require further clarification and detail. *Breadth* is intended to be an indication not

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[100] Although it goes beyond the scope of the present study, it might be suggested that the citizen science (Lakshminarayanan 2007; Cooper et al 2008; Bidwell 2009) and civic science (Fernandez-Gimenez et al 2008, Bäckstrand et al 2010) offer alternative prospects for democratizing science that incorporate the important notion of social learning.

only of the numbers involved but also of their representativeness. However, this needs to be defined and assessed more clearly. *Depth*, which signifies the extent to which the process moves beyond traditional decision-makers to include those previously excluded from the process, also requires amplification. However, it is the *Impact* dimension which potentially is most problematic and, arguably, may be further sub-divided. For instance, *Impact* may refer to the degree of engagement, the extent to which participants have ultimate control over how their contributions are used , the degree of iteration or the influence such engagement has over any final decision. In the model used here to assess MCA use, it was the degree of engagement, as evaluated by the number of stages in which participants had meaningful input, that was employed: this is a useful but only partial measure of overall impact.

It should also be noted that the model may be criticised for its predisposition towards a constructivist approach if there is an assumption that greater *Breadth* and *Depth* is always desirable. That is, may there be instances where the decision making is best done exclusively by a narrower range of experts? As discussed in the previous section, the degree to which participatory decision making should be extended – and the impact of such extension on scientific legitimacy – remains a sharply contested issue. However, the BID model does not necessarily align itself with any particular position in this debate: it can be used merely as a means of assessing the type and extent of participation so that better judgments may be made about how deliberative engagement should be planned and implemented.

It is concluded, therefore, that the BID model has the potential to make a valuable and innovative contribution to the research and practice of participatory decision making. It could, however, be subject to further research and testing.

7.6 Reflection on the methodology employed

As outlined in the first chapter, the first stage of this research arose from the earlier M.Res study (which is described in more detail in section 5.3, with the abstract included as

Appendix 7) as discussed in section 1.2. This was clearly advantageous in some respects, in that the researcher was already aware of many of the issues and the local context, as well as having made contacts with several of the stakeholders. In other words it provided a firm foundation for the first two steps of the MCA process (problem identification and identification of stakeholders). Relationships had already been constructed and the author had gained a knowledge and understanding of the nature of the problem – and how it was manifested in this particular location – that provided an invaluable basis for facilitating the MCA process. In most cases where participative MCA might be used this pre-existing knowledge base would be unavailable.

With hindsight, however, the problem identification could have been better defined. In particular, the locus of study has been consistently referred to as 'The River Cree'; however, it became clear during the study that stakeholders used the term in different ways. Some, for instance, did not include the Water of Minnoch (and its tributaries) – where initial water sampling was conducted – within the 'River Cree' (although it is clearly part of same catchment); others used the terms 'Upper' and 'High' Cree to designate portions of the overall system. Lack of clarity about the area under consideration caused some confusion during the early stages of the study.

Nevertheless, the fact that the author had undertaken the initial M.Res study was clearly an advantage and raises the question of how transferable this method would be in problems with quite different contexts. Moreover, this raises a further question concerning the pre-existing experience, knowledge and skills of the author, as the facilitator of the MCA process. Each facilitator would bring a unique combination of these to the process, and the impact of these on the outcomes – both concrete and less tangible – are complex and difficult to predict. For instance, the non-compliance of stakeholders with some of the MCA tasks that is often reported (even by generally exemplary studies: see section 7.3 above), might be especially sensitive to the nature of the facilitator-stakeholder relationship. In other words, the use of participative MCA methods such as SMARTEST is not a straightforward mechanical process; rather it requires various inter-personal skills as well as knowledge of diverse areas such as organisational structures, legislation and environmental science. As discussed in section 2.4, the skill and experience of the facilitator is a crucial determinant of how successful the procedure will be.

This was especially clear in ensuring that the design features of the SMARTEST method were implemented. Ease-of-use, stakeholder involvement and iterativity (that is, the design features 1-5 as described in section 5.1.2 and evaluated in section 7.3) require not only that an appropriate technique (the evidence suggesting that SMARTEST is indeed appropriate) but also a skilled facilitator who understands the reasons for this approach. For the SMARTEST method to be further developed further studies will need to be conducted to investigate how this can be achieved.

With regard to the second stage of the process, Model Building and Use, it can be concluded that process worked well. The level of cooperation and engagement provided by the Stakeholder A group was invaluable in enabling the modelling stage to proceed smoothly. The main problem encountered during this stage was the total duration over which it extended. The study ran from early 2009 to June 2010, and, because of the researcher's unfamiliarity with the method and the necessity for iteration (and hence careful consideration of results and feedback), there were significant gaps between activities with the Stakeholders. These gaps inevitably led to a loss of continuity and impetus: each new round of interviews had to commence with a reiteration of progress so far. Further use of the SMARTEST process should ideally be carried out over a significantly shorter period. The requirement for iterativity also provides some limits on the size of the participant group, in that the time required to complete each step (particularly steps 1-5 where agreement of all stakeholders is necessary) will increase rapidly with the number of participants. In other words, while SMARTEST's iterativity greatly increase the potential *Impact* of the process it does provide a limit on its *Breadth*. The development of an on-line version might be usefully investigated in this respect.

A crucial question must be asked: to what extent has the method employed in this study allowed conclusions to be drawn on how generally the SMARTEST method may be applied? There are, clearly, a number of important variables that may influence the extent to which

SMARTEST may facilitate environmental decision making: the nature of the problem itself; stakeholder factors (inter-relationships, power distribution, pre-existing knowledge); the experience, skill and knowledge of the facilitator and their impact on their relationships with the stakeholders. From the single case study reported here it is not possible to extrapolate with any degree of confidence to other case involving such variables. It can only be restated that SMARTEST appears to have performed well in this instance, meeting its design criteria and facilitating a complex decision process.

7.7 Future lines of research

The research that could lead on from this study falls into two categories: firstly, research into the subject of the study, that is, recovery from acidification of the River Cree; secondly, research into the feasibility of developing the SMARTEST method for wider use as a participatory MCA technique, specifically designed for environmental problems.

The first of these should not be neglected. While the primary aim of this study has been the development and evaluation of the SMARTEST method, it should be remembered that the issue of acidification is an important and pressing one. The individuals who gave their time to participate in this study were clearly motivated by the desire to find a solution to the recovery issue. It is to be hoped that the SMARTEST method has facilitated that, as the evidence reported here suggests. Further research into the outcome of the liming trials, which followed this study, is being undertaken and will contribute more widely to the literature on the recovery of aquatic ecosystems.

With regard to the implications for research into Participative MCA generally and SMARTEST in particular: it is to be hoped that research into participative MCA is about to enter a new phase. The method is now widely used, but much more infrequently is it used well (as indicated in section 3.5, where significant examples of poor practice were identified). There is a lack of standardisation and insufficient agreement about methods and techniques. A process by which practitioners, who are new to the method, can gain a straightforward overview of the techniques available, as well as guidance on which are most appropriate in a given context, is urgently needed.

SMARTEST seems to offer a valuable technique to the tool-box of environmental decision makers.   For it to be developed further, it needs to be tested in a range of different problem contexts, for instance where stakeholders are more heterogeneous and the problem area more contentious.   SMARTEST is designed to maximise usability and acceptability. In this case study it was used with a group of well educated professionals. A better test of its effectiveness as a participative method would be its use with diverse stakeholders who had very different educational and occupational backgrounds.   A series of case studies exploring the applicability of SMARTEST in a range of contexts would evaluate the potential and limitations, as well as enabling further development to be implemented.

7.8   Conclusions

Finally, what can be concluded about the problem of recovery from acidification of aquatic ecosystems? To some extent, the problem seems insoluble: too much damage has been done to ecosystems and most rehabilitation methods have other deleterious, even more serious effects.   Moreover, global climate change may well alter environmental conditions so much that any return to so called pristine conditions becomes impossible.   The search for a solution to the recovery problem reveals, perhaps, an inherent flaw in the Ecological Modernisation approach which underpins so much environmental management practice: it seeks to use technological solutions to solve problems created by technology, without addressing underlying causes of the original problem or fully recognising the interrelationships within ecosystems which any such solutions may imperil. In other words, the methods discussed here are founded on anthropocentric assumptions; perhaps only a more comprehensive ecocentric worldview can result in true sustainability. For the aquatic ecosystems of Southwest Scotland it may be too late: they may never return to the state they were in before the industrial revolution. But ecosystems are resilient and enduring: the 'flowery banks of Cree' may border an aquatic ecosystem that is still as viable as it was when Robert Burns wrote those lines.

Environmental issues, such as this, can present seemingly intractable problems that span the physical, biological and social spheres of knowledge. Integrative methods, such as participative MCA, may provide innovative opportunities for tackling such problems. With techniques such as SMARTEST it may be possible for our society to develop the collective 'ecological intelligence' (Coupe 2009) that will enable us to better decide on when and how to intervene in environmental problems.

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Appendices

Appendix 1
Comparison of three methods of calculating weights from rankings: Rank Order Centroid (ROC), Rank Sum (RS) and Rank Reciprocal (RR)

Appendix 2
Analysis of stakeholder participation in selected research articles

Appendix 3
Questionnaire A

Appendix 4
Questionnaire B

Appendix 5
Questionnaire C

Appendix 6
Stakeholders B group details

Appendix 7
M.Res study abstract

Appendix 8
Further information on stakeholder representatives

Appendix 1 Comparison of three methods of calculating weights from rankings: Rank Order Centroid (ROC), Rank Sum (RS) and Rank Reciprocal (RR)

The three methods produce appreciably different weighting values, as shown in the following illustrative examples. Table 1 compares weights for each rank given by each of the three methods, for N=3 to N=10

Table 1 Comparing ranking weights in three methods: ROC, RS and RR

ROC	**N**							
Ranks	3	4	5	6	7	8	9	10
1	0.611	0.521	0.457	0.408	0.37	0.34	0.314	0.293
2	0.278	0.271	0.257	0.242	0.228	0.215	0.203	0.193
3	0.111	0.146	0.157	0.158	0.156	0.152	0.148	0.143
4		0.063	0.09	0.103	0.109	0.111	0.111	0.11
5			0.04	0.061	0.073	0.079	0.083	0.085
6				0.028	0.044	0.054	0.061	0.065
7					0.02	0.033	0.042	0.048
8						0.016	0.026	0.034
9							0.012	0.021
10								0.01

RS	**N**							
Ranks	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	0.5	0.4	0.333	0.286	0.25	0.222	0.2	0.182
2	0.333	0.3	0.267	0.238	0.214	0.194	0.178	0.164
3	0.167	0.2	0.2	0.19	0.179	0.167	0.156	0.145
4		0.1	0.133	0.143	0.143	0.139	0.133	0.127
5			0.067	0.095	0.107	0.111	0.111	0.109
6				0.048	0.071	0.083	0.089	0.091
7					0.036	0.056	0.067	0.073
8						0.028	0.044	0.055
9							0.022	0.036
10								0.018

RR	**N**							
Ranks	**3**	**4**	**5**	**5**	**7**	**8**	**9**	**10**
1	0.545	0.48	0.438	0.408	0.386	0.368	0.353	0.341
2	0.273	0.24	0.219	0.204	0.193	0.184	0.177	0.171
3	0.182	0.16	0.146	0.136	0.129	0.123	0.118	0.114
4		0.12	0.109	0.102	0.096	0.092	0.088	0.085
5			0.088	0.082	0.077	0.074	0.071	0.068
6				0.068	0.064	0.061	0.059	0.057
7					0.055	0.053	0.05	0.049
8						0.046	0.044	0.043
9							0.039	0.038
10								0.034

Some of the significant differences between the methods can be illustrated by examining the weights for the case of N=8, as shown in 2.

Table 2 Weights derived from three methods when N=8

Ranks	ROC	RS	RR
1	0.340	0.222	0.368
2	0.215	0.194	0.184
3	0.152	0.167	0.123
4	0.111	0.139	0.092
5	0.079	0.111	0.074
6	0.054	0.083	0.061
7	0.033	0.056	0.053
8	0.016	0.028	0.046

Correlation coefficients for the correlations between the results of the three methods are shown in table 3

Table 3 Correlations between the weights derived from ROC, RS and RR when N=8.

	RS	RR
ROC	0.940	0.974
RS		0.840

There is a high degree of agreement between the results for ROC and RS, and between ROC and RR, but lower agreement between RS and RR. However, more significant deviations in the results of the three methods become apparent in figure 1

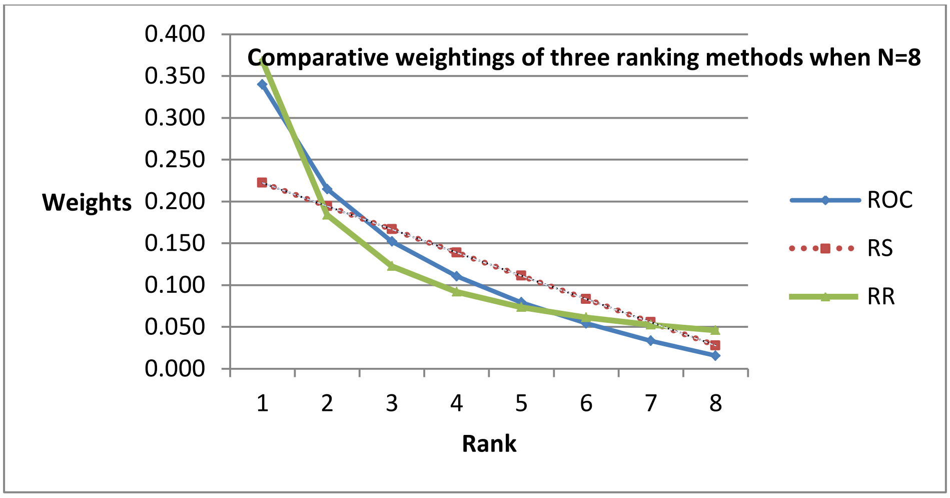

Figure 1 Comparing weighting of ROC, RS and RR methods for N=8

As can be seen, ROC and RR produces much higher weights than RS for the most preferred option (that is, rank 1) but rather lower values for middle ranked criteria.

Another way of exploring the differences between the three methods is to examine the ratios between the highest and lowest ranks (that is, between most and least preferred options) as shown in table 4. The ROC method produces very high ratios between weights for the most important criterion and the least important (Belton and Stewart 2002).

Table 4 Highest and lowest weights and ratios for three methods for N=3 to N=10

	N	3	4	5	6	7	8	9	10
	highest	0.61	0.52	0.46	0.41	0.37	0.34	0.31	0.29
ROC	lowest	0.11	0.06	0.04	0.03	0.02	0.02	0.01	0.01
	ratio	***5.50***	***8.33***	***11.42***	***14.70***	***18.15***	***21.74***	***25.46***	***29.29***
	highest	0.50	0.40	0.33	0.29	0.25	0.22	0.20	0.18
RS	lowest	0.17	0.10	0.07	0.05	0.04	0.03	0.02	0.02
	ratio	***3.00***	***4.00***	***5.00***	***6.00***	***7.00***	***8.00***	***9.00***	***10.00***
	highest	0.55	0.48	0.44	0.41	0.39	0.37	0.35	0.34
RR	lowest	0.18	0.12	0.09	0.07	0.06	0.05	0.04	0.03
	ratio	***3.00***	***4.00***	***5.00***	***6.00***	***7.00***	***8.00***	***9.00***	***10.00***

As can be seen ROC gives consistently higher ratios (of highest ranking weight compared to lowest ranking weight) and this increases with the number of criteria used. It should also be noted that this is despite the fact that with ROC the highest weights are lower than the corresponding RR weights. This apparent disparity can be explained by the fact that the lowest ranked ROC weights have very low values indeed as N increases. For instance with 12 criteria, the lowest ranked weight value is 0.007. With such low weights lower criteria will contribute proportionately so little to the final aggregation when N>8 that it seems scarcely worthwhile for them to be retained.

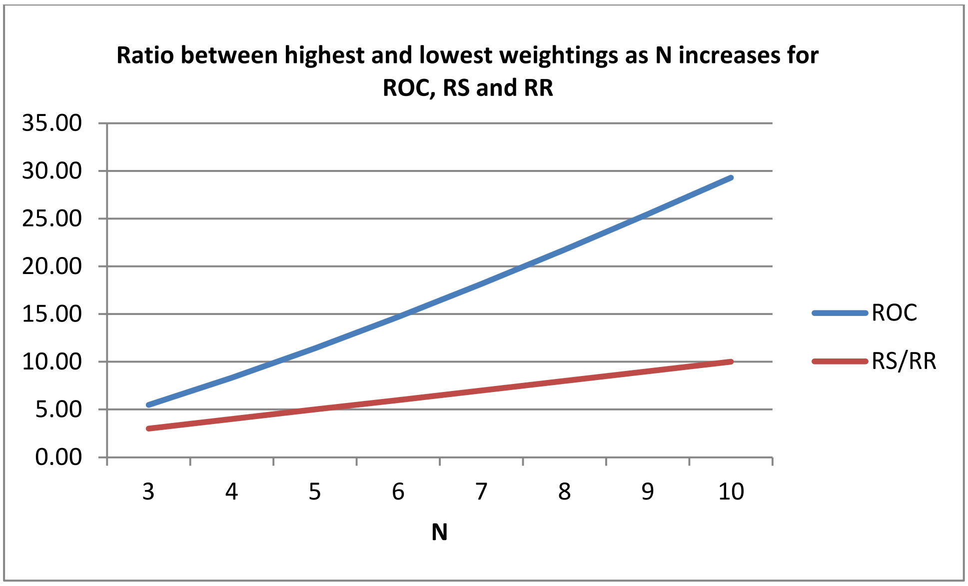

Figure 2 Ratio between highest and lowest weightings: comparison of ROC, RS and RR

Figure 2 shows the extent to which the Highest/Lowest criteria weightings ratio becomes inflated with the ROC method as N increases, while it stays much lower with RS and RR. This provides a powerful argument for using the RS method, especially when the number of criteria is high.

Table 5 Weights derived from ranks using the RS, RR and ROC methods when N=12

Rank	ROC	RS	RR
1	0.259	0.154	0.322
2	0.175	0.141	0.161
3	0.134	0.128	0.107
4	0.106	0.115	0.081
5	0.085	0.103	0.064
6	0.068	0.090	0.054
7	0.054	0.077	0.046
8	0.043	0.064	0.040
9	0.032	0.051	0.036
10	0.023	0.038	0.032
11	0.015	0.026	0.029
12	0.007	0.013	0.027

Appendix 2: Analysis of stakeholder participation in selected research articles

Author(s)	Nature of participants	Notes	MCA stages in which participants were engaged
Ananda and Herath (2003)	36 individuals from 5 stakeholder groups including industry, environmentalists and recreational users were identified using the "snowball method"[101].	This can be regarded as an incomplete form of PMCA[102]. Identification of criteria was obtained from discussion with experts; option identification carried out by authors.	Criteria weighting; Value Functions
Duke and Aull-Hyde (2002)	Residents of affected area interviewed to establish criteria weightings (N=129).	Interviews used AHP to determine weights but interviewees had no further involvement.	Criteria weighting only
Gamboa (2006)	Public (as well as experts) involved in three focus groups (N=20) (mainly local government), a workshop (for young people 14-18) : and in-depth interviews (N=25):	Used social MCE, but the "influence of public involvement … is limited to analyse and to comment on the Environmental Impact Study" (p166). Stakeholders' opinions were mediated by author – the extent of stakeholder engagement with the process is unclear.	Criteria identification
Hajkowicz (2006)	Members of public (residents and visitors) responded to street survey (N=901) but only 420 completed ranking	Interviews were designed to be short ("less than 5 minutes") but nevertheless the completion rate was less than 50%	Criteria weighting only (ranking)
Hermans et al (2007)	Stakeholders (number unstated) involved in workshops over 10 month period. Stakeholders were members of a Partnership group involving collaboration between "communities, citizens, conservation groups and ... government". Also a survey of residents was carried out. (N=121)	Stakeholders had no involvement in identifying alternatives. The Impact matrix was completed by experts.	Criteria identification; criteria weighting
Hostmann et al (2005)	26 individuals from 8 major stakeholder groups (snowball sampling). Interview based.	A two stage process: 26 individual in stage 1 and 20 in stage 2.	Criteria weighting; Value Functions

[101] The 'snowball' or 'referral sampling' method involves using pre-identified stakeholders to identify new, stakeholders previously unknown to the researchers.
[102] PMCA refers to participatory Multi Criteria Analysis.

Kallis et al (2006)	A two stage process. Stage 1: 16 stakeholders from stakeholder organisations, including public authorities, business and NGOs identified alternatives and criteria. Stage 2: Focus group with 11 individuals to discuss results.	Some stakeholders (such as the Association of Urban Developers) refused to participate "despite repeated invitations" (p225). Authors also stated that criteria identification was contentious and that a drawback of the method was lack of deliberation between stakeholders. The Impact matrix was completed by the authors.	Identify alternatives; Identify criteria
Kangas et al (2001).	Unspecified number of individuals from 6 stakeholder groups, including a National Forest Service and representatives of interest groups.	States a participatory approach is used, although the methodology is not explicit. Experts involved in all stages apart from criteria weighting	Criteria weighting only
Klauer et al (2006)	Individual and group interviews and discussions with stakeholders but method and numbers involved not further specified.	Initially "several" (number unspecified) stakeholders involved in identifying alternatives, but decision made before final MCA process could be completed.	Identifying alternatives
Mander (2008)	Four stage process, with 27 individuals undertaking the MCA. Stakeholders were 'key regional actors'. Methodology included semi-structured interviews and analysis of written material.	Note the high level of participation but also that 30% of stakeholders did not complete the Impact Matrix scoring (usually "too time consuming"). Author developed options (scenarios) but these were subject to stakeholder review.	Identified criteria and reviewed scenarios (alternatives). Criteria weighting; carried out Impact Matrix scoring and sensitivity analysis
Marttunen et al (2006)	36 Interviews with members of stakeholder groups plus questionnaire to 2500 residents ('citizens').	Extent of participation of stakeholders into process is incompletely specified. Use to which residents' questionnaire information is put is unspecified.	Identifying alternatives; criteria weighting
Moran et al (2007)	Initial public focus groups used to identify attributes. AHP conducted with representative citizen sample of 169.	AHP method – the pair-wise comparison of criteria (attributes) established criteria weightings only. Method similar to Duke and Aull-Hyde (2002). No Impact Matrix employed.	Criteria weighting only
Munda and Russi (2008)	Interviews with 15 social actors, including residents.	Used Social MCE (SMCE) which intends to "guarantee that all involved actors can participate" (p712) although "participation is used as an input for the analysis, but criteria and weights are not directly derived from participations" (p713): actors identified the alternatives and criteria but experts completed the Impact Matrix.	Identify alternatives; identify criteria

Paneque Salgado et al (2009)	16 stakeholders (social actors) from four groups: "public administration, business, non-governmental organisations and experts" (p995). Uses interviews, questionnaires and focus groups. Also a survey to general public (N=425).	Uses the Social MCE (SMCE) approach. Authors carried out Impact Matrix. Survey results "incorporated in SMCE via focus groups, but stakeholders questioned effects on impact matrix. Method used – NAIADE – does not differentially weigh criteria.	Identify alternatives; identify criteria
Prato and Herath (2007)	Survey of 20 farmers within affected catchment involved in survey	"Criteria weights were determined based on information obtained in a survey of 20 farmers" (p630); that is, the process was non-iterative[103]	Criteria weighting
Proctor and Drechsler (2006)	6 stakeholders (national resource managers) in citizens' jury (or more correctly 'stakeholders' jury)	Used a method the authors termed 'Deliberative MCE' (DMCE). Impact Matrix was completed with "input from experts" (p181). The process was highly iterative.	Identify alternatives; identify criteria; Criteria weighting; Sensitivity analysis
Refsgard (2003)	The process involved a discussion between two actors : stakeholder (the decision maker) and an expert - and the author	Actors had some involvement in criteria identification. Criteria were proposed by author.	Criteria weighting
Scolobig et al (2008)	Semi structured interviews with social actors ("qualified informers") plus survey (face to face) of 100 citizens in affected area.	Used the SMCE method. Identification of criteria and alternatives was carried out using data from interviews and the survey, but the details are not specified: the process was essentially non-iterative. Impact Matrix done by authors.	Identify alternatives; Identify criteria
Sharifi et al (2002)	Interviews with unspecified number of individual stakeholders from four representative groups plus residents.	Stakeholders had input into criteria identification and weighting with "several rounds of discussion": process at least partially iterative. However, it is unclear how much stakeholders were engaged with the process and Involvement was in some cases indirect and mediated by authors.	Identify criteria criteria weighting
Stirling and Mayer (2001)	Interviews with 12 participants who were "senior representatives of leading protagonists in the current UK debate" on the issue (p533).	Used Multicriteria mapping: a heuristic rather than prescriptive tool Initial alternatives designed by authors, but stakeholders could add new options. Highly iterative.	Identified alternatives ; Identified criteria; Criteria weighting; Impact Matrix scoring; sensitivity analysis

[103] The term 'Iterative' is used here to denote a process in which the researchers return to stakeholders for review or clarification of earlier input. In a typically non-iterative process the information flow is purely one-way: from the stakeholders to the researchers, with the overall control on how the information is used remaining firmly with the latter..

Strager and Rosenberger (2007)	Stakeholders (number not stated) involved in unspecified manner	Identification of criteria and options was "based on input from local stakeholders and technical Experts". No further information was supplied on this process	Identified alternatives; identified criteria
Tzeng et al (2002)	Questionnaire to residents used to obtain views (N=2739).	Non-iterative, survey based method.	Criteria weighting only

Appendix 3 Questionnaire A
Facilitating recovery from aquatic acidification in the River Cree

Robert Bray, David Livingstone Centre for Sustainability, Department of Civil Engineering, University of Strathclyde

I have now completed the first stage of this project, which has involved interviews in organisations working with the environment of the River Cree. From these interviews I have identified four main ***objectives*** of any programme to improve recovery from acidification.

These are:

- Improving biodiversity
- Supporting the local economy
- Supporting recreational and amenities uses
- Meeting environmental objectives

These each contain a number of ***secondary objectives*** as follows:

Main objectives	*Secondary Objectives*
Improving biodiversity	1. Improving **fish biodiversity**
	2. Improving **bird biodiversity**
	3. Improving **invertebrate biodiversity**
	4. Improving **plant biodiversity** and abundance
Supporting the local economy	5. Maintaining/ increasing **Forestry Enterprise income**
	6. Maintaining / increasing **private forest income**
Supporting recreational and amenities uses	7. Maintaining / increasing Recreational **access** (walkers, cyclists, visitors, local people, birdwatchers etc.)
	8. Maintaining/ Enhancing **Landscape features**
Meeting environmental objectives	**9.** Maintaining/ improving **water chemistry**
	10. Contributing to **Carbon sequestration**

How can we measure the extent to which secondary objectives are being met? The following table provides proposals for a measure of each secondary objective (these are termed '*attributes*'):

Secondary Objectives	***Attributes*: measures of the extent to which criteria can be achieved by 2015**
Improving **fish biodiversity**	Change in average fish species richness over all streams and tributaries
Improving **bird biodiversity**	Change in average bird species richness over catchment
Improving **invertebrate biodiversity**	Change in average species richness of acid sensitive invertebrates over all streams

Improving **plant biodiversity**	Change in average species richness and abundance of acid sensitive plants (macrophytes and phytobenthos) over all streams
Maintaining/ increasing **Forestry Enterprise income**	change in overall Forest Enterprise Income from the Cree
Maintaining / increasing **private forest income**	change in overall private forest income from the Cree
Maintaining / increasing Recreational **access** (walkers, cyclists, visitors, local people, birdwatchers etc.)	Change in number of visitors using amenities on the Cree
Maintaining/ Enhancing **Landscape features**	Valuation of the attractiveness of the overall landscape
Maintaining/ improving **water chemistry**	Meeting Water Framework Directive (WFD) 'Good Surface Water Chemical Status' targets
Contributing to **Carbon sequestration**	change in the estimated amount of Carbon stored in the Cree catchment

In the next stage of this project I will be sending out a questionnaire asking for these objectives to be prioritised. Before doing that I would be grateful for your views:

1 Would you want to add any main or secondary objectives?
2 Would you want to modify any main or secondary objectives?
3 Are the attributes useful ways of measuring the secondary objectives? Would you propose modifications?

Thanks you again for your contribution to this project.

Appendix 4 Questionnaire B
Facilitating recovery from aquatic acidification in the River Cree
Questionnaire B: ranking criteria

Robert Bray, David Livingstone Centre for Sustainability, Department of Civil Engineering, University of Strathclyde

During the first stage of this project we identified four main **objectives** for a programme to aid recovery from acidification of the river Cree. These are given in the left hand column of the table below. The middle column gives more detailed **secondary objectives**. The right hand column lists the ways in which each secondary objective might be measured ('attributes'), to see how far it has been achieved.

Main objectives	***Secondary Objectives***	***Attributes*: measures of the extent to which criteria can be achieved by 2015**
Improving ecology	Improving **fish species richness and abundance**	Change in overall fish biodiversity index (incorporating richness and abundance)
	Improving **mammal species richness and abundance**	Change in overall biodiversity index for mammals
	Improving aquatic **bird species richness and abundance**	Change in overall biodiversity index for aquatic birds
	Improving aquatic **invertebrate species richness and abundance**	Change in overall biodiversity index for aquatic invertebrates
	Improving **plant species richness** and abundance (in keeping with unmodified channel processes)	Change in overall biodiversity index for plants (macrophytes and phytobenthos)
Supporting the local economy	Maintaining / increasing **private forest income**	Change in overall private forest income from the Cree catchment
	Maintaining/ increasing **Forestry Enterprise asset value**	Change in overall Forest Enterprise Income from the Cree catchment
Supporting social recreational and amenities uses	Development of **Community involvement**	Overall development of community activities, events and projects in the Cree
	Maintaining / increasing Recreational **access** (walkers, cyclists, visitors, local people, birdwatchers, anglers etc.)	Change in number of visitors using amenities on the Cree catchment
	Maintaining/ Enhancing **Landscape features**	Valuation of the attractiveness of the overall landscape
Meeting environmental objectives	Contributing to **Carbon sequestration**	Change in the estimated amount of Carbon stored in the Cree catchment
	Maintaining/ improving **water chemistry**	Meeting Water Framework Directive (WFD) 'Good Surface Water Chemical Status' targets

For the next stage of the project we need to establish what stakeholders' priority objectives are. To participate in this stage of the process, please complete the three short steps below.

Step 1: Ranking the four main objectives
Please rank the four **main objectives** in order of importance: that is, your perceived preferences. Rank 1 would be the main objective that you believe should have the greatest priority, while rank 4 would be the least importance. You can use tied ranks if you wish, and for as many objectives as you need to. So, for instance, if you feel that the four main objectives are equally important you might give all four a rank of 1.

Main objective	Your rank ⬇
Improving ecology	
Supporting the local economy	
Supporting social recreational and amenities uses	
Meeting environmental objectives	

Step 2: Ranking the secondary objectives
Please rank the 12 secondary objectives in order of importance. Again, this refers to your perceived preferences. Rank 1 would be the objective that you believe should have the greatest priority, while rank 12 would be the least importance. You can use tied ranks if you wish, and for as many objectives as you need to.

Secondary Objectives	***Rank*** ⬇
Improving **fish species richness and abundance**	
Improving **mammal species richness and abundance**	
Improving aquatic **bird species richness and abundance**	
Improving aquatic **invertebrate species richness and abundance**	
Improving **plant species richness** and abundance (in keeping with unmodified channel processes)	
Maintaining / increasing **private forest income**	
Maintaining/ increasing **Forestry Enterprise asset value**	
Development of **Community involvement**	
Maintaining / increasing Recreational **access** (walkers, cyclists, visitors, local people, birdwatchers, anglers etc.)	
Maintaining/ Enhancing **Landscape features**	
Contributing to **Carbon sequestration**	
Maintaining/ improving **water chemistry**	

Step 3 Finally, taking the most important **secondary objective** (rank 1) and then comparing it with the least important secondary objective: can you say how many more times the most important objective is than the last objective (you can use any number between 3 and 20)? Please put the number in the box below.

The most important secondary objective is □ times more important than the least important objective.

Thank you for your participation.

Appendix 5 Questionnaire C
Facilitating recovery from aquatic acidification in the River Cree

Robert Bray, David Livingstone Centre for Sustainability, Department of Civil Engineering, University of Strathclyde

Impact Matrix

From the first round interviews with the key stakeholders, the following objectives were identified for a programme to aid recovery from acidification of the river Cree. These are given in the left hand column of the table below. The middle column gives more detailed **secondary objectives**. The right hand column lists the ways in which each secondary objective might be measured ('attributes'), to see how far it has been achieved.

Main objectives	***Secondary Objectives***	***Attributes*: measures of the extent to which criteria can be achieved by 2015**
Improving ecology	Improving **fish species richness and abundance**	Change in overall fish biodiversity index (incorporating richness and abundance)
	Improving **mammal species richness and abundance**	Change in overall biodiversity index for mammals
	Improving aquatic **bird species richness and abundance**	Change in overall biodiversity index for aquatic birds
	Improving aquatic **invertebrate species richness and abundance**	Change in overall biodiversity index for aquatic invertebrates
	Improving **plant species richness** and abundance (in keeping with unmodified channel processes)	Change in overall biodiversity index for plants (macrophytes and phytobenthos)
Supporting the local economy	Maintaining / increasing **private forest income**	Change in overall private forest income from the Cree catchment
	Maintaining/ increasing **Forestry Enterprise asset value**	Change in overall Forest Enterprise Income from the Cree catchment
Supporting social recreational and amenities uses	Development of **Community involvement**	Overall development of community activities, events and projects in the Cree
	Maintaining / increasing Recreational **access** (walkers, cyclists, visitors, local people, birdwatchers, anglers etc.)	Change in number of visitors using amenities on the Cree catchment
	Maintaining/ Enhancing **Landscape features**	Valuation of the attractiveness of the overall landscape
Meeting environmental objectives	Contributing to **Carbon sequestration**	Change in the estimated amount of Carbon stored in the Cree catchment
	Maintaining/ improving **water chemistry**	Meeting Water Framework Directive (WFD) 'Good Surface Water Chemical Status' targets

And six main alternatives courses of action – **'Options'** - were also identified

Option	Explanation
Status quo	The existing situation: this is used as a baseline measure
'Status Quo plus'	The situation as it is likely to develop without any significant changes in environmental management strategy
Large scale clearance with no replanting	An overall reduction of the coniferous forest cover of approximately 40% by 2015, by means of felling without coniferous replanting.
Liming (shells)	Targeted silos in particular critical watercourses
Change CL to the tripartite 'traffic lights' model	Replacing current Critical Load method with one with two thresholds: the current CL level ('red') and another higher threshold ('amber') derived for instance from biological monitoring data, indicating potential concern, need to look at further data to see if there are signs of recovery before proceeding
Continuous cover forestry	Selective harvesting as opposed to clear felling, thinning trees but maintaining canopy cover; to replace clear felling.

In this stage of the study we are looking at how each of the **Options** will affect each of the criteria, using the table below (the **Impact Matrix**). Each cell of the matrix will record the likely impact of one option on one of the attributes (which measures how far one criteria is met).

	Options					
***Attributes*:** measures of the extent to which criteria can be achieved by 2015	Status quo	'Status Quo plus'	Large scale clearanc e	Liming (shells)	Change CL to the tripartite 'traffic lights' model	Contin uous cover forestr y
1. Change in overall fish biodiversity index (incorporating richness and abundance)						
2. Change in overall biodiversity index for mammals						
3. Change in overall biodiversity index for aquatic birds						
4. Change in overall biodiversity index for aquatic invertebrates						
5. Change in overall biodiversity index for plants (macrophytes and phytobenthos)						
6. Change in overall private forest income from the Cree						

	Options					
catchment						
7. Change in overall Forest Enterprise Income from the Cree catchment						
8. Overall development of community activities, events and projects in the Cree						
9. Change in number of visitors using amenities on the Cree catchment						
10. Valuation of the attractiveness of the overall landscape						
11. Change in the estimated amount of Carbon stored in the Cree catchment						
12. Meeting Water Framework Directive (WFD) 'Good Surface Water Chemical Status' targets						

In order to complete the Impact Matrix, we are asking a number of experts to complete those aspects with which they have specialist knowledge.

Please identify which of the attributes (rows) you feel you have sufficient expertise in to make judgements:
……………………………………………………….

For each attribute that you have selected, indicate the impact of each option on that attribute. You can do this using any numerical format you feel is appropriate. For instance, this could be in percentage change.

Appendix 6 Stakeholders B group details

Organisation	Status	Responsibilities / objectives
Cree District Salmon Fishery Board	Public Body	Established by the 1986 Salmon Act [now consolidated into the Salmon & Freshwater Fisheries (Consolidation) (Scotland) Act 2003].
Cree Valley Community Council	Public body (Local Government)	Defined by the Local Government (Scotland) Act 1973 and Section 22 of the Local Government (Scotland) Act 1994:
Galloway Forestry Forum	Advisory Group	Regional Forestry Forums Give advice on the implementation of the Scottish Forestry Strategy
Glen Trool estates	Private landowners	
National Farmers Union	Trade Association	Professional representation and services to farmers and growers
Newton Stewart Angling Association	Voluntary organization	Maintains and provides game fishing in area, including River Cree .
Red Squirrels South Scotland	Voluntary organization (charity),	Conservation of Red Squirrels
RSPB	Voluntary organization (charity)	Conservation of wild birds
South Ayrshire Council Planning Department	Local Government	Responsible for Planning development of Galloway and South Ayrshire Biosphere
Southern Upland Partnership	Voluntary organization (charity),	To promote an integrated and sustainable approach to rural development and land use in Scotland's Southern Uplands
The Ramblers	Voluntary organization (charity),	Walkers' rights

The initial institutional analysis suggested a straightforward divide between the stakeholder A and B groups, with those in group A having significantly greater involvement in the problem than any of the B group. There was no sense, therefore, that any organisations felt unfairly excluded from being able to participate. The information provided by the stakeholder B group was very variable. With most of these being voluntary organisations, and consequentially having fewer resources than statutory bodies, few had the time available to provide detailed input concerning a problem that was not, for any of them, a central priority. The information from the Stakeholder B group could, therefore, only be used as general background.

Appendix 7: M.Res study abstract

Factors underlying differential ecosystem recovery from acidification of upland waters in the River Cree catchment area, Dumfries and Galloway, Scotland.

A dissertation submitted by Robert Bray to the Department of Civil Engineering, University of Strathclyde, in part completion of the requirements of the M. Res. in Integrated Pollution Prevention and Control. August 2008

Abstract

Acid Rain, or more correctly Acid Deposition, has been responsible for widespread damage to forests and to aquatic ecosystems, causing ecological simplification, the loss of acid-sensitive species and a reduction in biodiversity. Although major international agreements have succeeded in reducing acid deposition in Europe and North America, overall global emissions of acidifying pollutants continues to increase. Even in regions where the emissions have fallen substantially, biological recovery of many waters has been slower and more uneven than chemical recovery. In Scotland, the Galloway hills of the South West have been identified as showing particularly noteworthy discrepancies between predicted and observed recovery from acidification. Two main factors have been used to explain this: geology (specifically granitic bedrocks that have reduced buffering) and land-use (specifically coniferous afforestation that is widely associated with high levels of acidification impact). The present study tests the hypothesis that afforestation is more significant than underlying geology in limiting recovery. Six streams were sampled using a 2 x 3 design (three streams with sedimentary catchments and three with granitic; streams in each geological category had low, medium or high afforestation). Chemical and biological samples were taken twice in two different locations within each stream. The results provide evidence for substantial recovery in all sites in terms of chemical indicators, but more limited and uneven biological recovery. Some streams remained devoid of Acid Sensitive macroinvertebrates.

Analysis of the results suggests that both afforestation and geology had significant impacts on biological indicators of recovery, although geology was more of an influence on the richness of acid sensitive species. There was a strong interaction between the two factors. Possible reasons for the differentials between chemical and biological theories are discussed in light of these results, including the relevance of differential dispersal, the closure of disturbed ecosystems and variations in stream flow (episodicity). The limitations of this study and proposals for future research are briefly discussed.

Appendix 8: further information on stakeholder representatives involved in the project

Stakeholder Organisation	Representative	Job title
Dumfries and Galloway Council (D&G)	Peter Norman	Council Biodiversity Officer
Forestry Commission Scotland, Galloway District (FCS)	Rob Soutar	Forest District Manager. Galloway Forest District.
Galloway Fisheries Trust (GFT)	Jamie Ribbens	Senior Biologist
Scottish Environment Protection Agency (SEPA)	John Gorman	Senior Environment Protection Officer, Newton Stewart Area
Scottish Natural Heritage (SNH)	Andrew Bielinski	Area Officer, Newton Stewart
The Cree Valley Community Woodlands Trust (CVCWT)	Peter Robinson	Ecologist