Collaborative water-resource governance in the UK: Understanding network structure and functionality of a catchment-based approach to water-quality management

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Thesis submitted for the degree of Doctor of Philosophy

Department of Geography
Durham University
2017

Abstract

Since 2011 water resource governance in the UK has begun to integrate a collaborative multi-stakeholder approach to water-quality management. The Catchment-Based Approach (CaBA) facilitates local partnerships of stakeholders to co-create plans, align actions, and make collective decisions about efforts to improve and protect local river and stream environments. The approach offers potential for the enactment of effective, equitable and sustainable water management, but it is often unclear how such efforts are characterised practically. The multiplicity of stakeholders and complexity of issues and influences contribute to difficulty in discerning how governance change is functioning. This thesis uses a case study of the River Wear Catchment, North East England, where stakeholders have been operating CaBA, to begin to explore the patterns and drivers of actions and interactions that facilitate collaborative water-resource governance at the stakeholder level.

Drawing on the concept of the catchment as a complex, social-environmental system, this research utilises insights from stakeholders and a combination of analytical methods, including a network approach and agent-based modelling, to provide new perspectives on the network structure and functioning of multi-stakeholder water management. A network approach is used to build a picture of interactions amongst stakeholders and to reveal the nature of the new relationships built through CaBA. Qualitative analysis of interview data identifies key influences on the decision-making of stakeholders and the functionality of new and existing networks of relations at three levels; the interactional, individual and contextual. Agent-based modelling is then used as a heuristic research tool to combine knowledge of relational structures with influences on stakeholder behaviour to experiment with potential dynamics of the system through a specific water-quality, problem-based scenario. The combination of these analytical methods allows a more in-depth and dynamic understanding of the patterns and processes of CaBA than has been revealed previously. The thesis ultimately comments on the utility of such methods for creating new understandings of the operationalisation of water governance processes, and for the utility of those new understandings to inform and question the facilitation of effective and satisfactory delivery of collaborative multi-stakeholder water-quality management at the catchment-scale.

Table of Contents

Chapter Three: Context and Methodology: Gaining perspectives on a catchment management system

Chapter Four: Analytical methodology: Interpreting a catchment management system

Chapter Five: Networks in a catchment management system

List of Figures

List of Tables

Acknowledgements

There are many people to whom the production of this thesis is due and my thanks extend to each equally. The financial support of the Economic and Social Research Council has made the work possible and I am grateful for the opportunity it has offered and the doors it has opened.

To start, the research would not have been possible without the dedicated support and unfailing encouragement of my supervisors Professor Louise Bracken and Professor John Wainwright as well as Professor Rachel Pain. Your enthusiasm, wisdom, advice, feedback, ideas, energy, challenges and humour have anchored me and inspired me to make sense of the uncertain research process, get to grips with new methods and craft the research project beyond anything I could have achieved without your support.

I am indebted to the people and practitioners in the River Wear catchment who gave their time so willingly to be involved in the project and for sharing their experiences and opinions with me, inviting me to meetings and filling me in on issues and activities. You have been foundational to the research and are the reason for pursuing it. Thank you.

My time spent fulfilling an ESRC policy internship for three months was inspirational and energising and my thanks extend to the Communities team at DCLG in London for their support and company, and for introducing me to the world of policy research and analysis. Back in Durham, I have been privileged to be part of a supportive and dynamic department and Doctoral Training Centre. Many thanks to the staff who keep them running smoothly. Particular thanks to Bethan Kelly at NEDTC for helping so patiently with the many applications and forms at various stages. Along the journey in Durham, there have been so many encouraging colleagues and friends in the post-grad community who have offered their support and friendship throughout. There are too many to name and thank here personally, but special gratitude goes to all those in S105 and to Jack Williams, Hannah Bickerdike, Siobhan Whadcoat, Sarah Hughes, Johanne Bruun, Peter Forman, Naomi Maynard, John Morris, Jess Benjamin, Will Christiansen and Ingrid Medby among so many others who began this PhD journey together and have shared experiences, stresses, cups of tea, meals, walks, pub trips and jokes in and out of the Manley Room and department. I am grateful for your enduring friendships.

Thanks too, extend to fantastic friends and supportive communities outside of the PhD world who have offered welcome distractions, continued encouragement, space to talk, learn, relax, volunteer and belong. Thanks particularly to Katie, Naomi, Tim, Susanna, Frankie, Lizzie, Adam, Rebecca and Emily. You do so much without being aware. Thanks also to my family who have supported me throughout and been a source of encouragement. This document might go some way to explaining the mystery of my research to you.

Chapter One

Introduction

1.1 Complexity in water governance: the research premise

Governance of water resources is inherently affected by complexity and uncertainty (Chaffin *et al.*, 2016). It is affected by complexity because water-resource governance crosses biophysical and administrative boundaries and necessarily involves multiple, diverse actors, organisations and institutions who often have competing demands and expectations (Bellamy *et al.*, 2002; Ison *et al.*, 2007; Kerr, 2007). It is affected by uncertainty because social and ecological influences play out in non-linear and unpredictable ways, alongside the potential impacts of unknown influences such as climate change (Vörösmarty *et al.*, 2000). Problems prevalent in relation to water resources have often been labelled as 'wicked' problems. Wicked problems are themselves complex, uncertain, ambiguous, contested, unstable, and historically contingent, and are consequently evasive of traditional planning and management approaches (Rittel and Webber, 1973; Head, 2008). Responding purposefully to the need for governance change in relation to the emergence of wicked problems needs "capabilities to, first, simply recognise complexity and to understand the implications for planned intervention" (Woodhill, 2010:54).

In recent years, governments have become more dependent on multiple actors to help achieve specific goals due to the increasing complexity of the challenges they face (Klijn, 2008). In relation to environmental resource challenges and to water resource management problems in particular, there has been a move towards governance that involves collaboration of stakeholders across horizontal networks as an organising principle. A number of different types of governance systems have emerged as responses to a focus on complexity, contrasting to traditional technocratic solutions that assumed stability and mechanistic cause and effect. The types of governance alternatives that have arisen focus on reflexivity, resilience and responsiveness (Termeer *et al.*, 2013) through various emphases on the state or user groups to govern water (Meinzen-Dick, 2007). Amongst the approaches principles of adaptiveness, integration and collaboration have come to dominate conceptualisations of governance solutions. Such developments have led to the acceptance of normative principles of 'good water governance', which according to the UNDP (1997) should be participatory, consensus oriented, accountable, transparent, responsive, effective and efficient, equitable and inclusive and following the rule of law. Attempts to manage water differently through elements of good governance have emerged in the past 20 years and have been adopted by governments and bodies such as the EU. Changes have been facilitated by international and national legislative change and shifts in understanding, manifested in an important focus on localising decision-making and emphasising participation to tackle conflict or complex issues (e.g.Dewulf *et al.*, 2005; Faysee, 2006; Engle *et al.*, 2011).

Analysing and evaluating such governance arrangements and management mechanisms can be challenging (Pahl-Wostl *et al.*, 2007) and there is a recognition that no single governance model works across all cases and at all scales (Ostrom, 2007). Despite, or because of, such difficulties, "there is an urgent need to better understand and improve existing water governance systems"(Stein *et al.*, 2011:1086). An awareness of complexity is seen as a necessary but not sufficient condition for improving water-governance processes (Pahl-Wostl *et al.*, 2007). As such, Stein *et al.* (2011) imply that within the study of water governance:

> A major challenge is to find effective methods to analyse complex water governance arrangements, in particular the social dimension, which has often been neglected in the past (Pahl-Wostl, 2002c). Given the range and complexity of multi-actor natural resource governance arrangements, there is thus real need to develop analytical tools and methodologies that can capture and translate such complexity." (Stein *et al.*, 2011:1085)

This PhD research recognises the need to evaluate multi-actor natural resource governance arrangements in more detail in order to better understand how changes in governance are implemented within management systems and how they are (in)effective. The research identifies the shift in thinking around water resource governance and the prominence of the concept of complexity as an important framing for evaluation, particularly in relation to the components and relationships of a complex system (network structure), and their dynamics in relation to outcomes (function). The study aims to contribute to the exploration and development of analytical processes, perspectives and methodologies to better understand some of the social and social-ecological complexities of a specific and newly advocated natural resource governance process as developed in practice, both to better understand the system in order to contribute to conversations about future management within that governance system and to add to the understanding of the ability and need for research processes to reflect on practice by capturing and translating complexity.

The UK provides a context in which the governance of water resources has undergone a significant shift in the past 17 years, beginning with the application of the EU Water Framework Directive (WFD) in 2000, and culminating in the recent implementation of a Catchment-Based Approach (CaBA) to water-quality management. The aim of the approach is to more successfully implement the WFD and deliver local benefits (Watson, 2014). The trajectory of governance change has involved a decentralisation of decision-making, strategic planning and implementation to stakeholders at the river basin and catchment scale of management, focusing on a more holistic approach to restoring and protecting aquatic systems in order to ensure sustainable water use (McCormick, 2001). Governance change has incorporated ideals of Integrated Water Resource Management (IWRM) as well as participation through the encouragement of involvement of multiple stakeholders from a variety of cross-cutting sectors in management structures such as liaison panels and public consultations (during the development of River Basin Management Plans) and partnerships, steering groups, joint projects and stakeholder meetings (as part of CaBA). CaBA, in particular, symbolises an evolution of the governance approach to water management in the UK, focusing for the first time on collaborative elements that bring into formal and informal partnership a variety of state and non-state actors to implement catchment-scale management (Watson, 2014), arguably moving closer towards the principle of good governance laid out by the UNDP. The newness of this particular form of governance approach in relation to water-quality management provides an opportunity to evaluate and better understand its mechanism, patterns and complexities.

This PhD research aims to consider the characteristics and processes of the actions within the governance system through the application of a number of research perspectives to the context of catchment-scale water-quality management.. The study uses a systems perspective and the concept of networks, alongside qualitative analysis and the use of an agent-based modelling approach to explore and capture some of the aspects of complexity (including structure and function of management action and decision-making) in the governance system, based on the views and experiences of stakeholders. Such knowledge, 1) helps build a picture of practice in a particular catchment, which contributes to discussions around progress and problem-solving in that catchment, 2) adds to the ongoing evaluations of the CaBA approach to water management in England and Wales, providing learning points for other catchments, as well as 3) more broadly informing discussions of water management at the collaborative catchment scale, reflecting on the wider governance approach to water resource issues. The exploration of the system through multiple modes of analysis and perspectives also help contribute to discussions around the conceptualisation of complex systems of management and changing patterns of governance when focusing on understanding multi-stakeholder practices across natural resource contexts.

A distinct opportunity is identified to apply a combination of approaches and perspectives to explore the system of catchment management within a collaborative governance context in a distinct way, which includes bringing ABM into application where it has not previously been much used. (In addition, refer to Appendix I for a glossary of terms):

- **A systems approach** is used to underpin the analysis of the management activities and interactions in a catchment in order to allow a holistic view of the management and governance context. It recognises the multiplicity of influences from different scales on particular actions and decisions (Röling and Jiggins, 1998). It equally identifies conceptualisations of social-ecological systems, complex systems and complex adaptive systems as helpful for examining governance arrangements.
- **A network perspective** is used to allow the social complexity underpinning NRM and catchment governance approaches to be analysed and described in detail (Stein *et al.*, 2011), emphasising the structure of interactions between the components of a system, which is understood as the network structure (distinct from wider social structure and seen as a step towards identifying the way in which structures of governance are operationalised). A network perspective also helps to understand the way in which the network structure, in relation to contextual and influential factors affects the performance of the system (Janssen *et al.*, 2006).
- **A qualitative analysis** of empirical interview data is used to inform understandings of factors that affect the functionality of a networked system to allow the knowledge and experience of stakeholders to directly inform understandings of complexity, emphasising stories and experiences as valuable. The detail and depth of the qualitative analysis is supplementary to analysis of networks and fundamental to the development of a well-informed understanding of the dynamics of the system.
- **An agent-based modelling (ABM) process** is used to allow the exploration of properties of complex systems through the analysis of simulations (Axelrod, 1997), with a focus on the actions and interactions of individual agents. The heuristic role of an ABM means it can be used as a tool for testing theory, investigating possible outcomes of changes in behaviour or influential conditions, for example in relation to decision-making in the context of water-quality management and a reflection on the conditions and contexts that affect behaviour, and therefore for beginning conversations about the dynamics of the real systems they represent (Millington and Wainwright, 2016).

Although systems perspectives, networks and agent-based modelling have been applied to many and various NRM research contexts (see sections 2.3-2.5), there have been few studies that combine the approaches in this way to build a picture of complexity in relation to water-quality management at the catchment-scale, particularly in the UK. This PhD research therefore facilitates an exploration of the ability of the combination of such methods and perspectives to be useful modes of knowledge creation in relation to analysis of the operationalisation of certain collaborative governance approaches to natural resources.

1.2 The governance context: water management in the UK

The UK has undergone a shift in environmental governance approach in relation to water resources in the recent past, which is linked to the management actions and strategies of stakeholders within that governance system and affected by political change. Governance can be understood as a broad term referring to the processes of decision-making involving a variety of state and non-state actors (Walti et al. 2004; Halachmi 2005; Freeman and Peck 2007) in which the substance of management can be situated and examined as a part of the governance process. Current UK water management practices reflect a move away from top-down, technocratic solutions to natural resource problems, which were present in the early-mid 20th Century (Bonnell and Koontz, 2007) and emphasise the importance of holistic, landscape-scale considerations, and stakeholder and community involvement. Principles of IWRM have been at the forefront of water-management policy for the past 25 years, after coming to global attention following the International Conference on Water and the Environment in Dublin and the Earth Summit in Rio de Janeiro in 1992 (Mitchell, 2005). Attention was shifted away from (only) restoration and preservation of river and water environments for sustainability (Adams *et al.*, 2004) towards emphasising the true social value of water and the importance of users, planners and policy makers taking part in decisions about water resources at all levels (Global Water Patnership, 2006). The Aarhus Convention (1998) also played a significant role in influencing shifts in policy by emphasising links between environmental and human rights, particularly the right to know; the right to participate, and the right of access to justice. The principles of IWRM are implicit in public policy in the UK and have begun to represent a shift in water resource governance. The development of more participatory practices and landscape-scale considerations are evident in the application of the EU Water Framework Directive (WFD) and the catchment-management approach (Watson, 2014), which have become pillars of UK water governance.

In the UK, with the advent of the EU WFD in the early 2000s came a more holistic approach to water policy (European Commission, 2000), bringing together economic and ecological perspectives and combining key principles of IWRM within a legally binding instrument (Carter and White, 2012). Arguably the most ambitious legislation in the field of water (Fritch, 2017), the WFD, embodied a new framework that encompassed the successes of the past directives in a coherent way but focussed specifically on the integrated management of water resources across whole river basin units (Kallis and Butler, 2001). The revolutionary aspect of the WFD, was not only the unique emphasis on the holistic approach through a focus on the hydrological scale, a scale never used in European-wide legislation, that entailed the crossing of administrative boundaries, but also the commitment to turning environmental governance on its head and giving citizens and stakeholders a voice in agenda-setting and implementation of water-management actions. Specifically, Article 14 of the WFD specifies that efforts should be made "to encourage the active involvement of all interested parties" in the River Basin Management Planning process, which is the key outworking of the legislation (Petts, 2001; Carter and Howe, 2006). The Directive focuses on water pollution issues and was a direct response to the significant concern of European citizens around the issue of water pollution and developed through an open consultation with parties interested in water resource protection (European Commission, 2016).

The WFD sets a requirement for member states to achieve good ecological and chemical status for all surface waters, and good quantitative and chemical status for groundwater by 2027, within three management cycles (2009–2015, 2015–2021, 2021–2027), and through a process of River Basin Management Planning (RBMP) (Watson, 2014). In England, the Environment Agency, established in 1996, is the non-departmental government body designated as the competent authority for implementing the WFD across England and Wales and has a large influence on the way in which it is realised (Foster *et al.*, 2001). Described as a top-down process (Watson, 2014), the EA have designed and implemented RBMP processes in 10 River Basin Districts (RBD) across England (four with shared land in Scotland or Wales) containing 96 catchments and over 6000 waterbodies (Watson, 2014). Representatives of stakeholder groups were chosen by the EA to be involved in regional and national liaison panels and to be part of co-delivery organisations working to help deliver programmes of measures for each RBD. As part of the ongoing delivery of the WFD as a multi-stakeholder process a reworking of policy initiatives in the second cycle in England resulted in the development of CaBA in 2011.

The CaBA represented the shift in the governance approach to water resources and refers to the structures and systems that facilitate management actions that constitute part of the operationalisation of the governance change. CaBA aims to localise environmental improvement actions and bring a smaller, community-based focus to the management of natural resources. Although the catchment scale was a familiar scale for water management the collaborative approach had not previously been prioritised in UK policy. It focused on involving a wide range of stakeholders in decision making processes within each catchment and encouraged them to work collaboratively to identify issues, outcomes and actions that will lead to healthier and more accessible water environments (Environment Agency, 2011). On World Water Day in 2011, Richard Benyon, the UK Minister for Natural Environment and Fisheries, stated that the CaBA should:

> provide a clear understanding of the issues in the catchment, involve local communities in decision-making by sharing evidence, listening to their ideas, working out priorities for action and seeking to deliver integrated actions that address local issues in a cost effective way and protect local resources. (Benyon, 2011)

A pilot phase was proposed between 2011 and 2013, which involved 25 catchment management pilot projects. The outcome of the pilot was the creation of a policy framework in May 2013 to implement the CaBA across all catchments in England (Defra, 2013). The scope for learning from the more established catchment-management contexts where pilot projects were run is significant and offers an opportunity to observe the process of collaborative management in a post-pilot phase where structures are established and action is being implemented in order to reflect on the character and effectiveness of management systems as a part of governance processes. This PhD study focuses on a catchment (the River Wear Catchment in NE England) that has previously implemented a pilot phase and is now entering the delivery phase of CaBA. The context provides an arena in which to study the experiences of stakeholders as they become and enact the new governance process advocated in the UK. Questions arise around the characteristics of the approach and its challenges and successes, particularly in relation to the issues reported around participation, power, structural interactions and procedural patterns in the pilot phase, both in order to better understand the operationalisation of a change in governance approach and to inform better delivery of future approaches through reflection on management practices in the most advanced phase so far.

Such questions can be investigated by considering the complexities of the system through multiple perspectives and modes of analysis. This research will help contribute to the development of ways to explore the CaBA process and its function as a facilitator of sustainable, equitable water governance.

1.3 Principal modes of exploration

In order to better understand the catchment-management s a number of approaches and perspectives have been connected in this thesis to build a picture of the system. As such a particular understanding of NRM and the utility and function of such modes of exploration is presented as an understanding that:

- Processes of catchment management can be conceptualised holistically as a system, with component parts and dynamics identifiable through the study of interactions (human-human and human-environment).
- A catchment system is unable to be reduced to its component parts or interactions and is complex and adaptive.
- Systems can be both spatial and aspatial conceptualisations. They can be associated with a particular locality, and include aspatial dynamics.
- The concept of a networked system is real but only as a representation of time-independent histories of action and interaction and is not the only way that dynamics can be understood.
- Whilst aspects of networks and connections can be conceptualised and depicted, no agency is attached to networks of entities, only to the institutions that emerge.
- Stakeholders are considered as important agents of change in a governance system and their decisions, actions and interactions are important in shaping approaches.
- Where models of a system are created using ABM they are representative of very particular conceptualisations of dynamics and interpretations of decision structures.
- An ABM holds no predictive ability and is seen as a mode for hypothesis testing.
- The process of modelling is equally, if not more, valuable than the output or results of the model, and acts as a tool to develop understanding.

These principles feed into the utilisation of the perspectives further introduced in the following chapter to help build a new understanding of the complexities of the catchment management process in the UK. It is recognised that such perspectives and methodologies are not the only ways a catchment management system can be understood, but aim to show how they can be used to develop knowledge that might identify unique characteristics, successes, challenges and practices that may be useful for furthering knowledge in general and specifically in relation to governance processes.

1.4 Research questions

The study of a catchment-management system, considering the notion of complexity and the modes of exploration that can be used to facilitate better understanding inspire a focus on both structure and function of the system. The driving force behind the initial research premise was a desire to know more about the practices within a CaBA approach, and particularly the actions, motivations, goals, interactions and exchanges happening in relation to individual stakeholders. The objective is to characterise the system and its dynamics using multiple perspectives. The following research questions are formative of the approaches and analysis in this research:

What characterises the network structure of the catchment-management system and the collaborative catchment governance approach in the Wear catchment?

This question refers to the need to better understand the components of a complex system, particularly in relation to the social interactions. It attempts to find out who is involved in a catchment-management process and how they connect to one another. It also attempts to explore the actions and the interactions of the organisations, entities and stakeholders involved in order to better understand the interconnectedness of the system. The question also encompasses understandings of dynamics and outcomes, whereby explorations of any changes in structure are investigated and any outcomes from any processes of change in the structure and components of the system that can be observed. This question utilised the concepts of systems and networks to explore structure and interactions.

What factors are important for understanding the functioning of the catchment-management system and associated collaborative catchment governance processes? If the components of the system can be understood as a networked system the drivers and barriers of the successes and failures of the system need to be explored. This question attempts to understand better the elements that contribute to the dynamics of change and might be seen as a breakdown of complexity and as a chance to describe the effects of complex interactions of multiple factors. Such a question also encompasses exploration of the elements that make up good or effective practice.

How can ABM help to better understand the structures and functioning of catchment-management processes in relation to stakeholder behaviours?

This question relates the ability of ABM to dig deeper into the dynamics of the system of catchment management and to help understand how factors and elements of the system might combine in relation to the behaviour of stakeholders. The concept stems from the understanding of stakeholders as fundamental elements of the system through their ability to enact management actions and interactions facilitated by a particular governance system. By better understanding their behaviour, the enablers and barriers and the resultant outcomes, the dynamic changes of the management processes within the governance system might be better understood. The opportunity for ABM to contribute to the research process in relation to the particular situation of collaborative catchment management can be explored through this question, pulling together the results and findings from the previous questions in relation to the components of the system and the possible influence on the positives and difficulties that characterise the system.

1.5 Thesis structure

Chapter 2 describes and analyses the previous thinking and research around the core concepts and themes of this thesis. It first presents a background to conceptualisations of NRM and the core principles that underpin current approaches. It then describes and analyses the conceptualisation of NRM systems and the types of systems and characteristics that have influenced the approach in this research. The chapter also discusses the literature and previous research on networks, laying the foundation for the network perspective used. Finally, the chapter covers the previous thinking and research around ABM, in general and in relation to NRM and water resource management, justifying it as a mode for research and a tool for exploration and experimentation.

Chapter 3 covers aspects of the methodological approaches used in the thesis to collect qualitative interview data from stakeholders. The chapter first introduces the case study of the Wear Catchment, its characteristics and management history before describing the process of data collection.

Chapter 4 covers the approach to analysing the relations between stakeholders and components of the system of the Wear catchment-management process through network perspective methodology, as well as detailing the design, creation and testing of an ABM.

In **Chapter 5**, the first of the empirical analyses, the results from the qualitative data are explored in relation to conceptualising the system as a network. Components of the network in the catchment are described and analysed in relation to workings of a network (nodes and links), and their implication for understanding of roles and positions in the network. Changes in the structure are also described and explored in relation to positive effects as well as challenges.

Chapter 6 analyses and explores the factors that affect the functionality of the networks and governance processes and structures described in Chapter 4. It presents factors that are influential at three scales including the interactional, individual and contextual and analyses how they interact to produce particular enablers or barriers to functional practice and processes.

Chapter 7 presents the results of the ABM process, first describing the function and purpose of the model followed by the presentation and discussion of the results of four experiments within the modelling process. The implications of the results are analysed against the limitations of the process and in the context of catchment management.

Chapter 8 presents a discussion of the research findings and process. The chapter discusses the overall findings from the research in relation to core themes of complexity and emergence covered when researching a catchment management system as a complex system. It then discusses the contribution and implications of looking at the system of catchment management from the three different perspectives described in Chapters 4, 5 and 6. Finally, the chapter discusses the lessons from the research for management practice in the Wear catchment and applicability beyond the specific context.

Chapter 9 presents the conclusions of the research. It summarises the key findings in relation to the research questions laid outlined Chapter 1; discusses the limitations and specificities of the research context and methods; presents the potential contribution of the thesis to the research fields drawn upon; gives some recommendations based on the implications of the thesis for research and practice; and finally discusses some ideas for further research.

Chapter Two

Understanding Natural Resource Management (NRM) systems: Approaches and conceptualisations

2.1. Chapter overview

This chapter presents a critical review of core themes around natural resource management (NRM) that provide the theoretical foundation for the research. The chapter aims to highlight the past and current thinking around the concepts relating to NRM, governance, systems, and ABM, and emphasise the implications for water resource management and governance. The theoretical foundation refers both to the specific understandings of processes that affect and produce management practices relevant to water management, its outcomes and reflection on governance approaches, as well as the theoretical bases that underpin the methods to expose and help to explain those processes.

2.2 Conceptualising NRM

2.2.1 The context: Concepts of governance and management

A recent focus of studies around NRM has been on the processes of governance that produce changes in structure, behaviour and interaction in order to better manage environmental problems. The concept of governance is seen to concern the self-organising and interorganisational processes, networks and structures that shape individual and collective action, solidified through formal and informal rules (Rhodes, 1996; Lebel *et al.*, 2006; Young, 1992.). Peters and Pierre (1998: 232) claim that "[g]overnance is essentially a political theory—insofar as it describes a certain type of exchange between the state and the society". In relation to this notion, the principles of environmental governance may have originated from the idea that conventional government arrangements had limited capacity to deal with wicked problems (Ludwig, 2001). Moreover, environmental governance also emerged as an explanatory concept associated with social and economic change around the legitimacy of national states in relation to environmental resource issues (Bridge and Perreault, 2008). The concept of governance originated more broadly in the Anglophone world in the 1980s and 1990s as result of a change in social and political structure. New forms of intervention and control emerged as an alternative to state dominance, facilitated by newly elected neoliberal governments in countries such as the UK, USA, Australia and New Zealand (Goodwin, 2009). The growth of the concept was also supplemented by the emergence of coalitions and partnerships formed of political actors from voluntary and private sectors. The shift in the decision-making structure resulted in a change to the institutional map of government (Goodwin, 2009). Rhodes (1996:652-3) describes governance itself as "a change in the meaning of government, referring to a new process of governing; a changed condition of ordered rule; or the new method by which society is governed". The concept of governance is therefore broader than government and is specifically associated with the way that state and non-state actors work together. The relations between state, civil and private actors are at the centre of studies of governance practice, and governing is understood as a complex multiscalar process involving multiple actors. Governance can be referred to as multi-level, which references a political system in which decision-making powers are shared across different territorial levels between local, regional, national and international networks (Goodwin, 2009). Such a definition problematizes state-centric forms of regulation and administrative power (Bridge and Perreault, 2008) and recognises that political authority operates across several different spatial scales (Painter 2000: 360, Lemos and Agrawal 2006) as a result of shifts in the institutional balance of power (Bridge and Perreault, 2008). Ezzamel and Reed (2008: 600) also recognise that the regulative practice and form of governance is always mediated through particular socio-historical and spatial contexts. It is the shift in decision making powers facilitated through governance change in relation to water management in the UK that forms the context for this thesis.

In relation to setting out a background understanding of the term governance, Stoker (1998:18) outlines five propositions that refer to governance as a framework for interrogating the changing ways that society is governed:

1. Governance refers to a set of institutions and actors that are not only drawn from but also beyond government.
2. Governance identifies the blurring of boundaries and responsibilities for tackling social and economic issues.

3. Governance identifies the power dependence involved in the relationships between institutions involved in collective action.
4. Governance is about autonomous self-governing networks of actors.
5. Governance recognizes the capacity to get things done, which does not rest on the power of government to command or use its authority. It sees government as able to use new tools and techniques to steer and guide.

These principles and propositions form the basis of the contextual understanding of governance in this thesis. They are not listed to be proven or disproven through the course of this research, but to offer a guiding context for understanding the concept of governance.

Environmental governance has developed as a concept emergent from the study of governance. Bridge and Perreault (2008; 488) describe environmental governance through a geographical lens as "a broad analytical framework for addressing the institutional arrangements, spatial scales, organizational structures and social actors involved in decision-making around different environments and resources." The study of environmental governance allows a critical analysis of the spatial, ecological and administrative scales involved in environmental resource decision-making; analysis of coherence and the way that different people and non-human entities can be aligned despite tensions; and a critical understanding of politics, power and decision-making, and where questions can be asked about who participates and how, and the social depth of mechanisms that enact environmental and social changes (Bridge and Perreault, 2008).

Bridge and Perreault (2008) also highlight the multiplicity of claims that become loaded into the concept of environmental governance. These include interpreting governance as a problematic of scale; as commodity chain coordination; as collective action for resource management; as political participation; as a problematic of state (re-)regulation; and as rule and production of socio-natural order. In this thesis the main interpretation of environmental governance includes drawing from the idea of governance as collective action; as involving community-based, participatory, adaptive management (see Table 2.1). Governance is also contextualised in this thesis from the ideas of governance as a problematic of scale, where the need for a change in the scale at which governance is operational (in relation to water quality management) is important; and from governance as political participation where there is change in the political actors associated with decision-making.

Table 2.1 Environmental governance claims as laid out by Bridge and Perreault (2008).

Claim	Description
Governance as a problematic of scale	The concept of governance is scale-free and can refer to a variety of scales; it is therefore vague in defining the absolute scale at which governance is achieved. Contemporary environmental concerns have involved a radical re-working of geographical scale, including initiatives at the global and international scale to tackle transboundary problems. Equally, governance scales are often assumed as a hierarchy and governance change can involve jumps between scales. Much applied environmental management literature sees scale as an outcome of deliberation, but uses natural systems as a guide. Much current discourse surrounds the change to such scale away from traditional political boundaries to reduce costs of mismatched scales.
Governance as collective action for resource management	Drawing on human ecology and new institutional economics this strand of research emphasises the role of social institutions in regulating human activities and behaviours. Governance is seen as a social action problem and challenges Hardin's 'tragedy of the commons' metaphor by recognising that collective modes of environmental governance can be successful. This justifies a decentralised, participatory, community-based natural resource management that emphasises hybrid state and local groups (Mehta et al., 2001). Such research also emphasises the role of adaptive management via iterative processes, monitoring, intervention and evaluation in recognising uncertainty and the need for responsive social mechanisms.
Governance as political participation	Some researchers see the primary problematic of environmental governance as the expansion of the political realm to include a range of actors and spaces. There is seen to be a de-centring of political authority on the environment with the growth of non-governmental actors and a variety of state natures such as national parks and regulatory bodies emerging. The change in political actors also raises questions about the extent of agency and authority and highlights issues around rights, responsibilities and obligations. In particular, language around participation and partnership subverts old hierarchies and suggests an equality of agency. Where new political spaces can be stabilising (Zalik, 2004), it can also open up debates around adequacy of the participatory forms of governance.

Environmental governance, therefore, as interpreted in this thesis is focused on the mechanisms and processes of organisation amongst political actors aimed at influencing environmental actions and outcomes through changes in environmental incentives, knowledge, institutions and decision-making behaviour (Lemos and Agrawal, 2006). Often the adaptive nature of environmental governance is emphasised, specifically focusing on the involvement of actors in cross-scale interactions, having self-organising capabilities that extend beyond government, and collaborative arrangements such as networks and partnerships that allow processes of learning, social learning, collaboration and co-management (Folke *et al.*, 2005; Huitema *et al.*, 2009). Governance is seen as equivalent to governance networks (Klijn, 2008), and therefore the horizontal interactions of stakeholders through a web of relationships and interdependencies is seen as an important part of understanding governance approaches, particularly where explicit commitments to collaboration are given. Governance change in water resource management in the UK has developed through a change in legitimate knowledge, informal institutions and in decision-making behaviour. Change has led to the localisation of decision-making, facilitated through new structures, new roles, and new support systems. The approach is often referred to as collaborative governance, which Emerson et al. (2012:2) define as "the processes and structures of public policy decision making and management that engage people constructively across the boundaries of public agencies, levels of government, and/or the public, private and civic spheres in order to carry out a public purpose that could not otherwise be accomplished". Ostrom (1990) emphasise that collaborative governance refers to the jointly determined norms and rules designed to regulate individual and group behaviour. Governance change in relation to UK water resources is manifested in new rules of interaction and action combining with existing rules of behaviour, and which this research is interested in exploring further, particularly in relation to the ideals of good governance practice and the aim of continual improvement of the delivery of effective or 'good' governance.

The idea of 'good governance' is often used as an incentive to monitor and improve governance practices and can pertain to concepts of accountability, transparency, responsiveness, equity and inclusion, effectiveness and efficiency, and participatory, consensus-oriented decision making (Crabbé and LeRoy, 2008; Armitage *et al.*, 2012). Montgomery *et al.* (2016) conceptualise five pillars of 'good governance' in relation to the sustainable management of water, inspired by IWRM in Alberta, which include accountability, adaptability, participation, rule of law and transparency. They conclude that although broad categories of good governance can be discerned from practice and literature, stakeholders with divergent and conflicting interests make the need for a nuanced and contextual understanding paramount to any attempt at improving the functioning of governance. This refers back to the proponents of governance set out by Stocker (1998) in which power dependencies, and blurred boundaries and responsibilities can lead to difficulties and imbalances that are often complex to overcome. Therefore although modes of governance are consistently called upon, and the need for 'good governance' recognised, particularly for dealing with environmental issues, the exact mechanisms for best practice are multiple and often unclear.

Wyborn (2015:56) describes governance as a "constant negotiation of what we know about the world, how we choose to act, and how collective action is mobilised". Wyborn, emphasises a very active and negotiated ideal of governance, highlighting the need for reflexivity and the importance of considering good governance in context. Part of the reflexivity and contextualisation is the role of academic study in helping to reflect on and discern what and how governance is enacted and played out. This research aims to be part of the process by better understanding one particular context of environmental governance, in relation to its institutions and actors, blurred boundaries for responsibilities, power dependencies, self-governing networks, and capacity to get things done to identify elements that might contribute to a better understanding of the effectiveness of the governance approach.

By comparison, a term also familiar within environmental resource discourse is management (e.g. Natural Resource Management (NRM), Integrated Water Resource Management (IWRM), Adaptive Management). Management is not synonymous with governance, and governance, as distinct from government (Stoker, 1998), has become a term used to describe the wider structures, procedures and processes that create or hinder the conditions in which operational management decisions are made and action implemented (Armitage *et al.*, 2007; Armitage *et al.*, 2012). Management can be seen to be defined by its association with the 'how' of the action and decision-making within a system, compared to the 'what' of governance. The term water management refers to "operational activities including the operation, monitoring, strategic planning, and implementation of measures," (Pahl-Wostl, 2009: 1). Management is operational on a day-to-day level and is a term used in relation to managers and processes of practice. Managers are seen as active agents who aim to solve problems and produce outcomes and effects within a resource system in line with desired or expected change. The way a management approach is derived, justified and facilitated is significant for the decision-making process of managers and therefore the resultant effects on the system. There are a variety of ways management can be enacted, underpinned by theoretical approaches to risk, problem perception, social interaction, and economic drivers. The relationship between governance and management is identified within this thesis, particularly in terms of the way that governance structures and processes constitute and bound management decision-making and therefore interaction and action, which facilitates the production of effects on the social and environmental outcomes of a system. The problem context for this research is how governance change is shaped by and is shaping management decision-making and how the structure and function of the management system is characterised in relation to context.

Much of the operational language of water resource issues is focused on management as it is the term more often used by practitioners and policy makers through phrases such as 'catchment management' and 'water resource management' as well as via the language of the WFD (e.g. River Basin Management Plans). It is therefore used frequently throughout this thesis to refer to the operational activities of stakeholders and the norms of practice and structures of interactions associated with goal-directed active interventions.

2.2.2 The components: Stakeholders as agents

The concept of the stakeholder has come to be representative of legitimacy in NRM processes such as catchment management, as demonstrated by the strong focus on stakeholders in policies such as the WFD. Studies of the systems of management and governance of natural resources, as well as practical processes of collaborative NRM, often start with a conceptualisation of who is or who should be involved (for example through stakeholder analysis (Luyet *et al.*, 2012)). Such studies are founded on the capacity of stakeholders to act in multiple ways, interact with each other and the environment, and react to and enact ecological and social change, all of which form and constitute management of natural resource systems. The discussion of issues such as: legitimacy of stakeholders, relative levels of inclusion, power struggles, constraints on action, participatory processes, and knowledge validity reveal the agency and potential agency of stakeholders in the NRM process and therefore the way that mechanisms of the governance processes themselves are operationalised. Ideals are based on understandings of stakeholders as the important point of action and activity, as the knowledge creators and the sites of agency. An understanding of the way that stakeholder agency is harnessed, constrained, facilitated and legitimised underpins the conceptualisation of the process of NRM. Part of this thesis focuses on gaining a better understanding of current water management as a NRM process, therefore an understanding of the current conceptualisation of stakeholders and their agency is important.

The word 'stakeholder' itself can be traced back to the seventeenth century, where it first referred to a third party in charge of the stakes of a bet (Ramírez, 1999). It has deep roots in the business-management literature as a theoretical approach (e.g. Follett, 1918). Following reactions to grassroots social movements and the concept of a 'duty to do right' by recognising stakeholders as legitimate the notion of the stakeholder has migrated from business management (e.g. see Follett, 1918; Freeman, 1984; Ramírez, 1999; Porter and Kramer, 2006; Freeman *et al.*, 2010; Reed and Curzon, 2015) to environmental management, defined in both a normative and instrumental sense (Wesselink *et al.*, 2011). The following definitions demonstrate some of the conceptualisations of stakeholders in NRM:

> all those who have a stake, a material interest, from their perspective, in the situation under consideration (Collins *et al.*, 2007)

> persons or organisations with a vested interest in the outcomes of management decisions (Conroy and Peterson, 2013)

> those who have an interest in a particular decision, either as individuals or representatives of a group. This includes people who influence a decision, or who can influence it, as well as those affected by it. (Blackstock and Richards, 2007)

The final definition reflects the active role of stakeholders in influencing decisions and acknowledges the power that they hold in relation to trajectories of action. However, it is those with the authority to facilitate decision-making who label certain stakeholders as legitimate at certain times.

Participation of stakeholders in NRM

The way in which the stakeholder in NRM is constructed today in Western society is heavily influenced by the history of the development of the role of participation in the environmental and scientific fields. Within the field of Science and Technology Studies (STS) (Jasanoff *et al.*, 1995) the role of stakeholders has changed dramatically over the past 200 years. Lengwiler (2008) identified four periods of time since the late 19th Century in which the conceptualisation of stakeholders and their associated participation has changed. These include a hybrid period, in which individuals were at once politicians, scientists and citizens; a politicised period, in which science as a discipline set experts and expert knowledge apart; an autonomous period, in which public spending on science grew and institutions were formed; and a participatory period, in which non-scientists, citizens and lay people began to be included, recognising the need to involve all areas of society (Kindon, 2007). In modern environmental and scientific decision making it is widely recognised that stakeholders, as a result of the historical changes around science and participation, can play a key part in decision-making. However, claims on who has legitimate knowledge, and who is therefore valued as an active stakeholder, have since caused significant debates.

Debates have emerged from the conceptualisation of experts and non-experts and their relative legitimacy. For example Collins (2002) wrote a highly provocative paper, which outlined a need to reconceptualise stakeholder legitimacy through the concept of expertise. However, their ideas came across significant criticism from (Wynne, 2003) and (Jasanoff, 2003) for their reductionist approach to knowledge. Jasanoff in particular argued for deeper consideration of contexts in which certain types of knowledge and expertise are created, legitimised and sustained through everyday politics and institutional processes, demonstrating the complexities surrounding an understanding of agency through knowledge legitimisation. Callon (1999) supported the idea that knowledge is actively and socially constructed through the Co-production of Knowledge Model (CKM), in which knowledge is seen to be co-created through deliberative processes. The notion of a stakeholder, therefore, is one whose view of an issue or problem is unique, contextual and subjectively bounded, but one that is fluid enough to be stretched and shaped by others' perspectives and combined and reimagined to better define a problem or a solution to a problem. Such a definition underpins the current theoretical approaches to water-resource management in the UK and Europe, placing value on the individual stakeholder and giving legitimacy to the process of co-production through the requirement for inclusive processes of deliberation in targeted problem-solving. Jasanoff (2003) has named the more current focus on the representative and democratic process as 'the participatory turn'. Participation is often seen as a panacea for the problems and challenges of NRM, including catchment management (Gleick, 2000; Mostert *et al.*, 2007; Lane *et al.*, 2011a). However, the acknowledgement of participatory processes as the best approach does not make best-practice clear as there are multiple ways in which practice can be played out and collaborative governance enacted, particularly where management processes are newly implemented within a governance approach, such as within the CaBA in the UK.

Cook *et al.* (2013) conclude that despite the participatory turn in integrated catchment management (ICM) pre-existing frames (including representative democracy, professionalisation, statutory requirements and evidence-based decision-making) prevent the democratic effects of some forms of participation in particular contexts becoming reality. Similarly Waylen *et al.* (2015) recognise that real life attempts at participation have often fallen short of the ideals, and particularly emphasise the role of prescriptive environmental targets as restrictive. However, through their study of RBMP in Scottish water management, Waylen *et al.* also demonstrate the ability of participation to inform and benefit management despite constraints, but only if there exists space for participants to challenge one another's interests and knowledge (to co-produce knowledge). The key point of such an observation is whether participation operates in elite hierarchies or through flatter democratic processes (Cook *et al.*, 2013).

This PhD research uses the concept of the stakeholder as a central anchor for study of practice within the catchment management processes and tries to better understand the behaviour, interactions, action of individuals and organisations as part of collaborative governance processes.

2.2.3 The principles: Integration, adaption and collaboration

There are a number of principles that can be identified as important in NRM, the combination of which can be seen to constitute good practice. In catchment management Bissett *et al.* (2009:3) identify three key principles:

- Integration – where common issues, objectives, types of information or stakeholders in a catchment are identified and involved so multiple goals can be achieved.
- Adaptation – where the planning process can anticipate, accommodate and respond to change.
- Collaboration – where different stakeholders work together to agree actions and achieve goals.

Such principles have been part of the discourse around NRM, and water management in particular, in research projects and theoretical deliberations in relation to governance change as guiding ideals. Although the principles are well established, they are not always clearly defined or applied consistently to studies or management practices and the interconnection between the principles can make them difficult to discern. A fundamental challenge of NRM studies is to determine the relative importance of the multiple elements of such principles in relation to their relevance at particular times, and for particular problems and contexts.

2.2.3.1 Integration

Integrated environmental management acknowledges the interconnections between human and physical systems (Moote *et al.*, 1994) and has become a key part of water-resource management in relation to policy and governance (Margerum, 1999; Biswas, 2004; Lubell and Lippert, 2011; Hering and Ingold, 2012). IWRM embraces the complexity of water's socio-environmental system (Pahl-Wostl *et al.*, 2012) and recognises the institutional fragmentation that has caused disconnection and mis-matched responsibility (Lubell and Edelenbos, 2013). IWRM is described as "the integrated and coordinated management of water and land allowing resource protection to be balanced whilst meeting social and ecological needs and promoting economic development (Odendaal, 2002)" (Pahl-Wostl *et al.*, 2012:25). Warner (2007) states that IWRM aims to integrate relations between surface, groundwater and land use, relations between water and stakeholder interests, and relations between institutions. This gives IWRM three dimensions: multi-functional, through the consideration of all uses of water, multi-sectoral, which accounts for the coming together of different disciplines, and multi-scalar (Conca, 2006) which allows geographical units to be looked at and managed holistically (Margerum, 1999).

Elements of coordination and participation are often a clear focus in applications of integration and have been incorporated into many national and international water-management programmes including the UN Water for Life initiative (United Nations, 2016) and the WFD. Despite being heavily evidenced in the WFD documentation however, the application of integration practically in individual countries is arguably less evident due to the heavy dependency on the politics of institutions and the culture and history of each country (Lubell and Edelenbos, 2013). An additional difficulty is that integration is often offered as a normative "nirvana" (Molle, 2008) masking the potential for such a concept to fall short of its ideal. The adoption of IWRM in the UK has developed through the application of the WFD and both River Basin and Catchment Management processes. Fritsch and Benson (2013) argue that, despite a long history of integration policy and practice, problems occur in the UK particularly in relation to participation, equitable access and managing demand. Thus, they call for more productive research into how IWRM principles should be better achieved.

2.2.3.2 Adaption

The concept of adaptive management has become prolific in the theorisation of environmental management approaches. It often underpins practice around complex NRM issues where uncertainty and non-linearity are present, such as in water management (Armitage *et al.*, 2009). Such approaches began with processes to integrate existing expertise, knowledge and practice and attempted to evaluate the possible impacts of alternative policies through experimentation (Holling, 1978; Walters, 1986; Lee, 1993; Huitema *et al.*, 2009). The process of adaptive management is sometimes referred to as a structured process of 'learning by doing', as it involves learning through testing and innovation (Walters, 1997). It is seen not as a way to increase the capacity and knowledge needed to make predictions about a system, but to better understand response patterns by examining management actions and their effectiveness in hindsight. Adaptive management arguably provides an understanding of feedbacks and dynamic processes, which are used to inform new policies and practices that aim to profit from change and surprise, rather than seek the equilibrium status (Walters, 1986; Allen and Gunderson, 2011).

Folke *et al.* (2005) identified the importance of associating adaptive management with processes of participation, collective action and learning in order to address the social dimension of environmental management. The process of learning can be understood as both social learning (Pahl-Wostl and Hare, 2004) and institutional learning (Ostrom, 2008). Each management action should be seen as a chance to learn, socially and institutionally, about how to adapt to changing circumstances, thus coping with uncertainty and non-linear dynamics (Carpenter and Gunderson, 2001; Folke *et al.*, 2005). Adaptive management theory has been practically influential in a number of water and watershed management projects. For example Allan *et al.* (2008) claim adaptive management to have guided flow projects in South eastern Australia (Murray-Darling Basin Commission, 2005) and to have underpinned the development of the Northwest Forest plan in the United States (Stankey *et al.*, 2003). Pahl-Wostl has extensively explored the role of learning in integrated and adaptive co-management of water resources (Pahl-Wostl and Hare, 2004; Pahl-Wostl *et al.*, 2007) emphasising the importance of processes of social learning, particularly through the European HarmoniCOP project (Mostert *et al.*, 2007; Pahl-Wostl *et al.*, 2007). Factors and features of social learning such as trust, flexible networks, social capital, collaboration in formal and informal structures are seen to be the building blocks of adaptive institutional settings (Pahl-Wostl *et al.*, 2007).

However, adaptive management is not without critique. Medema *et al.* (2008) suggest that concepts such as adaptive management are difficult to translate into practice and they rarely produce successful examples. Allan *et al.* (2008) similarly argues that adaptive management is unlikely to be fully functional unless social and organisational norms are overturned through cultural change, which is believed to have been missing from adaptive management practice. Allen and Gunderson (2011) propose a number of reasons for the failure of current adaptive management approaches including lack of stakeholder engagement, practical difficulties, inability to accept surprises, overly prescriptive approaches, insufficient action, lack of learning to modify policy, lack of leadership and focus on planning. Such difficulties in achieving the ultimate goals of the theory of adaptive management suggest it is a complex ideal. However, Allen and Gunderson (2011) believe that adaptive management is conceptually robust and that the recognition of barriers and how to overcome them in various contexts will foster the development and application of the approach.

Others have agreed on the centrality of adaptive management and the concept has continued to be a focus of resource management discussions (Olsson *et al.*, 2004; Folke *et al.*, 2005; Plummer and Armitage, 2007; Nelson *et al.*, 2008; Huitema *et al.*, 2009). A number of studies have focussed on the combination of integrated and adaptive management in NRM (Gain *et al.*, 2013; Fritsch, 2016) and as concepts for water management in particular. For example Engle *et al.* (2011) explore the possible issues and challenges of an integrative and adaptive understanding of water resource management systems, using empirical examples of basin management in Brazil. They discovered that due to a legacy of hierarchical management there existed conflicts between aspects of decentralisation (as an enabler of deliberative, participatory and pluralistic systems) and the ability of management to make and implement rapid and transformative decisions to cope with change and surprise. Engle *et al.* (2011) call for more research into the factors enabling integrated and adaptive systems to succeed and a recognition of the difficulties faced when transforming existing approaches based on new ideals. The investment in research into systems where such theoretical combinations are enacted will add to the understanding of where they can be efficient, flexible and legitimate (Engle *et al.*, 2011).

2.2.3.3 Collaboration

Collaborative management is arguably one of the key modes through which adaptive and integrated management is delivered. It has not emerged as an alternative to integrated management but as a proponent or variable perspective of it, and in itself as an alternative to the more traditional forms of environmental management involving top-down policies (Sabatier *et al.*, 2005). A collaborative approach has been defined by Barbara Gray (1989:3) as offering "the opportunity for those with divergent view-points to explore their differences and search for solutions that go beyond their own limited vision". Multi-stakeholder partnerships are the expression of collaborative working in many cases and are often referred to as watershed partnerships or catchment partnerships in the context of water management, particularly stemming from projects in the USA and Australia (for examples the Landcare projects). The benefits and foundations of collaboration in systems such as stakeholder partnerships have been shown to be widespread, and include increased trust between stakeholders (Kenney, 1999; Pretty and Smith, 2004; Wagner and Fernandez Gimenez, 2009); deeper participation of stakeholders in decision making (McCloskey, 1996; Innes and Booher, 1999); and a more holistic understanding of environmental problems and their most appropriate solutions (Margerum, 2004). Figure 2.1 shows the underlying principles, values and features of a collaborative approach based on synthesis of studies into collaborative environmental management. In relation to water management many studies have focused on analysing the process of collaborative management through the development or implementation of watershed or river-basin management groups, centring on factors that affected success or generated difficulties in creating plans, reaching consensus in decision-making or overcoming conflict (e.g. Preister and Kent, 1997; Michaels, 2001; Margerum, 2004).

In reference to the European application of collaborative water-management approaches in the form of the WFD, Meyer and Thiel (2012) studied cooperative approaches in the River Elbe in Germany and the River Dordogne in France, and demonstrated that outcomes of similar projects were affected by the balance of formal and informal institutional change and differences in the participants' mental models of the problems and issues at hand. They concluded that good cooperation could be facilitated through accessible information and networking. Other key studies include the HarmoniCOP projects (mentioned previously), which explored social learning within the application of the WFD in European river basins (Craps, 2003; Ridder *et al.*, 2005; Tippett *et al.*, 2005; Mostert *et al.*, 2007; Pahl-Wostl *et al.*, 2007; Borowski *et al.*, 2008). Case studies in France and Germany, particularly demonstrate that successful collaboration is affected by the level of opportunity for social learning to take place (Borowski *et al.*, 2008).

Core themes often explored in studies of collaboration are the exchange of data, knowledge and evidence and the presence of trust and trusted relationships facilitated by ideas of legitimacy and expertise. Relations between collaborating stakeholders can be seen to be based on the collection and exchange of data, which are interpreted and translated into evidence at particular times to fulfil particular purposes, informed by ideas of legitimacy. The exchange of data and evidence is seen to inform and be informed by the value that is placed on river environments, but is often complicated by conflicting understandings, perceptions and priorities. Conflict can be due to the differential understandings of saliency, credibility and legitimacy across different groups working across different boundaries in an environment such as a catchment (Cash *et al.*, 2003). Legitimacy itself can be understood as the fairness, correctness or rightfulness of power relations (Beetham, 1991; Matti, 2009; Sandström *et al.*, 2014), and in co-management situations refers to the level of acceptance of a decision-making power (and their associated expertise: (Bracken and Oughton, 2013)), a particular procedure or method, or the outcome of a decision itself.

In relation to the process of collaborative management in the UK under the CaBA, driven by the WFD implementation, Watson (2014) highlights the difficulties faced by pushing for multi-party collaboration, particularly in relation to its depoliticised narrative in which the role of power is often paid little attention. Through an in-depth study of the collaborative processes in the pilot phases of CaBA in the UK Watson (2014) concludes that the CaBA process is limited by unequal power relations, whereby authority of partnerships is diminished by state-control and direction, and impact is restricted due to lack of diverse participation and lack of connection to other statutory processes. Watson claims that the CaBA is a "constrained approach to collaboration" and looks to future development of collaborative governance arrangements to provide more progress towards success. Watson highlights the uncertainty and problems with a new governance approach and the difficulty of enacting a truly collaborative management approach within that context. His analysis opens the door to further investigation of the collaborative approach in the UK, to investigate if the implementation of the approach after the pilot phase in 2011-2012 has changed in approach or scope and how that approach is created, sustained and facilitated. This is therefore one of the driving forces of the research in this PhD thesis.

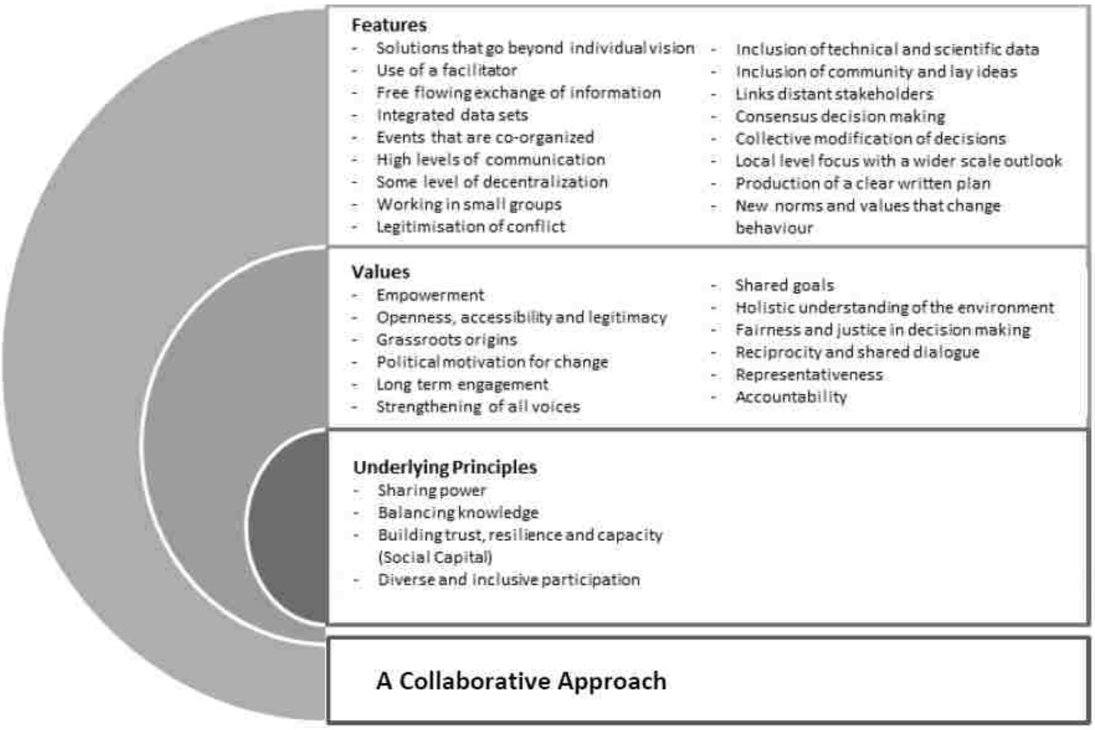


Figure 2.1 *Conceptualisation of the components of a collaborative approach, including the underlying principles, values and features (Tindale, 2013).*

2.3. Conceptualising 'systems' in NRM: Understanding complexity

2.3.1. Systems thinking

Systems thinking involves using a particular framework to approach the complex conceptualisation of a system brought about by systems theory. Grigg (2016) described the evolution of systems thinking in the late 20th century as moving from goal-orientated ways of thinking about a system to learning-orientated. Ison *et al.* (1997) further describe the growth of systems thinking as beginning to analyse and reveal the different and sometimes conflicting views, positions, opinions, actions and perspectives of stakeholders as important aspects of a complex natural resource system. Systems thinking is distinctly resonant with other understandings of water-resource management Grigg (2016). For example IWRM is based on a holistic view of the system and requires an understanding of the feedbacks, context and connectedness involved in order that problems might be identified and tackled in an integrated sense. Systems theory and thinking both help to conceptualise a system in which IWRM can be practiced and help navigate the detail of how it can be accomplished effectively. The learning-orientated approach to systems thinking means it provides a base framework to analyse processes and practices alongside a recognition of multiplicity, the presence of complexity and various and often competing perspectives and issues.

2.3.2. Social-ecological systems in NRM

Berkes and Folke (1998) first introduced the term social-ecological system in this context. Drawing on ideas of the co-evolutionary nature of biophysical and human systems (Norgaard 1994) they were among the first to articulate explicitly that when considering complex resource situations social and ecological systems are intertwined, so much so that the delineation between the two is arbitrary and artificial. The term emerged in the 1990s, arguably in response to the recognition that management policies in the past had often resulted in unintended consequences due to the lack of consideration of the coupling (Anderies and Janssen, 2013). Included in the conceptualisation of a SES is the idea that the components of the systems are coupled in complex, non-linear and potentially irreversible ways, through multiple feedbacks (O'Brien, 2012). Such feedbacks mean that social-ecological systems are seen as complex adaptive systems made up of sub-systems, themselves embedded in larger sub-systems (Anderies *et al.*, 2004).

Ostrom (2009) proposed a framework for the analysis of SES in which she presented four core sub-systems (resource systems; resource units; governance systems; and users: Figure 2.2), which were associated with second-order sub-systems such as system boundaries, collective choice rules, norms, performance measures, conflicts, networking, self-organisation, productivity, spatial and temporal distribution and monitoring processes, amongst others. Such observations transfer the concept of SES from a boundary object (metaphor) towards, if not fully into, an analytical construct (offering entry points or tools for management) (Nightingale, 2015: cited in West *et al.* (2015)). SES can be conceptualised as a collection of agents, rules, and resources that interact to produce emergent properties such as robustness (Anderies and Janssen, 2013) and resilience (Folke *et al.*, 2005). Such understanding can translate into policy approaches, and demonstrate that in order to accommodate the feedbacks and interactions, policy processes should stimulate experimentation, adaption and learning (Anderies and Janssen, 2013). Cote and Nightingale

(2012) argue that the notion of resilience encompassed by such conceptualisations of SES allows for the valuation of multiple types of knowledges, including local and indigenous knowledge, to be part of the process of learning and adaption. From this idea it can be seen that SESs conceptually encompass a number of the key features of NRM scholarship including adaptiveness, resilience, feedbacks, multiple knowledges, polycentric governance and self-organisation.

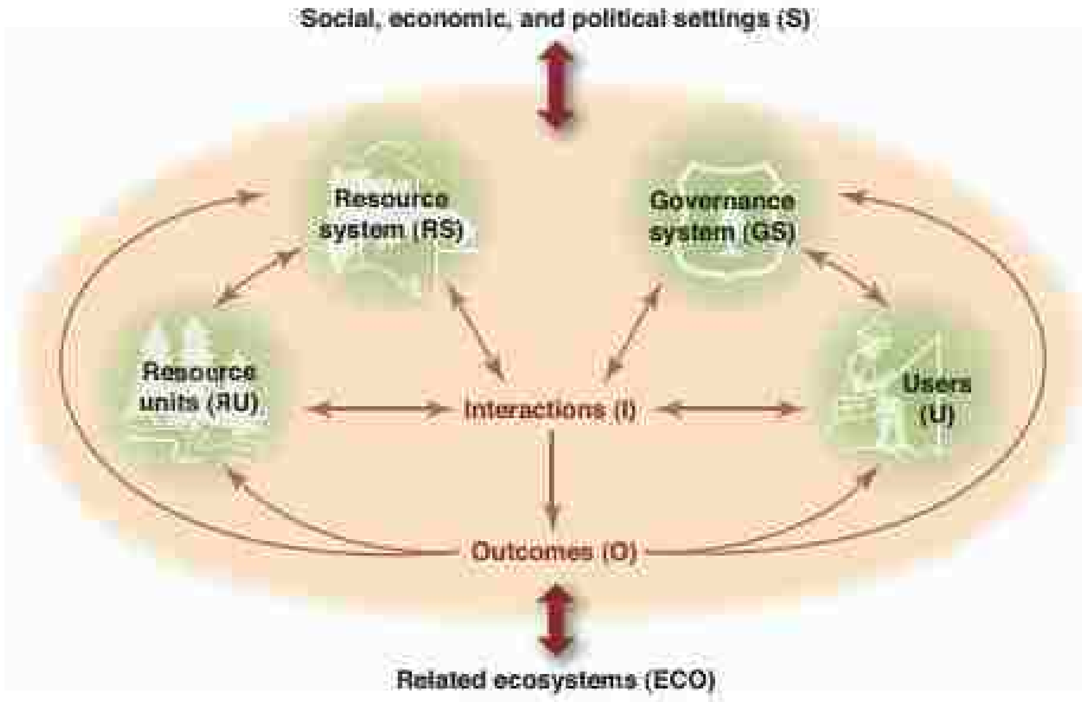


Figure 2.2 *Ostrom's (2009) framework for analysing social-ecological systems identifying the relationships between four first-level core subsystems of an SES that affect each other.*

The growth of the concept of the SES provided significant progress in the understanding of the social dimensions of ecosystem management (Cote and Nightingale, 2012). SES studies incorporated the concepts of social capital, trust, social networks and social memory in an understanding of how SES maintain capacity to adapt and shape change. In relation to water management, Short (2015) combined the conceptualisation of social-ecological systems with ideals of institutional design when focusing on Integrated Catchment Management (ICM) in research around the micro-level crafting of institutions, specifically analysing the CaBA in the UK Short (2015) used criteria such as the identification of social and ecological assets, establishment of multiple linkages, utilisation of networks, and cohesion of management activity to assess practice in the Upper Thames Catchment. The use of the social-ecological systems perspective was important for identifying a context in which management practice was conducted, and setting out expectations for good practice assessment.

However, Stone-Jovicich (2015) have highlighted that there have been, and still recently exist, critiques of the way some dimensions of social systems, such as cultural and political place-specific contingencies, normative issues and human agency are represented (Davidson, 2010). Stone-Jovicich (2015) argue that there are consequently unexplored areas in resilient SES research, which include the role of human actors and agency, the interrelation of different values, framings and discourses, as well as conceptualisations of power, politics and conflict that drive and produce complexity. Therefore there is a call to refer to the concept of social-ecological systems to explore such areas further. The use of an SES perspective is therefore relevant when analysing water resource management and the social systems that are encompassed in water governance and is used to underpin and contextualise this thesis.

2.3.3. Relational/ hybrid systems in NRM

As part of a review of SES it is pertinent to recognise that different authors present different ontologies relating to the integration of biophysical or ecological understandings and conceptualisations into social frameworks, theories and analyses. The first is an integrative or interactional approach where an ontological separation between the social and the non-human biophysical worlds is maintained (Stone-Jovicich, 2015), meaning that the focus is on the interactions and feedbacks between the multiple nested or linked systems. The interactional approach is usually adopted in SES research and can range from reductive and bounded views of social and ecological elements, to those that understand the role of knowledge, power and politics in constructing the science and management used to understand environmental problem systems (for example critical political ecology perspectives, Forsyth (2003)). However Nightingale (2015) (cited by West *et al.*, 2015) notes that the assumption that social and ecological elements can be analytically separated is a point of contention. She calls for more critical awareness of the ontological position when utilising the SES concept.

Hybrid or relational perspectives take a different ontological stance and attempt to blur the lines between society and nature to reject the dualism that characterises much of resource management theory (Rudy and White, 2013). Hybrid perspectives build on, but also attempt to go beyond, ideas such as socionature, wherein the causal relations between social-political and biophysical change cannot be clearly separated (Castree and Braun, 2001). Metaphors such as assemblage and actor-network-theory (ANT) have come to represent the hybrid perspective. The concept of assemblage was originally formed in the 1970s (Deleuze and Guattari, 1972; Deleuze and Guattari, 1987) and relates to a non-hierarchical system made up of many heterogeneous parts (human and non-human entities, with equal weight) linked together through relations to form a whole (Muller, 2015). Assemblages are theorised to be productive systems that create new behaviours and realities, each of which can be at once part of one or multiple assemblages that form associations that may or may not sustain (Anderson *et al.*, 2012; Muller, 2015). ANT is the more empirical of the two concepts and emerged from Science and Technology Studies in the 1980s (e.g. Callon and Latour, 1981; Latour, 1993; Callon and Law, 1995). ANT focuses on the mediation of relations in actor networks through non-human objects such as materials, technologies, objects, animals or ecosystems (Nimmo, 2011). Key methodological apparatus such as immutable mobiles and translation allow ANT to analyse the stability, durability or fleeting nature of associations. Both approaches have found productivity in environmental governance scholarship, and specifically in a small number of water resource research studies.

For example using the context of angling in the Swale, Esk and Ure catchments, Yorkshire, UK, Bracken and Oughton (2014) apply the concept of assemblages to freshwater environments. They examine its value for reconceptualising catchment systems and offering a new way of thinking about rivers that could offer positive perspectives to a constantly evolving governance process. The assemblage approach allowed a reimagining of relations through the examination of the constitution of evidence and the wildlife-physical environment-human nexus. In relation to incorporating ANT into water-resource management research, studies such as Gooch *et al.* (2008) and Roy (2015) apply ANT to studies of IWRM in border areas of Vietnam and Cambodia, and Spain and Portugal, and city water supply governance in New Delhi, India, respectively. Both studies find value in ANT's focus on the material, picking out the importance of dams, HEP stations, bi-lateral documents, pipelines, stand pipes and wells as crucial in the durability of networks relevant to governance. The application of such perspectives to water resource issues is still rare, which implies that there has been little conceptualisation of the relevance of the approach for understanding systems in ways outside the normative analyses.

This research recognises the value in the relational approach for reimagining what might be important and relevant about systems in order to better understand their dynamics, and thus reflects on diverse ways that networks might be constituted. However, the research recognises their critiques, and will not take an explicitly relational ontological approach, but an interactional view as discussed above.

2.3.4. Complex systems

Many processes in ecology and society are defined by non-linearity and a quality of uncertainty (Berkes *et al.*, 2003). Seminal work by groups such as the Santa Fe Institute theorised the place of non-linearity and uncertainty alongside spontaneous self-organisation, emergence and interrelation to conceive ideas of complexity as a property of a defined phenomenon or combination of phenomena (Waldrop, 1992). Complex systems are distinct from simple ones that can be explained through laws (Berkes *et al.*, 2003) and from complicated systems, albeit in fairly ambiguous ways, through their property of emergence: meaning that, in reference to Aristotle's metaphysical philosophy, in complex systems, 'the whole is [always] more than the sum of its parts'. Complex systems are seen as those that are difficult to understand (Sawyer, 2005), and were famously defined by Kauffman (1993) as being "at the edge of chaos". Cilliers (1998) notes that complexity is a characteristic of the system and arises from the interactions between components rather than from the individual properties of the components, and therefore complex systems should be considered holistically through the study of whole social-ecological systems, for example.

Cilliers *et al.* (2013) summarise the key characteristics of complex systems as the following:

- Systems are made up of a large number of components, each influencing one another through rich interactions.
- Interactions are often non-linear, create feedback loops and are short range (meaning components are unaware of the system as a whole).
- Complexity emerges as a result of interactions between components and emergent phenomena only arise as a complex system evolves over time (Goldstein, 1999).
- Complex systems are open systems that constantly evolve. The position and framing of the observer determine the extent to which the system can be described.
- Complex systems evolve through time and have histories that are important to consider in relation to influence on present behaviour.

Concepts of adaptiveness and resilience can be seen as emergent properties of complex systems. Such understandings demonstrate the value of the concept of a complex system to NRM systems, because such systems are also conceptualised through ideas of adaptive governance, understood through the identification of resilient phases (Holling and Gunderson, 2002). Understanding

NRM systems as complex systems allows aspects to be revealed that may not have been epistemologically accessible using other theoretical approaches.

2.3.5. Complex adaptive systems

Complex systems can also be conceived as complex adaptive systems (Kauffman, 1995; Pahl-Wostl, 1995). Potgieter and Bishop (2001:1) characterise complex adaptive systems as having "complex behaviour that emerges as a result of interactions among system components (or agents), and among system components (or agents) and the environment. Through interacting with and learning from its environment, a complex adaptive system modifies its behaviour to adapt to changes in its environment." The crucial reason for defining a system as complex and adaptive, as opposed to only complex, is the recognition of the ability of the system to learn. Studies of complex adaptive systems have focused on the facilitation of learning as governance within the complex system to facilitate adaptive behaviours and achieve sustainability (Pahl-Wostl *et al.*, 2010). A process of co-evolution, through processes such as learning, is central to the understanding of systems as complex and adaptive (Rammel *et al.*, 2007) and fits well with conceptualising natural resource-management systems as complex adaptive systems in particular (Levin, 1999; Abel, 1998). This is because it emphasises the collective evolution in rules, behaviour and structures in response to changing external environments (such as climate change, floods or resource price change) and the adaption of sub-systems to emergence at smaller scales (such as new management regimes, varying communication opportunities or organisational change) (Rammel *et al.*, 2007).

2.3.6. Emergence in complex systems

Adam Smith's 1776 writings on the 'Wealth of Nations' were some of the first to describe complexity, and included descriptions of a process arguably constitutive of emergence, described as an invisible hand leading self-interested agents into structures that none of them had individually chosen or intended. The metaphor of the invisible hand and unintended structures alluded to the concept that would later be known as emergence, where, according to (Bedau, 1997:2) emergent phenomena could be loosely defined as "somehow constituted by, and generated from, underlying processes as well as autonomous from underlying processes". The earliest ideas of emergence can be attributed to the study of evolution and the theories of development of complex phenomena such as the human mind. According to the 19th-century philosopher GH Lewes, certain phenomena in nature produce what he called "qualitative novelty" referring to changes that couldn't be expressed in simple terms (Corning, 2002). Early understandings emphasised downward causation and the arising of new and coherent structures, patterns and properties during the process of self-organisation, separating the emergent phenomena from the underlying parts via the concept of synergy (Goldstein, 1999:61). The 're-emergence' of the concept of emergence has arguably happened recently, coinciding with the growth of scientific interest in the concept of complexity and the development of tools (mathematical and computational) to model interactions in complex, dynamic systems in new ways (Corning, 2002:23). As such emergence is a key consideration in natural and social sciences, particularly where there has been a shift in understandings of systems as changing, discontinuous, unstable and non-equilibrium.

The use of the term emergence is various, resulting from an ambiguity in its meaning. There are several types and forms of emergence that are argued to best describe phenomena in complex systems. Bedau (1997) seminal thinking on emergence defined two types relevant for the conceptualisation of complex systems. First, the more traditional 'strong emergence' in which emergent phenomena are autonomous from the underlying processes that generate them through interactions that render processes unpredictable and non-linear, and secondly, 'weak emergence', which couples emergent structures more closely to changes in constituent parts, based on macro-states being derivable from external conditions (even if non-deterministically). Strong emergence is seen to be associated with highly complex systems in which self-organisation and therefore unpredictability play a large part. Bedau (1997) critiques the concept of strong emergence as "uncomfortably like magic" alluding to its seeming ability to illegitimately gain "something from nothing". He advocates a focus on weak emergence, particularly where simulation of systems can be involved in which external influences on emergent patterns can be more easily explored. However, the concept of weak emergence is also critiqued for being practically indistinguishable from reductionism (Brunner and Klauninger, 2003:23).

Despite critiques and ambiguity the concept of emergence features highly in understandings of social-environmental systems and has been used to describe and explain the existence of systems for adaptive co-management (Olsson *et al.*, 2004), governance institutions (McCay, 2002), and has been foundational to the understanding and negotiation of the utility of the concept of sustainability (Trosper, 2005). In relation to concepts such as ICM, (Collins and Ison, 2010:16) claim that:

> the concept of 'emergence' is a way of understanding ICM not as a pre-determined notion or thing, but as something which arises out of a set of practices for managing catchments in particular contexts. A shift in understanding of ICM from a deterministic goal to an emergent phenomenon requires a shift in practices away from prescription of outcomes towards theory-led process design and, ultimately, to the confidence that can be placed in the designs and the designing.

Such an understanding arguably refers to the concept of weak emergence, whereby there is a conceptual link between constituent parts and emergent phenomena. Collins and Ison (2010) advocate the ability to design processes and practices at the small scale that can lead to an effective management process at the larger scale. Such an understanding of emergence in NRM is one that is widely understood, but might also be taken in consideration of the ideas of stronger emergence of outcomes that are unpredictable and non-linear. It is therefore recognised that there are multiple ways in which the concept of emergence can be understood and applied as a theoretical grounding for management decisions and conceptualisations of the system as a whole.

2.3.7. Complexity in water-management systems

Catchments are increasingly described as complex systems. They are described as involving multiple and competing actors and values, alongside uncertainty and interconnectivity in multiple ecosystems, social systems and action arenas, leading to their conceptualisation as complex (Bellamy *et al.*, 2002; Hirsch, 2006; Ison *et al.*, 2007; Pahl-Wostl *et al.*, 2010; Patterson, 2016). Chaffin *et al.* (2016) describe the complexity unique to the wider context of water governance as the need to cross biophysical and administrative boundaries in order to manage water that transcends traditionally defined borders. The complexity arises from the negotiation of power within the necessary structures needed to allow multiple state and non-state actors from multiple operational scales to interact in new ways. Equally, that uncertainty in water governance is based on the unknown potential impacts of climate change on the distribution of water and on extreme and slow-onset events and the ability of governance processes to account for that uncertainty. Pahl-Wostl *et al.* (2012) claim that the introduction of IWRM was an acknowledgement of the complexity involved as well as the ability and capacity of management within wider governance practices to embrace it. Equally, the frequent study of the combination of integrated management and adaptive governance in water resource arenas (e.g. Engle *et al.*, 2011) demonstrates the conceptual presence of complexity through the need to address problems using multiple theories. However, complexity can also be demonstrated in the implementation of multiple theories in water management. For example, Fritch (2017) conceptualises the impact of practical applications of integrated water-resource management on adaptive capacity focusing on the complexities identified in the implementation of the WFD and the Floods Directive in UK catchments. Fritch concludes that in the current attempts to practically combine the two paradigms, the inherently complex reality of the water governance environment has been oversimplified and thus attempts at sustainable governance have failed so far despite changes in management practice.

In addition a focus in water resource studies on institutional complexity recognises the multiplicity of influences on governance processes and the possibilities to affect interconnectivity, character and potential adaptive capacity through transformation. For example Lubell (2013; 2015) demonstrates the institutional complexity of the water-governance system in San Francisco Bay in the US in relation to transformation towards new governance systems, by identifying the groups and institutions involved in decision-making and action and mapping the connections between them, capturing the multiplicity of components and interactions. Wallis and Ison (2011) use systems-mapping techniques to demonstrate and capture changes in institutional configuration in The Goulburn-Broken Catchment-Management Authority in Australia, part of the Murray-Darling Basin management-planning process. They demonstrate the need to pay more attention to organisational learning and cultural change if characteristics of complexity (affected by power) are to be fully incorporated into management approaches in the future, particularly in dynamic and uncertain systems such as Australian river catchments. Lubell's studies captured the institutional complexity that characterises governance and Wallis and Ison identified the 'how' of the complex institutional configuration through identifying key management actions associated with learning and cultural change. It is important therefore to understand both the contextual setting in relation to governance approach and the operational actions that facilitate and are affected by the system.

Although the need for a universal focus on complexity in water management is undisputed, Moore (2013) has highlighted the ambiguity in the definition and meaning of complexity in water governance in particular amongst scholars and practitioners. Moore emphasises that multiple actors at multiple scales may perceive complexity differently, leading to difficulties integrating across scales and prioritising issues. Using examples from Murray-Darling River Basin Authority in Australia and the Prachinburi River Basin Committee in Thailand, Moore demonstrates the differences in local and global conceptualisations of complexity. Crucially Moore concludes that complexity itself at the local scale is not necessarily problematic and that "complex challenges [faced by river basin organisations] served as a critical juncture in which the organisations demonstrated a capacity to adapt, respond, and transform how water was to be governed" (pg 501). Complexity therefore can be seen as a facilitator of change, particularly, in this case, in relation to a responsiveness needed within a collaborative organisation for discerning the practical actions and management decisions needed to enact governance processes. Consequently a better understanding of complexity and how its emergence or perception can identify and induce moments of transformation in a water management and governance system can be important, particularly where change is happening, such as in the UK context.

2.4 A network approach to understanding NRM systems

Networks have become a significant foundation of governance in the context of 'wicked problems' (van Bueren et al. 2003; 193) and are an implicit part of understanding NRM systems and can provide a means through which to analyse the approach to and conceptualisation of notions of complexity in natural resource governance processes (Carlsson and Sandström, 2008). Klijn (2008: 509) states that governance processes explicitly take place within governance networks and the term "governance network" describes public policy making and implementation through a web of relationships between government, business and civil society actors. Therefore there is an association between understanding networks and understanding governance processes. However, Parker (2007:113) highlights that "claims regarding the emergence of new forms of governance in local spaces may be exaggerated if all types of network arrangements are taken as evidence of a transformation from government to governance". It is therefore relevant to examine the application of a network mode of thinking to NRM in order to understand the relationship to governance processes and to water resource management in particular to better understand the potential it offers to reveal something about systems and of governance change.

2.4.1 Conceptualisation and utility of a network perspective

A network approach refers to a network as a set of actors linked through one or more meaningful relationships (Prell *et al.*, 2009; Marin and Wellman, 2010). Most studies describe networks as made up of nodes (for example individuals, communities, organisations (Janssen *et al.*, 2006)) and links (for example flows of resources, social relations, interactions and exchange of information or knowledge (Borgatti *et al.*, 2009)). The key element of the network perspective in SES analysis is the combination of scholarship from social science studies that have considered networks in terms of social interactions, with conceptualisations of ecological networks such as food webs (for example Dunne *et al.* (2004). Janssen *et al.* (2006) explore types of social-ecological networks, and their study was one of the first to propose the use and application of a network perspective to evaluate issues focused on resilience and adaptive governance in a natural resource context, which combined the need for social and ecological network perspectives with an understanding of heterogeneity and dynamism within the network. The concept of networks is consequently relevant for studies of water resource management, involving connected water systems bounded by a catchment's physical features, intertwined with various actors, stakeholders and governance systems at multiple scales. Stein *et al.* (2011) exemplify the interconnectivity of hydrological and governance systems through the concept of networks (Figure 2.3), using the conceptualisation in application to the Mkindo catchment in Tanzania to identify existing social structures and points for intervention.

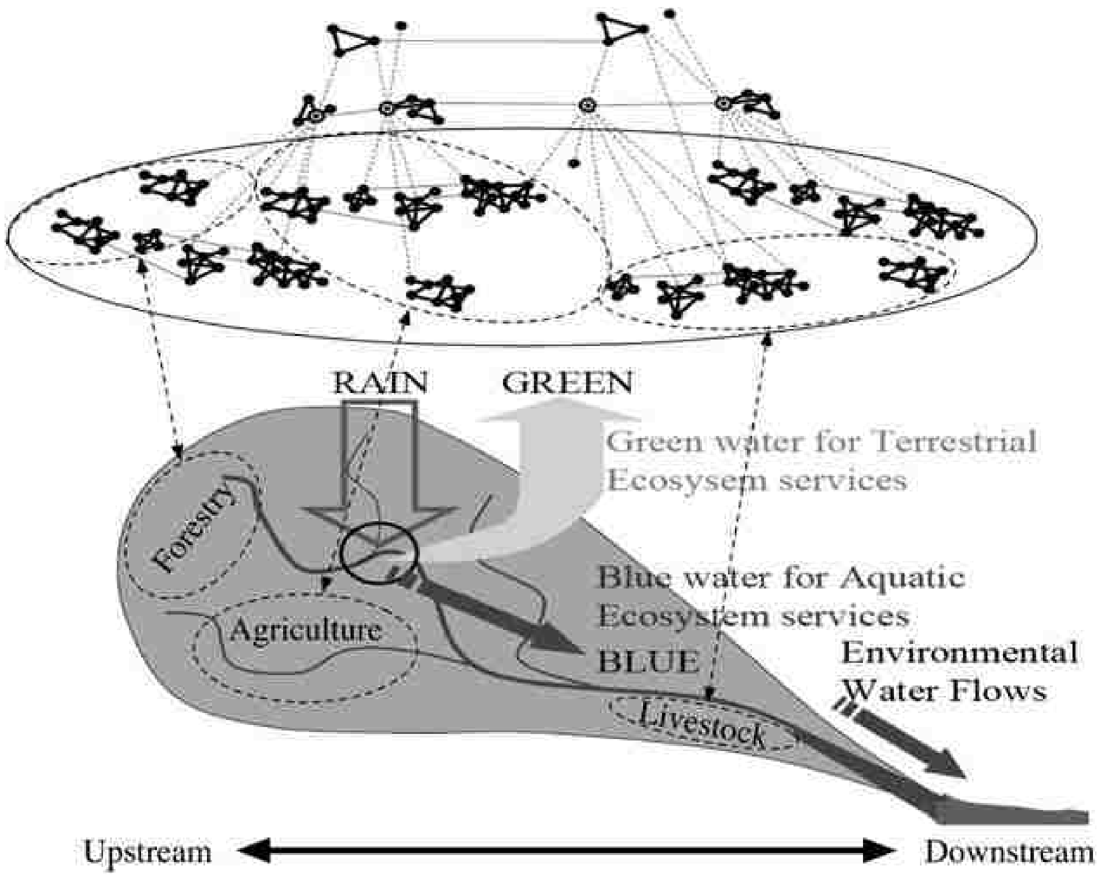


Figure 2.3 *Conceptual model of Stein et al. (2011) of an interconnected system of catchment and governance, where governance is represented as a network of actors that operate and interact at different scales relating to different aspects of the catchment system.*

Within the study of networks in NRM there is a distinction between studies that consider the ecological *and* social networks together (e.g. Janssen *et al.*, 2006) and those that apply an understanding of social networks to NRM contexts, focusing network analysis on social interactions. The majority of studies of networks and NRM are in the latter category and some build on the idea by focusing on institutional networks or describing governance networks. Often the interest is in the composition of the structure of the networks, constituted of the interrelations between the identified nodes and focused on the context that the nodes have created through their interactions (Janssen *et al.* 2006). Janssen *et al.* (2006) claim that it is the relationship between the micro-scale interactions and the grander scale structures that reveal insights into the functioning in each case. Multiple studies have advocated the need to pay attention to the structure and components of networks, for example in relation to features that represent and facilitate social capital, or the importance of the presence of brokers (Tompkins and Adger, 2004; Newman and Dale, 2005; Bodin *et al.*, 2006; Koppenjan, 2008). The formal consideration of such characteristics by Bodin *et al.* (2006) and other studies has been through social network analysis, which has grown as a method to expose social relations and is widely, but not uncritically, applied to NRM studies in various ways.

Effective networked systems are claimed to incorporate mutual trust, reciprocal relations and strong cooperation (Koppenjan, 2008). Newman and Dale (2005) responded to the claims of Tompkins and Adger (2004) and advocated the need to pay attention to and even facilitate a balance between bridging and bonding ties within networks (in reference to the building of social capital). As such Newman and Dale called for an awareness of the difference in utility of properties that can be revealed or imagined through social networks in relation to NRM issues. Bodin *et al.* (2006) focus on the balance of network measures such as density, reachability, betweenness and centrality, and their relation to network characteristics that facilitate structures conducive to adaptive co-management of natural resources. They particularly focus on the role of network brokers who use their structural positions between disparate groups to facilitate trust building and co-ordination, and conclude that network structure can be related to effective functioning of NRM.

2.4.1.1 Structure, networks and power relations

The relationship between network structure and structures of governance is key to interpreting natural resource management systems through a network perspective. However, there are many interpretations of the ideas, their meaning and application, particularly in reflecting on implications for analysing and understanding power and power relations. Critically, as claimed by (Kahler, 2009: 3) "network analysis has too often obscured or ignored questions of network power and power within networks, portraying networks as an antithesis of the hierarchical exercise of power that lies at the core of familiar political institutions". Whilst there are methods and interpretations that confound this, there are also particular interpretations of network perspectives that allow room for reflection on power and context.

Hybrid theoretical perspectives, as mentioned in Section 2.3.3, specifically Actor-Network Theory (ANT) hold a particular understanding of networks that is often critiqued for revealing little about power dynamics. ANT sees networks as networks of actants (both human and non-human). It makes no a priori assumptions about the causal efficacy of actants, analysing them symmetrically and breaking down the subject/object dualism (Latour, 2005:76). This is often described as 'ontological leveling' (Eden et al. 2000; Castree 2002; Kirsch and Mitchell 2004) and gives human and nonhuman actants equal agency in the sense of intentional action, Equally, it views the social as consisting only of networks and Latour claims that "society, culture, or structures of dominance cannot be used to explain particular outcomes because our social world consists not of these macro-level structures, but of undetermined agglomerations of star-shaped networks" (Lave, 2015). Latour believes that class, race and gender are not important social structures and that inequalities are not the result of structural forces but rely on the size of networks. This is at odds with scholarship from critical political ecologists who analyse relations of dominance in social and political systems. In critique of network approaches that follow such beliefs about the lack of structural influence Castree (2002;123) states that "to scrutinize society-nature relations in abstraction from processes of capital accumulation is to miss a vital aspect of their logic and consequences". Lave (2014) argues that the incompatibilities between the flattened network approach advocated within ANT, and the political ecology perspective that recognises wider influences of structure on the production of inequalities, are too significant for ANT to be relevant in nature-society research and where there are attempts to fit the approaches together this requires "weakening" ANT to a form that may no longer be recognizable as such (Castree, 2002).

As, Ezzamel and Reed (2008: 600) recognise, the regulative practice and form of governance is always mediated through particular socio-historical and spatial contexts. As such this thesis will not adopt an approach to a network perspective that draws on the ontological position of ANT, but recognises that the social is made up of more than just networks and that there is influence of wider social structures on producing and bounding networks, the study of which may help to understand governance and the modes through which governance is implemented (e.g. policy networks and governance networks). Equally, it recognises that the wider social structures can have a significant effect on power dynamics which effect inequalities in the system that need to be the subject of research.

Other interpretations of network structure in relation to governance and power relations are influenced by the study of policy networks and governance networks. In such studies network structure is understood as "how direct relations are combined or arranged in a network" (Friedkin 1981, 41). Thus, it is a reflection of the patterns of interaction, where human actors are the main element. However within such studies it is also recognised that there are multiple institutions, groups and alternative actors within the network. The ties or links in a network among the actors (nodes) create a structure (a persistent pattern of relations) that in turn serves to constrain actors or provide opportunities for action (Wasserman and Faust 1994, 4; Scott 2000, 2-3). Lin (2001) describes interactions as a transaction of resources (money, knowledge, information, legitimacy). Within networks there is assumed to be interdependence between actors based on resources, where control is exercised and where there may be gains to be had by pooling resources (Powell, 1990).

Importantly, Sandström (2008:31) recognises that the situations of interdependency do not necessarily have to be symmetrical:

> "On the contrary, and as emphasized by Lin (2001), the actors might be hierarchically related to one another depending on the resources they hold or can get a hold of. The common misconception about networks, presuming a flat structure (by definition), must be dismissed. Although the actual differences in authority might not be expressed in or correspond to any formal organizational schedule, this should not lead to the interpretation that the distribution of power and influence is equal. On the contrary, this is rarely the case."

The recognition that hierarchical interrelations might not be represented in a network structure is important for reflecting on the influence of power within governance systems and the utility of networks as representations of governance. It is likely that multiple forms of power come together within the system and might be difficult to identify empirically. However, Knoke (1990) argues that social networks reflect power relations and when such relations are made visible, networks can go some way to helping reveal existing power situations. The sticking point of network perspectives is therefore in their ability to make visible power dynamics needed to interpret and analyse governance.

Network studies have also analysed the structural effects that the institutions within a policy network in question put on the individual behaviour, and have questioned the difference between networks and governance (policy) networks. For example Parker (2007) concluded that "not all network arrangements can be described as governance networks" and that "networks must have depth, breadth and an association with values such as trust, mutuality and identity in order for them to perform a governance role. Considering this fluidity of interpretation, policy networks are perceived as "organized entities that reflect specific types of institutional arrangements" (Carlsson 2000, 58), which in turn are influenced by wider structural context and power dynamics. The strengths, as well as the substance of the processes of institutionalisation and the character of the institutions that shape and are shaped by interactions and rules of the game, will have an effect on collective action and problem solving (Sandström, 2008).

The relation between policy or governance networks and their performance or functioning is seen as complex. Figure 2.4 adapted by adopted Sandström, (2008) and based on Marsh and Smith (2000), shows how structural context, network structure and agency are linked to outcomes, which are related to policy outcomes of a policy network, but could also be governance outcomes of a governance network. It implies a dialectical relationship where there is iteration between outcomes and agency via learning and between outcomes and structure via network structure.

Within this thesis it is therefore understood that networks are not the only way that governance systems can be understood and that they go only some way to understanding the relations, structures and contexts that contribute to a system, such as environmental resource management. Networks should not be interpreted only as flat representations of symmetrical relations but as a form of mapping of interrelations, processes of learning, institutionalisation and helping to go some way to highlighting complex power dynamics, if alongside other forms of interpretation to strengthen the understanding of the system.

Modes of analysis of networks have a long history and are more typically associated with quantitative interpretations of relations, which is where this thesis recognises the importance of a qualitative evaluation of networks and network structures to reveal details of the hierarchical systems and wider contextual political structures that also influence outcomes and functionality.

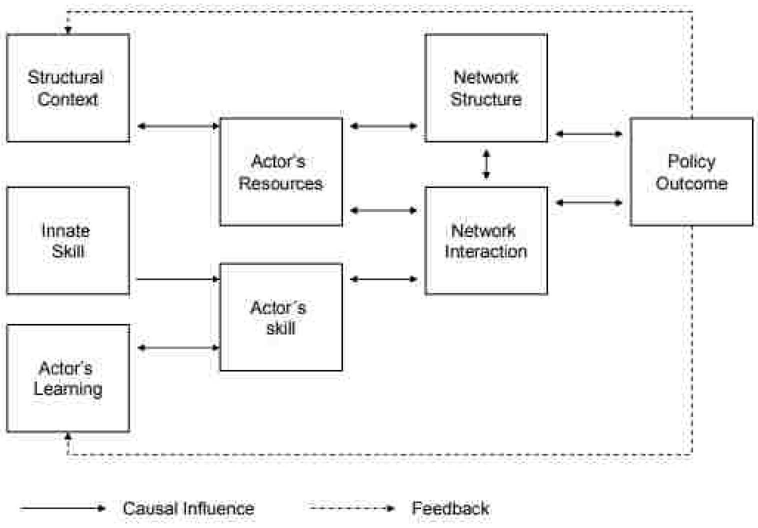


Figure 2.4 *How networks relate to outcomes (Sandström, 2008) based on Marsh and Smith (2000).*

2.4.2 Social network analysis (SNA)

The idea of social networks and their ability to be studied has a long history (Freeman, 2004). Those first writing about SNA (Wasserman and Faust, 1994; Borgatti and Everett, 1999; Degenne and Forsé, 1999) recognised the link between the topology of social networks and how actors actually behave. The core principles of SNA are based on a social theoretical understanding of how and why people communicate and connect, as well as graph theory, which informs a formal understanding of the relationships, configurations and combinations of nodes and links (or edges) in particular exemplified formations. Ideas from the study of complex networks informed through graph theory have allowed the theorisation of properties of complex networks such as scale-free and small-world organising principles (Wang and Chen, 2003). Standardised descriptors using measures such as betweenness, centrality, reachability and density, relating to features such as the number of nodes (actors), number of links between nodes, number of links from individual actors, or the existence of clusters or sub-groups allow networks to be compared across contexts. Seminal studies such as Granovetter (1973) have informed understanding about the detailed configuration of networks, by looking at the strength of ties (links) within a network and the effect of differing strengths (based on trust, closeness and frequency of exchange) on functionality.

Various studies in NRM have relied on the standardised language and interpretation of structural features and analysis processes of SNA to demonstrate the utility and value of various structural configurations in relation to desired concepts such as co-management, adaptive governance and resilience. Due to the variety of contexts in which SNA can be and is applied and the multiplicity of governance regimes, processes, aims, policies and physical environments involved in SESs, there are multiple conclusions from SNA studies. Scholarship does congregate around the identification of important features of environmental governance through SNA language and methodologies. As an example Alexander and Armitage (2015) demonstrate the conceptual link between some of the structural attributes identified through SNA and the processes and features linked to the governance of the SES, in their case of Marine Protected Areas, but that also apply to other natural resource contexts (Figure 2.5).

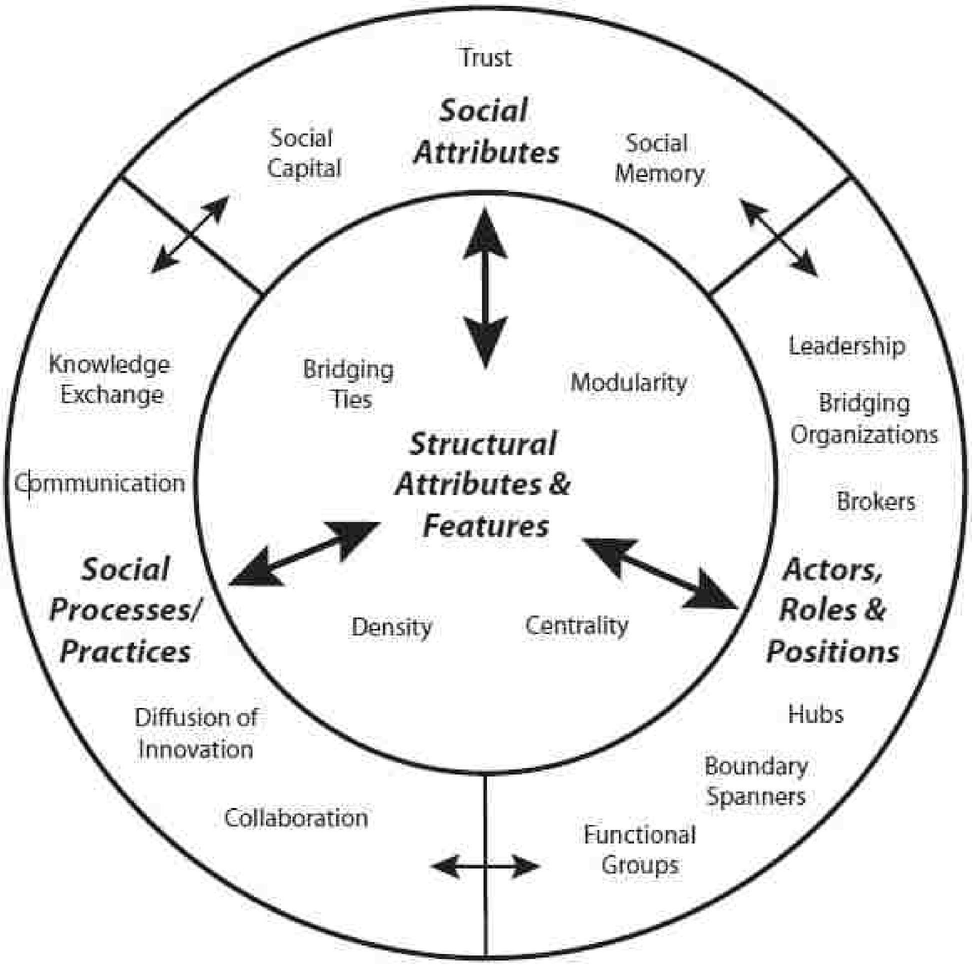


Figure 2.5 *Examples of the features, attributes and processes that can be associated with NRM networks (based on studies of Marine Protected Areas by Alexander and Armitage, 2015).*

There are a number of recent studies that have demonstrated the applicability of SNA to NRM as well as to water-resource management in particular. Sandström and Rova (2009) used a quantitative analysis of social networks in Fish-Management Areas in Västerbotten, Sweden to demonstrate the link between network structure and performance, particularly relating to policy making and performance. Sandström and Rova highlighted the impacts of network qualities on desired performance aspects. For example, they demonstrate that network density has an impact on collective action, particularly through evaluating the number of relational ties between different kinds of actors. Sandstrom and Rova's case study demonstrated the application and value of a structured approach to network analysis in NRM and the possibility to begin to make observations across contexts using the same language and approach.

Prell *et al.* (2009), using a study of The Dark Peak area of the Peak District National Park, UK, give an example of how network analysis can be used to expose the dynamics of stakeholder networks. By combining SNA with stakeholder analysis, Prell *et al.* demonstrate a productive use of the network approach to identify key, central groups and key marginalised groups among stakeholder categories. The value of the research was in the provision of evidence that could potentially be used to change practice by better balancing integration and participation of diverse stakeholders. It also provided a better understanding of facilitation of knowledge exchange in organised collaborative partnerships to manage the National Park.

Fliervoet *et al.* (2016) use SNA to challenge the assumption that there has been a transition to an equitable partnership role of governmental organisations in floodplain management in the Dutch Rhine delta. SNA is used to chart relationships between flood-protection organisations and nature management. Consequently, Flievolet *et al.* demonstrate the consequences of removing the most central actor and highlight the dependence of the stakeholders on the governmental actor despite the alleged shift in governance. Flievolet *et al.* demonstrate the applicability of SNA to analysis of governance. Similarly Stein *et al.* (2011) used SNA in the Mkindo catchment Tanzania to empirically map the social networks between actors in order to assess the effect of networks on the capacity to govern water. They discovered that informal networks, facilitated through the linking role of village leaders were important, but not acknowledged by current or imminent governance systems. Stein *et al.* proposed that the results of SNA analysis could help inform the planning and implementation of the future governance system of Water User Associations for the better, and place more value on strengthening informal water management networks as part of the governance system.

Ernstson *et al.* (2010) similarly focus on the combination of social and ecological networks but use a formal structural social network analysis merged with ecological scales to produce a framework for a 'well-working network governance structure'. Their study of the management of urban green areas in Stockholm reveals, similarly to Stein *et al.* (2011), that the role of smaller civil society groups engaged in local management, alongside cross-scale brokers who connect people across ecological scales, is crucial but overlooked by current governance. Therefore their study, using SNA has allowed them to define a governance framework based on an understanding of the productivity of structural networks. These examples demonstrate the applicability of SNA to the study of SES in order to help better understand practice and processes in systems of management and the relation to governance approaches and trajectories of governance change;

to reveal intricacies of relationships otherwise overlooked, and to help inform future management and governance change.

At the time of writing there is a lack of academic studies of SNA of UK catchment-management process, although there have been discussions amongst CaBA practitioners of the applicability of the method (CaBA Forum, 2015). Practitioners have debated the data-heavy nature of the method and therefore its relative difficulties compared to other approaches to understanding the system such as stakeholder analysis, which offer quick and instrumental views of who could and should be involved in decisions making. Network approaches, whether descriptive or comprehensively quantitative, brought from the academic angle offer a deeper picture of the system and could therefore be informative to practitioners who do not have the time or space to conduct in depth analyses.

2.4.3 Networks as modes of governance

Governance networks (understood as constitutive of governance (Klijn, 2008)) refer to systems of involvement that include collaborative or participatory aspects, but that go beyond the ad hoc and become formally or informally institutionalised (Newig *et al.*, 2010). Torfing (2005:307) defined governance networks as "(1) relatively stable horizontal articulations of interdependent, but operationally autonomous actors who (2) interact with one another ... (3) within a regulative, normative, [and cognitive] ... framework that is (4) self-regulating within limits set by external forces and which (5) contributes to the production of public purpose [such as natural resource sustainability]". Importantly, Torfing and Sørensen (2014) highlight that governance networks can perform many different functions, come in many different forms and be labelled in many different ways. On the latter point, they are often referred to as think tanks, strategic alliances, task forces, public boards and committees, commissions, collaborative arenas and planning cells. Torfing and Sørensen (2014) argue that the different labels, forms and functions of governance networks demonstrate the relevance of the concept for describing and thinking about the contemporary forms of interactive governance.

It is believed that governance conducted in networks makes a difference to the level of individual and collective learning and therefore the functioning of environmental management practice (Newig *et al.*, 2010). The formal feedbacks within networks are argued to be important for a reflexivity that allows more successful evolution of the network (Dedeurwaerdere, 2005). Despite their possible evolution, governance networks are defined specifically by their relative stability, by which the processes of learning and deliberation become grounded, helping to better cope with complexities and uncertainties in environmental problems (Head, 2008) and thus create the conditions for adaptive resource governance.

In a study of the relevance of governance networks against other theories and frameworks Montenegro and Bulgacov (2014;111) state that:

> "Governance in the form of self-organized networks doesn't seem to occur through planning. These networks are self-forming and, based upon observations, are gaining more strength and autonomy over time (Sorensen & Torfing, 2005). [...] The more we know about networks, the better we understand governance dynamics and its relationships with government, informal mechanisms, and private actors. Hence, we believe that qualitative research is essential for understanding some of the questions related to governance networks"

The recognition of governance networks as a desired state gives value to the process of SNA and social-ecological network analysis because questions are raised about the configuration of networks, their creation, maintenance, utility, stability and resilience. Olsson *et al.* (2006) use five case studies of water management to explore the modes and characteristics of transformation towards adaptive governance. They identify a number of arenas that appear to be important, including shadow networks, innovation, leadership, preparedness, shared visions and scales. Rammel *et al.* (2007) argue that co-evolution is possible and happening in NRM systems through the association of institutions, behaviour and environmental change. They argue that the possibility of change does not mean successful change and that further study of the mechanisms, feedbacks and relationships between behaviour, institutions and natural resource systems is needed. Such questions and challenges are relevant for the governance networks being created in UK catchments through the system of CaBA. Questions are raised about the stability, utility and relevance of new structures of interaction amongst stakeholders as each catchment considers how to adapt and focus the behaviour, actions and interactions amongst stakeholders to create partnerships and encourage collaborative working.

2.4.4 Complexities and critiques of the network-analysis approach

The approach can be hugely varied and is particularly complicated by the multiplicity of theoretical positions used to interpret the influence of individual agency on structure and the influence of structure on individual agency. Most studies have recognised the useful conceptualisation of two levels of analysis, the micro, or individual level, and the macro, or aggregate level (Latour *et al.*, 2012). Some argue that individual agents at the micro-level shape the macro-level network structure through their actions, often through a non-linear process of emergence, and some argue that it is the macro-network structure that constrains and enables individual action at the micro-level (Tasselli *et al.*, 2015). Key questions are raised through such debate about the origins of social, ecological, biological and universal organisation (e.g. Axelrod, 1984). Most studies however, recognise a co-evolutionary process of the micro- and macro-levels (e.g. Emirbayer and Mische, 1998; Tasselli *et al.*, 2015) (Figure 2.6). Each conceptualisation can have consequences for theorisation about the system. For example Boonstra (2016) highlights that if structure is given agency then abstract systems, such as capitalism, are given an autonomy linked to their power to influence. This might raise questions about ability to change systems, where seemingly abstract structures are seen to exert influence, and can be linked to questions of transformation of governance in relation to social-ecological network conceptions. Equally, when no power is attributed to structure but instead to individuals and groups, there is an implicit assignation of duty and responsibility to individuals to create happenings in society through direct design (Boonstra, 2016). This individualist perspective could be problematic if other constraints on action are ignored, such as context, history, experience, teaching, culture, norms and values (Morriss, 2006) and the ability to act in particular ways to meet ideals such as adaptive governance is misunderstood.

The questioning of the utility of network structure highlights the difficulty in conceptualising the cause-effect dynamics in complex networked systems. Such a difficulty reflects a critique of SNA, because SNA is based on a number of often unreported assumptions about structure and agency, emergence and change. If it is to be utilised effectively there are calls to be more reflexive of the ontological perspective taken and therefore the problems that may arise because of the assumptions made. This PhD research attempts to be critical of the use of a network approach but expectant of its value to help build a more detailed picture of aspects of complexity.

The application of SNA to the study of SES has also been critiqued. Scott (2015) criticises SNA for privileging network structure as the key to success in environmental governance and thus ignoring gender, class, scale, space, power, context, history and culture as equally legitimate influences, arguably unable to be captured through the prescriptive structural approach. Scott also highlights that by bracketing off political-economic dimensions, SNA promotes a form of resilience that fetishises the local (Joyce, 2003) as a point of governance, bounded tightly within existing (and perhaps defective) market and governance structures. Thus Scott (2015) critiques SNA for offering little opportunity to highlight sites of resistance or change. This is tied into the problem of networks as a performative element, whereby the method of SNA actively constructs and represents visions of networked forms of governance that are assumed to be real and amenable to modification (Law and Urry, 2004). Such ideas are problematic when the projected visions of stakeholder participation that arguably reiterate hegemonic ideals are built through a real reworking of the conceptualised networks identified by SNA. Therefore there is opportunity to use SNA, or elements of SNA, as part of larger multi-method studies in order to counter the interpretive problems potentially encountered, as will be done in this research.

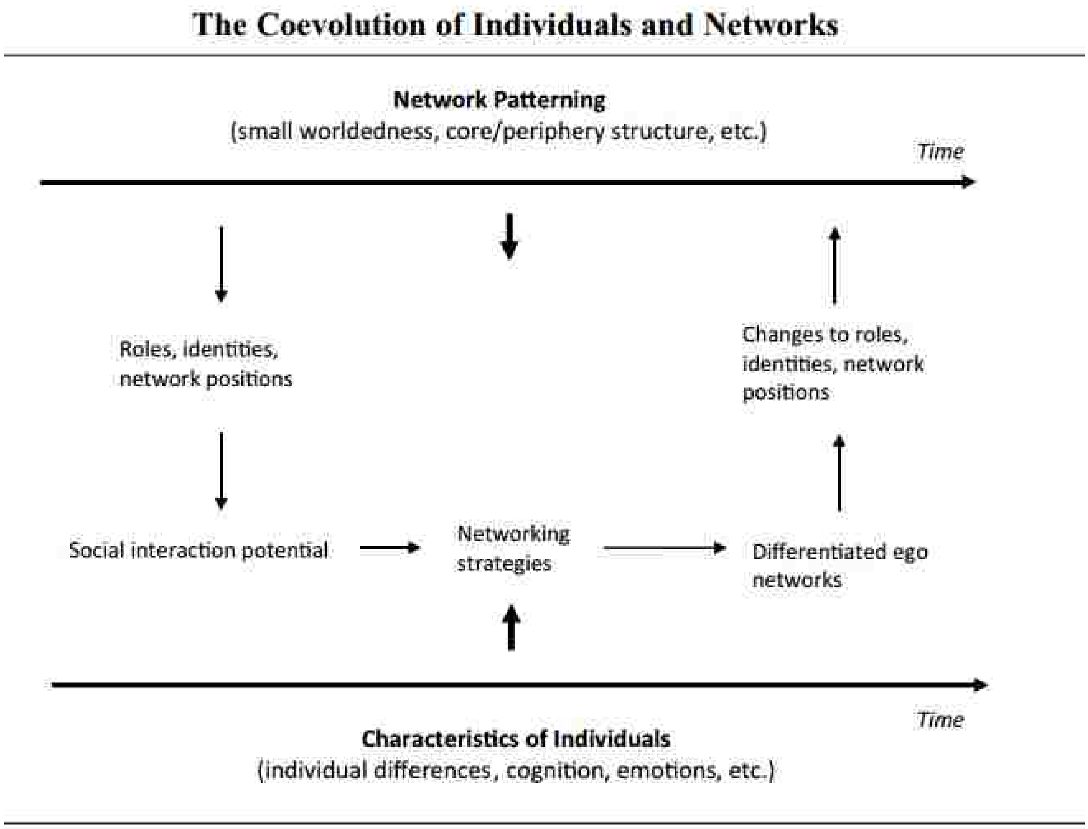


Figure 2.6 *Representation of the relationship between individuals and network patterns (Tasselli et al., 2015)*

2.5. Agent-based modelling (ABM) of NRM systems

ABM can offer a novel mode of exploration of a NRM system and is one that is taken up by this research in relation to the water management context.

2.5.1. Simulation in social science

In general a model represents a researcher's understanding of a situation, and it is recognised that models are defined by the way they function and their use as a tool for exploring a certain phenomenon (Harvey, 1969). In recent years computation has become the main mode by which models are created. Digital computation led to a 'quantitative revolution' in the 1950s and '60s (Barnes, 2004), favouring mathematical modelling, but which was subsequently heavily critiqued for its inability to recognise the complexity observed in the social world (Gilbert and Terna, 2000; Clifford, 2008). In 1988, Ostrom proposed an alternative 'third symbol system' involving simulation. Simulation can be understood as a particular type of modelling that involves a deeper exploration of the phenomena of interest and aims to gain an understanding of the processes and mechanisms that are at work, rather than just recreating patterns of correlation as in statistical models (Gilbert and Triotzsch, 2003). Simulation is argued to move away from imperialistic claims that quantification is the route of objective truth (Cosgrove, 1989) and recognises the dynamics in social and ecological systems through time and space.

Simulation is arguably one of the key roots of ABM, alongside the emphasis on modelling disaggregate systems, based itself on critiques of oversimplified homogenised populations used in statistical models. According to Gilbert and Triotzsch (2003), simulation introduces a new way of thinking about social processes by focusing on emergent properties of simple behaviours. The ideas are based in complexity theory (Waldrop, 1992; Kauffman, 1995), which looks at non-linear systems and interactions that produce unpredictable effects and patterns. Early simulation in the 1960s was based on systems dynamics and the earliest models involved simple studies of large-scale systems for prediction, for example, the future of the world economy (Meadows *et al.*, 1974). Microsimulation (Orcutt *et al.*, 1986) is another early simulation strategy and focussed on changes within a population based on probabilities (Gilbert and Triotzsch, 2003) which was used in policy research for predicting the effect of policy on wider society (Crooks and Heppenstall, 2012). The criticism of micro-simulation is that it was a one way simulation with no interaction between individuals.

In terms of the 'agent' in modelling, (Gilbert and Triotzsch, 2003) state that it wasn't until the 1980s and 1990s that ideas really emerged. In the physical sciences the idea took hold in the form of developments of the 'cellular automata' model, which in itself had its origins in the 1960s from researchers von Neumann and Ulam (Schiff, 2011), made popular through the 'Game of Life' by John Conway, which created a model in which cells/individuals could live or die depending on parameters such as overcrowding and reproduction (Epstein and Axtell, 1996). Cellular automata models involve representing the population and the environment together in discrete cells that with each time step can change between two states. The decision to change state is based on information about the states of each cell's neighbouring cells (Crooks and Heppenstall, 2012). The idea behind the cellular automata models was to create representations of systems level behaviour by using simple, local level behavioural rules. It was found to have widespread application, but the restriction with this type of model is that individuals or agents are limited in space, or interact separately with their environment, which is a critical feature of spatial socio-ecological systems that are of interest in geography, and which agent-based models came to represent (Batty *et al.*, 2012).

2.5.2. Agent-Based Models

Agent-based models have emerged alongside cellular automata models and involve diverse and heterogeneous agents that can interact with one another and with their environment. They allow the study of the local and the small scale in spatial systems as well as giving an overview of patterns and concepts in complex, interconnecting systems. The idea of ABM is to "understand properties of complex systems through the analysis of simulations" (Axelrod, 1997:3) with simulations involving "individual actions of diverse agents" and the measurement of the "resulting systems behaviour and outcomes over time" (Crooks and Heppenstall, 2012:86). The communication and interaction of agents between each other and their environment (O'Sullivan *et al.*, 2012) is a key facet of the agent based modelling approach (Millington and Wainwright, 2016). The emphasis is on the 'bottom-up' (Epstein, 2006) approach of ABMs, which is central to its opposition to aggregate mathematical models with central controls on large homogenous populations.

2.5.2.1. The concept of an agent

At the most basic level Millington and Wainwright (2016:5) describe an agent as "an object with defined attributes capable of executing functions autonomously". Based on the original ideas of Wooldridge and Jennings (e.g. Wooldridge and Jenninngs, 1995; Wooldridge, 1999). Jennings *et al.* (1998:276) state that: 'an agent is [essentially] a computer system, situated in some environment that is capable of flexible autonomous action in order to meet its design objectives'. Crooks and Heppenstall (2012) list that common attributes of an agent are:

- Autonomy: they are free to interact with other agents and there are no central controls on agents except for the influence of social norms and institutions that have built up through previous agent interaction (Epstein, 2006).
- Goal directed: each agent has a set of goals to fulfil.
- Reactive: they have a sense of their surroundings and can react to changes.
- Bounded rationality; each agent's behaviour is based on the rational choice paradigm (Axelrod, 2007), where agents make choices that are adaptive and inductive in order to move towards their goal, but which are bounded by the use of only local information to inform choices.
- Interactive: agents can communicate with others.
- Mobility: agents are free to roam through the space.
- Adaption/ learning: agents can be programmed to change their state depending on previous states to simulate a learning process.

Agents can be organisms, humans, businesses, institutions, or any other entity that pursues a certain goal (Railsback and Grimm, 2012) and can be considered as the 'people' of artificial societies (Epstein and Axtell, 1996). Each individual is placed in a simulated environment, and each has a set of states, some of which are fixed for the agent's life and some of which can be changed. Through the concept of 'weak' agency (as opposed to strong agency involving emotions and human cognitive characteristics in artificial intelligence), the interaction of agents and their associated and changing states and the states of the local environment can represent systems ranging from the operation of markets, movement of traffic, animals in an ecosystem or behaviour amongst government institutions, among others (O' Sullivan, 2008).

2.5.2.2. Early models and the growth of ABMs

One of the first applications of the concept of ABMs in social science was by Thomas Schelling in the 1960s and 1970s, with his classic series of papers: 'Models of Segregation' (1969), 'On the Ecology of Micromotives' (1974), and 'Dynamic Models of Segregation' (1971). Among these studies Schelling created a spatially distributed model of the composition of neighbourhoods, which involved agents having some level of preference for their neighbours being of the same 'colour' as them and moving neighbourhoods accordingly to maintain the preferred ratio of neighbours of the same colour as themselves. He found that even fairly 'colour blind' preferences produced segregated neighbourhoods (Epstein and Axtell, 1996). The experimentation with small scale social rules to observe the emergent patterns was a new way to do social research and opened up issues for debate and further research that might not previously have been identified in the same way.

Early use of ABM in terms of social-environmental systems experimented with the combination of complex interdisciplinary systems. For example the SugarScape model (Epstein and Axtell, 1996) is made up of a spatial distribution of a resource ("sugar") that agents use as food, which is relatively rich in some places in the landscape and relatively impoverished in others. Agents in the system have metabolism, vision and ability to reproduce and follow simple local behavioural rules that equate to searching for the richest areas of sugar, travelling to them and consuming them. Movement uses up energy and when energy is depleted the agent dies. The purpose of Epstein and Axtell creating this hypothetical situation was to observe the emergent behaviour of the 'society' that they had created through the simple behavioural rules. They observed that the concept of ecological carrying-capacity was important and evident, equally that when seasons were introduced the concept of migrant communities emerged. They also found that patterns of distribution of wealth (in terms of sugar collection) emerged and found that they appeared to mirror society in that there was a distinct skew, where most of the population had relatively little wealth, demonstrating that there are similarities between human societies and the artificial society in SugarScape (Epstein and Axtell, 1996).

ABM models can also be used in a more specific sense to try and understand patterns of past societies and can, according to Epstein (2006:12) provide a "powerful new way of doing empirical research". In a study attempting to reconstruct the Anasazi population dynamics, who lived in Arizona between 800-1300AD, and who disappeared from the valley after that time, Dean *et al.* (2000) used ABMs as an experimentation ground for possible theories. They derived that it could have been predominantly non-environmental, sociological and ideological factors that were responsible for the complete abandonment of the area. Dean *et al.,* acknowledge that although the model may never explain the 'real' history, it provides an instrument for making progress in a replicable and cumulative way in formulating principles and hypotheses about systems of interest.

2.5.2.3. Realism and simplicity

One issue that is constantly apparent in ABMs and throughout their development has been the issue of realism. Models are always an abstraction of some 'real' system and in general, most modellers appear to hold realist ontologies, in that they believe that there is some reality out there, for example, O' Sullivan (2008) states that modellers assume that there is at least some truth that is truer than others. Although there is recognition now that there are limits on the understanding that can be gained about that reality from models because the conception is influenced by human interpretation (cautious realism): each model is only an interpretation of a reality, and can be manipulated and constructed by the researcher (O' Sullivan, 2008). Models, therefore, are often described as falling along the scale of realism, from essential to complex (Dietrich *et al.*, 2003) and with each scale of realism comes a different function or development. Davidsson (2002) states that ABMs are most appropriate in situations where decisions are concentrated on particular locations, in which the structures and patterns of the observed actions are seen as emergent. This PhD research takes a cautious realism stance and expects a model to be a representative of an interpretation of one view of reality and acknowledges the role of construction in the interpretation of the model.

2.5.3. Principles of ABM

2.5.3.1. Complexity and Emergence

Complexity and emergence are two concepts that are central to the application and understanding of ABM. Complexity is seen as a property of a system, where elements are deeply interconnected, and where the removal of one element can change the system dramatically (Miller and Page, 2007). Behaviours of a complex system are theorised to emerge from the activities of lower-level components or local interactions of agents (Epstein, 2006; Miller and Page, 2007). In social systems, the lower-level components are seen as individuals who are enmeshed in a complex system through which they have to have adaptive behaviour to navigate (Sawyer, 2005). In order to understand and 'explain' complex systems, if emergence is thought to be true in some sense (see section 2.3.6), then understanding lower-level components of a system could reveal the mechanisms through which the higher level components develop.

Idea of hierarchies, in which the upper levels contain the elements of the lower levels, features in ABM Allen and Hoekstra (1992) present this idea in order to understand ecosystems, where analysis can be performed horizontally within levels, vertically between levels or diagonally across both dimensions. Complexity in ecological systems can be studied through observations of connectivity of the elements, their interactions and their organisation across various scales (Bousquet and Le Page, 2004). Understanding these base-level elements, within ideas of emergence, arguably lead to understanding higher-level patterns and systems. The study of these relationships is often referred to as a bottom-up approach. A bottom-up approach traditionally views the singular individual as the atom of society and focuses study on them to understand whole systems. Some core principles that underpin the use of bottom-up modelling are presented by Bousquet and Le Page (2004:318):

- Individuals, products of history are driven by collective values and rules;
- Collective values and rules evolve because of the interaction between individuals and groups;
- The individuals are neither similar nor equal but have their own specific roles and social status.

Such ideas of emergence explored through generative, bottom-up science using ABM is not without critique, however it is argued that ABM can be used to explore the relationships between structure and agency and can go beyond its critique of being overly focused on emergence (Halpin, 1998).

2.5.3.2. Justification of simulation as a social science

Based on the concepts of complexity and emergence, ABMs are 'generative' in that through the process of modelling, a population of autonomous heterogeneous agents can be situated in a spatial environment in which they can interact according to simple behavioural rules, which will thereby 'generate', or 'grow' the macroscopic patterns from the bottom up (Epstein, 2006:6). In this sense it is the process of modelling itself that becomes part of the theory (Batty *et al.*, 2012) and moves away from the nomothetic, or law-seeking epistemology (Cederman, 2005). ABM has been labelled as a 'third way of doing science' which is distinct from induction and deduction (Gilbert and Terna, 2000), but which could be argued to include both in its various stages. Winsberg (2010) argues that ABM has a downward epistemology from theory through data to knowledge. Equally, it can be used in a wide range of situations and at various stages of the research process from theory building to hypothesis generation and testing, to prediction and scenario development (O' Sullivan, 2008).

2.5.4. Addressing critiques of ABM

There is ongoing critique that models as abstractions of reality average away the heterogeneity and richness of socio-ecological systems (Batty *et al.*, 2012). Early ABMs such as SugarScape have been criticised for their simplicity and for being so epistemologically 'thin' (Millington and Wainwright, 2016) that they contribute nothing to sociological theory because they miss out aspects of institutions such as inequality, power and privilege (Goering, 2006). Equally, ABMs have been criticised as a method that reveals nothing about the lived experience of social phenomena (Millington and Wainwright, 2016). In response, because of their now frequent combination with in-depth qualitative data, they have the potential to be part of the research process that explores experience alongside the more theoretical ideas expressed through the generative process of modelling.

It is actively acknowledged that the value of ABM is expanded when informed by empirical data (Zellner *et al.*, 2014) and one of the distinct advantages of ABM is that it can incorporate many different forms of data (Chattoe-Brown, 2014). Surveys, questionnaires, experiments, GIS and other spatial data can be used to inform the patterns and rules within a model architecture, but it is ethnographic data, including interviews, that are an increasing focus of attention to inform model building as a social science.

However, it has been argued that there can exist an incompatibility between ethnographic data and ABM, if ABM is perceived as a quantitative form of research, due to the epistemological difficulty of translating a fuzzy, qualitative explanation into coded rules, variables and numbers. As a counter to this view Yang and Gilbert (2008) state that there is nothing inherently quantitative about ABMs and therefore there is no epistemological incompatibility but instead only translation issues (Agar, 2003). This research agrees with the view that ABMs are not a quantitative form of research and sees benefits to expressing the hypotheses generated from qualitative data analysis through a modelling process.

Nevertheless, difficulties still arise translating ideas through ABM and O'Sullivan and Haklay (2000) critique the individual nature of ABMs and the isolation of agency from the modelled environment, in that the agents act either within it or upon it in a closed representation, meaning that certain aspects of hybridity inherent in wicked problems cannot be represented. Significant aspects of agency at multiple scales in addition to the individual, including the action of institutions, are also argued to be restricted by ABMs. Moreover, causality is often a sticky issue in ABM (Ziman, 2003) because by the nature of modelling, particularly in black box systems, as ABMs tend to be, there is no evidence of the mechanisms that lead to emergence. Equally, the way in which emergence actually implies causality is incredibly fuzzy, because "pattern is not directly related to process" (Clifford, 2008:682) and ABMs may simply mimic emergence. Grimm *et al.* (2010) among others, have attempted to develop protocols in the method of ABM in order to acknowledge as clearly as possible that each model cannot be valid in representing (a certain interpretation of) reality simply because it reproduces data.

Concurrently, Simandan (2010) highlights that any output from a computer simulation will always be undermined through criticism of the choices made about what was included, leading with the argument, similarly posed against other modes of research (Millington and Wainwright, 2016), that an element crucial in the causal chain has been left out. Another concern with the modelling of an open system in a closed model is the absence of the iterative feedback between historical context and individual decision making, which O'Sullivan *et al.* (2012) argue to be a fundamental part of any decision-making system. Such criticisms lead to ABM's status as a 'thinner' method due its simplified and incomplete representations of the world compared to representations produced through 'thicker' methodological approaches such as ethnography that, although also simplified and incomplete, have traditionally been more often favoured for a social science study and seen as incompatible with thinner methods.

Despite the comparison, the difference between ABM and ethnography can be argued to be in relation to the detail in the representations rather than the fundamentals of the representations themselves (Millington and Wainwright, 2016). The strength of agent-based modelling is its ability to combine thick (qualitative) and thin (simulation) approaches through iterative knowledge and theory creation. The approach to modelling in this research is therefore to ground the model in empirical data to maintain a link to the thick descriptions provided by qualitative data. Simulation is then used as a heuristic tool to experiment with the assumptions and patterns deduced from the qualitative data, whilst remaining critical of outcomes of a model and to interrogate the usefulness of the outcomes, as well as the process, for building knowledge about the system.

Studies that have applied ABM to NRM issues have also addressed critiques. Bohensky (2014) in a study of learning dilemmas and barriers to learning in South African water management, emphasise that the model is a highly stylised version of reality and does not include potentially important dynamics such as risk perception and changing thresholds over time. In the acknowledgement of the limitations of the model, its potential as a starting point for better understanding, rather than an end point, is portrayed: "A great advantage of agent-based models is that they do not intend to predict future outcomes but stimulate thinking and initiate dialogue critical to addressing the challenges that are faced in this arena" (Bohensky, 2014:2). Such an understanding of ABM is adopted in this thesis and the role of the modelling process in the research is to act as an exploration of complexity and to raise questions about the possible mechanisms and processes involved in managing water resources in the UK context.

2.5.5. Application of ABM to NRM

2.5.5.1. Social-ecological systems research

The application of agent-based modelling to social-ecological systems is founded in the ability of ABM to facilitate investigation and better understanding of the consequences of decisions in complex systems (Smajgl *et al.*, 2011). Early work by Costanza *et al.* (1993) noted that both ecological and economic systems exhibit characteristics of complexity and their interconnection requires synthesised and integrated study. Modelling offers a way to comprehend and explore the holism of human-environment systems, particularly through the coupling of environmental models to the social systems that are embedded in them (Hare and Deadman, 2004). Schlüter and Pahl-Wostl (2007)claim that ABMs are particularly well-suited to the analysis of complex human-environment interactions in the context of management (Janssen, 2002; Barreteau *et al.*, 2003; Gotts *et al.*, 2003; Bousquet and Le Page, 2004; Jannsen and Ostrom, 2006) as ABMs explicitly take consideration of changes in the behaviour and actions of individual entities in response to perceptions of change in the natural or social environment. ABM also allows the study of interactions between different scales of decision-maker and the emergence of collective responses to the changing environment and environmental policies (Hare and Deadman, 2004). The application of ABM to ecosystem or NRM has grown out of the study of ecological (e.g.Drogoul, 1993) and social systems using ABM (e.g. Doran and Gilbert, 1994), which have since been able to be combined into one modelling system, so as to explore the interactions, where ABM can facilitate the combination of multiple hierarchies, scales and interactions.

Early work on the application of multi-agent systems through agent-based modelling to social-ecological management systems was begun by Lansing and Kremer (1993) whose study of Balinese techniques of water sharing and irrigation amongst farmers investigated complex coordination and collective problem-solving through the exploration of simple local rules used for individual community's decision-making. Other early studies included Bousquet *et al.* (1993) who use simulation modelling as a discussion tool to investigate space sharing rules and the evolution of an ecological equilibrium in fisheries management; Janssen and Carpenter (1999) who created a model of the management of lake eutrophication used to explore the interactions between the lake and social systems, to better understand resilience of lakes. Bousquet and Le Page (2004) and Hare and Deadman (2004) give good overviews of the evolution of the use of ABM in environmental management research, concluding with a demonstration of the benefits of using ABM to combine interdisciplinary studies of society and environmental systems, but with a need to focus on targeted ABM design to ensure it meets the modelling requirements of the problem its designed to tackle.

The important aspect of ABMs in natural-resource management research is their ability to experiment with hypotheses about the way that systems could, might, should and have worked, focusing on the mechanisms and intricacies of behaviour and environmental response feedbacks in order to build understanding. More recent applications of ABMs to social-ecological systems research have focused on governance and the way that it is operationalised through behavioural rules and interactions amongst stakeholders. Studies have picked up on aspects such as learning, social networks and structural interactions in an attempt to better understand the complexities. For example Agrawal *et al.* (2013) use ABM in a study of common-pool resource governance, looking at the way that formal governance such as written rules, organisational forms and hierarchical decision-making interact with informal social networks and social norms around the extraction of firewood. They draw on ideas such as Tompkins and Adger (2004) whose work looking at the effect of the consolidation of networks on ecosystem resilience, in order to experiment with thinking about the information networks that surround natural resource use in resource dependent communities and countries. Their study particularly focuses on contexts where governments may be decentralising resource management and trying to create new institutions amongst the already established norms and rules of social networks. Agrawal *et al.* (2013) were able to make conclusions about the effectiveness of organisations through the use of an ABM that allowed the authors to test the effects of specific variables and their interactions in a precise and systematic manner.

Watkins *et al.* (2013) also focus on the mechanisms, interactions and structures within governance approaches. They examine the structural and behaviour factors that might influence decision-making when restoring an ecosystem, using the example of the Chicago Wilderness. Characteristics such as "the number of actors and groups involved in decision making; the frequency and type of interactions among actors; the initial setup of positions and respect; outside information; and entrenchment and cost of dissent" (Watkins *et al.*, 2013:34) are used to experiment in an ABM with the way groups converge towards a collective position through particular decision-strategies. The role of the ABM is to help suggest the conditions in which specific decision-strategies are activated and to suggest new directions for additional empirical research, particularly about the role of leaders in facilitating the consideration of multiple perspectives and to explore the potential effects on biodiversity outcomes. The role of the ABM process as a support for building further understanding rather than as confirmation of any one truth is emphasised. Studies such as Martin and Schlüter (2015) have more recently emphasised the need to consider combining ABM with other forms of understanding such as system dynamics to allow ABM to be even more effective in building understandings by better recognising the diversity of modelling paradigms, spatial and temporal scales and data availabilities that are often combined in a modelling process. The hybridisation is argued to be able to unpack social-ecological system complexity to better analyse interactions between ecological dynamics and micro-level human actions through ABMs.

2.5.5.2. Participatory ABM

A significant mode of use of ABMs in social-ecological research has been through participatory modelling. Participatory modelling is a process that involves the participation and contribution of those whose behaviour is represented in the model, and who might later use the model for decision-making and strategic planning (Pahl-Wostl, 2002c). There have been approaches to technical environmental model creation that involve the participation of stakeholder groups, for example the seminal work on flood-risk modelling of, for example, Lane *et al.* (2011b) and Landstom *et al.* (2011), where scientists repositioned themselves in relation to modelling practices in order to unravel expertise and create new connections and knowledge about the flood risk environment by working across certified experts and non-certified experts (local people), resulting in the creation of a new computer model. Whilst this process helped to hybridise science and politics, bringing diverse knowledges together means its method is intensive and not often used.

Other forms of participatory modelling have developed for their ease of application, as well as for their facilitation of learning and reflection on goals, beliefs and perspectives amongst participants to create a model that is agreed upon and that synthesises the perspectives of those involved, facilitating discussions rather than providing answers. In relation to social-ecological systems, Companion Modelling (Bousquet *et al.*, 1996; Barreteau *et al.*, 1997; Étienne, 2014) is a specific methodology developed around the representation of social-ecological problem situations involving the participation of those involved in the system in a modelling process and is applied to a variety of resource-management situations (e.g. Trebuil *et al.*, 2002; Pahl-Wostl and Hare, 2004; Dray *et al.*, 2006; Garcıa-Barriosa *et al.*, 2008; Abrami *et al.*, 2012; Cleland *et al.*, 2012; Étienne, 2014).

Many of the underpinning ideas of participatory ABM are influential in conceptualising social-ecological resource management contexts, the role of stakeholders, and the potential role of modelling. Therefore although a participatory element will not be explicitly applied in this research, some of the lessons are important to reflect on. In particular it is acknowledged in this research (as it is in a Companion Modelling approach) that every stakeholder in a system has their own perspective and mental model of a situation (Lynam *et al.*, 2012) and it is important to understand and integrate the variety of perspectives when trying to understand complexity. Equally, in contexts of decentralisation and changing governance (which is happening in the UK currently within water-resource governance) the process of modelling is seen to be important for experimenting with management behaviours and scenarios to potentially contribute to future practice. Modelling can also contribute to a process of evaluation and learning that inevitably comes with new governance and may help begin to hypothesise the connection between management and governance contexts. The prevalence of water management issues in studies using modelling and participatory modelling also demonstrates the interest and suitability of modelling to water management issues and encourages further exploration of different types of water management issues using the benefits of ABM modelling.

2.5.5.3. Water resource research

Although ABMs of social-ecological systems cover a wide variety of topics, one of the most popular applications, both through participatory and non-participatory modelling is to water resource management. Izquierdo *et al.* (2003) claims that ABM is particularly appropriate to address integrated water-management issues in particular due to:

- The importance of heterogeneity among agents (Axtell, 2000)
- The importance of adaptation (at appropriator and resource management levels)
- The crucial role of the geography of the physical space concerned
- The significance of social networks (often spatially structured)
- The importance of addressing the relationship between the attributes and behaviour of individuals (the 'micro' level) and the global properties of social groups (the 'macro' level) (Gilbert and Triotzsch, 2003)

The spatial scale of water-resource management and the nature of interactions across sectors, communities and landscapes means that a mode of analysis and exploration that brings together the heterogeneous elements is advantageous. ABM can fulfil that function in multiple ways and is a growing tool for research around water management.

Table 2.1 lists a number of studies that have used ABM to better understand issues surrounding water management, where a non-participatory process of model creation informed a process of learning and reflection of complexities of each of the systems. There are a variety of themes, locations and scales covered by the studies, demonstrating the ability of ABM to be a useful tool in many areas.

The scale and scope of ABM use in water-management studies is broad and does not seem to be restricted to particular times or places, but is always in contexts where there are a variety of stakeholders interacting with each other and with the water and land environments, often with competing or conflicting interests and approaches. It seems that modelling is also used in contexts where there is a need for or external demand for a change in practice, perhaps through governance change or based on environmental or social pressures. The variety of contexts and the flexibility of modelling approaches shows the diversity of the mode of ABM to aid exploration of social-ecological systems, particularly in water management where ABM is arguably well suited to representing the complexity of agents and environmental interactions.

Amongst the studies of water management and ABM there are very few studies using ABM around water management in the UK. There are studies of applications of ABM across other European countries, including Spain, Switzerland and France, including companion modelling approaches. In the UK there are a few studies utilising ABM for analysis of flood-risk management (e.g. Dawson *et al.*, 2011; Jenkins *et al.*, 2016; Dubbelboer *et al.*, 2017) and Izquierdo *et al.* (2003) used ABM in the FEARLUS-W model applied to a Scottish catchment with reference to the legislative context created by the WFD and the subsequent need to understand behaviours around land management in relation to water management. There are very few studies focused on UK catchments using ABM and none, as far as the scope of this study is aware, on the current governance context of the CaBA. There is an opportunity to experiment with the use of ABM as a heuristic device to explore aspects of water management in a UK context, which this PhD research aims to do in relation to understandings of the system as networked and as complex.

Author	Theme	Problem context	Type/ purpose of model	Locational link	Scale	Description and findings
Becu *et al.* (2003)	Water supply management/ negotiation	Conflict between upstream and downstream communities in relation to irrigation and water supply	CATCHSCAPE – simulates catchment features and farmers decisions to explore consequences of alternative management strategies	Northern Thailand	Catchment	• Model is a coupled biophysical and social model (including factors of water balance, irrigation, crop and vegetation dynamics, and water, land, cash, labour as social dynamics) • Elements include farmers, crops, rivers and villages • Measure crop choices and distribution of water and cash throughout the catchment • The model results could be used to help tackle changes brought about by decentralisation and to explore the consequences of alternative management options
Bohensky (2014)	Water supply and use	Understanding how social and ecological interactions motivate or inhibit learning	WaterScape - model is used to explore potential 'learning dilemmas', or barriers to learning in the South African water sector	South Africa	National (multiple catchments)	• Agents represent water use sectors including agriculture, forestry, mining and industry, rural and urban alongside the Catchment Management Agency who make decisions based on feedbacks with the water environment • Experiments investigate how 1) agents' selection of different indicators to evaluate their actions, and 2) different social-ecological conditions affect understanding of how and what to learn, willingness to learn, and capacity to learn.
Chu *et al.* (2009)	Urban water supply, use and demand	Understanding water supply and demand requires an understanding of complex behaviours of water users	Residental Water Use Model (RWUM) – simulates behavioural characteristics of water users to evaluate	Beijing, China	Urban	• Calibrated against residential water use data in Beijing city over 15 years based on municipal statistical, government planning, social and market survey data. • Three types of agents - regulator, water appliance market and households • Model can act as a tool to highlight the areas of domestic water use that might benefit from interventions

			different water usage policies			
Galán *et al.* (2009)	Domestic water supply and demand	A need for more descriptive and explanatory models around water demand and use	Designed as a tool to think with; to advance knowledge about the whole water management system	Villadolid, Spain	Urban	• Consists of a GIS environment characterised by social and economic features, and family units within the environment. • Factors affecting consumption such as type of urban area, price, socio-cultural perceptions, technological adoption are included • The ABM is combined with scenario analysis • Model results are able to provide managers with new insights into the complex issues that characterise water management and influence patterns of water demand
Izquierdo *et al.* (2003)	River basin land use and water manageme nt	Common-pool resource management under the WFD needs an understanding of stakeholder behaviours in order to identify effective interventions	FEARLUS –W – built to increase understanding of complex interactions between stakeholders and explore solutions through management strategies to shape interactions	Tarland Catchment , Scotland	Catch ment/ river basin	• Use of the FEARLUS model to develop scenarios of possible futures for the catchment with attention to phosphate pollution • Land managers choose land use options • Factors like social approval and economic returns incorporated into land managers decision making • Factors such as water course morphology and hydrological connectivity are incorporated • Focus on the spatial dynamics of the resource and how the structure of social networks affect pollution
Valkering *et al.* (2009)	Cultural and behavioural change in water manageme	Overcoming problems of unsustainable water management through a better understanding	Interactive computer game – to explore future pathways of water management and	Ebro River Basin, Spain	River basin	• Water management is represented as the dynamic outcome of interactions between water culture, water policy and autonomous actor behaviour • Based in participatory modelling and companion modelling • Use a pressure, state, impact, response concept • Model could be used to analyse some of the drivers of social change • Model constitutes a lens to observe the interaction processes observed by game play

	nt in river basins	of cultural and behavioural change	contribute to social learning			
Zechman (2007)	Contamination management in water supply	Need to understand the nonlinear interactions amongst consumers and water utility managers in the event of contamination of the water supply	Simulation of a contamination event with the responsive actions of utility managers and water consumers –provides analysis of theat containment strategies	A virtual city	Urban	• Consumer behaviours including ingestion, mobility, reduction of water demands, and word-of-mouth communication are included. • Management strategies are evaluated, including opening hydrants to flush the contaminant and broadcasts. • Able to experiment with developing rules to characterise the interactions among, utility operators, the media, public health and perpetrators to identify efficient strategies
Schlüter and Pahl-Wostl (2007)	Resilience in social-ecological systems	Limited understanding of suitable interventions to implement resilience-based management	Exploring system characteristics and mechanisms of resielence	Amundarya River basin, Central Asia	River basin	• Three sub-systems – social, irrigation and aquatic • Looking at the resilience of the different ways that a water system can be managed in relation to variability and uncertainty in water availability • Comparing centralised and decentralised regimes • Analysis of the systems can reveal structural features and rules that are important for understanding resilience and functioning of the system
Akhbari and Grigg (2013)	Water availability conflict		The Delta Game - explain the interactions amongst parties and to experiment with	Sacramento-San Joaquin Delta	River basin	• Conflict scenario is modelled as a game • Based on conflict over water transfer in California • The ABM proposed is intended to provide a tool that helps to find effective management scenarios to encourage conflicting parties to cooperate. • agents are defined as a decision-making agent, the state; and demand agents: water diversions/farmers (demanding for water), and the environmental sector (demanding for enough water flowing along the river with an acceptable quality).

			management scenarios			• Social and institutional enhancements such as incentives, penalties, new regulations, etc. were introduced to the ABM model as encouragement strategies.
Bars *et al.* (2002)	Water allocation	Need better understanding of rules and behaviours of farmers who use a limited water resource affected by climate, regulations and irrigation	Model aimed to help negotiations between different players by showing the consequences of water allocation rules	France	River basin	• Includes farmer agents and water supplier agents and incorporates climate factors, yield objectives, investment and information sharing • Test a number of water allocation rules and scenarios • Model helped contribute to negotiations without being a tool for negotiations • ABM very suitable for representing multiple and complex interactions between cognative agents (farmers and water supply agents) which are composed by complex knowledge modules and reactive agents (crops and climate agents). • Authors would want to imporove the model by adding communication and validating the ideas against more detailed empirical observations
Barthel *et al.* (2010)	Water supply and demand	GLOWA – Danube projects includes multiple simulation models to look at the effects of global change on the water cycle	WaterSupply model focuses on the water resource utilisation and distribution from water supply companies and aims to optimise resource use decisions.	Upper Danube catchment	River basin	• The model helps make decisions based on sustainability requirements, the state of resources and user demand • Part of a bigger Danubia model which is run by very high level strategic decision makers. • Its main aim is planning for worst case scenarios and interventions • Seen as a set of 'adjusting screws' for the larger model because of its application to experimentation with decisions that inform plans and actions • Aims to help water supply companies to identify critical regions for adaption under changing climatic conditions
Kock (2008)	Water conflict	Testing the theory that	Models of society and	Albacete, Spain, and Snake	River Basin	• Model includes proactive deliberative agents • Economic and social dynamics are represented through databases and additional rules

		higher levels of institutional capacity will lead to reduced levels of water conflict	hydrology to explore the societal effects of adding an additional institution to the existing water resources management institutions	River, Idaho, USA		• The models are run over historical and projected time periods, looking at different scenarios of variation in agent environment • Model is able to identify critical elements of the design of institutions, when considering their potential success in mitigating conflict

2.6. Summary

This chapter has brought together and analysed scholarship from multiple disciplines, carving out an interdisciplinary perspective within which the research is situated. A perspective on collaborative water quality management and governance has been provided by bringing together an understanding of complexity and a systems perspective, through an understanding of networks and network analysis alongside the application of ABM to better understand dynamics. The studies and development of knowledge outlined in this chapter will form the background and basis for an analysis of catchment management processes and associated systems of governance. The scholarship has highlighted the importance of stakeholders as points of agency in management systems and the focus of network analysis and rule creation for simulation modelling. As such, stakeholders are the main focus of data collection, whereby qualitative translation of experiences and knowledge through interviews is used to explore the themes identified in this chapter as important for the study of water resource management. Chapter 3 outlines the case study in which a system of management will be explored, and Chapter 4 outlines the processes of data collection through interviews, and data analysis through a network perspective and modelling approach, underpinned by the knowledge and ideas summarised in this chapter.

Chapter Three

Context and data-collection methodology: gaining perspectives on a catchment-management system

3.1 Chapter overview

The process of exploring the system of catchment management in relation to stakeholder involvement in the UK context has been approached in this project from a case-study perspective (Yin, 1993; Stake, 2005). The River Wear catchment is used as a case study, allowing comment to be made on the circumstances found in that area, whilst also using the study to begin to reflect more widely on the context of water governance. This chapter documents firstly, the River Wear situation and secondly details the processes and practices undertaken to collect and analyse qualitative data in that context.

3.2 The context and starting point: The River Wear Catchment

The starting point for this research is the situation observed in the River Wear Catchment, chosen as a particularly rich example of the operationalisation of the current water resource governance approach focusing on the catchment scale. It has been a lens through which to discern and begin to understand the changing governance of water resources in the UK. This catchment has been part of the Catchment Based Approach (CaBA) since its inception in 2011. The Lower River Wear Catchment was one of the 25 areas chosen to pilot a collaborative catchment-management approach between 2011 and 2013; and one of 10 to be led by the Environment Agency, as opposed to an NGO. The area was chosen to pilot the approach due to its complex pollution problems and a fairly high level of "failing" waterbodies under the WFD (23 out of 25 waterbodies at the time of the pilot were on course to fail to reach required standards by 2015), as well as a lack of history of high-level, organised collaboration prior to the pilot scheme. This PhD research began relatively soon after the pilot scheme had ended and the CaBA approach was being rolled out across England, including to the wider Wear catchment. The transition from pilot to fully functioning catchment-wide practice meant that there was a concentration on change amongst the stakeholders and a reflection on learning and expansion of patterns of interaction and participation. The wide variety of stakeholders involved from both the pilot scheme and as new partners also allowed reflection on both the trajectory of recent change and the implementation of new practice.

3.2.1 Characteristics of the Wear Catchment

The River Wear catchment is located in the Northumbrian River Basin District in the North East of England (Figure 3.1). The catchment area is one of the smallest of the 100 catchments delineated by the EA throughout England, at 1,311 km^2 (Lower River Wear Catchment Action Plan, 2012). The river has its headwaters in the East Pennines and flows east/south east through rural Weardale, then runs north east, along a meandering path through the urban areas of Bishop Auckland, Durham and Chester-le-Street, until it reaches the North Sea at Wearmouth in Sunderland (Figure 3.2). The upper catchment is characterised by areas of grouse moorland, attracting visitors and sports, some livestock agriculture and some arable use. In its upper reaches the river runs through a narrow valley where many industries, including lead, limestone and coal mining have been based. The lower catchment is characterised by land uses including arable farming, residential areas (including villages linked to historic collieries) and larger urban centres. In the lower catchment, the river and its tributaries are well used for recreation including angling, rowing or bankside activities where accessible. Some tributaries are hidden in culverted sections or are inaccessible through development. The specific (industrial) history of the catchment gives rise to unique habitats and biodiversity able to survive in mobile river gravels made of metal-rich spoil (Wear Rivers Trust, 2017).

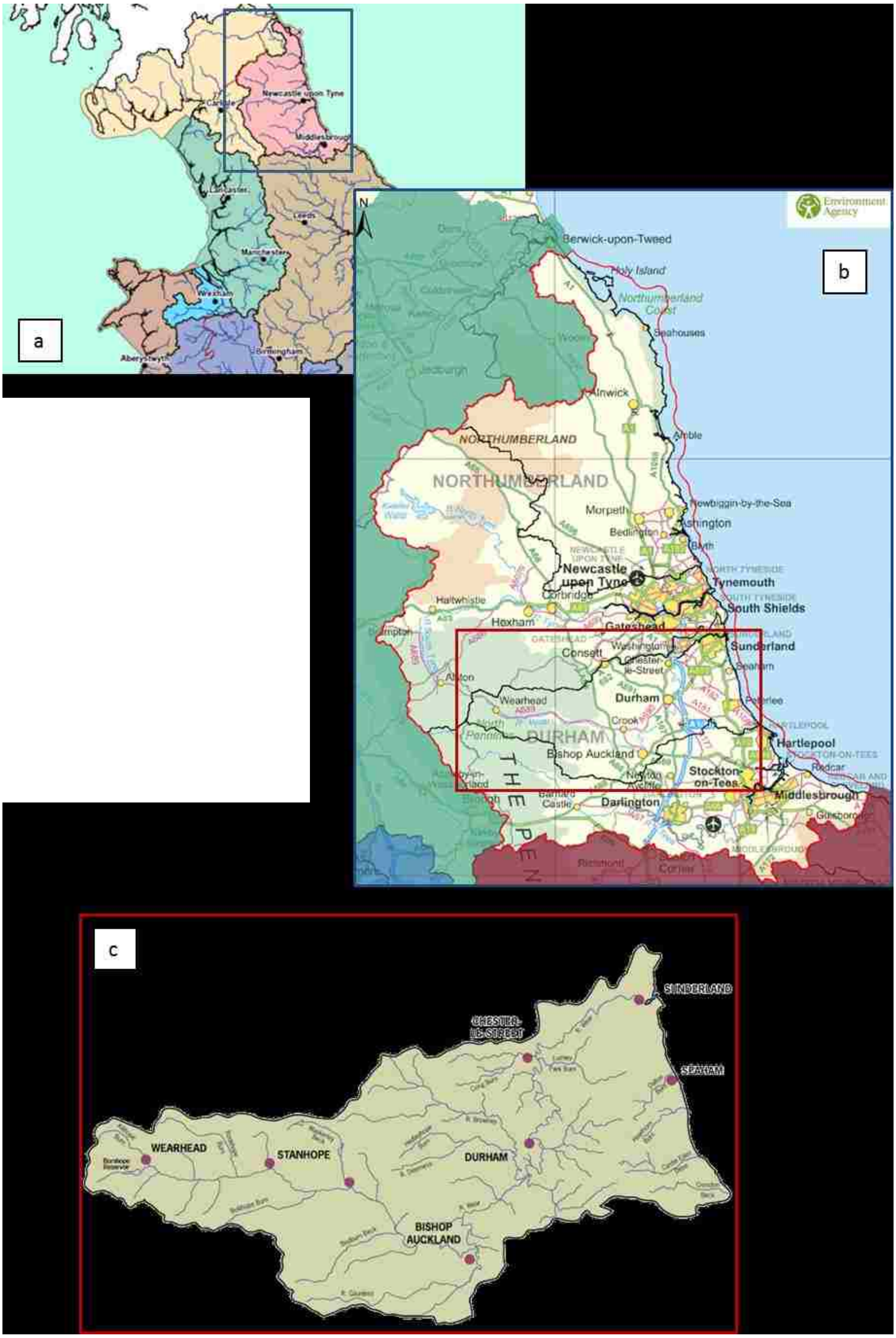


Figure 3.1 *a) Location of the Northumbrian River Basin District within NE England, b) the location of the River Wear catchment within the Northumbrian River Basin District and c) the organisation of water courses and key urban areas in the River Wear Catchment.*

Figure 3.2 *Images from a water courses throughout the Wear catchment. For photo credits see Appendix H.*

[redacted]

River Wear at Durham

[redacted]

As a result of the mining heritage the area has historically been subject to diffuse acidic heavy metal pollution from minewater discharge (Neal *et al.*, 2000). Since the cessation of mining in the North East, pollution levels have decreased. Schemes have been implemented to help reduce pollution, including small-scale passive treatments such as reed beds as well as larger-scale minewater pumping stations that extract and treat contaminated discharges from disused mines to prevent contamination of surface water and groundwater (for example the Horden Active Treatment Plant run by the Coal Authority (Johnston *et al.*, 2008)). By these means, minewater pollution has been significantly reduced in the past 40 years (Neal *et al.*, 2000) and the River Wear has been celebrated as moving on from the negative influence of its industrial past and is now one of the best sea trout fisheries in the country (Lower River Wear Catchment Action Plan, 2012). However, there are still significant issues that attract the need for continued management.

For the purposes of the WFD, the EA has divided the River Wear catchment into 64 management units (waterbodies). Significantly, at the beginning of this research ~79% of the waterbodies in the catchment were predicted to fail to reach 'good' ecological status under the WFD by 2015 if no action was taken. Since the beginning of the project the first cycle of WFD has ended and the new management cycle begun (2015-2021), which pushes the target of universal 'good' status for waterbodies to 2021 (with the third cycle and ultimate deadline for meeting objectives being in 2027). Current information from the EA claims that in 2016 ~91% of a total of 64 waterbodies were below good status (Environment Agency, 2017) with deterioration as well as some improvements over the course of the year previous to the most recent figures.

The assessment by the EA concludes that the water industry is responsible for the majority of failures across the catchment. Despite recent improvements to treatment works, sewage discharges are still problematic. Mining and quarrying are the second most significant influences on water-body failure, attributed to abandoned mines and quarries. A small number of failures are attributed to urban and transport sectors as well as to industry, waste treatment, domestic use, local and central government, and agriculture and rural land management (EA 2017). There are also many waterbodies still under investigation with problems attributed to no particular source or sector, making it difficult to decipher effective solutions. The uncertainty and variety of pollution sources are a significant contribution to the need for coordinated and collaborative efforts to manage the water quality and meet the targets set by the WFD.

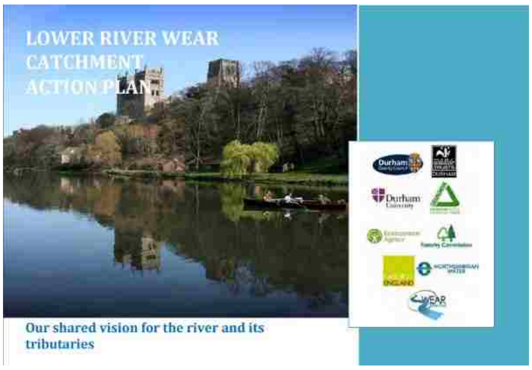
3.2.2 Water-quality management in the Wear catchment

Since the introduction of the WFD in 2000, water management has been coordinated at the river-basin scale through the creation of River Basin Management Plans (RBMP), with each informed by evidence from the River Basin Liaison Panels and public consultations in each area. Since 2015, the second versions of the RBMPs have been adopted as the second delivery cycle begun. Prior to the introduction of the CaBA in the UK the RBMPs formed the basis for coordinated action around water management. Since 2013 (or 2011 for pilot areas) the introduction of catchment partnerships has localised the coordination of priorities and activities and allowed the development of planning and coordination for water quality management to be localised. Plans even exist at the waterbody level. Water-quality management is now firmly embedded at the catchment scale with the RBMP acting as a unifying system of coordination, priority and target setting, and as a link to wider policy and legislation.

In the Northumbria River Basin District, the Wear Catchment Partnership (WCP) has been established since 2011 as it was a pilot area for the CaBA, which means it is significantly more established than the other partnerships in the District, which include the Tyne, Tees and Northumberland Catchment Partnerships. When the WCP first began the EA acted as catchment-host, coordinating meetings, inviting participation and leading on production of documents and applications for funding. Such leadership took advantage of the resources and contacts available to the EA and, in combination with the personality and knowledgeability of the catchment-coordinator as well as the willingness of key partners to invest in the new way of working, the participants were guided and motivated to work together to form a positive partnership. The pilot scheme involved a process of organising and inviting participants to several stakeholders meetings over the course of two years, with the ultimate goal of the creation of a Catchment Action Plan that would lay out the problems and potential collaborative solutions to water management issues in the Lower River Wear catchment. The process involved the formation of a development group of key stakeholders including groups such as the EA, the water company, wildlife trust, rivers trust, university and community charity, who worked more closely together to research, deliberate, create and edit the Catchment Action Plan, whilst organising and coordinating any joint action, data collection, sharing events, consultation and meetings. The work of the development group was supplemented by several wider stakeholder meetings, which gained opinions, evidence, priorities and information from other affected and interested groups in the catchment, with the aim of better designing the Catchment Action Plan and coordinating new efforts with those already happening and with the skills and potential resources already available. Equally, the aim was to find new ways of working together to achieve the joint aims also deliberated.

The Lower River Wear Pilot Catchment Action Plan was completed in April 2013 and included a vision for the catchment, key themes to focus on and a list of 106 actions in three categories (ongoing, planned and new) with consideration of focus, priority to meet aims, funding and lead organisation for each (Figure 3.3). Such actions, themes and priorities had been the subject of discussions and conversations within the stakeholder and development group meetings and communication. Most stakeholders felt positively about being involved in ongoing wider catchment-based efforts.

After the pilot scheme was complete the WCP entered into an action implementation phase and expanded to incorporate the Upper River Wear catchment and the coastal streams area in the collaborative efforts. During the course of the pilot scheme, the Wear Rivers Trust had become joint-host with the EA, and eventually became the lead host of the catchment partnership. Such a transition supported the vision of the CaBA to have local, NGO hosts of each catchment and to move away from the central governmental leadership of the EA. In the post-pilot phase the participation in the WCP has become more stable with groups committing to being involved at the strategic level to help deliver the aims set out in the pilot phase. Core participants include Durham County Council, Durham Heritage Coast Partnership, Durham University, Durham Wildlife Trust, the Environment Agency, Groundwork North East and Cumbria, Natural England, North Pennines AONB Partnership, Northumbrian Water Ltd and Sunderland City Council. Significantly two priority projects in the area led to the formation of two separate delivery partnerships within the structure of the WCP including 'Greening the Twizell', and 'Coastal Streams' partnerships, both allowing more local participation in decision making around each location (Northumbria River Basin Management Plan, 2015). The ongoing efforts to work collaboratively formed the context in which this research was set and which justified a multi-method approach to better understanding the situation.



"BY 2020 DURHAM'S RIVERS WILL RUN CLEAR, TEEMING WITH WILDLIFE AND ENJOYED BY ALL"

EDUCATION AND AWARENESS

- To share information about the river Wear and understand what people value and want to see improved about their local rivers
- To reconnect communities to their local river environment and enable them to access and enjoy the river Wear valley
- To support, recognise, and increase opportunities for volunteering in the river Wear valley

WATER QUALITY

- To improve communication between local, regional and national organisations using the river Wear and work in partnership to improve water quality
- To make better use of local knowledge to understand the causes of diffuse pollution in the lower Wear catchment and take action to resolve them
- To raise awareness and educate local communities and businesses about the impact of their actions on water quality

PLANNING FOR WATER

- To work with land owners, land managers and planning authorities to improve the quality of rivers in the lower wear and promote sustainable development
- To promote the incorporation of more green infrastructure to better manage water flow through the catchment

WILDLIFE HABITATS

- To improve the range and quantity of native fish and eel stocks in the river Wear and its tributaries
- To provide improved, bigger and better connected wildlife habitats in the catchment leading to an increased diversity of native species and protected habitats

No.	Issue	Action	Potential partners (Lead/others)	Supporting aims and targets	Status
1	rural diffuse pollution (phosphates, nitrates & pesticides)	Set up Wear Farming Partnership to address agricultural and rural diffuse pollution across the catchment. Identify particular rivers or tributaries where there is evidence of problems (e.g. Lumley Park Burn & Old Durham Beck). Look to address sources of agricultural derived phosphorus, nitrates, and pesticides and identify a series of measures through landowner engagement and	Wear Rivers Trust; Wear Development Group; landowners, Woodland Trust; angling clubs	2a; 5a; 5b; 5d	On-going

Cost (£K)	Time frame	Comments	Education & Awareness	Water Quality	Planning for water	Wildlife Habitats
Low	S	Majority of consultees identified this as a high priority. Look at involving NGOs and universities to deploy water quality monitoring equipment (sondes) and to analyse data. Engagement with relevant landowners and identification of sites for mitigation should be outcome. Ownership and priority for this action includes CLA/NFU; local estates, and anglers. Link to Drinking Water Protected areas work.	x	x		x

Figure 3.3 *Excerpts from the Lower River Wear Catchment Action Plan, including front cover listing collaborative partners, the vision for the catchment, the key themes and problem arenas to tackle and an example of an action as part of the 106 actions reported.*

3.3 Exploring the catchment system: the methodological structure

In order to be able to explore fully the catchment-management system of the Wear and to understand better the connections and interactions between stakeholders and the resultant actions and activities, a combination of methods were used The philosophy that underpins this combination of approaches is summarised by Berkes *et al.* (2003:8) that "a complex social-ecological system cannot be captured using a single perspective". The methods capture multiple voices through the use of interviews with stakeholders and multiple perspectives using network analysis and agent-based modelling as modes of analysis (Figure 3.4).

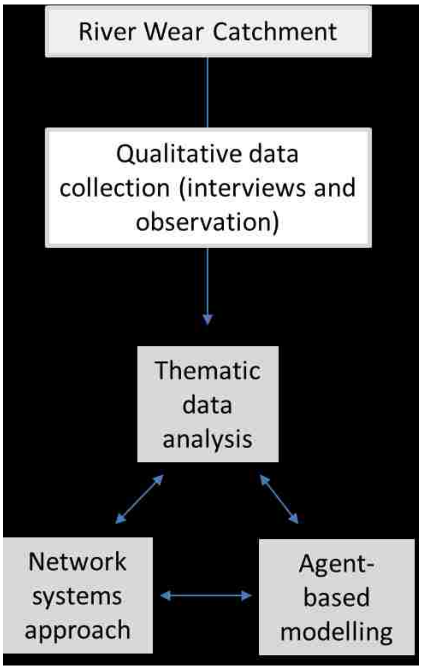


Figure 3.4 *The basic structure of the methodological approach to exploring the case study.*

3.4 Gaining perspectives from stakeholders

The stakeholders involved in water-management practices are at the centre of this research. It is through their actions and interactions that practice is enacted at the everyday level and it is through their feedback, discussions and deliberations that the experience and outcomes of practices are analysed. The following sections describe and justify the processes of interviewing stakeholders and analysing their views and opinions in qualitative ways in order to gain in-depth perspectives.

3.4.1 An interview- based approach

In-depth, semi-structured interviews were chosen as the primary method through which to investigate the system of water management. Interviews allow a focus on the complex behaviours and motivations of individuals (Dunn, 2016) as well as the chance to investigate a diversity of meaning, opinion and experiences (Valentine, 2005). Such qualities mean that interviews can potentially offer the chance to build a picture of each stakeholder's world in relation to water-management activities, and a chance to compare and analyse the diversity of experiences and descriptions across multiple stakeholder groups. For example Miller and Glassner (2016:52) argue that interviews provide access to social worlds, evidence of activities in those worlds and of how individuals make sense of themselves, their experiences and their place. Such an approach acknowledges the ability of interviews to give the stakeholders a platform, to use their own words and descriptions to reconstruct and portray their activities and experience in a way that is meaningful for them (Rubin and Rubin, 2005; Presser and Sandberg, 2015). The emphasis on meaning for the stakeholders was an important driver of the choice of method, as the chance to express their opinions gives the stakeholders chance to construct their own narrative (Kvale and Brinkmann, 2009).

Interviews also allow the interviewer a chance to become familiar with activities and opinions that may be difficult to access, understand or experience by an outsider, particularly allowing reflection on past events, future hopes, feelings and opinions about experiences or relationships (Valentine, 2005). The interpretation of stakeholder experiences is based on the understanding that humans are conversational beings and that language, although transient, represents reality for many people (Gadamer, 1975). The interview is a chance to get a glimpse of that interpreted reality and to attempt to understand the views of the interviewee as consistently with their meaning as possible (Silverman, 2010). The interview data can then be triangulated with other forms of data collection including observation. Particularly important in this research is the reflection that each stakeholder in the management system has their own experiences, patterns of interaction and exchange and makes a unique set of decisions, based on their unique position, experience, motivations, goals and influences.

In utilising interviews as a method it is acknowledged that it is the relationship between the interviewer and the interviewee that is the locus of knowledge, rather than the individual (Gergen, 1994) which consequentially requires a constructionist understanding of knowledge (Miller and Glassner, 2016). In accordance with (Kvale and Brinkmann, 2009) it is interpreted in this research that interview knowledge is produced, relational, conversational, contextual, linguistic, narrative and pragmatic, meaning that there is no one single reality represented by certain knowledges and able to be understood or exposed, but only interpretations of individual realities produced through linguistic and social construction of knowledge. The construction of knowledge means that it is also acknowledged that interviewees are likely to respond with familiar narrative constructs, which may sometimes replace insights into their subjective view (Holstein and Gubrium, 1995). The research acknowledges that by basing analysis on qualitative interview data, the system will be portrayed in a specific way, unique to the time, place, space, context and relationship of the specific conversations. It also interprets the words spoken as representative of meaningful (if personal) realities that are relevant for better understanding some parts of the system of catchment management, that are also likely to resonate, if not be directly applicable, in part with wider experiences in other contexts.

3.4.2 Supplementing interviews with participation and observation

Participation is a feature of all social research (Atkinson and Hammersley, 1994) as the researcher must enter in some way into the world shared by those communities or people in the situations they are researching in order to understand and learn about any phenomena. The specific methodology of participant observation adds a purposeful element to participation, combining it with a process of reflection and documentation through observation to produce intersubjective understandings between researcher and researched (Crang and Cook, 2005). Although fully immersive participant observation was not undertaken in this research, the desire to know and experience in more detail the relationships and interactions taking place as well as to get a better understanding of the issues and the processes underway, encouraged me to take part in some of the meetings that were happening within the catchment. The meetings felt like an important and central part of the processes and practices of collaborative water management and therefore essential for me to participate and observe.

The very nature of (some) of the collaborative meetings, in their inclusion of a wide variety of stakeholders, meant that I was able to attend in the capacity of a stakeholder in the catchment, one with experience of the situation (through previous research (Tindale, 2013)) and therefore able to contribute to some aspects and activities. This approach meant I could sometimes transcend the insider-outsider dynamic often negotiated in social research (England (1994), with opportunities to more closely identify with stakeholders and interviewees. I attended a number of meetings and fora in 2014 and 2015 (Table 3.1).

Table 3.1. *Events attended in 2014 and 2015.*

Event	Description
Wear Catchment Steering Group meeting (Jan 2014)	A meeting of the core stakeholder groups for the Wear Catchment Partnership, who meet regularly to plan and discuss progress, action and decisions within the partnership in preparation for wider stakeholder meetings. The meeting was organised by the Wear Rivers Trust as the lead organisation in the Wear Catchment Partnership.
Soil and Water Management Seminar (June 2014)	A meeting for farmers and landowners managing land encompassing a number of tributaries in the Lower Wear area. The meeting emphasised reducing costs and business risk and included information about retaining topsoil and nutrients, demonstration of tools to evaluate risk, examples of successful interventions and a farm visit. The event was organised through the Wear Rivers Trust and hosted by a local farmer representing the National Farmers Union.
Old Durham Beck stakeholder meeting (Oct 2014)	A "Task and Finish" Group of multiple stakeholders designed to pull together information about challenges across the Old Durham Beck sub-catchment and to design partnership projects to address the issues. Organised under the Wear Catchment Partnership, hosted by Wear Rivers Trust.
Twizell Burn Green Infrastructure Plan Partnership Meetings (Oct 2014, Nov 2014 and March 2015)	The aim of the project was to produce a Green Infrastructure plan for the Twizell Burn catchment that brought together existing issues and infrastructure in a cohesive way. The meetings were attended by a wide variety of stakeholders and consisted of activities and discussions about problems, potential solutions, available resources and current activities around the specific sub-catchment with the production of an actionable plan as the goal. The project was led by Groundwork North East and Cumbria, supported through the Wear Catchment Partnership.
North East Fisheries Forum (Feb 2015)	A regular open meeting aimed at anglers and fishery owners, including presentations, updates and information about fisheries and water management from the Environment Agency, Angling Trust, Wear Rivers Trust and local angling clubs. Organised jointly by the Angling Trust and Environment Agency.
Riverfly training (March 2015)	A training session for volunteers looking to take on the role of monitoring sections of water courses on a monthly basis using macroinvertebrate sampling. The session was run by the Wear Rivers Trust, supported by the Environment Agency
Site visit, Dawdon minewater treatment scheme (May 2015)	Site visit attended by Environment Agency and organised by the Coal Authority.

During the meetings and visits I participated in the actions and activities as much as possible within the bounds of the knowledge and experience I had, which allowed me to learn about the issues and activities in the catchment as well as the nature of the relations and interactions amongst the stakeholders who attended the meetings. Attendance supplemented my understanding, but also gave opportunity to talk to the stakeholders involved and find those willing to be involved in a further interview. My attendance at the meetings gave a shared experience to relate to the interviewees with, which helped to build the relationship and to establish a common language and experience about the process of water management. My knowledge of the content of the meetings helped to contextualise some of the aspects mentioned by stakeholders during interviews and it was interesting to compare the different experiences and opinions of the same events within the meetings or forums from the perspective of the different stakeholders involved. Therefore my attendance at the meetings and events was important for understanding multiple perspectives and for building my own understanding of processes and practices.

3.4.3 Identifying stakeholders and inviting participation

The process of identifying stakeholders to take part in interviews for the research began from the contacts previously made with the stakeholders taking part in the WCP meetings as part of the Lower River Wear Catchment Pilot (LRWCP). I had made some contacts previously with the core stakeholders during a previous research project in 2012/13 analysing the pilot process of CaBA in the Wear catchment. A number of those stakeholders were happy to be involved again and agreed to be consulted about the research and give their recommendations of other groups or individuals to speak to. Other stakeholders were identified through attendance at meetings and workshops. Others were approached directly (usually via email) on the recommendation of others I had spoken to. Valentine (2005) advocates a snowballing method such as this to be used in order to meet new people and groups not ordinarily possible to meet or know of.

The stakeholder groups who were the most unresponsive to requests for interview, and therefore shaped the knowledge available to the research project, were those in farming, land management or community volunteer groups. The reasons for lack of response can never be fully known. However, although they had been previously engaged with other groups in the area involved in water management such as the Wear Rivers Trust, the lack of trust between myself and those groups due to a lack of familiarity may have contributed to unresponsiveness. Equally, judgements about the relative (un)importance of the research in relation to their own priorities and activities may have played a part. In a number of cases, particularly with the land managers, the Wear Rivers Trust practitioners had mentioned a general lack of engagement with their own efforts, therefore the lack of involvement in this research is also likely to be a general reflection of the patterns of engagement and involvement in management activities. Even if all the groups could not be directly accessed in an interview capacity, their presence and role, or lack of either, in the catchment could be acknowledged through the discussions and explanations given by those who were interviewed.

Overall I interviewed 33 individuals from 15 organisations or interest groups, all of whom played some role in maintaining, protecting, monitoring or utilising the water environments throughout the catchment. Most had some connection to core groups involved in the Wear Catchment Partnership, if not directly involved in the strategic management processes themselves. The organisations and groups included:

- Environment Agency (EA)
- Northumbrian Water (NWL)
- Natural England (NE)
- Wear Rivers Trust (WRT)
- Coal Authority (CA)
- Angling Trust
- Durham County Council (DCC)
- Durham Wildlife Trust (DWT)
- Durham City Angling Club (DCAC)
- Chester-le-Street Angling Club (ChleSt AC)
- Hetton Green Watch
- North Pennines Area of Natural Beauty (NP AONB)
- Two local land agents
- Chester-le-Street Area Action Partnership
- A local farmer

The interviewees ranged from professionals with sole responsibility for considering water resource management on a day to day basis, to others whose activities around water management were considered alongside other activities, roles and responsibilities. Each interviewee demonstrated a passion and motivation for their actions and involvements in different ways. Most interviews took place in a professional, work or university environment, or in some cases, a café environment, inside, sat around a table conversing fairly formally. Such an approach was appropriate for the discussion of abstract ideas and past and future activities without the need of a particular location as a reference point and suited the interviewer-interviewee relationship that I had chosen to establish. The interviewees were given a choice of locations and the chance to name the place and time that was most suitable for them. The interviews took place at various locations across the local area (Figure 3.5), lasted for around an hour and were recorded with the permission of the interviewee.

Figure 3.5 *Location of interviews (white boxes) and events, meetings or visits attended (yellow boxes) within and around the Wear catchment area, with the number of interviews or meetings attended at each location.*

In this research one interviewee exercised their power to control the interview by refusing permission for their interview to be recorded. It might be speculated that the interviewee feared misinterpretation and misuse of his words if they were recorded. Such action is part of the process of interviewing and is an important mode of power for an interviewee, just as having their words accurately recorded can also be empowering. It is a demonstration of the fluidity of interpretation of the site of the interview (Kvale and Brinkmann, 2009).

3.4.4 "Conversations with a purpose": content and focus

For this project the interviews were designed as semi-structured to allow the conversation to be led by the interviewee (McCracken, 1988). The interviews consisted of "ordered but flexible questioning" (Dunn, 2016:110) where questions could be crafted *in situ* based on what had already been covered and the tone of the conversation (Dunn, 2016). For each interview a prompt sheet of questions was created, which included starter questions and themes. Some of the questions were similar across stakeholders in order to be able to compare, but others were tailored to their specific circumstances and intricacies of their situation, some details of which were often known beforehand Table 3.2 shows the broad themes and key questions that were used to guide interviews.

Interview topics and questions	
General • Do you want to say a bit about your role? • What are your top 3-5 priorities or goals? • What are the 3 key challenges you face achieving your priorities?	
Water resources	**Partnerships and interactions**
• What changes have you seen in the water environments? • What management processes have you been involved in? • Do you feel they have been effective? • What problems and issues do you face in the water management process? • Does the WFD influence you? • What do you think of the CaBA? • What data and evidence do you rely on? • How do you decide what action or projects to run?	• Which organisations and groups do you work most closely with on water related issues? • Where are the tensions and why do you think they arise and how can they be overcome? • Which stakeholders do you think should be more engaged or active? • Who would you improve your relationships with? • What would ideal management look like?

Table 3.2 *Broad guiding themes and questions for the interviews. These questions would be supplemented with additional question tailored to the stakeholders and during the interview questions are guided by the subsequent answers.*

An additional feature of the interviews for this research was the use of a scenario to act as a catalyst for discussions about stakeholders' behaviour and decision-making processes. As an important focus of the research was to understand and explore the dynamics of stakeholder behaviour, a scenario was devised and each interviewee was asked a series of questions that allowed them to explain how they might react within that scenario. The scenario involved a minewater pollution incident caused by heavy rain and groundwater overflow (Figure 3.6). The interviewee was asked to read the scenario and then asked questions relating to the people affected by the incident, the process of dealing with the problem, and their own potential role and the role of others. The scenario was kept fairly vague in order to allow the stakeholders to add their own interpretation and be able to relate more easily to other similar scenarios without getting bogged down by fictitious detail. The familiarity of the scenario and its plausibility in the Wear catchment (due to its mining legacy) was part of the decision to include the scenario as a catalyst for discussion.

A particular purpose of the scenarios was to identify the networks that might be operational when dealing with a problem. The answers that the stakeholders gave have been able to be incorporated into the development of behavioural rules for stakeholders in an agent-based modelling process described in Chapter 7. The scenario was essential for allowing the stakeholders to describe their activities and relationships in more specific detail than could be gathered otherwise. The descriptions the stakeholders gave allowed 'if-then' rules to be developed, particularly as interviewees, in reaction to the vague description, used 'if' statements themselves, such as, for example "if there was more of it (pollution) and it wasn't being cleared up…". The addition of a different way of reflecting by being prompted visually rather than just responding to questions also allowed the interviewees to think differently and to remember or refer to situations and experiences in a different way, which was positive for the interview experience. Although most interviewees did have the chance to respond to it, a few stakeholders did not due to time constraints and a consideration that similar issues had already been covered within the interview. As such, it was not always possible to base some of the rules for the agent-based model created later in the research (see section7.2.1) on potential reactions described through the scenario. In these cases, they were based on other descriptions and explanations of behaviour discussed in the interviews.

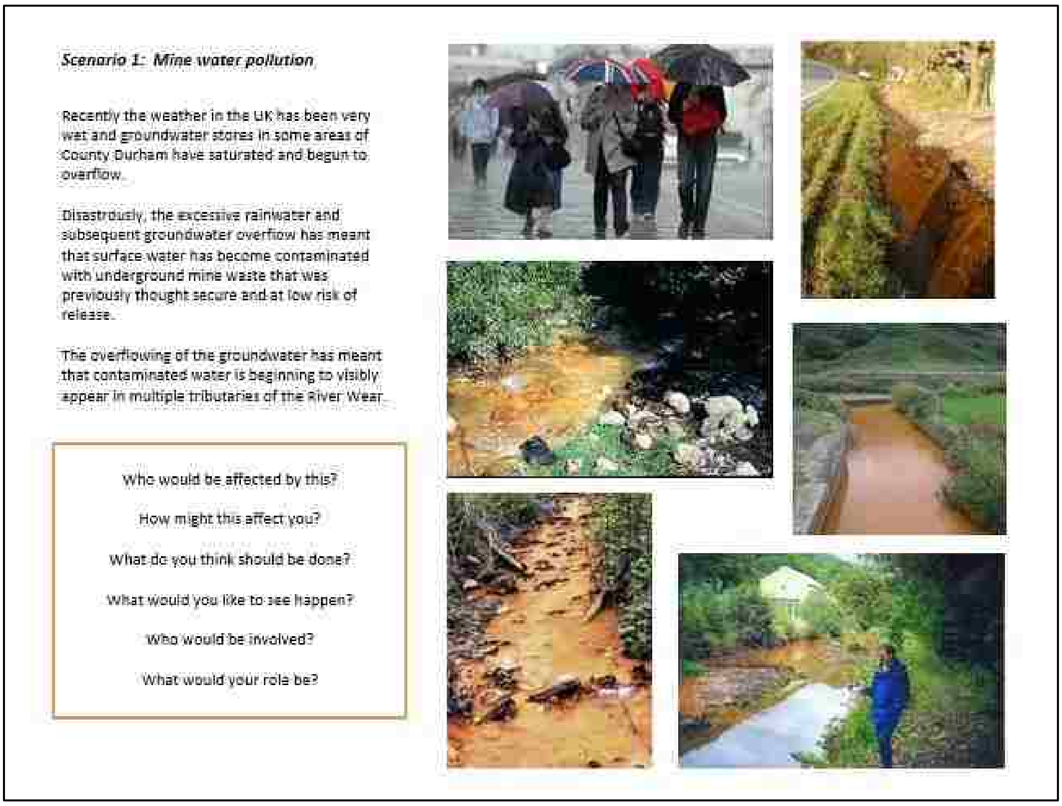


Figure 3.6 *The scenario that was presented to stakeholders detailing a minewater pollution event.*

3.4.5 Positionality

Positionality is always an important aspect of research (Skelton, 2001) and should therefore form part of the understanding and interpretation of the knowledge emerging from interviews. Valentine (2005) describes positionality as a researcher reflecting on how their own identity, not only as a researcher but as an individual (defined by gender, class, race, nationality, politics, history and experiences (Schoenberger, 1992)), shapes the type and form of research they are doing and the interactions they will have with participants. Schoenberger (1992) argues that knowing the position of a researcher leads to significant discoveries about the nature of research and the research process. By enacting constant, self-conscious scrutiny of the self as researcher (England, 1994) aspects of positionality can be explored. For example, my own experience of researching has been influenced by my previous involvement with the catchment management process through a previous research project. I found my previous involvement to be a benefit as it allowed me to occupy a certain knowledgeable status with stakeholders who knew my history with the project and therefore perhaps considered me a more legitimate participant, particularly when talking informally or requesting further interviews or access to meetings and forums. Equally, having a shared experience, such as an association with the Geography Department at Durham University, or knowledge and familiarity with another stakeholders that the interviewee also knew and worked with helped to create a relationship within the interviews.

There were also times when there was a distinct difference in experience and social background between myself and interviewees and as an additional reflection on difference in the research process, it can often be assumed that becoming as much of an insider as possible builds trust in the research process (Kvale and Brinkmann, 2009:58) and that being distinct from the groups I was talking to would adversely affect my ability to successfully research. I can relate to such an assumption and often had a desire to prove my knowledge or understanding of a situation to show that I was capable and legitimately qualified to research the complex issues mentioned. This sometimes meant that I did not push hard enough for detailed explanations of certain processes, structures or even acronyms to maintain an image of knowledgeability. However, I also was aware of my perceived status as a 'student' which was widely accepted, and was able to use that perception of my desire to learn about the situation to ask clarifying questions at the end of the interview and tapping into the narrative of the interviewees 'helping' me to research their context. Therefore, it was clear that trust can also be built through being different and being able to give an observation from afar, which I believe a number of the participants involved in the project valued and identified.

3.4.6 Considering ethical issues

Social research is not without impact or consequence for those directly and indirectly involved (Dowling, 2000). It is necessary therefore, that impact should be carefully monitored through the conduct and actions of the researcher in relation to their responsibility towards those they have invited to participate and those communities they have chosen to analyse and study (O'Connell Davidson and Layder, 1994). The core principles underpinning ethical research relate to fairness in the distribution of benefits and burdens; minimization of physical, emotional, economic and environmental harm; and having consideration for the welfare, beliefs, rights, heritage and customs of people involved in the research (Hay, 2010). In this research the most significant ethical issue surrounding the interview process was the protection of interviewees from harm through ensuring that they were aware of the potential use of their words and their rights to control that use should they wish. The topics discussed were not particularly sensitive in a personal sense but the discussion of difficulties and problems, perhaps with particular relationships or even individuals in the management system, may have professional consequences and therefore certain processes of protection needed to be in place.

The first key ethical issue to be tackled was anonymity and confidentiality. It was made clear to stakeholders before the interviews through an information sheet about the project and within it an informed consent form signed by each participant (Appendix A), that their words would be recorded, with their permission, and may be used for direct quotes, but that their interviews would be stored confidentially (following a definition from Babbie, 2004) and their name would not be associated with their words in any written work. The participants were made aware that the name of their organisation might be used in association with their words in order to contextualise the knowledge and information. This approach was acceptable to all interviewees. Most interviewees were clearly representing an organisation and were aware of their ability to be speaking for that organisation and aware of the responsibility of adhering to the message of that organisation. However in some cases there was an acknowledgement that the individual had multiple identities within the management process (a theme that is picked up in Chapter 5) and that they could be speaking in different capacities. One interviewee asked at one point "do you want me to answer that in terms of the [organisation's] position or for my own role?", acknowledging that there was a difference in perspective from a scalar and hierarchical point of view. The organisation chosen as a label for the interviewee's quotes was the organisation with which they were associated when contacted about the project and asked to be involved. Maintaining the acknowledged organisational identity of each interviewee meant that it was clear for them to understand their position and monitor their words accordingly.

Informed consent was an important aspect of maintaining ethical research and an information sheet was sent in order that the participants knew exactly what the research involved and could make an informed choice about participating (Dowling, 2000). An information sheet included details of the rights of the participants to withdraw at any time and a reminder that the participation in the research was voluntary (Hay, 2010). A number of participants exercised their control of the information they were discussing and asked for certain aspects not to be included directly. Examples of such occasions were where they had revealed information about an uncertain future project or change, or revealed a personal opinion or comment on a situation that they thought may not be fair or fully informed, therefore should not be shared directly. The reassurance I could give them that those sections would not be used directly meant they could converse more easily and feel secure in the control of the information they shared and how it was used.

Chapter Four

Analytical methodology: Interpreting a catchment-management system

4.1. Analysing and interpreting qualitative data

This research project involves multiple modes of analysis of qualitative data provided by the interviews with stakeholders. Each stage of analysis is progressive and is built on the understandings and themes perceived through other stages of analysis. The first stage of analysis was the coding and thematic exploration of the raw interview data, which provided an understanding of the components and dynamics of the system as described by the stakeholders involved. This knowledge could then be used to inform a network approach to analysis in which relationships, exchanges and interactions were the focus of analysis. The combination of thematic and network analysis of the interview data informed the final stage of analysis through a process of agent-based modelling, which facilitated experimentation with the dynamics of the system of water management. The following sections describe the processes of each stage of analysis.

4.1.1. Understanding themes and narratives

The process of analysing themes and narrative comes in transcribing the interview conversation. The benefit of the process of transcription is reported by Sacks (1992) as allowing the researcher to encounter the data repeatedly in order to find patterns that might not be obvious at first, as well as increasing the researcher's familiarity with the data (Atkinson and Hammersley, 1994). All interviews were transcribed in full. The second stage of analysis was coding the transcribed data in order to identify themes and ascribe meaning to help interpret and interrogate the information provided (Strauss and Corbin, 1990). Coding is recognised as a process of abstraction (Flick, 1998) and this research undertook a thematic analysis of the abstracted codes, aiming to identify key ideas and processes by breaking down the data to compare across the circumstances and context of the case study.

The software package NVivo was used to facilitate the process of coding and allowed an ease of cross-referencing amongst transcripts and codes that enabled better coordinated thematic analysis. The first stage of coding to be enacted was open coding, in which each transcript was read through on a line-by-line basis and core, cross-cutting themes were identified (Strauss, 1987; Flick, 1998). The core themes identified were driven by both ideas that emerged directly from the interviewees and ideas that were already considered important by the researcher, neither was privileged and a combination of emic and etic codes were produced. The initial coding exercise gave 54 initial categories ranging from "changing practice" to "funding sources and strategies" to "connections and contacts" to "uncertainty and risk" and "problems and challenges" amongst others. The coding process was completed when no new categories seemed to emerge (Esterberg, 2002). The final stage of the coding process was to complete focused coding, which involves a breaking down of themes further in sub-categories to aid explanation and exemplification of the intricacies of the original codes (Coffey and Atkinson, 1996).

Coding offers the opportunity to analyse and compare themes within the qualitative data, however the process of coding is an abstraction and necessitates the fracturing of narratives, meaning that only parts of stories that get told through coding (Charmaz, 1995). The use of codes in the process of writing up the research in this project highlighted the need to reduce distorted interpretation and Jackson (2001) suggests that as a precaution the researcher should go back over the transcripts to examine the original context of the quote and assess the flow of conversation. This was a process that was constantly done throughout the further analysis of the qualitative data and the use of NVivo as a database for the quotes and their original setting in the interview conversation greatly aided that process.

4.1.2. Interpreting relationships and structures

One of the specific aims of the research alongside building a general understanding is to comprehend the actions and interactions through the concept of networks and systems, therefore the interview data and subsequent analysis was also used to inform a process of analysis of the relationships and structures within the catchment management system. A diagramming approach was used to transform the words of the stakeholders into system or network depictions and a process informed by network analysis was used to more formally conceptualise the system as a network in order to enhance understandings of interactions and the processes of exchange.

4.1.2.1. Diagramming inspired by the ARDI method

In order to make sense of the system of water management and to better understand the dynamics between the multiple stakeholders in the catchment a diagramming method was used to interpret the interview data alongside the analysis of codes and themes. The method used was inspired by the ARDI (Actors, Resources, Dynamics, Interactions) method (Étienne *et al.*, 2011) from the companion modelling approach (e.g. Barreteau *et al.*, 2003). The ARDI method involves researchers working closely with a core group of stakeholders in the area of study. Through a series of workshops and deliberations the core group comes up with a diagram of the system that represents their shared understanding of the actors and resources involved and the interactions amongst them, incorporating knowledge of the dynamics of the system that informs the patterns (see Figure 4.1 as an example).. The core theme of the process is to elicit shared mental-models of the system. The ARDI process is designed as part of a modelling process in which an agent-based model would be created based on the ARDI diagram in order to explore further dynamics and solutions (Biggs *et al.*, 2008; Rouan *et al.*, 2010; Simon and Etienne, 2010).

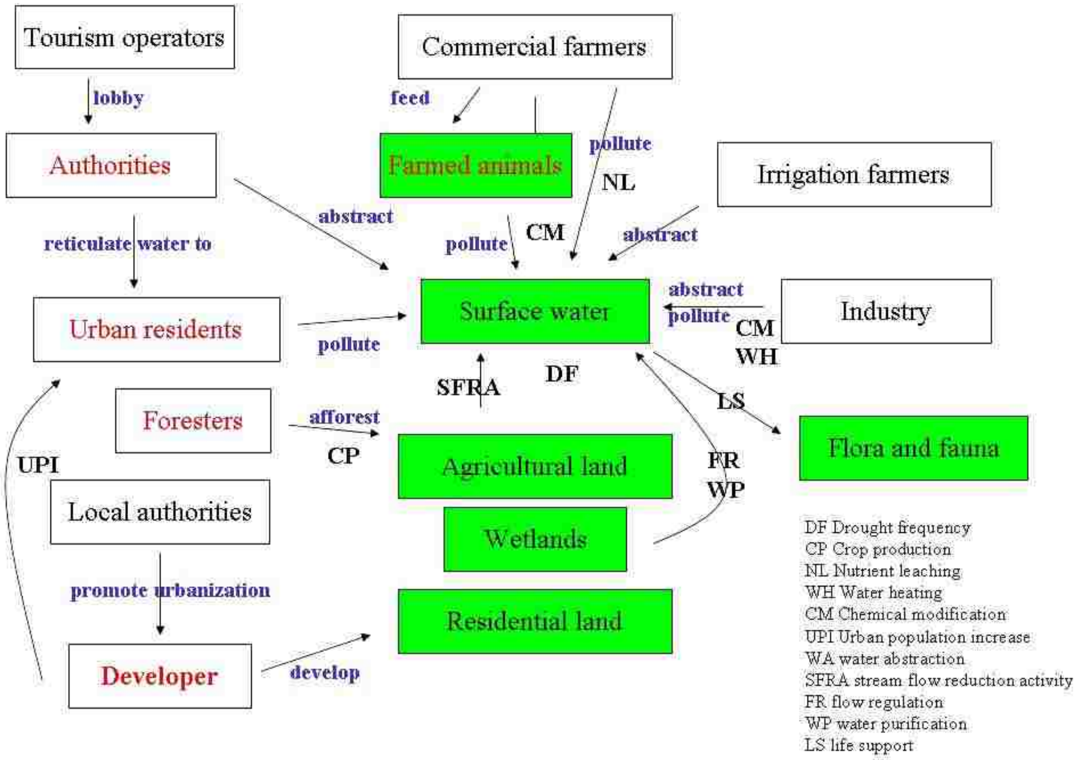


Figure 4.1 *An ARDI diagram created for the Crocodile River system, depicting stakeholders (white), resources (green), processes (bold) and actions (blue). Reproduced from Etienne et al (2011).*

This research recognises the benefits a process of diagramming offers to better understand the system and the mental-models of a wide variety of stakeholders, but it does not follow the ARDI method as closely as to create a core group of stakeholders who work together to produce the diagram. The purpose of studies that have previously used the method has been 'action-research', where the act of participating in the workshops becomes part of a practical way to build relationships in an area where problems may have been caused by lack of communication and lack of understanding across disparate groups and perhaps a lack of opportunity to meet and deliberate and share information. Through sensitive facilitation the process is able to act as the beginnings of a collaborative approach in place of any other formal modes of collaborative NRM. An ARDI process conducted similarly in the Wear catchment context would be repetitive of the types of interactions and discussions that stakeholders involved in CaBA had already been through in the pilot phase.

Consequently, the process of ARDI in this research is a way to synthesise a variety of stakeholders' mental-models of the system in the Wear catchment. The interviews act as a mode of expression for the stakeholders to define their own views about dynamics and interactions, which form the basis for diagrams. As an addition to the ARDI process, in this research individual ARDI diagrams were created for each interviewee in order to represent their individual perceptions and networks of interactions and opinions about dynamics (see Figure 4.2 as an example and Appendix B for an example diagram). The individual diagrams were collated into a larger diagram of the whole system. Although the diagram is not co-created, as in other applications of the method, the content is based on the words and descriptions of the stakeholders and on the understanding of each of their worlds based on their individual diagrams.

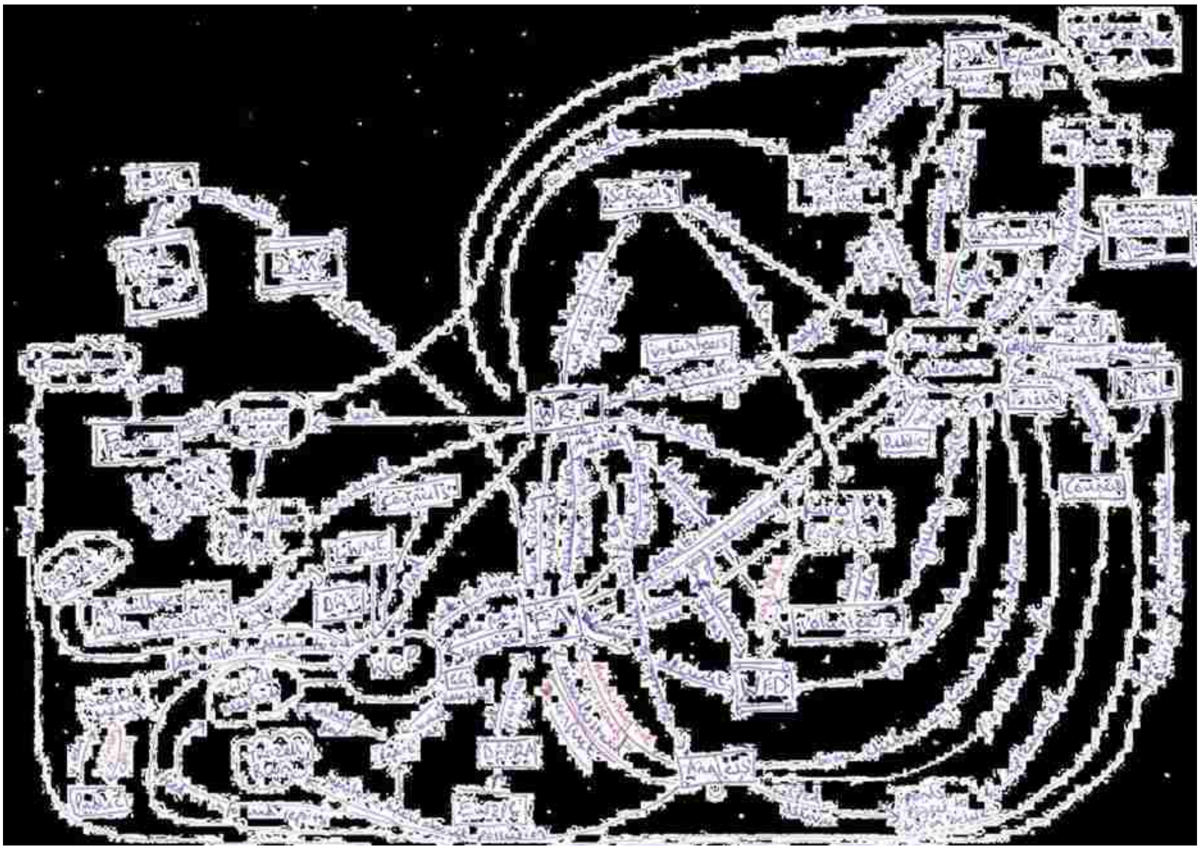


Figure 4.2 *Depiction of the hand-written ARDI- inspired diagram for an individual stakeholder (in this case a representative of the Wear Rivers Trust).*

The process of ARDI is described by Étienne *et al.* (2011) and the identification of the four core principles (actors, resources, interactions and dynamics) are the elements of the method utilised in this research to create individual and collective diagrams. Each of the elements were identified for this research as follows:

Actors (“A”)

Actors in the system are usually identified by asking the participants to list all the people they believe are relevant to the system based on their experience. In this research the actors (defined firstly as human actors, organisations and institutions) were identified by working through the interview material and recording all the groups mentioned. One of the research questions focused on asking the stakeholders about their key contacts, which fed into the identification of actors. Actors were recorded at the organisational level in order to standardise the reporting (as some stakeholders would refer to individuals and others to only the organisation). Some problems occurred when stakeholders referred to generic groups such as 'the public', which are difficult to identify specifically, therefore specific publics were associated with specific groups rather than including one generic 'public' actor.

Within the ARDI process, actors are also interpreted as non-human elements and can refer to management entities or animals (but should be delineated from elements included in the resource category). This research interpreted elements such as legislation, management plans, specific meetings and partnerships or even infrastructure (around waste water for example) to have agency in the decision-making practices and therefore were included in the diagram. Importantly the links between actors (and other elements) are also identified as part of the ARDI process. At this stage there is simply an acknowledgement of association. The interactions and dynamics stage of the process identify the exact nature of the relations.

Resources ("R")

Resources are identified as goods or products in the ARDI process (Étienne *et al.*, 2011) but were more loosely interpreted as natural systems or types of environment relevant to stakeholders. As all stakeholders are focused on the same environment and the same resources the main elements included in the diagram were simply rivers and streams, riparian land, ground water and peatland. Within each category it is recognised that there are many types of resources and environments that are valued, utilised and maintained but were not needed at this level of abstraction.

Dynamics ("D")

Dynamics refer to the key processes in the system, in particular those that drive changes. Processes could be ecological dynamics, social processes or economic dynamics. In the ARDI method, dynamics are ranked by importance by the stakeholders, however in this research the analysis of the importance of different dynamics is done through in depth analysis rather than deliberation with stakeholders therefore dynamics are included in the links between elements in the diagram.

Interactions ("I")

This stage of the process brings together all the other elements of the ARDI process by identifying the interactions between the elements of the system. For ease of representation interactions are represented as links or lines between nodes on the diagram with a words or phrases attached (usually including a verb) to represent the influence or exchange as well as dynamics between actors. The diagramming process encourages just one link to represent the relationship between actors, which is potentially problematic if there is a complex and multi-layered relationship, therefore sometimes multiple or more explanatory links were included, particularly to help depict the dynamics of the system.

Figure 4.3 shows the first-hand version of the final ARDI-inspired diagram for the Wear catchment system. The diagram was kept in draft format and utilised to feed into the analysis of the networked system, through informing the components of the system and the links between actors and elements.

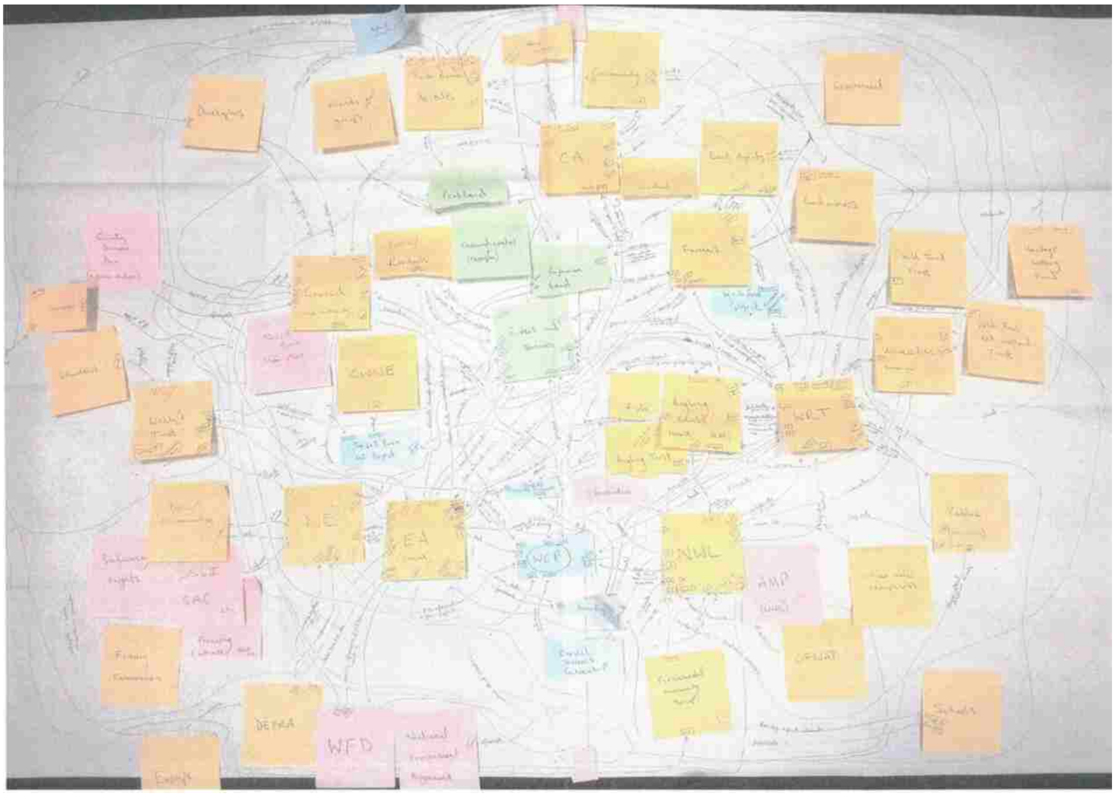


Figure 4.3 *ARDI-inspired diagram of the Wear catchment system. Yellow notes indicate stakeholders and actors, green notes indicate resources, blue notes indicate meetings or projects, pink notes indicate legislation or plans.*

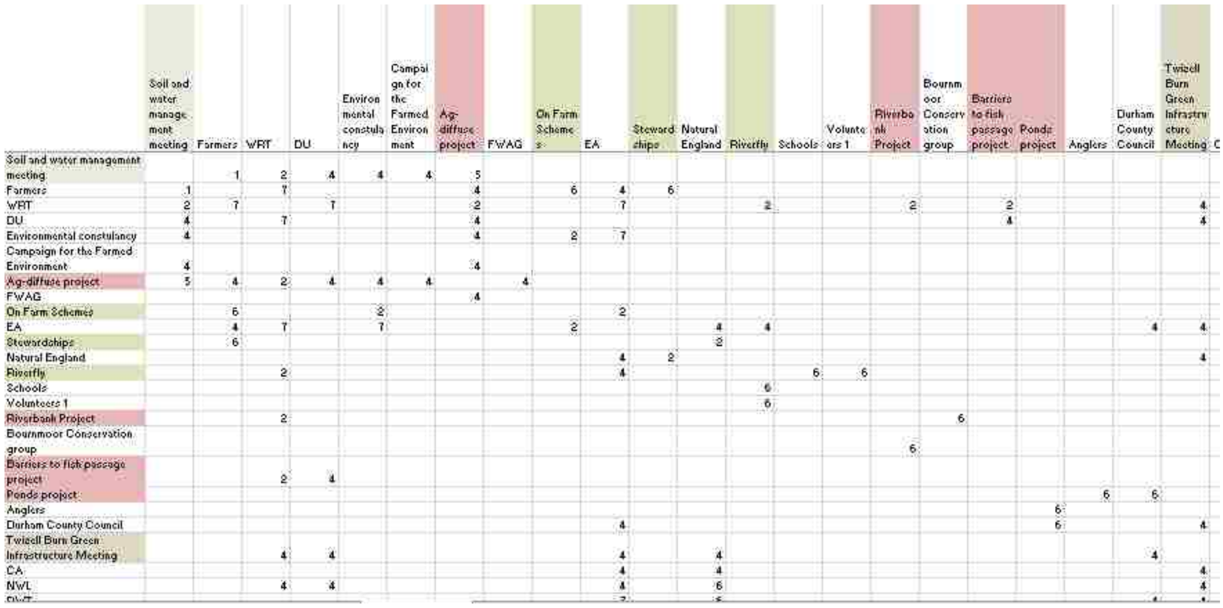
4.1.2.2. Identifying network structure

The ARDI method establishes that the catchment-management system can be conceived as a connected whole (within the limited boundaries and scope of the data used to understand the system). By conceptualising the water-management system as a social network, an additional in-depth analysis was made. SNA offers a system of standard practices to analyse the configuration of a social network in relation to ties (links) and to the position of actors or 'nodes' within the network. It does, however require there to be quantitative data about the contacts and communication between actors in order to quantitatively analyse the outputs. For this research, a full social network analysis was not the aim and therefore the information collected about stakeholder interactions offers a qualitative understanding.

The software package NetDraw (Borgatti, 2002), part of the larger UCINET package, was used to visualise the network. In order to create a network graph and begin to analyse its structure, a network matrix was created. The components of the matrix represent those components that were seen to have power or importance in the system of management and decisions were made to include all stakeholders mentioned by interviewees, any partnerships in existence, any large multi-stakeholder meetings mentioned, as well as projects and actions within those projects. The network is therefore conceptualised differently to a stand-alone social network to encompass the different spaces and place of interactions identified through the ARDI process.

The matrix created was a symmetric matrix in which it is assumed that the ties between nodes are undirected and that there is an equality of relationship between each entity. The strength of the ties (Granovetter, 1973) was not included as the qualitative information produced during interviews was not consistent enough to translate to a standardised quantitative measure. Figure 4.4 shows part of the matrix created for the Wear catchment network with the components of the network listed against one another and the existence and type of relationship marked by categories. The types of relationships between actors were defined by the dominating relationship, which in itself is a difficult measure as many of the actors have complex relationships that involve many forms of interaction, however a certain level of abstraction was needed in order to assess the network. Once the matrix had been fed into the software package, graphs (or socio-grams) of the whole network as well as some 'ego' (node) graphs were produced to highlight the individual networks of some actors.

SNA allows for the production of quantitative measures about the network structure, reflecting on the power, centrality, positions and roles of the entities that make up the network. From UCINET various measures were produced for the Wear catchment graph including centrality and betweenness measure, for isolated parts of the network (e.g. only stakeholders) as well as the whole network. It is important to note, however, that the use of quantitative measures is balanced within the context of other forms of analysis and that they are not taken to be representative of an absolute truth or permanency but one possible understanding of one construction of the system.



	Soil and water management meeting	Farmers	WRT	DU	Environmental constulancy	Campaign for the Farmed Environment	Ag-diffuse project	FWAG	On Farm Schemes	EA	Stewardships	Natural England	Riverfly	Schools	Volunteers 1	Riverbank Project	Bournmoor Conservation group	Barriers to fish passage project	Ponds project	Anglers	Durham County Council	Twizell Burn Green Infrastructure Meeting
Soil and water management meeting		1	2	4	4	4	5															
Farmers	1		7				4		6	4	6											
WRT	2	7		7			2			7			2			2		2				4
DU	4		7				4											4				4
Environmental constulancy	4						4		2	7												
Campaign for the Farmed Environment	4						4															
Ag-diffuse project	5	4	2	4	4	4		4														
FWAG							4															
On Farm Schemes		6			2					2												
EA		4	7		7				2			4	4								4	4
Stewardships		6										2										
Natural England										4	2											4
Riverfly			2							4				6	6							
Schools													6									
Volunteers 1													6									
Riverbank Project			2														6					
Bournmoor Conservation group																6						
Barriers to fish passage project			2	4																		
Ponds project																				6	6	
Anglers																			6			
Durham County Council										4									6			4
Twizell Burn Green Infrastructure Meeting			4	4						4		4									4	
CA										4		4										4
NWL			4	4						4		6										4

Figure 4.4 *Section of the matrix created for the catchment network showing the network nodes against one another and the types of relationships.*

4.2. Exploring the system through Agent-Based Modelling (ABM)

4.2.1. The epistemology of ABM

It has been argued that ABM's mode of knowledge creation is not fundamentally epistemologically different from other methodological approaches in (human) geography (Millington and Wainwright, 2016). In this research a dialogical mode of use of ABMs was adopted, in which no one single model is acknowledged as right, but that any given model can offer alternatives, explore conceptual models of the world and contribute to debates on practice, understanding or knowledge and their desirability and acceptability amongst a certain society or within a certain context (Millington and Wainwright, 2016). The use of ABM as a heuristic tool is an important emphasis of the epistemological approach in this research.

4.2.2. Using qualitative data to inform a model

The ABM in this research is grounded in empirical data from qualitative interviews with stakeholder actors in the Wear catchment system. The process of testing and experimenting with mechanisms and rules is the role of the ABM, and therefore a translation from qualitative information from 'actors' to rules relevant to 'agents' in a model of the system is important (Rounsevell *et al.*, 2012). As the ABM is conceptualised through functions that are logic-based it is necessary to transform ideas conveyed through ethnographic data into coded rules, or to "make numbers out of words" Agar (2003: paragraph 1.3). Such a process can be seen as controversial and can be critiqued as messy or inaccurate if the decisions made about the numbers that represent behaviour are definitive and absolute. Where an acknowledgement of the muddiness of the process is given, and processes are enacted to allow space for sensitivity analysis and for an iterative process of checking between data and model processes and outputs, the confluence of ethnographic data and modelling is relevant. Previous studies have successfully combined ethnographic data and modelling (e.g. Altaweel *et al.*, 2010).

In this research the philosophy for transformation of ideas and conclusions from the empirical data analysis into an ABM followed Agar (2003), Yang and Gilbert (2008) and Zellner *et al.* (2014) who advocate that change within the system be the focus of decisions made about numbers and rules. The use of conceptual thresholds, represented as a number (of any unit appropriate), that define the point at which an important change happens in the system is a central part of the translation of data into a model.

Therefore the approach taken in this research was to ascertain theories or hypotheses about the changes in the system. These theories then informed estimates of the numbers and their thresholds that might represent the system described by the stakeholders in the ethnographic data. The process of estimation was loose, for example Zellner *et al.* (2014:2) state:

> Since a model is not meant to replicate what a change of behaviour feels like or means for a person, but rather to replicate the process and result of behaviour change, using thresholds that are valid in a "more or less" sense is appropriate.

The use of numbers that are 'more-or-less' valid is also a philosophy adopted in this research, based on the idea that any function created for the model will be grounded in differences that were described as making a difference based on the experience of the modeller and the accounts of the informants (Agar, 2003). Equally the judgements made can be later evaluated through sensitivity analysis. Agar's understanding of validity as "feeling" (he makes decisions where he feels that a number is right in an ordinal rather than absolute sense) based on knowledge and stories is an important influence on the process also taken in this research. The significant addition to the creation of thresholds and use of numbers based on instinct and knowledge is the understanding of the need to initially create a range within which the values can fluctuate, perhaps representing extremes of behaviour leading to different outcomes for the model. The sensitivity of such values can then be checked, which then connects or checks the assumptions back to the system being modelled and creates an iterative dialogue between the empirical data and the model outputs.

4.2.3. Creating a model with NetLogo

NetLogo (Wilensky, 1999) is a widely used modelling platform and language for multi-agent systems (Wilensky and Rand, 2015) and is particularly well suited to modelling social and natural systems (Sakellariou, 2008). Other languages exist, including Swarm, Repast and MASON and other platforms including Ascape, Breve, Cormas, MASS and SeSam, but are arguably more complex, less well supported (through tutorials, textbooks, forums, examples and dictionaries) or less well used than NetLogo. NetLogo's design principle is "low threshold, no ceiling", which, if restrictions from hardware and the Java virtual machine (which enables Java to run) are discounted, is achieved through the learnability of its language for beginners and through its use by a large number of researchers for cutting edge explorations (Wilensky and Rand, 2015). The language of NetLogo is arguably expressive, simple and functional, which alongside the popularity of NetLogo, makes it a suitable choice for modelling in this project.

The agents in NetLogo perceive their environment and act upon it, carry their own threads of control and are autonomous. The main elements of the NetLogo system are:

- **Patches:** stationary 'agents' or components of a grid
- **Turtles:** agents that are able to move and interact on the patches
- **Observer:** the controller of the experiments

Different types of agents can be defined within both the turtles and patches (called different "breeds" in the NetLogo terminology), which can have their own user-defined variables, which allow agents to hold their own state and allow patches to have multiple attributes. The NetLogo system facilitates the use of primitives (pre-programmed functions) that allow the behaviour of the agents to be controlled by commands that 'ask' the agents to execute procedures. NetLogo also allow the visualisation of the system being modelled and the simple production of outputs through charts, graphs and tables.

4.2.4. Principles for developing the model structure

4.2.4.1. The ODD protocol

ODD (Overview, Design concepts, and Details) is a protocol used to describe the details and concepts of an ABM, and was developed by Grimm *et al.* (2005). It is widely used to create factual model descriptions and is growing as a universal way to describe models so that others can easily understand and even replicate other modellers' ABM systems. Figure 4.5 shows the elements of an ODD protocol. Its structure is used as both a description and a guide for the elements of the model and in combination with the transformation of qualitative data into a modelled system, the ODD protocol guides the dynamics that need to be considered to create a functioning model that utilises the principles of ABM as a method. This research uses the framework set out in Figure 4.7 to guide the design and write up of the modelling process (section 7.3).

	Elements of the ODD protocol
Overview	1. Purpose
	2. Entities, state variables, and scales
	3. Process overview and scheduling
Design concepts	4. Design concepts • Basic principles • Emergence • Adaptation • Objectives • Learning • Prediction • Sensing • Interaction • Stochasticity • Collectives • Observation
Details	5. Initialization
	6. Input data
	7. Submodels

Figure 4.5 *Elements of the ODD protocol (reproduced from Grimm and Railsback, 2012).*

4.2.4.2. Bounded rationality

Theories about the decision-making processes are an important part of the conceptualisation of the agents in an ABM, and moreover important for reflecting on the way that humans think and the way that culture might shape the implementation of NRM (World Bank, 2015). It has been traditionally assumed that actors in social-ecological systems follow the pattern of the standard model in economic theory of the selfish rational actor (e.g. Godelier, 1972 [1966]) who has perfect knowledge, stable preferences and makes calculations in order to make decisions that maximise utility (Schlüter *et al.*, 2017). However, it is now recognised that there are a range of alternative theories of behaviour, and as a result many different models of choice (Gsottbauer and van den Bergh, 2011). The most recognised and understood in relation to modelling agents is bounded rationality, which acknowledges that individuals deviate from rational decision making because they are bounded by cognitive limits, lack of information and limited willpower, particularly when solving complex problems. Aspects of human behaviour such as heuristics, mental models, pro-social behaviour, rules of thumb, status, learning, interaction, habits, altruism and self-identity can complicate decisions and mean that people do not always choose the most 'profitable' (in the broadest sense) option when faced with a number of alternative paths. Barros (2010) reports the centrality of Herbert Simon's pioneering work in defining bounded rationality in which Simon replaced the goal of maximising (in traditional decision-theory) with the goal of satisficing, which refers to finding a course of action that is 'good enough' (Simon, 1957). Instead of meeting a top level criterion, the agent makes a choice based on that which exceeds a set of minimal acceptability criteria. This means that there is not one best solution, but a number of options, meaning that the agent is able to cope with multiple demands and complexities.

In this research it is acknowledged that each stakeholder is bounded by elements such as lack of knowledge, limited cognition and complex cultural and behavioural influences. Whilst theories of agent behaviour were not formalised in the ABM, the assumptions made about the way that the agents interact were influenced by the concepts of bounded rationality and related theories such as the theory of planned behaviour. The theories were applied within the rules of interactions and decision making given to each of the types of agent in the ABM and underpinned the understanding about why certain patterns of behaviour might happen. The fundamental understanding of the concepts of bounded rationality were combined with model architectures to support such theories.

4.2.4.3. The BDI (Beliefs, Desires, Intentions) framework and communicating agents

To transform the conceptualisation and theorisation of agents into the architecture of the model a BDI (Beliefs, Desires, Intentions) approach was used. The BDI approach originated in artificial intelligence (Bratman, 1987) as a system to symbolise rational agents with certain mental attitudes representing the information, motivation and deliberation phases of an agent's decision making processes (Rao and Georgeff, 1995). Its development was driven by the need to better represent the reality and expression of agents, through their complex reasoning. BDI is claimed to play an important role in multi-agent systems research (Bordini and Hübner, 2006). BDI in multi-agent systems stemmed from the ideas of the Procedural Reasoning System (PRS) in which an agent is seen to perceive the environment, interpret that environment and deliberate to choose an action, then execute intentions representing the agent's reaction (Myers, 1997). It has been applied through a number of modelling languages (e.g. Bordini and Hübner, 2006) and Sakellariou *et al.* (2008) developed the idea of BDI agents, based on PRS, for NetLogo, as a way to allow modellers to utilise the BDI concept in a simple language. A BDI extension to the NetLogo programming language, in the form of a NetLogo library, developed by Sakellariou was adapted and utilised in this research to develop the complex reasoning capabilities of the agents.

The concept of a belief can be seen to represent the agent's understanding or mental model of the world. Through a process of sensing the environment or communicating with other agents beliefs can be updated and changed based on observed changes. These beliefs can be used as a system to inform the action that the agent takes. Action is represented in the form of intentions, which describe an intended action of an agent and a state or checkpoint at which that action should end. Intentions are stored in a stack, meaning that agents can have multiple goals or aims at once, but that can be changed and interrupted based on the interaction with their environment or other agents. Beliefs and change in beliefs can inform the creation and execution of certain intentions at certain times. The dynamism of the interactions between the agent's intentions, beliefs, other agents and their environment allows a small level of complexity to be represented through the modelled system. Caillou *et al.* (2015) highlight the ease of use, improvement and analysis of the BDI system as part of its advantage over other more complex representations of reasoning. This simplicity in representing complexity formed the basis for the use of BDI in this project.

Communication between agents is an important aspect of the BDI system, but a detailed communication system is missing from the basic NetLogo language. Hence the creation of an additional library for NetLogo by Sakellariou *et al.* (2008) containing primitives that facilitate the sending and receiving of messages between agents (modelled on what is referred to as a FIPA-ACL system (The Foundation for Intelligent Physical Agents - Agent Communication Language (FIPA, 2002)). Alongside the BDI library, the message-passing library was also used as an extension to NetLogo for this research to allow agents to create and send specific information to specific other agents in the system as well as broadcast information to particular groups or the whole community of agents. Agents can then respond to the messages through their own actions or by sending replies. The system allows for a more realistic communication structure to exist amongst the agents and symbolises the multiple and competing messages that agents may receive as part of a wider group of communicating agents. Messages can also be a trigger for the change of belief or the choice or creation of particular intentions.

Despite their logical structure, ease of use and representative nature BDI and FIPA-ACL messaging functions have not been widely used in agent-based modelling around social-ecological and water management systems and therefore this research offers an opportunity to evaluate their utility for such systems.

4.2.5. Verifying and validating a model

Verification and validation are two important processes in the model development (Crooks *et al.*, 2008) and provide the mode by which the explanation (hypothesis) of the way the world works presented in the model can be tested (Rand and Rust, 2011). Once completed, the processes allow the model to be transformed from a toy into a tool (North and Macal, 2007). Verification assesses how well the implemented model corresponds to the conceptual model, and validation assesses how well the implemented model compares to the real world. Although it is arguably impossible to fully validate and verify models (Refsgaard and Storm, 1996; Senarath *et al.*, 2000), the process aims to give some confidence in the modelling process and convince the users of the model's rigor and its utility for the purpose for which it was designed (Rand and Rust, 2011). However Oreskes *et al.* (1994) have highlighted the difficulty in communicating the value of verification and validation processes due to the confusion amongst non-modellers about the meaning of the terms. A validated and verified model may be understood as more 'truthful' and more internally consistent than the author intended when using such terms (Wainwright and Mulligan, 2013). Both processes were enacted in this research, with the verification process happening during the construction and design of the model and validation incorporated into the analysis and evaluation of the model and modelling method. It is recognised that the processes can only produce information about the performance of the model with respect to observational data, other models or ideas about the same site, and the modeller's own theoretical expectations (Oreskes *et al.*, 1994).

Verification involves the process of checking the computer model against, for example, the process of ODD, whereby the logic of the computer programme can be compared to the expected logic as described in the ODD process. Equally, there should be adequate documentation within the code itself, so that even an inexperienced programmer can compare the documentation of the code to the conceptual documentation and understand which parts of the code represent which ideas in the conceptual model (Gilbert, 2008). In this research, the process of verification was ongoing throughout the model creation process with each section of code tested in relation to its intended logic. Some sections of code were tested against a simple intended outcome in order to identify bugs or inconsistencies if that outcome was not achieved. Each of the separately tested sections of code were combined to create a more complex model. Due to the processes of checking the model can be considered to have been partly verified (as full verification is not possible) against conceptual models. The next step was to validate the model in relation to real-world understandings.

Validation relates to the extent to which the model created is representative of the system aiming to be modelled (Casti, 1997). Rykiel (1996) suggests that there are three core ways in which validation of models is employed including whole-model validation, which refers to the correspondence of the model output to real world observations; conceptual validation, which refers to the evaluation of the theories, ideas and assumptions that underpin the model; and data validation, which refers to the evaluation of the inputs into the model. Although the more validation procedures a modelling process can use, the higher the confidence in the model as a reasonable and contextually appropriate representation, Rand and Rust (2011) advocate the need for just three stages of validation: face validation (micro- and macro-), which relate to conceptual validation of the implemented model; empirical input validation, which relates to the correspondence of the data used as inputs to the real world; and empirical output validation, which relates to the way that the outputs of the model relate to sets of real data about the world. Face validation and input validation were the main focus of validation processes, where, due to the absence of any predictive element to the model, validating outputs against a real-world data set of the same situation was unnecessary in relation to the purpose of the model (Chapter 7). In each case the process of validation allowed the model to be compared to other forms of knowledge, if there was a mismatch then there was seen to be a problem with the model. However, Oreskes *et al.* (1994) highlight that the problem in itself may not be identifiable and requires step-by-step process of checking to rectify. However, even when a fit is found between other forms of knowledge and the model, there is no way of knowing the value of the particular hypothesis over another version of the same model that produces the same results. Such equifinality means that the validation process needs to be treated with caution. Where validity and verification are enacted successfully they are seen to indicate support for the probability of the given system in a model being in some way acceptably representative of an external system, but in no way actually representative (Oreskes *et al.*, 1994). In this research care was taken to highlight the model as one idea and one representation amongst many possible explanations, emphasising the model's role to provoke the asking of new questions rather than the provision of answers.

Important aspects of the input validation process are sensitivity analysis and calibration. Sensitivity analysis establishes the influence of certain parameters and parameter values on model outputs and can be used to calibrate the model and to experiment with scenarios. If certain parameters appear to have little effect on the outputs of the model there may be an overparameterisation of the model, or equally a misrepresentation of a process (Wainwright and Mulligan, 2013). In this research, NetLogo Behaviour Space was used to perform sensitivity analysis as part of the assessment of the validity of the model. The conclusions of the sensitivity analysis give a better understanding of the model and the way in which the parameters interact, allowing observations to be made about the assumptions and theories of the model, which facilitate a reflection on the understandings of the system being modelled. The iterative evaluation process then extends to the observations and data informing the model and raises questions about how to better investigate the system based on the results of the modelling process (Wainwright and Mulligan, 2013).

In this research it was not possible to validate the model directly with stakeholders in the Wear catchment due to time constraints. Equally, the purpose of the model in this research was as a heuristic for analysis within the research process, and its broader reflections on the context and processes of stakeholder behaviour were aimed to be the valuable output outside of the context of the research process, rather than the model itself. Therefore if the model were presented directly to stakeholders, the criteria that stakeholders might use to evaluate and validate the 'truth' of the model would have been different. Had the model been aimed to be transformed into a tool for decision-making or as a practical thought experiment for practitioners, this participatory process of validation would have been appropriate.

4.2.6. Ethical considerations in modelling

Agent-based modelling, as with any other form of methodology, may have harmful consequences if performed unethically. Therefore the consideration of reducing harm throughout the process is important. This is particularly true in modelling, where the researcher has responsibility for the creation of a world and of direct representations of actors, supposedly representative of some reality that may be relevant for others. The problems may arise from the socially embedded nature of the processes of creation, interpretation and communication models or model results. Therefore model results may get a life of their own beyond the intended consequences due to social systems and practices, particularly if the processes of verification and validation are misunderstood or miscommunicated (Oreskes *et al.*, 1994). In this research, several issues were considered:

The transformation of data into the model was considered due to the direct relation of the words of stakeholders in the interviews to the rule for agents' behaviours in the model. There may be potential for a misunderstanding about how the model might be created based on what they say. The first consideration was to make the stakeholders aware of the possibility of the use of their words to inform a model and modelling process. The information sheet distributed to interviewees (Appendix A) detailed the possible inclusion of their ideas in a model, but reassured that their contributions would be generalised. Such information meant that all interviewees were aware that the information they gave might be used and interpreted in several ways. Ören (2005) advocates, in a description of a code of ethics for modelling and simulation, that professional competence should play a large role in reducing harm to participants and audiences. For example in order to ensure ethical transformation of data into a model, clear and justified methods should be used. Equally, the process should be documented comprehensively so that the decisions of the modeller can be traced back. In this research the processes of thoroughly reporting and documenting methodology at each point in the modelling process means that the decisions can be justified and the process validated should problems arise with representation.

The representation of agents in the model was the second consideration as the choices made about each actor may be acceptable or disagreeable to those actors when presented back. Again, documenting decisions was used to mitigate against potential problems. Important decisions such as the scale of agents represented in the model (e.g. individual and organisational) could be impactful on outcomes. For example if individuals were represented the conclusions of the research may have personal consequences for those involved if they were seen to be directly represented, which may be more contentious than if just organisations were represented. Equally, there could be room for misrepresentation at such a level. Therefore the decisions need to be justified, documented and communicated correctly (here, using the ODD protocol).

The communication and dissemination of outcomes is another important aspect and relates to the need to avoid misleading the audiences of the model as to its purpose. In this research the model results are planned to be communicated back to the stakeholders involved in the research post-write-up, but the emphasis will be on the experimental format of the model and the purpose of the model to start discussions rather than predict any future behaviour or realistically represent a future scenario. There will be an emphasis on the use of the model in the research and its purpose as part of the evaluation process.

4.3. Summary

Chapters 3 and 4 have introduced and described the combination of methodological approaches utilised in this study to gain perspectives on a catchment management system. Chapter 3 first introduced the case study of the River Wear catchment in NE England as a suitable location to observe the collaborative Catchment-Based Approach to water management. The involvement of the stakeholders in the Wear catchment in CaBA through a pilot phase and into the full roll out of the approach over a six year period meant they had experience of the transition of practice and were able to reflect on its impact and on its manifestation in current actions and activities. The chapter outlined the process of data collection for the project, which foremost consisted of qualitative interviews with stakeholders involved in management activities. Chapter 4 then detailed the methodological approached to analysis of the qualitative interview data through a network approach and ABM. The techniques involved in transforming the data into representations of networks through diagramming and analysis, and by ABM as a heuristic research tool.

The following chapters describe and analyse the observations about the system of catchment management and the practices and mechanisms of stakeholder actions and interactions, that result from the multiple methodological approaches; Chapter 5 will outline the inferences from a network approach to analysing the system; Chapter 6 will explore the drivers and enablers of networked practice from the stakeholders perspectives; and Chapter 7 will present an ABM and analyse how it can offer a deeper understanding of processes and raise important questions about behaviour and influence on change.

Chapter Five

Networks in a catchment-management system

5.1. Chapter overview

This chapter presents the understanding of the catchment system that has arisen from adopting a network perspective. The chapter looks at the components and dynamics of the network using an understanding that the network is made up of structures that represent and produce particular functions at particular times, sometimes through complex mechanisms. The chapter first explores the components and structure of a networked catchment conceptualisation for management purposes. Communication and exchange are analysed as links between the components of the network and the general pattern of nodes and links explored through network metrics and diagrams in order to discuss roles of various stakeholders in the network.

The chapter also highlights the changes that have been observed by stakeholders within the networked system as a result of the growth of CaBA, pertaining to different interactions, roles and institutions that have emerged in the recent past. The outcomes of the change in governance approach as seen through changes in management practices, and network structures in the Wear are then explored through an analysis of stakeholders' understanding of positive outcomes they have observed in the catchment, as well as an analysis of challenges and possible future changes as indication of the most critical features of a system. The final section comments on the possibility of using the network approach to better understand practices of good governance and the possibility of determining how better outcomes can be brought about through reflection on the governance structure.

5.2. Identifying components of catchment governance: characterising the catchment as a network

This section identifies the actors and organisations involved in water resource management actions and activities in the Wear, conceptualises the relationships of communication between the actors and uses network visualisation and measures to assess the roles and positions of actors in the Wear network. Such analysis helps build a picture of the operationalisation of processes of catchment governance happening at the time of research in the Wear and helps identify the components of the network that might be part of the governance process.

Figure 5.1 depicts a representation of the catchment network as a combination of nodes and links. Nodes are representative of stakeholders, and of the spaces and places in which stakeholders interact and act, such as partnerships, meetings, schemes and projects. The diagram also depicts specific on-the-ground actions as being part of the networked system. Figure 5.1 shows the complicated nature of a network and the variety of elements contributing to the connected nature of a managements system around water quality management. The components represent a snapshot in time (early-mid 2015), due to both the temporary nature of some of the relationships (perhaps only at the project scale or single one-off interactions), and the changes in context that occur over time. This snapshot, however, can also be valuable in suggesting the state of the system at a particular point in time in relation to the stage of the CaBA approach reached and the particular economic and political circumstances at the time.

Figure 5.1 underlines that the network is made up of multiple actors and significant points of activity (170 nodes), all of which are involved in a complex web of interactions. The most connected nodes appear closer to the centre of the diagram and can be seen to be stakeholders and core CaBA partnerships, with the nodes representing projects and actions further away from the centre. The nodes at the edge of the diagram do not necessarily represent those that are unimportant or peripheral stakeholders, but represent the extent of this particular catchment network.

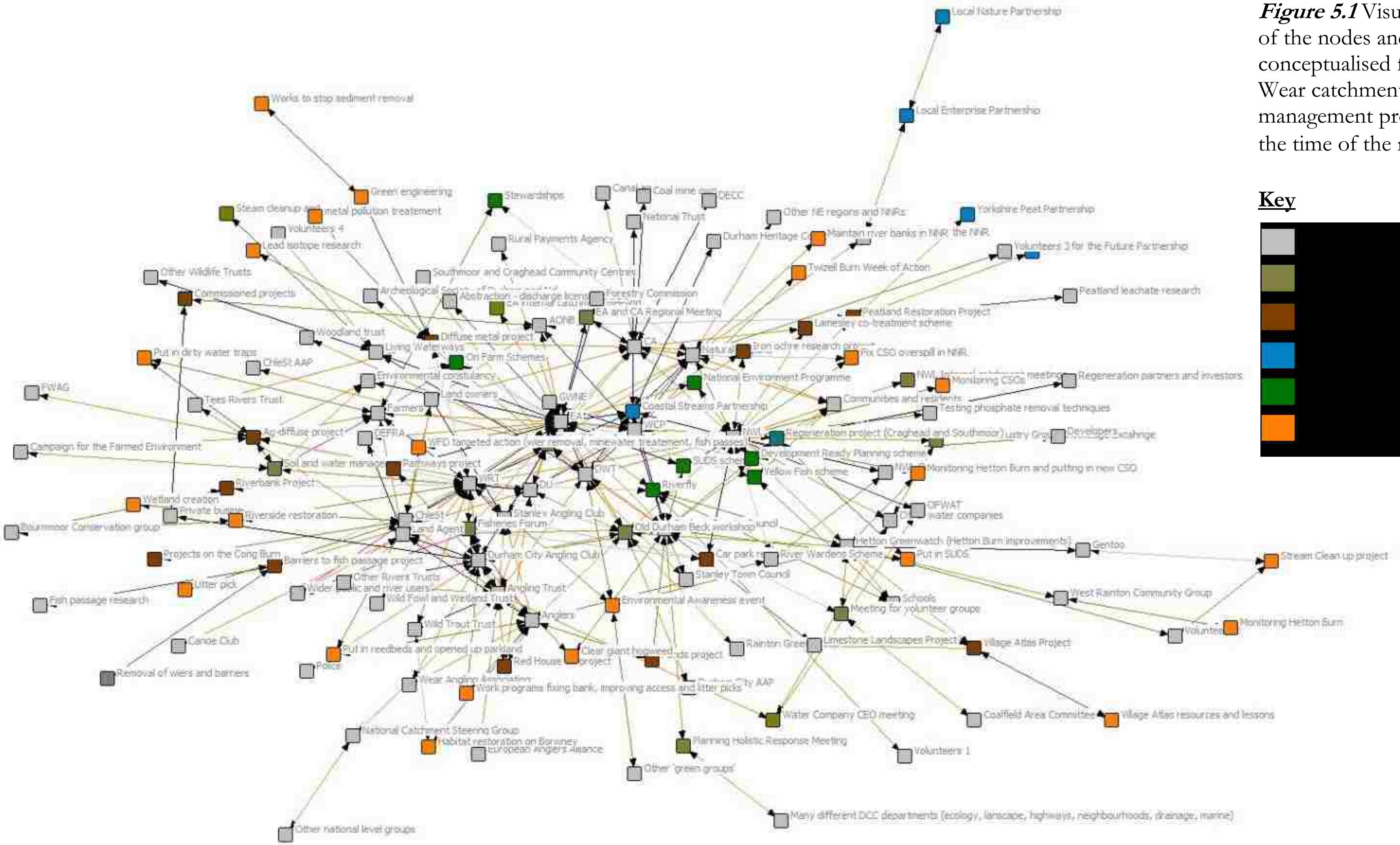


Figure 5.1 Visualisation of the nodes and links conceptualised for the Wear catchment management processes at the time of the research.

Key

[redacted]

[redacted]

5.2.1. Nodes in the network: spaces and scales of agency

Within the conceptualisation of a network, nodes can be interpreted as representing the actors or key components of a network and are usually conceptualised as individuals and organisations; as human actors with agency to interact and act. In the case of the Wear catchment, stakeholder groups and organisations are seen as the primary nodes of agency. However, it is acknowledged that network structure representative of governance networks is not only made up of stakeholders but also the institutionalised and informal spaces and places of interaction and action, conceived as additional nodes in the network. Whilst this is different to conventional configurations of social networks it is a way to reflect the embeddedness of collective social relations that become repeated through time and may represent the outcomes of processes of negotiated institutionalisation that reveal something about governance systems. Such alternative nodes exist in a variety of temporalities (for example, short-term interactions, ephemeral connections or embedded or semi-institutionalised spaces) and therefore represent multiple scales and spaces of agency (understood as points of potential change, particularly in relation to decision-making).

5.2.1.1. Traditional nodes: stakeholders

There were over 60 organisations or groups of organisations mentioned by the interviewees as being involved in or related to decision-making and action in the Wear catchment. These groups can be seen to represent part of a network of stakeholders who have the potential to influence the social-environmental system within the catchment. They are representative of multiple types of actor, multiple values, knowledges, opportunities, positions and behaviours. They operate at multiple spatial scales of action and influence. The stakeholders can be categorised into the following groups:

Land managers and land owners: Representative of those who have direct, private, ownership or management of land, such as farmers and land agents, as well as those with private interests such as coal mine owners. They operate at a local and regional scale.

Charities: Groups who exist for public benefit, are not-for-profit, and who have an interest in protecting environments and enhancing communities. These are groups such as Durham Wildlife Trust (DWT), Wear Rivers Trust (WRT), Wild Fowl and Wetland Trust (WWT), National Trust, Angling Trust, Woodland Trust and Groundwork North East (GWNE). Such organisations operate at a local or regional scale but are often associated with larger national scale coordination of activities and agendas.

Government agencies, regulators and groups with state responsibility: Organisations whose agenda and funding are derived from central government and often regulate or set legislative agenda for others operating in the area. They may be representative of direct government departments such as DEFRA or Department for Energy and Climate Change (DECC) (DECC at the time of interviewing, but became part of the Department for Business, Energy & Industrial Strategy in July 2016); of devolved, non-ministerial or non-departmental organisations such as, OFWAT, the Environment Agency (EA), Forestry Commission (FC), Coal Authority (CA) and Natural England (NE); executive agencies such as the Rural Payments Agency; and groups with devolved responsibility for land management such as the North Pennines AONB. All such organisations are nationally coordinated but have regional delivery processes and plans.

Local government: Organisations and roles affiliated with regional government such as within Durham County Council (DCC), or neighbourhood government such as Stanley Town Council. Such organisations follow local and regional agendas delivered within the bounds of national or regional political priorities and practices.

Academics: Organisations such as universities, for example Durham University. Often their work is local but will bring experience and knowledge from multiple scales.

Consultants: Private environmental consultancies. Usually commissioned to carry out projects set by stakeholders in the system.

Agricultural support: Organisations such as National Farmers Union (NFU) and Campaign for the Farmed Environment that are independently run. They are concerned for the interest of farmers and agriculturalist land managers. Often coordinated at the national level with local or regional delivery.

Vested interests: Organisations with a considered and valued interest in the decisions that are made within the catchment about water resources. They may not be directly involved in environmental management decision-making but whose activities and interests overlap with the processes of management. For example schools, residents represented by Area Action Partnerships (AAP) or Community Centres developers, businesses located near water courses, investors in green infrastructure projects, wider public and river users. Often their activities are locally focused and parochially derived and led.

Recreation groups: Organisations, usually funded through membership, with a specific recreational interest in water environments. Anglers are the most common recreational group and may be represented by angling clubs, but also canoeists, represented by canoe clubs. These groups are often locally active and may be coordinated at the regional scale or affiliated with national scale initiatives.

Conservation groups: Organisations who work actively to conserve specific local environments for biodiversity, wildlife and leisure, for example Bournmoor Conservation Group, Rainton Green Group, Hetton Greenwatch and West Rainton Community Group. Their agendas are often locally derived in relation to a specific local area.

Water companies: Privately owned organisations with responsibility for managing water and waste water in a particular region. The water company operating in the region of the Wear catchment is Northumbrian Water Ltd (NWL), who operate across the NE region, covering multiple catchment areas. This is a regionally operational organisation that also operates in Suffolk and Essex.

The type and range of organisations mentioned within the catchment context is fairly broad and the multiplicity is a representation of the complexity of the social-ecological system at the organisational scale, the scale at which activity is effective and significant. However, individuals within the organisations also play a role in adding to the complexity of the network. For example Newig *et al.* (2010) identify that individuals tend to have different values from those of their official body, and equally that relationships between organisations are dependent on trust between individuals, which can be problematic when individuals move on. In the Wear context, organisations have been chosen as the scale of representation in this research due to the difficulty in tracking and recording individuals, particularly as stakeholders do not consistently make the distinction between individual and organisation.

It is, however, observed that extra complexity exists within the assumption that organisations are the operational level, because individuals can be part of multiple organisations at once. For example, one individual noted that they themselves sat on the boards of two charities in the area, claiming that it was the ability to share knowledge across organisations that provided the advantage for him to have multiple roles. Another participant noted the following:

> *I am a member of various professional organisations such as the RICS [Royal Institute of Chartered Surveyors] and CAB [Citizens Advice Bureau] and I am a member of the Country Landowners Association, and others will be members of those and the likes of the NFU or whatever, and of course you will have those that are members of angling clubs as well. There is a great overlap because people value the catchment in so many different ways (Stakeholder #10)*

The multiple valuation of the catchment is something that is recognised more broadly in the underpinning values of schemes such as CaBA that aim to take into account diversity of experiences. However the role of the individual in maintaining and portraying multiple values and multiple places and spaces in which those values play out is less well considered. It is an important observation when understanding the conceptualisation of a network, particularly considering that organisational structure is not representative of distinct and bounded nodes but ones that are fluid in their construction in relation to individuals and to the values they hold.

The stability of the organisational level relies on the manifestation of the multiple values at the point of decision-making or information sharing, where the individual is representing one of their roles. For example one interviewee described the balance of values:

> *If your personal opinion doesn't tie to Natural England (NE) you wouldn't be giving it if you are representing NE, so that's an important part of corporate advocacy (Stakeholder # 15)*

This duty to toe the line and represent the views of the organisation, particularly if it is in conflict with the stakeholder's own opinion reveals a level of influence at the organisational level on behaviour that goes beyond the individual. This is particularly true for larger, nationally or centrally coordinated organisations such as NE or the EA. For example another stakeholder talks of a push from the national agency DEFRA to represent one organisational voice:

> *DEFRA are really keen for us to have the one voice, so we wouldn't have, say NE and ourselves [EA] and Forestry [Commission] on every panel of every meeting and every project […]. [It's about] making sure that if we do step into that one voice that we are representing not just the EA but other needs and wants as well (Stakeholder #14).*

The representation of other needs and wants demonstrates the conflations of values that are also happening in the catchment at even the supra-organisational scale, particularly at points of decision-making such as meetings and panels. Equally, in the example given by stakeholder #15, values and opinions are even described as travelling beyond the organisation itself. For example the stakeholder states that:

> *In fact I have been involved in external meetings with other hats on, where I have not got a NE hat on, and I still advocated NE because it's what I see as a duty. (Stakeholder #15)*

The duty to advocate a particular position is possibly driven by the alignment of personal views and organisational views, and is perhaps dependent on the role of each individual within the larger corporate body. In more independently governed organisations than the state represented organisation of stakeholder #15, experience and opinion are less obviously differentiated from an organisational view, perhaps due to the lack of need for an agreed voice across scales because of the small operational scale. The differences that exist amongst stakeholders with regard to the representation of an organisation demonstrates the complex merging of the individual and the organisational scale, and therefore the relative strength of considering the organisational level as one that encompasses the individual and helps understand longevity of a network, but which must be considered in terms of the dynamics of individual values and relationships.

5.2.1.2. Additional nodes: Places and times of interaction and action

Within the network of the Wear catchment (which may be conceived as evidence of a governance network in which there are horizontal interactional processes and negotiations between multiple groups and organisations) it is evident from the conversations with stakeholders that multiple spaces and processes of relations are important and formative of behaviours and activities. Such spaces and processes form, or are representative of, relatively stable structures. As such, additional nodes have been added to the conceptualisation of the network alongside stakeholders. The type and style of structures, including meetings, partnerships, schemes, projects and the resulting action, characterise the governance network in the Wear because they reveal an intentionality and embeddedness of interactions that move towards a governance outcome (better relations and improved water quality). By being mentioned during interviews the structures can be assumed to have a legitimacy and a stability enough to influence the behaviour or attitude of stakeholders, therefore to be seen as part of the governance network.

Table 5.1 gives details of the additional nodes seen as important within the governance network, their conceptualisation, idealised functionality within the network and selected examples of each. Functions of the nodes range from facilitating face-to-face contact, to creating spaces of deliberation, learning and resource exchange, to legitimising action and interaction and incentivising participation, to enabling action, empowering actors and facilitating physical environmental change. Meetings and partnerships were prominently mentioned by stakeholders when talking about their involvement and activities in the Wear, perhaps because they stand out as new or transformative ways of working. Meetings and partnerships are representative of the collaborative approaches encouraged through CaBA, although their existence alone does not necessarily constitute success, which would more likely depend on the nature of participation and collaboration within the spaces and structures of the network. Schemes and projects were mentioned by the stakeholders during interviews to describe the practical process of enacting water resource management representing a legitimisation of certain forms of action and relationships. Schemes and projects represent the operationalisation of governance through action, crossing from abstract decision-making spaces to physical, localised spaces and places of action.

Specific actions and activity were also mentioned by the stakeholders as important mechanisms of behaviour and enactments of schemes or projects, often described as resulting from or facilitated through meetings or collaborative discussions, perhaps at partnership level. Patterson (2016) describes on-the-ground action and strategic planning action as the two key types of action associated with tackling wicked environmental problems. The actions and activities described in Table 5.1 relate to on-the-ground action and are seen as important by stakeholders influenced by the general discourse of action in environmental management as a goal or sign of progress. Equally, knowledge of where and how action emerges can act to exemplify some of the spatiality of the governance system. The nodes identified in the Wear catchment governance network thus provide a conceptualisation of the system as social-ecological.

Table 5.1. Details of the additional nodes in the Wear catchment network.

	Description and temporal scale	Ideal function	Selected examples from the Wear network
Meetings	Meetings constitute a group of stakeholders coming together in the same space at the same time, sharing in discussions. They can be both formal and informal. Meetings have a limited temporal duration individually (usually a few hours), but may be facilitated regularly through an ongoing project, scheme or partnership.	Facilitates: • Face to face contact • Collaboration • Deliberation • Social learning • Building trust	• **Fisheries forum** – a regular, formally organised, open public meeting of angling club members in the NE to discuss problems, issues and share information about the local rivers and streams. Organised by the Angling Trust with contribution from EA and WRT. • **Twizell Burn Green Infrastructure Meeting** – multi-stakeholder discussion and planning meeting. Part of a series of meetings as part of a project derived from discussions amongst the Wear Catchment Partnership. • Soil and water management meeting – formally organised, attended by farmers, WRT, Durham University, FWAG, CFE, involving exchange of knowledge and management techniques. Part of a wider project focused on agricultural diffuse pollution facilitated by WRT through WCP discussions. • **Old Durham Beck workshop** – planned, formal multi-stakeholder meeting to discern priorities for action in the sub-catchment. Hosted by the WRT, organised as a result of prioritisation discussions within the WCP. • **Regional meeting of EA and CA** - formally organised, closed meeting of EA and CA professionals to share information and discuss new and ongoing projects, problems or agendas. • **Internal organisational meetings** - Both NWL and EA organise formal, internal, closed meetings to share knowledge and information amongst colleagues about the Wear catchment. • **Individual meeting** – for example a one off meeting between NWL and local conservation group to share information about a specific local problem.
Partnerships	Groups of stakeholders who are committed to working together for a length of time, sharing resources, knowledge, information and skills. Usually over a number of	Facilitates: • Long term resource exchange • Co-production of knowledge	• **Wear Catchment Partnership** – central group of stakeholders, including led by WRT who work together in collaboration on priority setting, agenda setting, planning, implementation and evaluation of water resource management in the Wear catchment. Authorise and support a number of projects, schemes and meetings. • **Coastal Streams Partnership** – emerged from Durham Heritage Coast Partnership specifically focused on improving the water quality of the coastal streams in County Durham. Led by NE and Durham Heritage Coast.

	years. Partnerships are a core element of CaBA and can relate to catchment wide partnerships or specific issue or locality driven partnerships.	• Long term learning • Strong bonds of trust	• **Moors for the Future Partnership** – group of stakeholders including land, wildlife and water managers working together to protect and restore upland areas in the Pea k District. Covers multiple catchments. • **North East Local Nature Partnership** – a multi-stakeholder group derived by DEFRA including local councils, environmental and community interests working across the NE to restore, enhance and conserve environmental quality. • **North East Local Enterprise Partnership** - a public, private, and education sector partnership working to improve the economy across the NE area
Schemes	Broadly defined programmes of activities and management options, usually driven by core environmental improvement aims. Schemes usually run over a time period of years. Schemes might be the enactment of partnerships or groups of organisations and might incorporate projects and meetings.	• Legitimises action and interaction • Provides a common purpose • Incentivises and supports wider participation in management	• **On-farm schemes** – term used by farmers to describe the options available to them when attempting to reduce water pollution from farm land, machinery and buildings. Schemes facilitated and supported in the Wear by FWAG and WRT. • **Riverfly monitoring scheme** – Coordinated nationally by the Riverfly Partnership run by the Salmon and Trout Trust, implemented in the Wear by WRT, Riverfly is a monitoring scheme to involve volunteers, anglers and schools in recording pollution levels in local streams. • **SUDS schemes** – Sustainable urban drainage systems. Variously derived by local councils, developers, charities and water companies, with opportunities to involve local communities and businesses. • **Yellow Fish scheme** – derived by the EA nationally and implemented by Durham Wildlife Trust in the Wear. Mainly educational scheme involving volunteers, schools and businesses to raise awareness of water pollution pathways. • **Development ready planning scheme** – used by Durham County Council to describe forward looking planning processes that involve developers and multiple council departments. Raises awareness of water management issues. • **Water Rangers scheme** – implemented by NWL the scheme offers opportunities to volunteers and anglers to monitor rivers and streams for water pollution.
Projects	Activity coordinated within a focused timeframe and usually with pre-defined aims. May be singly delivered by an organisation or, more likely, delivered	• Enable action (through funding or skills/ knowledge)	• **Iron-ochre research project** – jointly implemented between NWL, Durham University and the Coal Authority, monitoring levels of iron ochre in streams within the catchment • **Agricultural diffuse pollution project** – led by WRT but jointly delivered with farmers and farming support groups to reduce diffuse pollution.

	across two or more organisations.	• Legitimise and empower actors	• **Barriers to fish passage project** – grant funded project running over three years to tackle barrier to fish passage on the River Deerness, led by WRT. Inclusive activities involving anglers, EA, conservation groups. • **Limestone landscapes project** - • **Green engineering** – involving the North Pennines AONB, the WRT and Tees Rivers Trust investigating ways to prevent metal mining spoil sediment entering water courses in the uplands and affecting water quality downstream. • **Pathway restoration project** – project to restore pathways along the lower Wear to improve access to the river, delivered jointly by EA and Durham City Angling Club. • **Riverbank project** – joint project implemented by WRT and Bournmoor conservation group to restore vegetation to the banks of the Lumley Park Burn. • **Ponds project** – implemented jointly by anglers and DCC to install ponds and wetland areas • **Red House Gill project** -	
Action	On-the-ground action that relates to points of change in the physical environment or influence on behaviour or knowledge to enable change. Representative of physical activity and tasks associated with projects or schemes. May happen over a relatively short time frame of days – months.	• Facilitates change in the physical processes and morphology • Creates new knowledge about problems • Enables behaviour change	• Install SUDS • Test phosphate removal techniques • Maintain river banks in national nature reserve • Install dirty water traps on farm • Remove wiers and replace with baffles, fish passes or step pools • Monitor fish mobility • Research lead isotope pollution • Create new bankside paths • Remove giant hogweed • Change infrastructure to stop CSO overspill	• Create area of wetland • Stream clean-up • Day-light culverts and install reedbeds • Twizell Burn week of action • Treat minewater • Replace CSO • Monitor water quality in burn • Deliver education about the river • Environmental awareness event • Monitor CSOs • Grip blocking on peatland

[redacted]

[redacted]

By describing the structures such as partnerships or meetings or new forms of organisations it is possible to discern more about the institutionalisation of governance. Both formal and informal institutions arguably provide stability, expectations and meaning, which create contexts for decision-making and action at the individual, collective and constitutional level (Vatn, 2015). Understanding the institutions present through an understanding of the basic structures of a catchment network can help to understand the context for the decisions and decision rules that govern the behaviour of stakeholders.

5.2.2. Links in the network: relations and exchanges

Links or ties in a network represent the relations and exchanges between the actors. They can represent social relations, interactions such as knowledge exchange, and flows of information or resources such as money (Borgatti *et al.*, 2009; Scott, 2015). In the process of creating an image or quantified diagram of the Wear governance network, one core link was assigned between two nodes and presumed to be two-directional (whether there was an equity or satisfaction with the exchange is an additional issue contributing to the dynamics of a networked system of governance and identifies one of the limitations of studying the network structure in isolation). Links were defined based on the language used to describe relationships by interviewees (detailed in Chapter 4) and are listed in Table 5.2. Some of the links are demonstrated in Figure 5.2 in association with the agricultural diffuse pollution project led by WRT. The most significant and prolific link category is 'sharing knowledge and resources' as this can represent multiple ways of interacting including communicating, meeting, discussing and exchanging data or information. Most interactions are based on knowledge and resource sharing, but some can be distinguished by their focus on funding or by a deeper commitment to the relationship (collaboration), the ability to coordinate and change the aims and direction of a project (lead a project) and show a physical presence in a space of interaction (attend). By understanding the different ways in which stakeholders interact, the mechanisms of the governance network can be explored.

In the representation of the elements of the governance network identified in Figure 5.1, links are conceptualised as facilitated through the formalised structures of meetings and partnerships as well as long-standing professional connections where a history of institutional interaction has established a long-standing link, as well as more informal exchanges between organisations, perhaps over a shorter timescale. Organisations may have multiple ways in which they are connected to other groups that are not recorded through the static diagramming process. Therefore the diagram is a representation of some of the key interactions, but not of some of the dynamics of change or nuance in relationships.

Table 5.2 *Multiple types of links associated with relations between nodes within the Wear catchment network (exemplifies key, simplified interactions).*

Link	Description	Example
Attend/ take part in	The physical presence of an organisation at an event or meeting. The distinction between only attending, and then sharing knowledge or information is defined by the use of language by the stakeholders (e.g. 'went along to'/ 'attended'), and where no mention of significant exchange beyond participation was given.	Durham City Angling Club attended a Fisheries Forum meeting.
Lead	The role of coordinator of a project or partnership.	WRT lead the WCP.
Share data, knowledge and resources	Exchange either directly between organisations or within the context of a meeting or partnership. This is the most common type of link and can take multiple forms.	DCC share information about invasive species along stream banks within the context of the Twizell Burn Green Infrastructure meeting.
Collaborate	Interaction beyond exchange that involves co-production of knowledge and a commitment to working together. The distinction from sharing knowledge is usually the use of the word 'collaborate' by the stakeholder to describe the relation.	WRT collaborate with the EA in the Wear catchment
Implement	Plan and deliver an on-the-ground action using their own or shared resources and skills.	DWT implement a stream clean-up of the Valley Burn.
Fund	Provide financial resources for a project or scheme. May be one off grant or ongoing funding.	DEFRA provide funding through grants for WRT fish passage project on the River Deerness.
Part of	The association between a project and a meeting or a project and an action.	Soil and water management meeting is part of the agricultural diffuse pollution project.

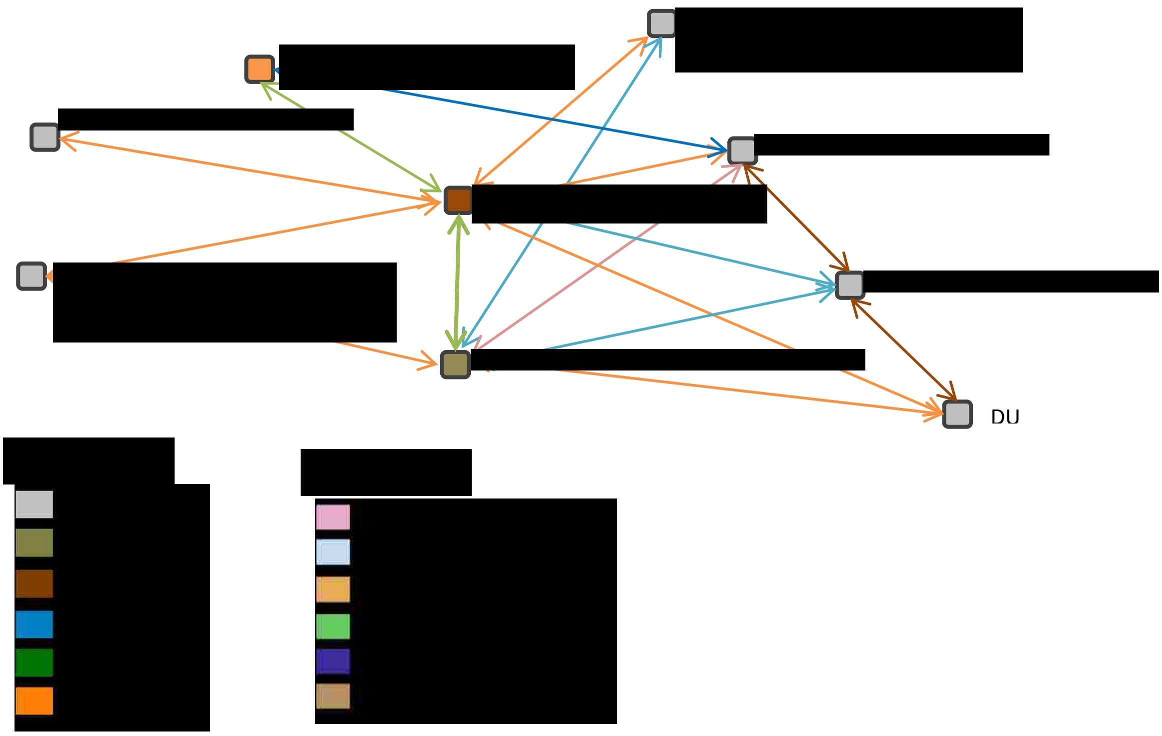


Figure 5.2 *Exemplification of some of the interactions and links that are conceptualised to make up the catchment network. Depicted is an ego diagram (direct links only) of the agricultural diffuse pollution project and its immediate links and associated nodes.*

5.2.2.1. Creating links through communication and exchange

Data, information and resources are seen as elements that are exchanged and used in processes of co-creation and learning through links. For example, a number of the stakeholders in the Wear catchment use the language of giving and taking in relation to data, resources and information, indicating the ability to withhold and release, whether through choice or opportunity. Communication is seen as an important facilitating element of exchange between organisations. For example one stakeholder states that his connection with other organisations consists of "*basically a lot of talking to people and going to meetings and making sure that people know the opportunities and [that] you are keen to support them*" (Stakeholder #15). The willingness and openness to communicate through talking demonstrates a willingness to offer some form of support. This openness to potential exchange is qualified by comments from stakeholders at DCC, who have not previously focused on broadening their connections, but who are taking on more cross-organisational communication:

> *the important thing […] would be to do with collaboration and communication between different departments within the authority, and between the authority and the partners outside* (Stakeholders #13).

There is an acknowledgement that communication is important for connecting stakeholders, but that the motivation for communication also needs to exist for links to become strong.

Communication can also facilitate more informal exchange, such as that which acts to connect actors not associated with the meeting structures. For example a stakeholder representing a land agent claimed not to be directly involved in the Wear Catchment Partnership meetings, but communication with a member of the WRT through "*report[ing] to me about what they are doing*" (Stakeholder #10), allowed the land agent to stay up to date with the activities. The informal communication, facilitated by the efforts of the WRT, represents the existence of a link of a different strength and style, valuable in connecting marginal actors to central decision processes.

Communication is also seen to facilitate relationships even in times of stability, where there may be no new information. For example the stakeholder representing an angling group reported that:

> *we always say to people, keep your lines of communication open, and that's what got pushed onto me from […] the EA[…] and we know that all along, as long as you are communicating, even if there is nothing going on, keep communicating.* (Stakeholder #12).

The advocacy for communication, even when there is seemingly nothing to exchange or inform others about is an indication of the means by which links are maintained. Stakeholder #12 mentioned that their angling club held a strong relationship with the EA, perhaps in part attributable to the regular communication between the two organisations.

Information transmission and diffusion of ideas is one of the key features of networks (Valente, 2005; Newig *et al.*, 2010) and an example of an exchange of knowledge and information, leading to co-creation of knowledge facilitated through communication is described by one stakeholder representing the EA in relation to building relationships with anglers. The exchange involved the anglers sharing information about problems they encountered on the water course and the EA representative sharing specialist knowledge of the causes and solutions to those problems.

> *if somebody has a particular issue that is absolutely burning I will spend time with them, I will be on the river, I will actually point at what they are looking at, what is their issue? I will bring some technical science into what they are trying to describe to me, trying to get them to explain what their problems might be, even get them to think that they come up with the answer just by giving them some basic background knowledge, and kind of work on them at that level until eventually they kind of, 'ah I understand now', and they will probably go away happy. (Stakeholder #11)*

The exchange is facilitated by conversation and communication, and a listening and sharing proportional to the outcome of the exchange (a change in the anglers' state of mind). There is evidence of complex relations of power, expertise and legitimacy playing into the form and style of communications used. Stakeholder #11 uses language that could show that a manipulative type of communication could be used for instrumental purposes, but stresses the outcome of happiness of the anglers to indicate a mutual satisfaction with the communication to build the relation between the two groups. Although instrumental communication raises issues around participation and the degree to which creation of a link is fair or moral, it highlights the degree to which communication is used as a tool to form relationships, which are the vital building blocks of a governance network.

Equally, power relations can affect the existence of links and relationships through the ability of some groups to withhold communication and therefore the exchange of information, data and knowledge. Links can be affected particularly if one group is expecting communication that they do not receive, which then brings an element of mistrust. For example a stakeholder representing an environmental community group said:

> *I think we need to form more partnerships between local authorities […] I think that if you have got a volunteer group in your area like ours who deal with the water in that area I think there should be feedback given. I don't think it should be held behind closed doors [so] you are not aware of it, and yet you [are] out in that area trying to do things. I think there is a big lack of communication* (Stakeholder #18).

Stakeholder #18 identifies the need for the existence of structures that could facilitate more communication in the form of partnerships. She recognises that there is a withholding of information by local authorities in relation to volunteer groups that could be overcome if both groups committed to partnership working, which is inherently defined by open communication and exchange. This opinion highlights that if communication is missing then the network may not be functioning as well as could be.

Exchange of information via communication does not automatically indicate a positive relationship, due to the ability of each actor to affect and also be affected in unexpected ways by the nature of exchange or lack of exchange. The relationship may be dependent on the amount of trust present; whether information being exchanged matches the expectations and agendas of the parties involves; whether there are contradictions; and what action, if any, the information goes on to effect. For example, the Fisheries Forum is a space created for the sharing of information between anglers and various groups such as the EA, Angling Trust and Rivers Trust. Within the forum there is an expectation on all sides that in sharing information the relationships will be made stronger, usually based on an expectation of a change in behaviour or attitude from other parties involved. However, where there is a conflict of interest or a difference in expectation, the exchange of information can engender mistrust. One EA participant involved in the Fisheries Forum, stated:

> T*he guy who was on about the flow data in the river Wear, we'd already provided him with all the information, so why he then had to shout that he knew for a fact that it was all wrong [I don't know].* (Stakeholder #11).

This comment shows a certain amount of exasperation that the exchange of information didn't solve misunderstandings and suggests that there are very strong opinions about the constitution of truth through data (further expanded in Chapter 6). Equally, it demonstrates the complexity of links and the possible presence of conflict through communication as well as positive dialogue and change. It is likely that historical relationships of mistrust existed between the groups at the Fisheries Forum, which affected expectations and opinions through the process of exchange and communication.

Therefore, communication and exchange can be seen as the foundation of the links within the governance network and facilitate activities, management actions and knowledge growth within the catchment. The way in which communication and knowledge exchange are facilitated, understood and enacted within each of the interactions between stakeholders can affect the resulting opinions, attitudes and actions happening (see Chapter 6).

5.2.2.2. Strength and duration of relationships

The strength of ties or links is an important consideration in network analysis (Granovetter, 1973). Strong and weak ties can be both advantageous and restrictive. The balance of ties, therefore, is seen to be indicative of the nature of the network. Strong ties indicate the ability of stakeholders to influence each other, share views, offer emotional support, communicate effectively and trust one another (Prell *et al.*, 2009). However, they can be problematic as they usually exist between groups that are similar, causing a tendency to get locked into ways of thinking, which may lead to cognitive blocking (Messner, 1995) and group thinking (Janis, 1982). Weak ties are seen as less frequent communication or communication with those outside of the central network. They can be advantageous because they tend to be between more diverse individuals, which mean that more diverse information can be exchanged (Prell *et al.*, 2009; Newig *et al.*, 2010). Multiple sources of information can add to the ability of a network to adjust to change. However, too many weak ties in a network can mean it becomes vulnerable, as weak ties are easily broken and may lack trust.

Seminal network analysis theory has stated that the strength of ties are likely to be affected by a linear combination of the amount of time, intensity and reciprocal services (Granovetter, 1973). In the Wear catchment there are strong ties between some of the stakeholders, evidenced by the strong communication indicated in the previous section. By using language such as 'working closely with' and 'collaborating with', in the context of structures that have an endurance, such as partnerships and projects, stakeholders are likely valuing longer lasting relationships, which can be seen to be representative of stronger links. For example, in her interview, Stakeholder #17 specifically referred to the length of time she had been working with a particular group and indicated that it had an effect on influencing the ease of exchange of knowledge. For example:

> "*[our exchange of knowledge] has improved now that I know them and I have worked in the area for nearly three years*" (Stakeholder #17).

Knowledge of other stakeholders and building up a pattern of interaction over a length of time is therefore a factor in contributing to stronger relationships. Each organisation can be seen to have a small number of other stakeholders who resemble an inner circle of the strongest links, which have a certain amount of flexibility and might resemble different types of interaction at different times. As each stakeholder changes their understanding, expectation, ability to act or motivation to change, as well as reaction to other changes in the catchment system, they might change the nature of their relationship with other organisations. The strong relationships are those that stay present and productive to all involved through time, but which can take multiple forms. One stakeholder from the EA described the way in which their organisation's relationship with the WRT had been able to change over time. At first they describe the relationship as one in which the WRT were helping deliver on EA priorities, but when the WCP began to develop and the WRT grew in knowledge of the WFD, the relationship remained close but was described as a much more proactive, two-way interaction:

> *They are very proactive now and have hit the ground running and understand WFD, so they come to us, they come to stakeholder meetings and say we have done a walkover here we have identified these issues that could address WFD, so it's a much more proactive, two-way interaction. (Stakeholder #18)*

The ability of the relationship to change, be based on new interactions and exchanges but still remain present and productive is demonstrative of a strong relationship within the network. It also exemplifies that relationships have the possibility to strengthen and change over time.

Structures such as partnerships may act to open up the possibility of creating more and stronger ties with other stakeholders by the facilitation of open, regular and flexible ties additional to, but also potentially strengthening the usual relationships each organisation holds through their own practice. Strong ties, however may cause problems in encouraging homogenous opinions, knowledge or action. In the Wear, in contrast to this issue, one stakeholder explained that "*we all have different areas of speciality (sic) which helps create a broader picture" (Stakeholder #17).* This observation reflects the nature of the partnership structure in bringing together those with different knowledges and demonstrates that strong ties can exist within the partnership structure.

Weaker links also exist within the Wear catchment network. These might be considered as less frequent exchanges that might be dormant for a length of time but opened up when a need arises. For example, one land agent in the Wear catchment describes that they "*liaise with an awful lot of people*" but only when specific issues arise, for example:

> *"[we speak to] [WRT] [for] anything to do with the river, and [the] treasurer of the angling club […]. We don't really get involved with NE, [but] there is [..] NE, who obviously deal with land management issues but that's more moorland, so if we have any issues on the moorland, which I guess is the catchment, then […] we could always speak to […] NE. Public access, […] DCC. Highways and bridges, […] DCC […], [they] might not be the right person but [they are] the first person we would go to" (Stakeholder #2).*

This land agent implies that there is, in general, less contact, or involvement or knowledge associated with the links he describes, but that he would count such associations as useful and relevant when the time arose. Such established but infrequent links are perhaps just as valuable as the stronger, more collaborative links associated with partnership working, particularly for coping with times of change.

Weak links, however might also represent those interactions that are uncertain or lacking in trust or reciprocity and therefore represent difficulties, rather than strengths in the network. For example the links may be seen as vulnerable where there is a perceived lack of reciprocity. For example, one stakeholder described that:

> *In the Wear we have provided [to the project] a lot of information on Lumley Park Burn and the Twizell , but in terms of what we are getting out of what we have done so far we are not really seeing anything that is of direct benefit and that is important. (Stakeholder #23).*

The representative went on to talk of the consequences of the lack of reciprocity in the link and its potential impact on the ability of the organisation to justify continued support for the project. The vulnerability of the link is therefore evident and the consequences of the breaking of that link could be detrimental for the project and the other stakeholders involved. Although the comment made by the stakeholder was made in the context of a discussion about how they were considering changing the relationship with the Twizell Burn project in order to strengthen the reciprocity of exchange, it highlights the difficulty associated with weak links, but also, equally, their ability to motivate change. The number and pattern of such links throughout the catchment is unknown but may be present where there is mistrust, confusion or a new and unfamiliar form of practice.

In relation to the capacity for change, weak links can be transformed into stronger links. For example an EA representative describes the transformation of a weak, mistrustful link with an angling club into a good working relationship. He describes:

> [I've had] *stakeholders over the years where they probably initially were quite antagonistic towards the Agency. They didn't quite see what we were doing […].We had a lot of bad communication with [them] over the years […]. That was quite a tricky time".* (Stakeholder #11)

But he describes that through building a "*working relationship*", partly through communication and meetings, now "*they understand our role and […] are very supportive of what we do and that's a good working relationship and that's all you can hope for really*". The angling club had also described the relationship as strong and reciprocal. The ability of links to transform over time with specific effort or behaviour change is indicative of the potential for transformation on a network scale.

Change in the pattern and strength of links in the network structure can represent behavioural change, as well as institutional and organisational change and can be argued to be indicative of a micro-level crafting of management processes (Short, 2015). In order to understand the possible and potential processes of transformation of links within a network, reference to the links that are lacking and therefore a focus on transformation is important. Within the Wear catchment many of the stakeholders interviewed were asked to identify those stakeholders they thought were missing from the process of catchment management and subsequently how they hoped they might be involved in the future. Such reflections indicated the way in which stakeholders perceive a lack of a particular knowledge, voice, resource or partner in decision-making, which could be seen as missing links in the network, perhaps reflecting upon the effectiveness of the operationalisation of a collaborative catchment governance approach. Table 5.3 represents some of the groups and links identified as missing or weaker alongside the hoped future connection of that group and an assessment in terms of link characteristic. The table suggests that lack of information transfer, lack of trust through lack of engagement, or need for new network structure to support stronger links characterises the stakeholders' view of missing or weak links. The table also highlights that there are complex aspects of the situations described that affect the choice, ability, motivation, capacity and opportunity of the actors involved to either change the way they themselves interact with others, or act to influence or persuade others to change the way they behave and interact in order to form what is perceived to be desirable links. There exist issues (of politics, power, social relation and structural change) that make the building of those links challenging. The challenging nature of changing the network structure highlights the complexity of effective network governance. However, the strength and duration of relations are important for balancing needs at particular times in the network and can offer a flexibility that can be positive and productive for the governance process.

Table 5.3 *Summary of missing links in the catchment management process and their capacity for potential transformation, indicating the desires and even the potential intensions of current stakeholders for the management processes of the future.*

Group with missing link	Reasons	Hoped capacity for transformed links	Stake-holder	Link to strength of links concept
Nothumbrian Water Limited (NWL)	NWL don't invest unless there are monetary benefits – very tricky to coordinate with their 5 year programme	*"come in with a wedge"*	#1	Build more reciprocal links with fairer exchange. (Conflicting views of reciprocity, however, cause problems).
		Take advantage of opportunities to work together	#19	More desire to work closely together and share more information and knowledge
	The Angling Trust are working with NWL but in a lesser than ideal capacity	Give out more information	#5	More information exchange (may be a affected by difference in priorities)
Durham County Council (DCC) drainage team	The team gets spread very thinly, they have got their own agenda, but they have got plenty of resource	Be able to see the value in projects like the Twizell and think in more partnership terms, not only focus on their own projects	#1	Change in mindset of DCC as to how and when to exchange resources.
Communities / public	Tricky to reach them and balance involvement with too many people involved	WCP present ideas and information to the communities, link to Friends Of groups, more standardised structure of community engagement.	#17	Turning a weak link into a stronger link by sharing more information

	Disinterested public. Have to fight to get the message across	*"Get them on board"*		Changing the nature of the
Local Enterprise Partnership/ Local Nature Partnership (LEP/LNP)	Too far removed from people on the ground	More openness within their higher level steering groups	#7	Creating stronger trusting links by including at higher decision levels
Businesses	Previous involvement fell on deaf ears	More engagement in environmental concerns	#7	Bring broken links into existence through establishment of exchange
Unknown or marginalised groups	Generally underrepresented, some people's voices are louder	Better represented	#3	Actively choosing to share and engage with marginal groups – establish even a weak link
	"I don't know what I can't see"	More engaged in the future	#14	
River user groups	Shouldn't be involved at the higher level because it's too strategic	Encouraged to contribute via official consultations, get more transparency about decision making	#4	Maintain weak links
Developers	They don't engage with stakeholders because they are fearful of conflict and anger	Engage with the angling community	#14	Lack of trust creates a weak or non-existent link
Canal and Rivers Trust	Because they transport water and that service might be needed more in the future	Engage more around water transport	#19	Create stronger links in reaction to changing context
Science and innovation groups	Engage with people we haven't even thought of yet	Through the Science and Water Hub	#13	Utilisation of new network structure to establish relationships
Landowners	Council at Team Valley, and the owners of estates	Talk about misconnections	#20	Specific forms of communication used to create stronger links
Local council	Lack of involvement in licensing	More engaged with licensing needs	#12	Specific forms of communication used to create stronger links
Farmers	In the process of being brought on board	More involved with fencing and animal care and fertilisers	#20	Specific projects and actions could form stronger links

The conceptualisation of relationships and exchanges in the catchment system as links is arguably helpful in order to identify process of change and transformation, points of conflict, difficulty or mistrust, as well as points of productivity and success. The balance of strong and weak ties within the network is indicative of the nature of the network, if not the success of the processes. The individual relationships built and maintained by stakeholders are contextual and individual, affected by both smaller and larger scale factors. Arguably a stakeholder's position in a networked system is defined by the relationships they utilise and build.

5.2.3. Roles and positions in the network

Links and patterns of links can be analysed to gain an understanding of the whole network and the relative positions of actors (and additional nodes) within the network. The analysis of network structures in this way can help understand the importance of the elements of the network, which may help to begin to reflect on the role of specific agents in catchment management because their positions in the network reveal something about their relationships and the scope of their interactions. This is particularly as previous learning about networks has shown that actors holding particular positions can be associated with particular characteristics (such as brokerage). However, networks are also restricted in what they can reveal about the role of actors and although it is likely that the role played influences the number and configuration of links (relationships) it does not reveal some of the complexities of the role that the actor. It may be that centrality in a network does not translate to centrality in a governance network. In this section the patterns identified through a network analysis begin to reveal (but do not wholly explain) the relationships between individual agents. Taking onto account the idea that networks are not necessarily constitutive of governance networks, it is pertinent to take into account supplmentary qualitative knowledge about the system and about the individuals involved. The value of the analysis of the network structure is the ability to compare across the network in relation to importance (perhaps in relation to their potential as well as practiced power), which then allows inference about the roles, which can reveal something about the operationalisation of a catchment governance system.

In this section the metrics of centrality and betweeness centrality are used to indicate the relative positions of actors (and alternative nodes) within the system. The meanings assoicated with actors holding central or linking (high betweenness centrality) positions forefront their importance in the system. Evidence from the stakeholders themselves describing the roles of those groups is used to supplement the dicsussion and bound an understanding of the relation beteween individual agents in the system. The nature of the descriptions of the relationships alongside the visual and metric understanding of their relative position helps to provide a richer picture of the nature of the governance network (an to highlight if an how the system is indicative of a networked governance process). This allows reflection on the catchment management system as well as the individual relationships within it.

Social network analysis uses metric analyses of links and nodes that can be interpreted as being representative of relations of relative position, power, influence and legitimacy (Prell *et al.*, 2009; Newig *et al.*, 2010). Traditional SNA uses metrics to better understand the pattern of direct interactions between actors as individual agents, whereas in this thesis the nodes and links in the network are much more heterogeneous (different types and scales of interactive spaces and multiple types of interaction: attending, leading, sharing data, collaborating, implementing, funding, and participating). There is value derived from the ability to compare the different elements of network organisation (sometimes individual actors, sometimes collections of actors) originating from the emphasis given by stakeholders when referring to the system. It allows the research to build on the ARDI process, to use the theoretical (graph theory) associations to assign a level of importance to particular focus points, and to create meaning (albeit that needs to be discussed and interrogated in light of limitations) from the large network interpretation depicted in Figure 5.1. The value in the amalgamation of the various forms of interaction into one representative link between each of the nodes is that it becomes representative of connectivity; any form of connection is valid to understand the structure of a network at its most basic level, if not the dynamics or nuance of power relations (this is acknowledged within this thesis and the reason for a multi-layered approach to analysis). The interpretation of the meaning of the metrics is taken in consideration of the heterogeneity of nodes and links and the act of comparison can expose the different contexts and circumstances of the different elements more clearly, helping to interpret the multiple features of a networked system at its most fundamental representation of connectivity. It is the relative comparisons within the system that lead to interesting observations about the operationalisation of a new governance approach. It is acknowledged that the interpretation needs to be supplemented with a deeper understanding of the balance of power and disparity between actors that lead to particular patterns of behaviour within the network to reveal something about the governance network as a whole (see chapter 6).

As such, a metric that can be used as a guide to interpretation of the network in this context is centrality. Centrality can be defined individually for each node, as well as across the total network. Individually, centrality is the number of links a node is associated with (Freeman, 1979). A highly centralised network is where a minority of nodes hold the majority of ties (Prell *et al.*, 2009). When representing the Wear catchment network using centrality measures, and referring to all nodes there is a bias towards stakeholders as the most centralised points in the network. This bias occurs because the additional nodes are more likely to have a limited amount of ties by the nature of their operation. For example, a project is usually formulated between a small number of individuals due to the specialised nature and spatial and funding constraints; a partnership is likely to have a maximum number of partners based on the ability to work collaboratively; and actions are implemented by one or two groups due to resource and logistical delegation at that scale. However, if the relative potential for links is considered there is value in assessing the full network conceptualisation.

Figures 5.3 and 5.4 depict the most centralised nodes in the network (~top 20 for each measure). The diagrams specifically show degree-centrality (Figure 5.3), which is a measure of the number of links associated with each node, and betweenness centrality (Figure 5.4), which is a measure of how many times an actor rests between two other actors that are disconnected and therefore indicates which actors or entities best link the network (Freeman, 1979; Bodin *et al.*, 2006). Such measures have an implicit relationship to the notion of brokerage and to the presence of intermediary roles. As such, the value of using a network perspective to analyse the catchment management system is to help understand the relationships of brokerage and intermediation between individual agents in the system, which may be representative of the way in which a catchment governance approach is operationalised through the way in which actors and agents relate to one another.

Intermediation is seen to be an important part of NRM, particularly for collaborative NRM such as catchment management, where disparate groups are often connected via organisations that bridge difficult differences. Moss *et al.* (2009:19) define intermediary work as "facilitating dialogue, providing guidance, bridging gaps, advocating reform or pioneering novel forms of interaction, their arenas of action are defined by their 'in-between-ness'". The role of intermediary groups is recognised, particularly in IWRM where the nature of the approach is to bridge gaps and scales and its success relies on the presence and skills of groups who can fulfil that role. Whilst an intermediary organisation can facilitate and mediate, it does not occupy a neutral position and has the ability to change the course of management. In contrast a broker might adopt the role of an 'independent, honest broker' (Pielke, 2007) who acts as a translator or facilitator of co-produced knowledge or information between groups. The key role of knowledge brokers in providing, often informally, a mode through which collaborative decisions can be made, is often identified in collaborative management (e.g. Pettit *et al.*, 2011; Bracken and Oughton, 2013). Similarly to intermediaries, brokers can also be defined as those actors with many exclusive links, such as links to groups that would otherwise not be in direct contact. As a result, the broker is in a unique position to gain and synthesise multiple knowledges, as well as to control the flow of information through the network, perhaps influencing behaviour, particularly in times of change or crisis. Groups and individuals can take on both brokerage and intermediary characteristics at different times for different purposes. The presence of such groups can be indicated by the study of network metrics.

5.2.3.1. Using analysis of network interactions to understand the role of agents in catchment management

The degree centrality measure ranged from 1 – 35 within the Wear catchment network. Figure 5.3 shows that the EA has the highest level of centrality in the network, meaning that it has the most links associated with it. The second and third most centrally placed nodes are the WRT and NWL.

Central position, central role?

The centrality of the EA is likely to be indicative of its regulatory function and wide-ranging association with groups involved in management of and interaction with the natural environment. Newig *et al.* (2010) claim that the centrality of an actor relates to their power or influence in the network. It is likely that the EA is an influential actor in the network as their interaction ranges from regulation, to policy information and advice, to funding, to co-leading partnerships, to monitoring, to delivering projects, to assigning pollution status, to responding to emergencies. Therefore they are interacting with a wide range of stakeholders, for a wide range of reasons, enabled through the size of the organisation and the number of staff that can maintain relationships and varying capacities of interaction. This observation in itself is not new as the EA have occupied an arguably central position in water management (as a government actor) since their formation in the 1990s. What might be indicative of new relationships in the context of a change in water resource governance is the EAs association with partnership network structures and with (perhaps) a wider variety of stakeholders than would have been described before collaborative governance approaches in water management were introduced. The EA are also a key player and initiator in the CaBA and have therefore been part of network structure changes, such as the creation of WCP, which is picked up by the network diagram and metrics allowing inferences to be made about the central role of the EA. . The use of a network approach to assess the position of the EA in the network highlights the processes of interaction with others, which can be supplemented with qualitative understanding of the nature of their interactions, as well as matched against their associations and links to new emerging network structures such as the WCP and meetings and schemes, to indicate how management practices are being implemented and how that might begin to reveal the provisional components and characteristics of a catchment governance approach. The network map has the potential to indicate the significance of the EA as a central actor.

The link between the network structure and the role of the EA can be demonstrated at the aggregate level and more directly through their relation to others. For example, the network structure shows that as a central actor they have developed connections with a high number of entities and organisations. This might have increased with the advent of the collaborative governance approach. The links also take into account connection with network features such as the Wear Catchment Partnership (WCP), which can reveal something about the role of the EA in utilising the partnership as a mode of connection to other organisations within the network, thus increasing their centrality. This connectivity can be seen in the network structure with many different groups, including volunteer groups and with the WRT (who play a leading role in the WCP). Although the specific nature of their role is not detailed within the basic network structure, the knowledge of their connectivity can be supplemented by stakeholder's analysis of their actions and interaction. For example, in relation to the role of the EA in the catchment management systems stakeholder #4 stated that:

> *I think [the EA] have got much better at listening, accepting and then following up and also getting back to people, even if it's through the catchment partnership, getting back to people who have volunteered some information and shown them that that is actually valuable, that they haven't just pooh-poohed it, as it were, so that's got better. (Stakeholder #4)*

This type of interaction with the volunteer groups (often associated with the WRT) through activities of listening and following up, mediated through the WCP structure shows that the EA have seen the process of feedback (as connection) as an important part of their role in relation to management activities. This is seen to evidence the operationalisation of a collaborative approach where information from volunteers is seen to contribute to decision-making that the EA make (as a powerful actor in the system, which is also indicated by their centrality) about the rivers and streams (see section 6.3.2.1 for a more detailed discussion of how such understandings of legitimacy affect the functioning of a management system). An understanding of the role of the EA is therefore able to be gauged from the network structure but is supplemented by qualitative descriptions of the nature of the relations depicted by diagrams and metrics.

By their centrality, NWL also indicate their importance in the network, with lots of other actors linking in some form to NWL. Similarly to the EA they are a large organisation who have a large number of staff who interact with a variety of groups for a variety of reasons. Similarly, their geographical reach across the catchment makes their activities relevant to numerous groups. The network mapping approach helps to highlight the extent of their relationship to other groups. However in relation to their role in the catchment management and governance network, their centrality might not fully reveal the nature of their role. For example some of the centrality and the presence of links to other organisations are indicative of their increased presence and involvement with CaBA activities such as attending meetings and taking more responsibility in the WCP steering group. Through such actions their individual relationships with other actors have changed by virtue of, exchanging knowledge with others, or planning joint projects, which translates into the recording of a connection in the networked system. However some observations of their behaviour and the quality of interactions with other agents have sometimes been observed to be less effective than expected due to a number of contextual and institutional reasons (see chapter 6 for expanded ideas on functionality of relationships). The network mapping therefore indicates the significance of their relationships and the potential for positive interaction, but does not give the full picture of the powerfulness of their role linked to a need to better understand functionality (an acknowledged limitation of network mapping and the reason for supplementing an understanding of complexity with knowledge gained through multiple methods). This could be particularly reflective on the analysis of the governance network.

The WRT is a much smaller organisation with significantly fewer staff, whose central position in the network indicates their relative comparable significance to both the EA and NWL. Their central position is likely associated with their ability to engage a wide range of actors. Although their centrality is less (on the metric scale) than NWL their role in relation to the strategic catchment management system and governance network is arguably different. Their role as lead or co-lead in the WCP is likely to influence their network position and means they have likely come into contact with a large range of groups through the partnership structure encouraged by the CaBA.

Understanding relations between actors through the network structure

The information presented by network metrics and network diagrams (Figures 5.3. and 5.4) can indicate the position of the WRT in the network, which can reveal something about their relations to others (when taken in consideration of the context of their actions and the functionality of relationships).

One stakeholder sums up the role of the rivers trusts:

> *Rivers trusts' role is delivering on-the-ground improvement, done with the sort of working together principle; non-political, even if it takes a long time it is partnership working to get things delivered and improved on the ground, basically. (Stakeholder #5)*

The stakeholder emphasises the river trusts' approach to partnership working that is non-political, which may be a reflection of their charitable status and ability to talk to and work with multiple groups without obviously biased agenda. This may be in comparison to government organisations who have legislative remits to fulfil, or even angling clubs who have a specific idea of their requirements for the river environment, both of which may cause conflicts. The WRT's status as a connected, apolitical stakeholder in the network may also be reflected in their high betweenness centrality (Figure 5.4), which may be an indication of their position as a broker between disparate groups in the network (Prell *et al.*, 2009). The network diagramming approach helps to identify the betweenness of their position and therefore there can be inferences made about the role that the WRT might play. Betweenness centrality is perhaps a measure that more clearly links to role than centrality, particularly in a system that is seen to actively seek to connect across networks (the collaborative governance approach). It is an indicator of the nature of the WRT relations to other organisations within the network. A representative of the WRT reflected on their position, often acting as mediator between conflicting groups. It also indicates the nature of their role in relation to others (a persuasive role, likely to involve dialogue and negotiations as well as activities):

> *"We do feel a bit stuck in the middle of those [conflicting groups] sometimes, trying to persuade the anglers that the EA aren't terrible and are doing the best they can, and [trying to] persuade the EA to take in account [of] what we are getting back from the people on the ground. They are getting that and I think I have seen that in my time as well actually" (Stakeholder #4)*

This shows that the analysis of the network strutcure can help begin to reveal something about the role that the WRT play because high betweenness centrality indicates a broker position, which could indicate a mediator role, which is evidenced in the above quote through the WRT role in persuading groups of the benefits of listening and working with diverse others. This is also an example of how individual agents relate to one another. The mention of a change in behaviour of the EA ("*They are getting that*") as a result of the intermediation of the WRT ("*trying to persuade the EA*") suggests that the WRT approach can be effective in encouraging change in the nature of links within the network. Brokers have adaptive implementation capacities, which means they can coordinate the actions of a network and see new opportunities and innovations that other actors cannot. The following example demonstrate the WRT ability to identify opportunities:

> *"[The WRT] came out here and had a look round and wrote a report of potential projects to do here. [I] thought, there's a good partner who might be interested in picking something up here, and [the WRT were] really intrested in the site and very enthusiastic about possibilities" (Stakeholder #15)*

This example demonstrates the proactive nature of WRT in identifying opportunities for action, which is conducive to their role in the catchment of delivering projects in partnership with other groups. The nature of their role makes the WRT an active intermediary across multiple groups (which is indicated by their betweenness centrality in the network), acting to engage and to facilitate change by identifying opportunities for cooperation through new collaborative projects, and are therefore an important actor in the catchment network.

The network metrics reveal the importance of the actors in the system and help to better understand where there is significance in the volume and diversity of connectedness. When linking to roles in the catchment management system the metrics go some way to helping to build an understanding using assuptions based on the understanding that, for example, actors with high betweenness scores usually act as brokers. However the network structure is not the full picture.

Not all important roles within the catchment are picked up by the network diagams or metric measurements. As metrics take into account relative positions within the whole of the network, there are some groups who act as brokers between specific sections of the network and therefore are not widely connected but may be vital in connecting one or two disparate sections of the network. For example the AONB are not identified as one of the most connected actors in the network metric diagram, but act as a broker, translating knowledge and facilitating new knowledge between the EA and landowners in the upland areas of the Wear catchment:

> *"Specifically our role within that partnership is to look at stakeholder engagement and be that link between the technical side of things and the people on the ground and […] smoothing the pathway really and being a conduit of information in both directions […] so there is quite an explanation role there and talking to local land owners to start the negotiation process as to whether their best lambing field, which is next to the mine, would be available to purchase or lease for a mining scheme, the first contact really, we are the friendly face, […] and not the statutory organisations that are pushing for things." (Stakeholder #16).*

The information transfer, negotiation and explanation facilitated through talking and communciation indicates the brokerage role is sustained through building strong, trusting links with different groups. Similarly to the WRT, the lack of an obvious agenda is important in sustaining the brokerage position of the organisation. The importance of such roles away from the very centre of a network are likely to be no less valuable than the actors who connect across the whole of the network.

The network metrics indicate that partnerships, projects and schemes play a central role in the network. However, this centrality should be considered of a different form than the centrality indicated through traditional SNA analysis due to the heterogenity of the nodes and links associated with this interpretation of network structure in the Wear catchment. The centrality refers to the relative importance of the spaces and places of interaction for the stakeholders when talking about activities that happen in the catchment management system, rather than their power within the network (as might be able to be associated with highly centralised actors in a traditional SNA). Figure 5.3 gives a fairly high centrality score to the Twizell Burn Green Infrastructure meeting. The meetings associated with the Twizell Burn project were wide reaching in their inclusion and therefore had a large number of attendees, hence the high degree centrality score. Similarly with the Old Durham Beck meeting, there were a high number of attendees. Both meetings were a specific focus of the research and although deemed representative of the type of activity happening in the catchment, are not likley to be any more significant than other similar activities not captured in this research. Their inclusion does highlight, however, that meetings are an important space of connection and although the meeting are likely to be fleeting in duration, the resultant links of trusting relationship or resource exchange that are created are likely to outlive the meeting or project. For example Alexander and Armitage (2015) claim that affiliation ties (attending an event or meeting) can lead to direct ties (exchanging information). The transformation of the link will be dependent on the nature of the exchange within the meeting space and the processes of learning and social learning that are facilitated.

The WCP appears as a highly centralised node within the network when degree centrality is considered (Figure 5.4), with many organisations taking part in its activities. The centrality of the partnership reflects the CaBA structure and indicates that the partnership is succeeding in pulling together a large number of actors within the catchment. There are various ways in which actors engage with the partnership, with some sitting on a central steering group and others attending wider partnership meetings. These dynamics are not picked up by the diagram, however the presence of WCP among the most central actors is indicative of its influence and power amongst the actors. When betweenness centrality is considered the WCP no longer features in the most central nodes, instead the more specialist and smaller Coastal Streams Partnership is present. The distinction that the network metrics pick up may allude to the fact that the WCP is made up of actors who normally connect with one another regularly (perhaps due to the work that the CaBA and the formation of the WCP had already induced), whereas the Coastal Streams Partnership is a newer initiative that is perhaps newly connecting groups who have not been in contact, therefore acts more as an intermediary entity between disparate groups. Such a distinction of the partnerships through time might demonstrate the role of partnerships in solidifying network structures (institutionalisation) through creating strong bonds between dispirate participant organisations over time.

On a shorter timescale, projects appear amongst the most central nodes when betweenness is considered, perhaps indicating the ability of such activity to connect groups that do not otherwise connect, demonstrating the value of projects in acting as intermediary points in the network. The potential institutionalisation role of projects may be informal through their ability to solidify relationships and working practice, for example it is likely that those groups who have worked together on projects previously are more likley to work together in the future, building up a pattern of interaction. Successful projects (such as those that can provide evidence of progress against agreed markers) can be seen as justification for future funding in similar projects and therefore become part of a feedback system that solidifies a particular type of practice. The short-term nature of projects, alongside their ability to pull together new or dispirate actors indicates a dynamism to the network and a flexibility that may be positive in dealing with new issues as they arise.

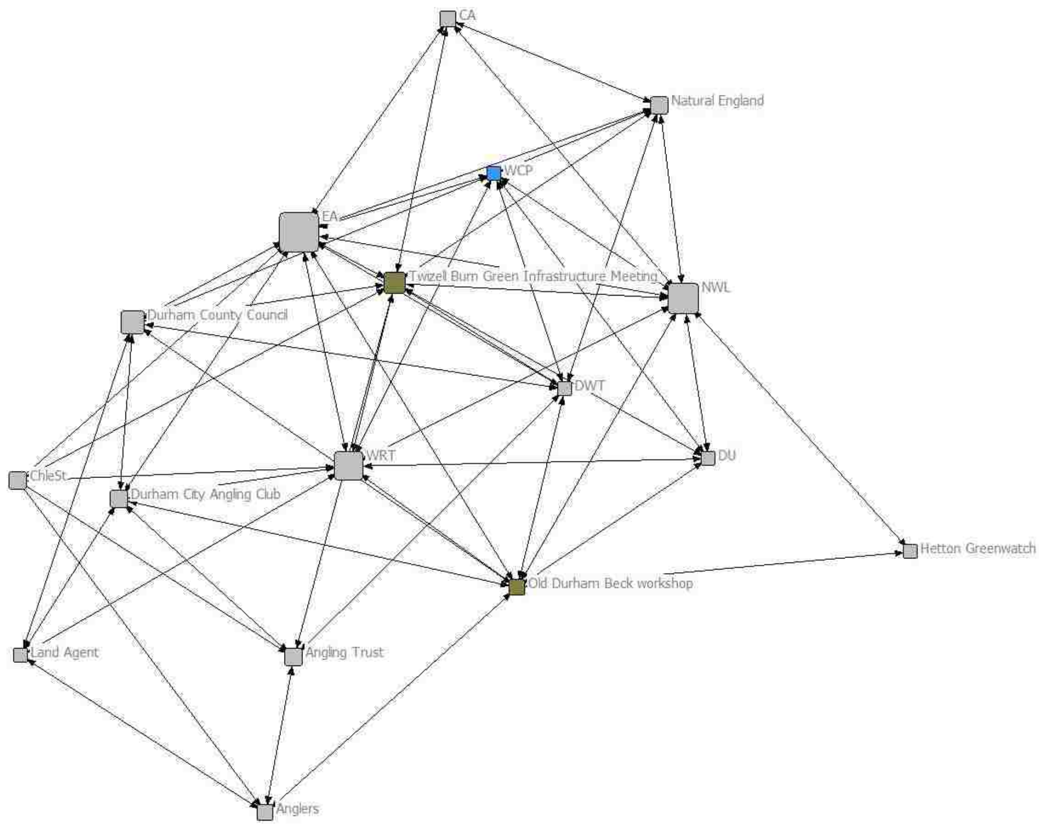


Figure 5.3 *Network diagram indicating the top nodes associated with degree centrality measurements. The size of each node is representative of its degree score. Larger nodes equate to higher degree centrality*

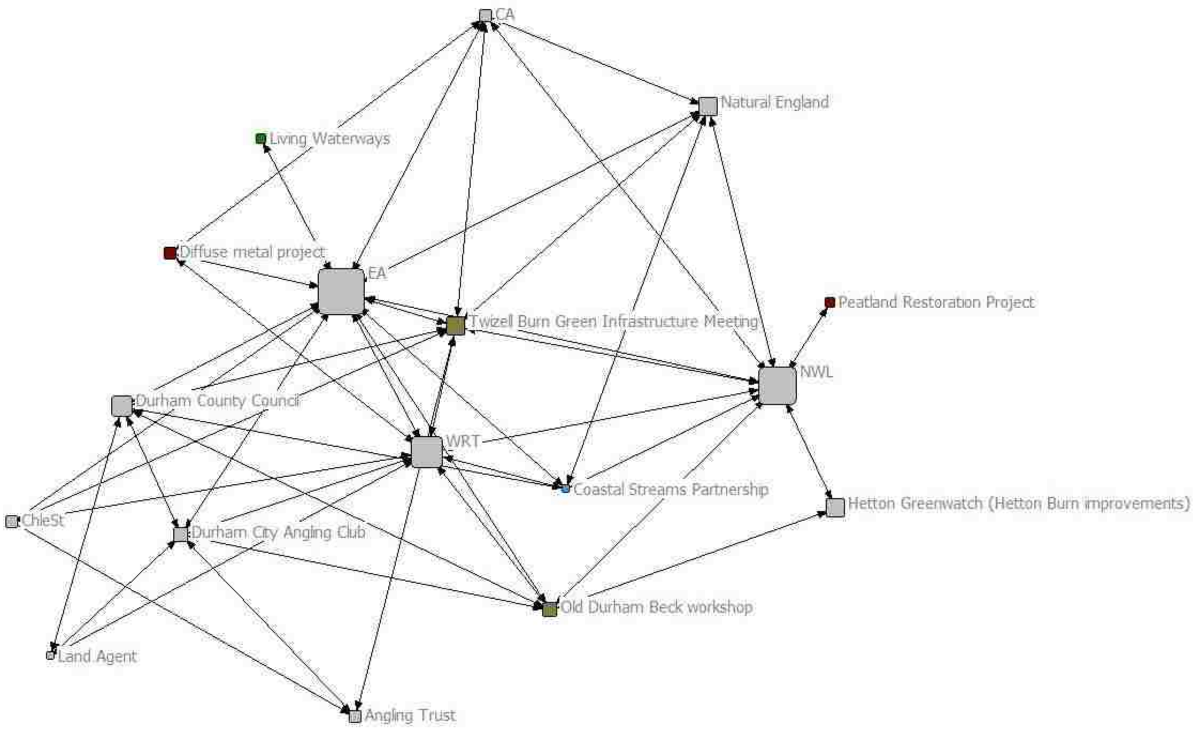


Figure 5.4 *Network diagram indicating the top nodes associated with betweenness centrality measurements. The size of each node is representative of its betweenness score. Larger nodes equate to higher betweeneness centrality.*

5.3. Exemplifying governance change: relational and interactional change and observed outcomes

5.3.1. Characterising features of change in a networked governance process

The interactions between the components of the catchment governance system can change and fluctuate through the transformation of links and the introduction of new network structures. Stakeholders in the Wear catchment have observed changes in patterns of interactions in the recent past, which can be interpreted in terms of changes in the configuration of the governance network. Over the course of the two years prior to the interviews with stakeholders for this project, there had been a widening of the application of the CaBA approach as the pilot phase for the Wear catchment evolved into the main delivery phase. The descriptions that the participants in this research give of changes in the structure of interactions broadly fit within the descriptive understanding of CaBA. The changes discussed specifically represent the morphing of practice and the refining of the network structures, institutions and practices as the process continues to be embedded in the catchment.

The Wear Catchment Partnership is a central feature of the CaBA and although it represents a major change to the configuration of the governance network, its establishment is not a major focus of the changes described by stakeholders due to its familiarity; only the more recent changes and transformations are the focus. One stakeholder notes that changes in the partnership are evident and the group is "*now much more organised and there is more opportunity for that cross fertilisation of information, so I think that will be a growing area.*" (Stakeholder #8). Other stakeholders mentioned that at the time of interviews their organisation was going through a time of change or restructuring, either due to a push for more integrated, collaborative management or in combination with other factors such as political or economic change. In each case, the changes represent parts of the catchment network that can be seen as new to the stakeholders.

The changes described in Table 5.4 represent those mentioned by the interviewees in the Wear catchment. Each of the changes described represent ways that new links and resultant socio-environmental network structures are being built by the choices and opportunities of each of the groups and stakeholders.

Table 5.4. *A description of the changes observed in management practice by stakeholders in the Wear catchment.*

Change	Scale	Network features	Purpose (based on direct paraphrased comments of Wear stakeholders)	Drivers	Example	Analysis
1. Internal group meetings	Individual/ organisation	Strengthening relational ties between departments, increased exchange of knowledge	• Knowing what others are up to in the catchment • Bring all the people round the table • Maximise the benefits of actions.	A change in scale focus; strategic change in staff or budget allocation	EA, DCC and NWL all mentioned an increased frequency of internal meetings focused on catchment-specific issues	Likely that CaBA has influenced a new way of working. Evident only in larger organisations. Likely smaller organisations already have modes of informal communication to discuss catchment-scale issues. Very positively assessed by stakeholders.
2. Collaborative projects	Sub-catchment	Cross-organisational collaborative links, bridging position in the network	• To help deliver more effectively • Working together and sharing knowledge and expertise • Building the best picture possible • Seeing how knowledge interlinks • Developing the best answer	Striving for specific targets, environmental quality standards or aims of management plans; outcomes of meeting or partnership discussions	NWL and CA collaboration on a co-treatment works for minewater and wastewater at Lamelsely (example of a new project)	Can be both formal and informal. There is often an implicit understanding of collaboration as co-creation of knowledge in order to problem-solve. Communication, conversation and drive to achieve a goal are evident in the process of setting up projects. Often a more powerful actor taking the lead 'picks' participants (EA for example has the power to include and exclude). Others mutually discuss opportunities to work together. Mostly focused on research or on-the-ground action.
3. Specialist partnerships	Sub-catchment	Stronger ties around specific issues – share specialist knowledge but remain part of the wider network	• Active discussions • Bringing people together • Work up projects • Channel for funding	Issue driven; need for a coordinated effort; need for shared knowledge and resources; long term goals for an area	Coastal Streams Partnership • WRT, DCC, National Trust and DWT, NE and Durham Heritage Coast and hope of involvement from farmers and landowners including a local golf course	Network metrics have also suggested the value of partnerships, particularly in the early stages in bringing together disparate groups in order to bridge knowledge and create spaces for co-creation. The Coastal Streams Partnership is specifically a new partnership in which meetings are focused on gaining funding and pooling ideas for projects.

Change	Scale	Network features	Purpose (based on direct paraphrased comments of Wear stakeholders)	Drivers	Examples	Analysis
4. Multi-stakeholder knowledge sharing for action and behaviour change	Sub-catchment	Increase ties across diverse groups – encourage wider information sharing	• Pull together information about a specific location • Set up relationships for partnership projects at that location • Education, experimentation, community building, conflict resolution and influence on behaviour	Need to meet a target for a specific location; lack of knowledge about possible opportunities	• Old Durham Beck "task and finish group meeting" • Twizell Burn Green Infrastructure meeting • Soil and water management meeting • Fisheries forum	The meetings are seen as temporary structures that emerge to meet specific needs at a specific place, mainly to share information in order to facilitate action, but also to change attitudes or behaviours in order that action outside of the context of the structured network might meet the specific goals.
5. Powerful actors in core decision structures	Catchment	Increase the strength of ties between core groups at core times	• To include a powerful voice • Influence decisions • Exchange priorities	Enable more targeted action; improve allocation/ ease of allocation of resources	• NWL included in catchment host meetings	It is likely to be a strategic act of the WRT and EA (both catchment hosts) to include NWL in catchment host meetings in order to bring them into collaborative relationship with the other organisations and facilitate the sharing of resources, knowledge and data, but to also influence and align behaviours and priority setting.

6. Communication across geographies	Catchment / Inter-catchment	Brokering of knowledge among disparate groups	• Share information and knowledge • Learn across boundaries • Establish who takes the lead • Influence behaviour and decisions of distant actors	Improved knowledge of implication up/down stream; need for effective learning sources	• NWL communicating with partner organisation in Sussex also applying CaBA • Community group contacting up-stream counterparts • WRT and Tyne River's Trust sharing learning	It is implicit that the stakeholders believed that the learning opportunities offered across scales would lead to a more informed process of decision-making and priority setting having learned lessons from others in similar situations. Decisions to communicate across geographies might manifest in collaborative projects or more informally in regular communication.
7. Strategic intermediary role creation	**Individual/ organisation**	**Linking between conflicting groups – using strong ties to bridge a broader weak or non-existent tie**	**• Supporting catchment partnerships • Linking priorities • Transfer important knowledge between organisation and partnership • Work with other partners in the business • Build slightly different relationships to previously**	**CaBA; start thinking differently about water management**	**• NWL creation of catchment advisors • AONB creation of catchment co-ordinator role**	**The catchment advisers in NWL, for example, as intermediaries are able to take an overview by building relationships with other stakeholders in the area and therefore understand the activities happening throughout the catchments and consequently influence practice within NWL, by being an ambassador of CaBA in line with internal strategies. This change in structure may be a sign that the partnerships and CaBA are becoming permanently embedded in practice and the adjustment of engaged organisations is a solidifying of governance process and an institutionalisation.**

The changes observed by the stakeholders span individual and organisational change; broader strategic change in network structure at the sub-catchment or inter-organisational level; changes that affect catchment wide structures, such as the WCP; and changes that stem from inter-catchment communication that have the potential to affect multiple catchment systems. Most changes aim to affect relationships, usually strengthening links through the increased exchange of knowledge and information or offering opportunities to repeatedly meet or share in an activity and thus build trust. The purposes of changes are variable but are possibly connected by bringing people together, to share or transfer knowledge, better devise solutions or decisions, and influence behaviour. The drivers of changes are based around an awareness of the need to fulfil a particular target or expected standard, and are mostly proactive changes based on strategic planning. At the level of individual groups, there is also some influence of a need to react to the change that is already happening and a need to match the practice and attitude of other groups in the catchment, which is perhaps representative of an aligning of practice. The complexities of the specific examples in the Wear demonstrate a mix of formal and informal changes in interaction, of which the formal changes may represent an institutionalisation of the CaBA approach in practice and, particularly in the operational style of organisations. In general the changes observed pick up on the proactive nature of the approaches within the Wear (if arguably generally reactive to national and international scale drivers) and the ability of the network to transform through changes at multiple scales representing a change in configuration of governance, and facilitating change aimed at strengthening relationships to help meet strategic goals through particular management mechanisms.

5.3.2. Identifying outcomes: the effects of network change

The outcomes and observed effects of certain types or forms of governance networks, which can be understood to be revealed by changes in network structure, have been noted in previous studies. For example Newig *et al.* (2010) focus on the ability of governance networks to facilitate learning or to represent the presence of learning, which is argued to be a core feature of environmental management mechanisms (e.g. social learning and learning-by-doing). Newig *et al.* (2010) claimed that networks provide access to novel information easy methods of transmission of information and also influence the way information is processed, mainly through communication with other network members. They also argued that networks provide opportunities for deliberation, and are thought to produce more creative ideas. Bodin *et al.* (2006) illustrate the link between selected outcomes of management of natural resources and network structures such as centrality, density, betweenness and reachability. Therefore by pinpointing the outcomes stakeholders in the Wear perceive to be present, a link can be hypothesised between the particular features of the catchment network and the observed outcomes as a configuration of a governance approach, giving an insight into the effectiveness of practice in the Wear.

In the Wear catchment there was a recognition amongst stakeholders that there were many positive effects able to be observed. Some stakeholders were able to attribute positive effects to particular activities or changes (such as the creation of new projects or the formation of new roles) and some noted the positives as being derived from general activity, which could be linked to a general change in practice and approach.

5.3.2.1. Positive effects

Table 5.5 shows five key positive effects of recent changes in practice identified by stakeholders in the Wear catchment. The positives range from tangible observations of 1) physical change in water quality, to intangible assessments of interactions such as 2) good relationships, 3) access to resources, 4) delivery across scales and 5) improved understanding. Most stakeholders mentioned positive effects and those listed in Table 5.5 represent the most cross-cutting benefits. Stakeholders were very enthusiastic about improvements in water quality over and above the other benefits. This focus on tangible positives shows that the quality of the river environment is the main goal and driver for most stakeholders, and this was found across all groups, whether involved in strategic planning of the CaBA or not.

Many of the benefits are attributable to the presence of network features that allow for better communication and the exchange of resources. In the case of improved water quality, some stakeholders were able to describe the exact effects of an on-the-ground action on water quality having described the association of the action with collaborative projects. Other positives, such as good relationships can be associated with strong ties that were based on trust and openness. The Wear catchment was seen to hold particularly positive relationships when compared to stakeholders' experiences of other catchments. This positivity could be attributed to strong leadership in the Wear catchment, shared responsibility and the lack of collaboration before CaBA that might have complicated new relationships. Positivity also results in or facilitates the exchange of resources, which is another significant positive, attributable to the nature of links between stakeholders as well as the presence of forums for sharing, such as partnerships. Equally, such structures are claimed to enable opportunities to deliver across scales, particularly referring to catchment wide aims and upstream-downstream thinking. Moreover the ability to share resources is entwined with the ability to improve understanding, which is associated with spaces and places of sharing and discussion, particularly across disciplinary or spatial divides.

Complexities with the positive effects means they are not always signs of effective overall governance, and may be unevenly experienced across time and space. It is understood that governance processes are inherently political and they are about reconciling different values as well as the different actors representing those values (Klijn, 2008). Processes of governance can be highly complex and lead to and result in uneven power balances and uneven experiences Koppenjan & Klijn, 2004). The uneven experience of positive outcomes can be hypothesised to be affected by multiple factors including attitude, choices, expectations and willingness; opportunity of stakeholders, affected by access to decision-structures, resources, network spaces of interaction; external change such as political, legislative, economic, and environmental including disturbances such as pollution events and floods.

Overall, the effects of network change can be evidenced within the Wear and be fairly closely attributable to network structures and features, particularly associated with changes induced by CaBA. The benefits however are uneven and the nuances and dynamics of the processes operating within the network structures and features are likely to be important for understanding the governance structures that influence the system.

__Table 5.5__ Descriptions of the positive outcomes observed in the Wear catchment associated with change in governance processes.

Positive outcome	Description	Evidence	Network governance drivers	Complexities	Unevenly experienced?
1. Improved water quality	Water quality is one of the main focuses of the success of water management practices and is mainly manifested in reduction in pollution levels, return of fish species or natural habitat. The values of the WFD have entered into the expectation of the majority of stakeholders in the catchment, and as such, during interviews, stakeholders spoke with enthusiasm whenever they could report an improvement in water quality.	• *"[We've] actually got fish in the lower reaches"* • *"[It] stopped raw sewage coming out of a manhole"* • *"Sediment traps are stopping runoff"* • *Bullhead fish found upstream of a culvert* • *"Within those two years we have had the sewage litter reduced by nearly 70% near CSOs"* • *"There is an improvement in the stream that was the worst [quality previously….] we were able to detect when there was a pollution event"* • *"[Results suggest] a decrease in the dissolved organic carbon coming off of our restoration site"* • *"Makes you really proud"* • *"Effective technique"* • *"[He] was over the moon that there was a trout further up"* • *"It is fantastic"* • *"Significant improvements I would say, there has been huge improvements to meet the wastewater treatment directives and WFD"*	The majority of the qualitatively assessed improvements in water quality were attributable by the stakeholders to the efforts of collaborative projects or as the results of information or resource sharing. For example, stakeholder #18 mentions sewage litter was reduced by 70% in two years in the Hetton Burn as a result of knowledge and resource exchange between Hetton Greenwatch conservation group and NWL. Equally, the effectiveness of sediment traps in stopping runoff, was reported by a farmer (stakeholder #6) who had developed mitigation schemes as part of the collaborative agricultural diffuse pollution project, supported by the Wear Catchment Partnership.	It is sometimes difficult to attribute causality to specific network change due to long feedback processes and delayed recovery of aquatic environments. As a result there is difficulty in gaining funding for long-term monitoring, which contributes to difficulty in assessment.	Spatially uneven. Depends on funding prioritisation and availability, interest and perseverance of stakeholders; skills and resources of stakeholders; willingness to cooperate; occurrence of outside disturbances. Acceptability of unevenness depends on expectation of stakeholders.
2. Good relationships	The good relationships mentioned both create and are facilitated by easy exchanges, whether that be of information, ideas or resources. The exchanges can lead onto the achievement of goals or functions unachievable as effectively without such good relationships.	• *"I think the relationships are fairly strong between the groups and I think that definitely makes it easier for everyone to do their job if we are communicating better. The CaBA; I personally think that it really is working and I'm not sure if it's different in other areas, I think on the Wear we have got quite a strong catchment group" (Stakeholder #17)* • *"I think [our relationships with other stakeholders] are very, very constructive and very good. I think that we have got a form where we can all be honest and open" (stakeholder #14)*	The positivity of some of the relationships within the Wear network represent strong ties (based on trust and openness). One stakeholder claimed that repeated communication over time with the same stakeholders helped build up trust and relationships that they could "get more out of" (Stakeholder #17). Another talked of a helpful attitude of partners, being willing to go out of their way to help, which built the strong relationships (Stakeholder #12).	Only some stakeholders reported good relationships explicitly, therefore it's difficult to map the extent of the strong relations across the network. It's likely that the strongest ties are the most collaborative and associated with the central actors in the network.	Uneven over time and across the network in general. Might depend on opportunity to interact (existence o[redacted] structures like partnerships); attitude of other stakeholders; external challenges.

3. Access to resources	Access to resources, might include money/ funding, skills, knowledge, all contributing to an increased capacity for action through the ability to plan and deliver more effective projects. The access was described as leading to processes of co-creation in terms of designing projects, or learning about others activities, or in gaining support for planned projects. The transfer and the sharing of resources was seen by stakeholders to be facilitated by new ways of interacting.	• *"[With partnership working] you cover everything, and you cover all bases and you know, you draw in all the resources that are available in a particular neighbourhood, you can't work in silos" (Stakeholder #1)* • *"[He] was really interested in the site and very enthusiastic about possibilities, but […] they hadn't got the resource […]. But now they are part of the Coastal Streams thing so that's good." (Stakeholder #15)* • *"The catchment partnerships are great in terms of dissipation of information across the catchments, it is a great conduit for us to talk to others about what we do and hope we can get their support for somethings" (Stakeholder #16)* • *"The catchment partnerships that are now set up are a great way to exchange information about what everyone is doing […].yeah I think it is all very helpful. (Stakeholder #16)* • *"I don't know if everyone did their projects separately you wouldn't get as much value as trying to do things together and also when you are applying for funding and stuff you can use what other people are already doing as match funding or more for justification" (Stakeholder #4)*	Access to resources is seen to stem from the increased opportunity for interaction and exchange offered within the structures of the network, such as partnerships or collaborative projects. The close cooperation engendered through strong links allows trust to develop, which is more likely to facilitate exchange of resource.	In as much as strong relations and links can facilitate and represent the exchange of information, broken or weak links can stop or stifle access to resources. Particularly problematic are where stakeholders may have different expectations about the exchange of resources at particular times, for particular purposes.	Uneven based o strength of relationships, and mirrors the structural network ; can also be affected by stakeholder attitudes and expectations; affected by wide political and financial policies [redacted]
4. Delivering across scales	Cross scale delivery of action and interaction is claimed to be a positive outcome. Stakeholders allude to the ability to influence, communicate and create links with organisations in	• *"you have got to be working with other land owners and other organisations and that's the only way we could deliver the big landscape scale ecosystems stuff that we are supposed to be doing as well" (Stakeholder #15)* • *"[Partnerships facilitate] that bigger picture and that step back" (Stakeholder #14)*	The structure of partnership working, particularly at the catchment scale, allows coordination of actions and activities beyond the individual scale. Sharing across strong collaborative ties means	Delivering across scale is a significant goal of CaBA and the catchment scale is generally seen as a fairly new way of working (emerged in the last 5-6 years). All stakeholders are aware of the need to consider different areas	Uneven based o the engagement of actors at scales of decision-making Dependent upo the opportunity [redacted]

	different parts of the catchment, to align agendas and deliver projects that meet the same goals across the catchment, previously unable to be met.	• *" we are presenting our projects and the information and the results of it and how we feel [they] impact on the catchment as a whole to those lower down, and all you can do is that you hope that they find the links themselves and link back to us" (Stakeholder #16)*	sharing knowledge of activities and opportunities, identifying cross-overs and gaps that could be filled at a new scale.	and coordinate priorities. Some use mental models of the whole catchment, others think in terms of immediate upstream, downstream consequences on a reach scale. Action and opportunity for action at those scales don't always materialise.	for organisations to come into contact and discuss priorities or create new goals. Affected by decision-structure.	[redacted]
5. Improved understan ding	The process of learning, highlighted by the identification of an improved understanding is seen as an important outcome for stakeholders. Improved understanding involves conceptualising the bigger picture, building or gathering knowledge and using multiple sources of information to grow comprehension.	• *"Prior to those meetings I probably didn't understand where the minewater issues were or why phosphate levels were failing, but you sit in those groups now and you suddenly get an overall picture and you see where this all fits into place, that's quite good" (Stakeholder #11)* • *"It's understanding other people's language, because obviously engineers have a totally different language to us. I think it actually helped drainage engineers talking planning and planners talking engineering things, so it just made understanding […] a whole [lot] easier" (Stakeholders #13)* • *"[…]more opportunity for the cross fertilisation of information" (Stakeholder #8)*	The forum and spaces of exchange created by partnerships and collaborative projects and meetings and the links to and around those spaces means there are opportunities to hear or learn about new activities, dynamics or actions unknown previously.	Understanding is one of the outcomes of learning processes that might happen within the catchment and does not necessarily link to increased action or a change in behaviour, it is part of a complex combination of factors that might lead to change.	Likely dependen upon the nature of relationships and the willingness to share; likely based on willingness to change opinion or mental model there might be differential expectations of possibility of learning.	[redacted]

5.3.2.2. Problems and challenges

Despite the positive assessments of the current observable changes in processes and networks in the Wear catchment by stakeholders, problems were also identified. In a dynamic and changing environment, the existence of problems is inevitable and not necessarily a signal of poor practice. However, the existence of problems is likely to indicate where the expectations of the governance system and associated management mechanisms and strategies have not been met, which reveals the standards believed appropriate for success. It may also indicate the attitude of stakeholders to continuous problem-solving, a mind-set that they are likely to adopt as problem-driven practitioners.

The majority of stakeholders first referred to physical problems within the catchment when talking of challenges faced, which is expected given the emphasis on water quality as the factor most associated with positive effects. The focus was mainly on water quality, both in terms of pollution sources and of riparian land management issues. Problems in the Wear catchment mentioned by stakeholders are shown in Table 5.6, with the most prominent being issues with Combined Sewer Outlets (CSOs), littering and the mining legacy. These issues relate to very particular problems that are characteristic of the Wear catchment. Other issues that might be considered important, such as agricultural land management, are mentioned by fewer stakeholders, which is not necessarily representative of the unimportance of the issue, but representative of the fact that fewer stakeholders (associated with this research project) are currently involved with monitoring or managing that problem. The prominence of the physical water quality in perceptions of the core issues shows the stakeholders have an expectation of the standards to be met in terms of environmental quality, and where the expected standards are not being met, a problem or issue is perceived. Amongst the stakeholders there is frustration with the existence of problems when most believe there exists the capacity or potential capacity to manage the issues. The problems are therefore seen as a driver for change and a motivation for action.

Stakeholders also recognised the role of certain groups or individuals or systems or policies in each of the problems in supporting, facilitating and enabling the physical environmental change they see as a goal. Examples from conversations with stakeholders, where they also mentioned the configuration of the system of governance in relation to roles and relationships among actors alongside the physical problems, are: where sewage problems linked with the role of NWL and their ability to fund or decide to prioritise action; where minewater pollution was associated with the difficulty of working up joint projects to tackle issues; where general water quality problems linked to the legislative context of assignment of waterbody status or funding associated with that status; and where problems of fish populations were associated with difficulties of mixed expectations of river environments. There is often a link between changes made or lack of changes made to the interactions and exchanges within the management system and the existence or severity of problems perceived. .

The stakeholders also mentioned problems with the management process directly, recognising more formally the systems of interconnection, exchange and relations conceptualised within a network approach. Management problems in the Wear catchment are shown in Table 5.6. Other concerns mentioned were uncertainty, bureaucracy, changing standards, mistrust and timeframes. Each of these challenges is associated with processes and structural features of the current governance network and perhaps reflects on the modes through which the complexities of the governance system are (negatively) facilitated and dealt with through current management mechanisms.

Table 5.6 *Physical problems in existence in the Wear catchments, listed by mention by most number of stakeholders.*

Physical problem	Number of stakeholders who specifically mentioned the problem
Sewage and CSOs	10
Anti-social behaviour, littering, social problems	10
Mining legacy	10
General water quality	9
Urban environments	8
Fish passage and populations	7
Invasive species	6
Specific areas	4
Hydropower	3
Bank collapse	3
Agriculture	3
Poaching, predation	2
Phosphates	2
Trees	2
Extreme weather events	2

Peatland	1
Water supply (general)	1
Invertebrates	1
Industry	1

Table 5.7 *Management problems in existence in the Wear catchments, listed by mention by most number of stakeholders.*

Management problem	Number of stakeholders who specifically mentioned the problem
Money and resources	7
Conflict of interest	7
Relationships	7
Lack of knowledge	5
Mix of issues - complex	5
Mixed up roles	4
Inaction	4
Public apathy	3
Process of decision making, delivery	3
Uncertainty	2
Bureaucracy	2
Tightening standards	1
Access	1
Mistrust	1
Balancing time frames	1
Monitoring	1
Balancing legislative demands	1

5.3.2.3. Future change: expectations of the network

In relation to problems in the catchment-management process, stakeholders also reflected on ideal management and the changes that would be necessary to improve current practices. The changes that the stakeholders recommended reflect their hopes and aims for the future of the system, which informs a better understanding of the processes, interactions and exchanges that might contribute towards more effective practice (if effective practice is understood as stakeholder-satisfaction with practice).

Many of the stakeholders referred to connections and collaboration as featuring in an ideal management system as well as more sharing of information and knowledge. Such emphasis shows that value was placed on interaction within a catchment-management system (Table 5.8 and 5.9).

Most stakeholders based their ideas for future management on the positive processes they had experienced, or as a counter to some of the problems. There appeared to be an awareness amongst stakeholders of the normative expectations of a collaborative approach, and in some cases, stakeholders may have felt obliged to describe ideal management as being a better fulfilment of the current advocated approach, perhaps because there was not an expectation or the creative space in the interviews to allow stakeholders to think outside the box to describe alternative approaches, or because of the embeddedness of the features and expectation of a collaborative approach.

The specificities mentioned by each stakeholder are likely to reflect their own values and agendas as well as their own positions and capacities in the catchment management process. Those hoping for more collaboration were mainly the more centralised organisations with more resources and capacity to seek collaborative interaction, such as NWL, EA and DCC, who might hope to see behaviour change in actors in the catchment system. Those engaged individuals seeking more information and knowledge sharing and closer links represented or spoke for those groups usually less directly involved in the central WCP, such as landowners, local people, DWT, anglers, conservation groups, and wider communities, who are likely to want to increase their ability to know what is going on. Such hope for future links and relationships shows that the stronger, closer, more sharing links are desirable across the whole catchment and whilst relationships between the more central actors are hoped to improve, so too are the ties and exchanges with groups in the periphery. Therefore, it may be likely that more meetings and collaborative projects would facilitate the growth of stronger relations and the information- and knowledge-sharing in the specific circumstances mentioned by stakeholders.

Table 5.8 *Suggestions related to communication and collaboration from stakeholders in the Wear catchment about ideal management approaches.*

Example	Analysis
"keep working with other interest groups and stakeholders [through more project work in the future]" (Stakeholder #17) *Have more multi-agency, multi-group projects to build relationships (Stakeholders #10)*	The importance of project work for building relationships is stressed by these stakeholders indicating their key role in the networked system, particularly for building relationships.
Work collaboratively (by combining budgets) (Stakeholder #7)	The financial collaboration is picked out as an important way to work closer together.
Continue CaBA partnerships, because it is "the best way forward […in] bringing together all the stakeholders to explore, because that way you have got a forum, where any conflicts or any tensions or the opportunities […] can all be explored with all the right people in one room" (Stakeholder #14)	The particular importance of the partnership structure is identified by this stakeholder as an aim for the future. This indicates the potential strength of the approach, particularly as the stakeholder is able to identify specific examples of its benefit including discussion of tension and the identification that the right people are included.
"work collaboratively […in order] to be able to move forward", by having "those group discussions", and finding "innovative ways of doing things" (Stakeholders #13)	The specific benefits of a collaborative way of working are identified by this stakeholder, indicating a positive attitude to the processes already happening and a tangible understanding (or expectation) of the positive effects.
Do better "joined up thinking" "so that we all know how we are impacting and influencing each other" (Stakeholder #8)	This stakeholder specifically identifies the joined-up nature of practice, identifying an increased knowledge as the hoped-for benefit.

Table 5.9 *Suggestions related to knowledge and information sharing from stakeholders in the Wear catchment about ideal management approaches.*

Example	Analysis
"have all the landowners sitting in the […] partnership" (Stakeholder #15)	This stakeholder is suggesting that the partnership structure could be more inclusive in order for more knowledge to be shared.
Enable more local people to have more access to the EA decision-making process (more trust), more taking on board of local knowledge (Stakeholder #4)	An increase in the opportunity to share knowledge is desired by this stakeholder and highlights the need for stakeholders to feel included and able to share information within the more strategic management structures.
Have more knowledge about what is going on in the catchment (Stakeholder #20)	Although no tangible method of exchange is suggested, this stakeholder is emphasising the importance of gaining knowledge.
Have a central point to share knowledge, particularly from EA and NWL, more open communication (Stakeholder #12)	This stakeholder is suggesting a mode by which knowledge and information could be physically or digitally shared, perhaps arising from a frustration that there is currently a disconnect and a lack of information to more peripheral groups from those group making strategic decisions.
Volunteer workers attending local authority meetings, closer links, more transparency (Stakeholder #18)	This stakeholder is suggesting a stronger link across hierarchies in the catchment, particularly around decision-making in order to build trust.
Keep improving data sharing through friendly relationships, be able to share data for analysis, increase trust, increase involvement in water quality sampling and more community involvement (Stakeholder #16)	Here the stakeholder emphasises the need to build trust through friendly relationships in order for data to be shared effectively and for practice to be inclusive.

5.4. Summary: network structure in a catchment management system

The analysis of the catchment management system through a network approach adds to current understandings of both the mechanisms and patterns of a catchment management approach, and the utility of a network approach in such a context for revealing something about a governance network and governance structure. First, the analysis in this chapter has demonstrated the importance of considering the spaces and places of interaction as extra nodes in a network representation of a catchment management system. Their presence in a conceptualisation allows the relationships between traditional actors in a (social) network to be better understood, particularly in relation to the creation links between actors. The network approach also allows reflection on the role of organisations in the catchment management system based on their relative positions in a network, particularly suggesting that organisations are able to operate in similar ways in relation to the specific processes of catchment management despite their organisational type, for example through exchange of knowledge or information and participation in meetings and projects. The study of links as an indication of relationships of exchange and interaction within the conceptualisation of the network has indicated that sustainability of links, rather than strength, is key. For example the strength of connection, measured by trust or exchange, may fluctuate but the knowledge of the existence of the opportunity to contact or connect with groups is vital in terms of reacting to change or creating new modes of action such as projects. This is useful for reflecting on the way that network structure can imply certain understandings of governance structure as the features indicate the purposive action triggering change in the environment and learning in the actors. Finally, network analysis provides a more systematic approach to understanding how catchment management is working in practice. Analysis is helpful in identifying brokering and intermediation roles, but also where the gaps, barriers, problems and lack of communication exists. The approach, therefore, is a useful way to characterise the system and to highlight the areas where more understanding and analysis is needed. Chapter 6 focuses on some of the complexities and dynamics highlighted throughout this chapter in relation to the interactions and actions described, in order to identify the enablers and barriers of good management practice in relation to the system as a networked system.

Chapter Six

Functionality of catchment management: enablers and barriers

6.1. Chapter overview

The previous chapter presented the interactions and relationships amongst stakeholders in the Wear catchment as a network, made up of nodes and links. This process of mapping patterns of interaction forms the first step towards identifying how governance is operationalised. . Understanding the he functionality of the network helps build a picture of the power relations and mechanisms that facilitate the observed network structures. Functionality relates to the balance of effective practices, as assessed by the stakeholders, in terms of their satisfaction and approval of processes, and against universally understood conceptualisations of success in natural resource management and governance.

This chapter focuses on the dynamics of the processes and interactions that are seen to be part of the network governance system in the Wear, and the processes, practices and factors that enable or hinder functionality. As catchments are understood as complex systems, functionality is an important concept to consider in relation to network structure and its association to processes of governance in order to conceptualise the ability of the system to self-organise, transform and adapt. Examining the barriers and enabling factors to functionality of the relationships within the system may help understand how the dynamics of the system play a part in achieving goals or outcomes such as the positive effects identified by stakeholders giving a better understanding of the links between network structure, governance approach and desired outcomes.

Three different scales are used as lenses through which to examine factors that contribute to the dynamics and complexity of the interactions and relationship identified. The three scales represent the individual or organisational level; the interactional level; and the contextual or policy level (Figure 6.1). The interactions between the scales are a representation of the complexity of the catchment management process but give an insight into the areas that could be a focus for consideration when evaluating and designing catchment management actions in the future.

The chapter is divided by sections based on levels to explore the nuances of the factors that are seen to contribute towards the functioning of the relationships, related management practices and configuration of catchment governance network.

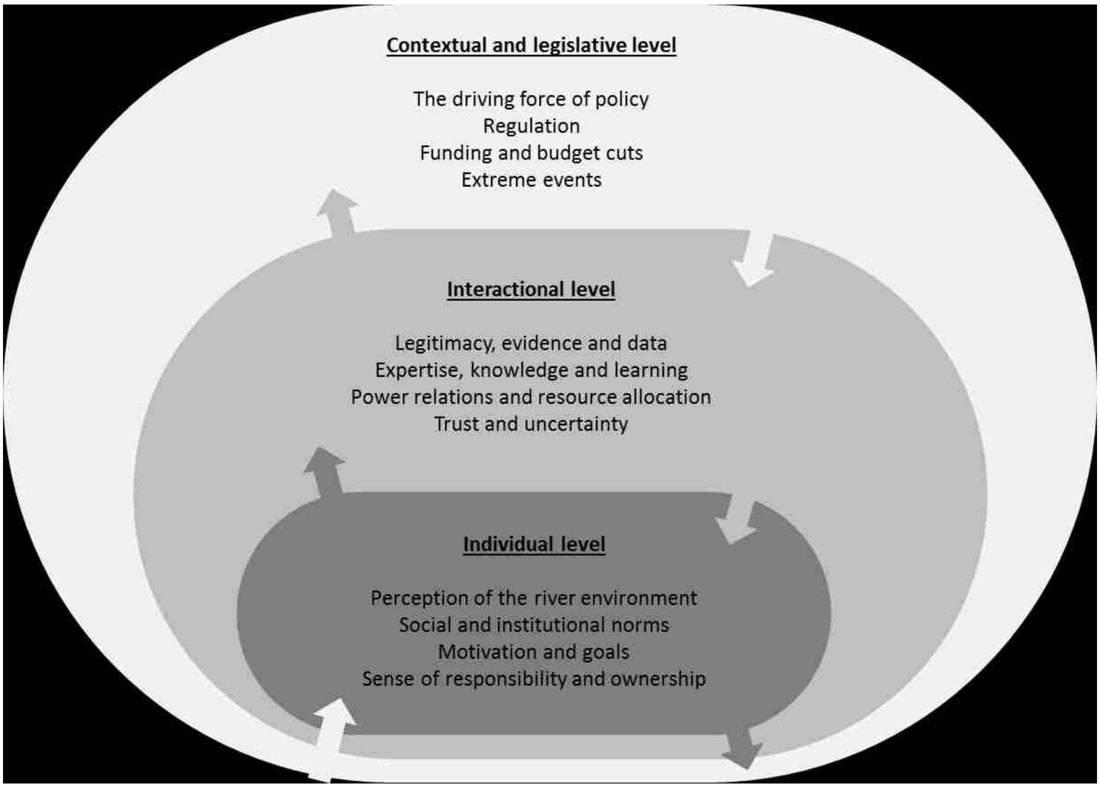


Figure 6.1 *Conceptualisation of the factors that may contribute to the functionality management practices and the configuration of the catchment governance networks. Arrows represent possible interaction between the levels of influence.*

6.2. Types and scales of functionality

Figure 6.2 outlines the relationship between different levels of functionality of the system and suggests several points of the system at which functionality can be understood; the stakeholder, the network and the outcomes. The stakeholders' decisions, actions and interactions are affected by factors at multiple levels, including the interactional level (which includes aspects such as power dynamics, legitimacy and knowledge sharing, uncertainty, trust, learning and data access), the individual level (which includes aspects such as social norms, motivations, goals, perceptions and ownership), and the contextual level (referring to aspects such as policy influences, economic and political factors as well as resources and physical processes and change). The particular patterns of action and interaction that result from the balance of factors affects the nature of the network structure, which can be portrayed as the pattern of spaces and scales of interaction and the strength and duration of the relationships within the network. The components and formation of the network can lead to particular outcomes such as improved water quality, good relationships, access to resources and improved understanding. The wider influence of social structure in relation to political, cultural, economic and historical aspects, alongside the broader governance structure and the resulting power dynamics and institutions also have an effect on the configuration of network structure (and the resulting catchment governance structure) and it is important to recognise the wider context in which the management system is situated. The outcomes of the management processes realised through the networked interactions and broader context feedback to the stakeholder through a change in factors across the levels and scales, which affect the next decisions, actions and interactions they carry out. An understanding, therefore of the different components of the system of feedback could help better conceptualise where there are successes and where there are problems with the current ways of working (the functioning of the management system as a whole) that may be changed or discussed as part of future planning for a process of catchment management.

The following sections expand the findings about the details of each of the factors shown on Figure 6.2 relating to the factors at the interactional, individual and contextual scales.

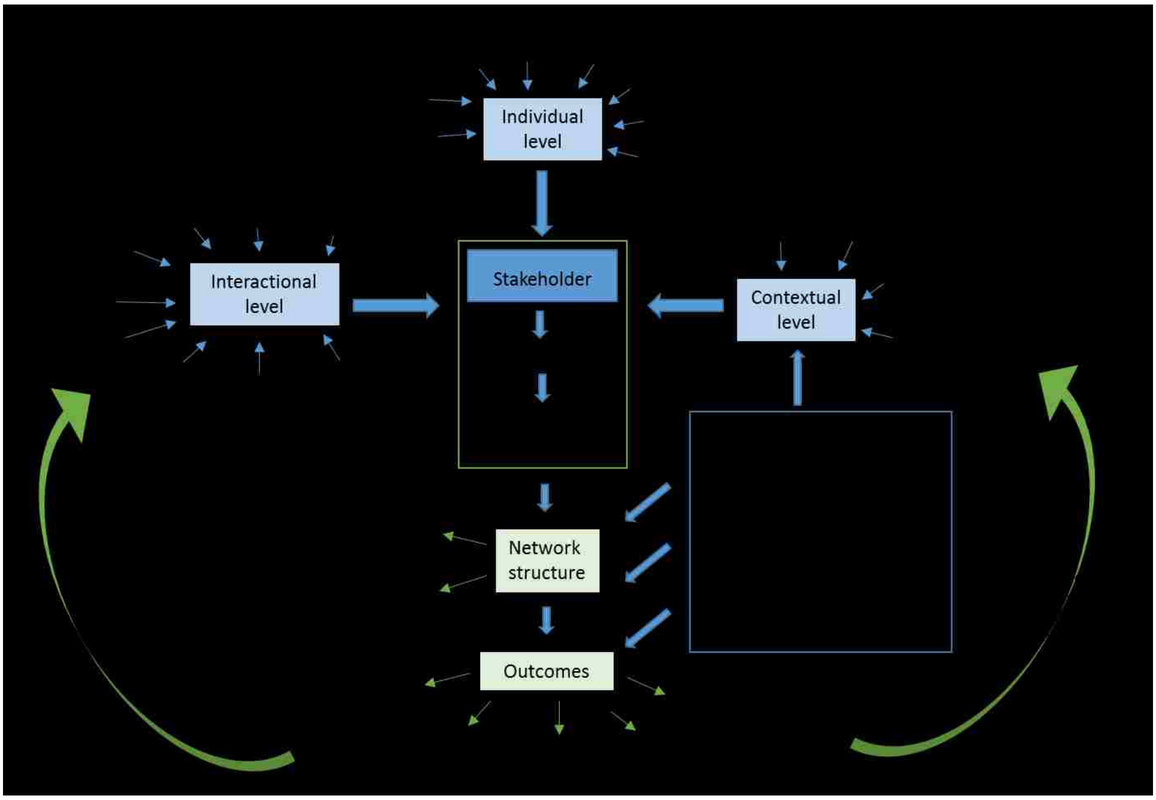


Figure 6.2 *Theoretical associations between the factors contributing to functionality of the system and the network structure and outcomes of the system.*

6.3. The interactional level of functionality

The interactional level consists of a consideration of factors that affect the relationships and dynamics of interactions between stakeholders. It is perhaps the most significant level at which the functionality of the catchment management system is affected through the dynamics of power, legitimacy and evidence underpinned by levels of trust and certainty. The effect of a change in the factors at this level can affect the way in which relationships are formed or action made possible or challenging.

6.3.2. Factors affecting functionality

6.3.2.1. Legitimacy, evidence and data

Overall, in relation to the use and interpretation of data and evidence in the Wear catchment, key points will be expanded on and illustrated in the following subsections connecting data and legitimacy, the role of intermediary groups, the power of data as evidence and its strategic use and mistrust.

Data and legitimacy

Within the Wear catchment there are multiple forms of data that are referred to by stakeholders, and that each of the stakeholders collect and use in different ways. Quite often stakeholders seem to portray a sense of ownership over the data, pertaining to who has arranged and carried out collection and how it has been done. For example stakeholders often use phrases such as "our data", "their data", "the EA's data", "other people's data". Such a perspective also translates into the language of sharing and exchange and often it is up to a group to 'give' their data if involved in a partnership setting. Sometimes data can be seen to be co-created for a project, and therefore belong to the project, but still generated by a particular group within that project. Data therefore, are always associated with a particular group and if there are problems or difficulties with the data, they can often translate into difficult relationships. Processes of legitimisation are associated with both the form of data and the group collecting that data as well as the purpose of the use of the data.

Particular forms of data appear to be more universally accepted than others when the state of the river and stream environments are being assessed. For example, acceptable and useful data are sometimes (not always) described as "*accredited*" (Stakeholder #7), "*robust, academic*" (Stakeholder #4), "*rigorous, fact based"* (Stakeholder #13), "*quality, scientific*" (Stakeholder #11), "*baseline, chemical*" (Stakeholder #18), which are associated with stakeholders such as Durham University, DCC, NWL and EA. Such data are representative of fairly traditional forms of science knowledge and are referred to by stakeholders for their utility in enabling, for example, better understanding of the river quality, better understanding of what is happening in the area, better ability to prove a point using the data, and better ability to know the exact effect of pollution sources on the water quality. Some of the stakeholders hold the traditional forms of data in contrast to less traditionally accepted forms such as "*anecdotes*" (#11) or, as one stakeholder described, "*a consultation process*" (#13) (which referred to the Twizell Burn Green Infrastructure meetings). Associated with each of the types of data mentioned, is the opinion that they are acceptable and therefore legitimate for a number of aims within the process of catchment management, and therefore that the stakeholders associated with those forms of data also carry legitimacy to be involved in the management process.

The pursuit of such data has likely had an effect on the shape of the relationships in the Wear network, for example two other stakeholders, representing the CA and NWL mentioned that they had recently increased their association or interaction with the EA, as both organisations have not historically collected river water monitoring data and rely on the EA to provide data with which they can use to decide whether to change their practice. As there has been an increased focus on more groups taking responsibility for change in water quality and therefore a change in practice, their association with the EA has been seen to change and intensify to facilitate the sharing of acceptable and legitimate data. More specifically, the CA mentioned purposefully seeking to work closely with NWL and Durham University on a joint water treatment project for the reason that both groups would have access to or ability to create data about the area to inform action within the aims of a particular project. Such relationships form the configuration and operationalisation of the governance network within the catchment and can be seen as functional as the stakeholders involved spoke positively about their utility. Functionality may therefore arise when groups seek relationships based on data sharing where groups share the same understanding of acceptability and utility of particular types of data.

Barriers to functionality in relation to legitimacy

Barriers to functionality may exist where different types of data are seen as acceptable, useful and legitimate by different interacting groups, giving therefore a lack of legitimacy or perceived legitimacy to particular actors at particular times, which can be seen to be representative of broken or weakened links in a network. Within the Wear some angling groups have less positive relationships with representatives of the EA, due to disputes over the legitimacy of data. The importance of the disagreements lie in the power the data have to provide evidence for a need for a (potentially unwanted) change in practice. Within the structure of the North East fisheries forum meetings, EA and angling groups come together to present and discuss data. The meetings take the form of groups such as EA, WRT and AT presenting information, research and data about the river, with times of discussion for members of the angling clubs to ask questions. One EA representative reflects on the frustration felt when attempting to argue for the legitimacy of his own data:

> *we have to deal with anecdotes all the time, we go there and we have to give cast-iron, quality, scientific data to prove our point and there will be people in that room that won't believe it, no matter how […] many times you give it to them, no matter which way round you give it to them, if he [an angler] counted two oranges going past his flow gauge as far as he is concerned his data is correct and ours is wrong, and you will always beg to differ on that, but I know whose data I would believe at that moment in time (Stakeholder #11)*

The difficulty described relates to the understanding of legitimacy that the EA officer holds, perceiving that his data are more reliable, useful, appropriate and believable than the data collected by the flow gauge of the angler. This legitimacy is perhaps based on the familiarity of the accepted norms and practice of data gathering and analysis established within the large institution of the EA, likely operationalised between multiple teams through accepted methods, compared to an unknown method carried out by one individual. Uncertainty, therefore, is likely to play a part in the mistrust of the angler's data by the EA, compounded by a lack of opportunity to check its credibility. Uncertainty and unfamiliarity of method and motive may also have been the cause of mistrust of the EA data on the angler's part. Equally, a defensive attitude may also play a part on both sides. For example, one angling stakeholder stated that "*I don't think [the EA take different forms of data and knowledge seriously], I think that there is quite a bit of arrogance on both sides" (Stakeholder #10)*, suggesting that perhaps a certain closed nature, or at least a perception of a closed nature, may be part of the problem.

Within the Fisheries Forum meeting the angler's data seemed to be dismissed by the EA officer who was running the session, demonstrating that the EA data were valued more highly as contributions to the system of knowledge at that moment in time, influenced by the central and powerful position of the EA as an organisation in the governance of the catchment with the ability to make decisions. This links to questions of power within the catchment system and the potential strength of the EA as a government actor despite change to governance approaches that attempt to diversify the political actors within decision-making. The angler who made the claim about data may have left the meeting feeling distrustful of the EA creating a lack of a trusting, open, flexible link at that moment in time that would be highly valued in a networked system and an approach founded on a co-production of knowledge conceptualization. At a different time the nature of the relationship may change, as it is possible for links to transform if effort is made by both involved to connect and communicate, even if to discuss conflicting opinions. The promise of a chance to meet again in a different setting to discuss the data was alluded to by the EA officer in the meeting, demonstrating the role of dialogue in attempting to create more trusting relationships where unfamiliarity of data creates a barrier. Power relations and ideas of legitimacy are still likely to dominate communication, but the repetitive contact may form a link between conflicting groups that is beneficial to the sustainability of the network of actors.

Similarly, another example of a possible barrier to functionality is through the way that the data collected as part of the Riverfly project (table 5.1) are used to inform (or not) decisions about the official WFD status of a waterbody (for which the EA is responsible) as well as prioritising action on the waterbody. One representative of the Angling Trust mentioned that "*There's always been an issue. […] There has been and continues to be a reluctance of the [Environment] Agency to accept the [Riverfly] data.*" (Stakeholder #5). This reluctance refers to the fact that the invertebrate counts and subsequent analysis of pollution levels in water courses assessed through Riverfly projects does not inform the WFD status of the waterbody, compared to sampling and monitoring by the EA, which does act to change the status as well as acting to change priorities for action. The reluctance is again mentioned by a representative of the WRT, where the invertebrate data *"wouldn't do something like change their actual status of a waterbody*" (Stakeholder #4). The changing of the status of the waterbody is seen as a powerful act within management practice as the status of the waterbodies is the measure by which many of the actors base their actions. Without being able to contribute to the changing of the status the Riverfly volunteers may feel unimportant or powerless through the lack of acceptance of their data for this purpose, creating a mistrust and a weakness in the network of communication.

Legitimacy built through the role of intermediary groups

In contrast to the dismissal of angler's data, the Riverfly scheme is officially endorsed by the EA as an early-warning system and the volunteers' observations are the catalyst for EA action. The significant enabler of the translation of data from volunteers to EA is the role of the intermediary group of the WRT. The WRT are the lead organisation in charge of the coordination of the Riverfly project on the Wear and as such are the point of contact for the volunteers. When there is a change in the invertebrate levels (below a trigger level or simply an observation of significant change) the volunteers will report to the WRT, who then contact the EA officers who will go out to the location and collect their own samples and monitoring in order to make an assessment of what has happened. The Riverfly data are supplementary to the EA's own data and act to flag up potential pollution events that the EA would not have been able to pick up. The feedback from the EA comes back to the WRT who then feel it is vital that they let the volunteers know what has happened:

> *A key part of Riverfly [is that] [the volunteers] get the data back and if [the volunteers] say that they have had a trigger-level breach it is just as important that I get back to them and say this is what's happened [according to the EA feedback].They want to be able to see why they are doing it. And that makes them feel like they have helped out. (Stakeholder #4)*

The intermediary role of the WRT in the translation of the data to the EA and of the feedback to the volunteers is vital for maintaining a sense of value, and legitimacy of the volunteer groups through the valuation of their data. Eden (2012) previously noted the need for relationships to be nurtured, which Bell *et al.* (2008) has claimed may involve showing that the data reported by volunteers are valued and useful. The WRT act as the translator through which value is demonstrated and usefulness communicated. They are therefore central to the maintenance of a sense of inclusion and fairness and legitimacy, which could arguably be vital for maintaining the functionality of the governance network, particularly in the form of strong, trusting links between groups.

A change in attitude of the EA and the presence of the WCP as a structure through which to feedback to the WRT have also been claimed as enabling factors for the maintenance of the relationship necessary within the network. For example a representative of the WRT claimed that:

> *I think [the EA] have got much better at listening, accepting and then following up and also getting back to people, even if it's through the catchment partnership, getting back to people who have volunteered some information and shown them that that is actually valuable, that they haven't just pooh-poohed it, as it were, so that's got better. (Stakeholder #4)*

Such a change in attitude is associated with the existence of the WCP as a structure through which relationships can be nurtured more easily than perhaps previously.

Data become powerful as evidence

Data can be used to fulfil aims and goals within the catchment when it is used as evidence and therefore interpreted as valid support for particular courses of action. Certain judgments of legitimacy, expectations and goals determine the utility of different types of evidence, based on both the data and associated knowledge systems (Juntti *et al.*, 2009). Evidence can be utilised to gain funding and justify action or inaction. The functionality of activities within a governance network might be affected by the way in which evidence is used and interpreted to produce action, affected in turn by the relations and power dynamics amongst the stakeholders.

Certain actors have different relationships with data as evidence, for example a large business such as NWL needs to have access to evidence that demonstrates certainty in terms of pollution levels, or evidence of the source of pollution, in order to be able to justify resources used to carry out actions:

> *I suppose it's the evidence to know what the problem is. [In] some of [the waterbodies] it's maybe not defined fully as to why it is failing for fish or invertebrates. […] So some of the areas we don't know who is responsible and who should be paying, basically […]. But I think where we have got good evidence from the EA, from the sampling in the right place, well then we can say that yes, well that's definitely down to us or, yes we can make a difference because we know this. (Stakeholder #7)*

NWL rely on evidence that they deem to be 'good', from the EA, as a legitimate actor, to justify action. Their need for evidence relates to an understanding of responsibility as payment for damage attributed to their own activities in the past, and relies on data and sampling to be able to prove where pollution is sourced and thus who is responsible. Due to the restrictive nature of this method of justification and often the lack of data to act as evidence for their action, they can be seen to be inactive in collaborative situations. For example one stakeholders commented:

[NWL] don't come forward with any resource at all, […] if you see where any of their names are against any of the actions on the action plan, you won't see NWL coming forward. […] 'Is it going to deliver enough for us?' NWL will always ask that question. (Stakeholder #1)

The acknowledgement of a lack of engagement reflects on the different abilities and expectations of different types of stakeholders in collaborative situations. Private companies have different priorities than charities or governments and this plays out in the relationships within partnerships. A factor for the perceived lack of involvement of NWL may be a lack of evidence for problems clearly attributable to them, which may make financial or time commitments difficult. The effect of NWL's attitude and behaviour around the use of evidence affects the relationships that are possible in the catchment networks, through exchange or lack of exchange of resources and commitment to collaborative action.

Equally, the power of evidence can be felt by the absence of data to be used as evidence. Much of the connectivity of a network within a catchment-management process based on collaborative and partnership working relies on the existence of easy and open processes of data sharing to provide opportunities to transform data into evidence to justify action. If such processes do not exist due to legal issues, lack of willingness, difficulties of translation and data integration, or technical difficulties, data is not shared easily and progress cannot be made in terms of decision-making or action based on that data (Paudyal *et al.*, 2013). Problems arise when different stakeholders have different understandings and strategies for data sharing depending on the requirements of the organisation and the nature and form of the data being shared. In the Wear catchment an NWL representative stated the difficulty faced by the organisation to share data within the WCP:

It's really difficult to get the information out because [of] data sharing. […] We should be more open about how we share things but that again comes back to the business being very closed and private, and getting that [sharing] mentality is quite difficult. When as a business we don't really understand what we should and shouldn't be sharing and a catchment partnership is coming up with quite reasonable requests really, [our ability is affected by the fact that] some of that information is almost business sensitive. But if you can't share that then you can't be open about the opportunities for investment or [meet] the needs. (Stakeholder #23)

The stakeholder recognises the importance of data sharing and the demand that working in partnership puts on sharing data. The difficulty this specific organisation face in sharing is the fact that, due to the newness of the catchment partnership structure, officials within NWL had only just picked up on the issue. The representative of NWL later states that the business is currently looking into the possibility of drawing up data sharing agreements amongst the partnership in order that they can ensure the legal policies are in place to free up an ability to contribute as fully as possible. Stakeholder #23 feels that an important part of her role is to ensure NWL is contributing as much as it can. Her passion can be felt in the way that she reports on the difficulties faced, and she demonstrates a committed attitude to changing practice, despite difficulties. Although the functionality of the catchment governance network is affected by the lack of data sharing through limiting the ability to make effective decisions about management actions, demonstrated by the lack of commitment of organisations such as NWL due to uncertainty over data sharing policies, the new changes in the network (the creation of intermediary roles in NWL for example), create an opportunity for change in practice and an opportunity for increased functionality in the network.

Strategic use of data as evidence

Evidence can also be used strategically in order to persuade others of the importance and validity of a project or action and therefore to support a particular agenda for the management of the water resources, becoming the enabler of new relationships. For example, a representative of the WRT hopes that data collected during a project to remove barriers to fish passage in the Wear would help gain funding for other similar initiatives:

> *You would hope that we can say that we can prove that this worked really well because we have this data so please fund us to do another one (Stakeholder #4)*

The exchange of resource such as funding is seen to represent links within a network of management and the awarding of funding, the creation of new projects or action and the strengthening of links in the network as well as opportunities for new groups to come together in new projects or actions are positive actions.

Links within a network may also be built on the strategic use of evidence to persuade powerful actors of the legitimacy of other groups and of their agendas, such that they might change their behaviour or attitude. Eden (2012) reports that anglers are particularly aware of the power of evidence to effect action and can be seen to strategically report and use data to support their own agendas, when context and power relations allow. This is also a behaviour that can be observed in the Wear catchment. For example, an angler related the way he strategically uses photographic evidence of pollution to 'prove' to the EA that particular water courses need action. He describes the importance of photographic data:

I always take photographic evidence because […] when we say something happened and they say no it didn't, then 'clock' there's the photograph, there's the time and date stamp, there's the GPS coordinates, there's the altitude. Yes data gathering is very, very important. (Stakeholder #12)

The stakeholder alludes to the power of the evidence to locate and give temporality to evidence to counter claims that the event or situation is not worthy of action. It can be seen as a technique to overcome the potential uncertainty that could inform the rejection of certain data and evidence by groups such as EA. The angler believes in the immutability of the evidence enough that it should be legitimate and accepted by the EA:

We went round one year [and] one day after the first report [about the state of the burn], we took photographs and it was literally one sewerage outlet, it had the same traffic cone, it happened to be the same two bits of sanitary wear […] hanging on the traffic cone […] one year and one day previous. So basically they had this big publicity stunt to say we've cleaned up this, [but] I say [to them], see that, see that [photograph], what's the difference? Nothing. 366 days that's it. […] And about six months after that they had a Twizell Burn week of action event (Stakeholder #12)

The stakeholder demonstrates the use of data as evidence and makes direct links from the sharing of the data to the action that followed. He talks confidently of his ability to influence the agenda and priorities of the catchment management process. It is likely that it is the nature of the relationships within the governance network at the time of the evidence being shared, alongside the agenda already set for the group that contributed to the power of the evidence and the subsequent action. For example, one stakeholder comments on the process of data sharing at the time:

[The angling club] for years have been trying to get the message across that the Twizell Burn is really bad and that there are all these issues and I think they had sent in at least one report that just didn't really get looked at, not for a while at least, but I think it was really down to [the catchment co-ordinator of the Wear Partnership at the time] and that team, that [the message] actually got taken seriously and got looked at and then there was action round there because of it" (Participant #4)

The functionality of the network at the time (related to factors such as responsiveness, participatory decision-making, inclusivity, accountability) was related to the role of catchment co-ordinator as an individual ambassador and environmental champion (Andersson and Bateman, 2000; Taylor, 2008) with an open attitude to new and different sources of evidence than had been previously used. The leadership of the catchment-coordinator meant that a change in practice and thus a change in the network structure was enabled. The collaborative space opened up through the newly formed catchment partnership at the time was likely to be an important enabler of the action that followed, including the 'week of action' on the Twizell, alongside the Twizell Burn Green Infrastructure project operating later in the same sub-catchment. Therefore the strategic use of evidence was enabled by the relationships, attitudes and interactions of the stakeholders in particular roles based on the particular opportunities for interaction representative of the networked governance structure.

Data and evidence can also be used strategically to build relationships amongst stakeholders as part of the networked system. For example, the often complex relationship between anglers and the EA is associated with differential ideas of legitimacy. The EA sometimes presume anglers to have a lack of knowledge of the techniques and methods used to collect and validate data the EA collect. Therefore, one EA representative spoke of the attempt he made to bridge the gap:

> *We sometimes invite them out if they want to see fish surveys or something. If someone has complained about the lack of fish in the River Wear, well, come and have a look at what happens when we do a fish survey, when I say we catch 200 trout in this stretch of river and you don't believe me, come and actually see it happen. (Stakeholder #11)*

The emphasis on seeing and experiencing the data being collected is expected to reduce conflict by creating a shared understanding. For some anglers the sharing and learning offered in such meeting spaces is welcomed (e.g. "*I would love the opportunity to sit down with an EA scientist and to gain knowledge and to maybe take some of that ignorance away*" (Stakeholders #10)), which shows an attitude and a desire to adapt knowledge based on new evidence or data. For others there is still a need to stake a claim on the legitimacy of knowledge. For example the EA representative goes on to say that while anglers then more readily accept the data collected during fish survey, they go on to challenge the meaning of the data in terms of evidence of prosperity of fish stocks in the river, claiming that there is more potential for improvement, when the EA claim the stocking levels to be sustainable. The continuing negotiation of legitimacy transfers from the data collection to the interpretation of data as evidence, continually manipulated to further particular agendas at particular times. The process of negotiation is facilitated by the spaces and times of interaction and communication between the groups, which is part of the governance network. The willingness of the EA to provide times and spaces for deliberation is perhaps part of the functioning of the network as, although there are conflicts, the act of attempting to bridge the gap gives value to anglers, for example, as stakeholders.

The mistrust of data as evidence

Data can also be dismissed and ignored. A farmer in the Wear catchment claimed to ignore soil-nutrient data in favour of his own experiential understanding in order to inform decisions about fertiliser application. He claimed that the results of a soil survey that assessed nitrogen, phosphorous and acidity across his fields was not helpful in informing how much fertiliser to apply. He claimed that the results were always telling him to put on more nutrients but he knew how much to put on generally anyway and that changing the amount would not make much different based on his experience, so he does not do it. The valuation of his own experiential understanding of the land is considered more legitimate and trustworthy than the results of the soil survey that he was perhaps obliged to carry out. Such an understanding has implications for the way in which other stakeholders create relationships with farmers. For example the WRT knew to approach farmers through trusted partners who shared the same experiential understanding of land and decision-making processes. This is potentially opposed to an approach where external data (such as EA WFD water-quality data) may have been used to demonstrate the need for a change in decisions being made by farmers that would have been rejected or ignored. The functionality of the network is therefore affected by the way in which farmers use and understand the legitimacy of data, alongside an awareness of the potential differences by those seeking to make new links within the catchment system.

There can also be a lack of trust in the processes that transform data into evidence, which may lead to feelings of confusion or dissatisfaction that may then represent dysfunctional management systems. For example a stakeholder gives an example of a seemingly illogical jump between data, evidence and outcomes (in the Tyne catchment, however, rather than the Wear):

> *There is a burn there, a tributary of the Tyne, which is dead and the fisheries team at the EA have done survey, after survey, after survey, and find hardly an eel, let alone a salmonid and the assessment that came out three weeks ago […] of the latest fisheries based assessment, had it as good. They know, they absolutely know that it's dead, and it comes out as good." (Stakeholder #3)*

The ambiguity over the process in which the data is transformed into evidence and used to inform decisions about the state of the water course is the source of conflict for the stakeholder. It is a difference (seemingly) in the interpretation of data and its meaning in relation to other factors, demonstrating that multiple interpretations can cause conflict around the same data. He, himself, however did not have the ability to directly challenge the process. Therefore despite the disagreement, actions and relationships were created based on that status as a result because it was legitimised. The lack of trust in the process may inform the perceptions, motivations and goals of the stakeholder individually within his role in the catchment network, affecting the decisions he makes and his satisfaction with the functionality of the system. The multiplicity of interpretations of data as evidence is therefore an important factor in the functionality of a catchment system.

6.3.2.2. Expertise, knowledge and learning

The interpretation, use and production of data and evidence in the catchment management process can be seen to be based upon the expertise and knowledge drawn upon by the stakeholders involved (Bracken and Oughton, 2013). Whilst there are multiple expertise and knowledges within the system of catchment management, it is the framing of credible expertise and relevant knowledge at different times to fulfil particular purposes that facilitate the functioning of the governance system. Sometimes a lack of credible expertise deemed necessary to fulfil a particular purpose can negatively affect a decision-making process. Equally, different understandings of expertise can cause misunderstandings and even conflict.

Overall in relations to the factors that influence the interactional level of functionality relating to expertise, knowledge and learning, key points will be expanded on and exemplified in the following sections exploring the understanding of diverse expertise, its role in building relationships and the utility of learning, experimentation and the pursuit of knowledge.

Understanding diverse expertise

Where there is an understanding of differential expertise and the need to balance expertise when making decisions, relationships are both sought and dropped as is deemed appropriate. For example one EA practitioner talked of the process of decision-making around seeking to work with particular partners on particular projects based on their expertise:

> *"I think we are not all experts in everything so it's about making sure that the expertise in this team is working with expertise in other organisations so that we are building the best picture that we can […]. Sometimes, it's better and right for [partner organisations] to be talking to communities rather than us, or they might already be linked into a community and working with a community and it's silly for us to go to them and start a new conversation" (Stakeholder #14)*

There is a recognition of the need to know where the expertise of other organisations lie in order to strategically draw on their knowledge in order to further the aims of the project. The links that are made are representative of the short term structures of interaction that can exist in a governance network around projects and the flexibility of the links, are seen as important.

There is an increasing emphasis on experiential expertise as valuable in the system, sometimes referred to as local knowledge. Local knowledge is a concept on which paradigms of participation are based and are foundational to the development of initiatives such as CaBA. In the Wear catchment the importance of local knowledge is emphasised. For example one EA representative talked of the success of an internal group meeting focused on the Wear catchment based on the reliance of local knowledge:

> *I can only speak for this area but yeah, to see the knowledge in the meeting today where we have drilled down on reasons for failure in a waterbody, so that every group whether it is an environment officer or a hydrologist or a geomorphologist all knew how to fix that waterbody, all understood the failure and knew how to offer solutions, so it comes down to local knowledge I think. (Stakeholder #11)*

The stakeholder alludes to local knowledge as being the basis of the expertise in relation to the water courses, and the collective process of problem definition and solving in the meeting effective because of the sharing of local knowledge. This conceptualisation of local knowledge as expert could be argued to be in contrast to the traditional understanding of local knowledge that associates local with non-experts or those not closely involved in management. In contrast, the understanding of local knowledge could be seen as one that is situated in experience in a particular place, no longer only associated with the expert-lay divide (Collins *et al.*, 2007). It is the recognition of the importance of the sharing and co-creation of such local knowledge in order to carry out the practice of catchment management that has facilitated new structures such as meetings and partnerships. .

Knowledge through experience and time spent in a locality is also highlighted by the angling community, who acknowledge that their own practical knowledge is being increasingly recognised by the EA as valuable. One angler notes that he and his angling club are asked by the EA to report any problems they see on the river and are frequently asked to produce reports on certain areas of the catchment, based on their experience and knowledge of the water courses:

> *If you want to know if there is a problem on a river, if you get a knowledgeable angler who might spend 100 hours a year on that river, he knows, like the back of his hand, that bit of river that he fishes on, and the slightest problem he sees, he will know that there is something wrong. So we have always said that you have to use the people that are available, and it sounds awful, but it's been admitted that there is a lot of our lads on the river know a lot more about what is going on on the river than the EA and that's why even they now are getting more interlinked with the fishing clubs because, utilise us, we are there all the time. (Stakeholder #12)*

The experience and time spent on the river banks, observing changes is seen as the basis for legitimacy in the opinion of the angler. By admitting that the claim that the angling community knows more than the EA practitioners as 'awful' shows that the dominant discourse is one of the EA as experts, and even the anglers themselves must excuse their position and legitimacy. But by admitting to the reversal of the traditional roles the angler is acknowledging that there is a recognised legitimacy in his experiences and ability to make a contribution to decision making. At another point the angler states:

> *we are 'the lay people' at the moment but we do to the best of our knowledge, I mean we are educated people, we think, well if I saw a problem I'll research that problem and I'll talk with people behind the scenes (Stakeholder #12).*

The acknowledgement of the label of 'lay people' again highlights the traditional view of non-experts, but the care, effort and discussion around that problem described by the anglers shows the way in which knowledge is built and argued as credible and legitimate. The angler describes the interlinking of angling clubs and the EA and implies that that is part of the endorsing process of their knowledge. It is the recognition of the value of the anglers' knowledge that may have enabled the stronger link to exist between the two organisations and become understood as part of the structure of the catchment management process.

Although this endorsement may be the foundation of a link between the groups as part of the way that a governance network is operational the way in which such relationships play out may not be straightforward. Eden (2012) describes the environmental engagement of anglers as both discursive and practical, where they are both valued in discussion groups, and as capable actors implementing practical projects and facilitating change to the river or stream morphology. Anglers themselves in the Wear catchment recognise this duality but show a preference for practical action:

> *The steering groups and the management groups, we tend to look at them and follow them from the outside and if they have totally missed the point on that then we will give input, but we would rather be out there doing stuff than in a room talking about it, so we let them get on with it, while we look for the next [problem]. (Stakeholder #12)*

The recognition of their opportunity to get involved in the discursive aspects of the management process is indicative of the inclusivity of the wider stakeholder meetings within the network structure. However, it is recognised that the main power of the angling groups lies in their practical action. Other stakeholders often describe the angling groups as "eyes and ears" on the ground, equally, that their actions to restore banks, build wetlands, help with weir removals, maintain footpaths and clear litter are highly valued, reinforcing the idea of anglers as practical contributors. Eden (2012) argues that the practical aspects of angler's engagement, as enactment of their experiential knowledge, rarely become theoretically embedded in understandings of the management process.

In the Wear it is the recognition of the anglers' role by the EA, perhaps increasingly through the growth of CaBA, that has created a link between their practical action and the more discursive decision-making processes facilitated by meetings, collaboration and partnership working. Eden (2012) encourages the behind-the-scenes hands-on activity of stakeholders such as anglers to be expanded and recognised by policy makers and central actors so as to improve public participation in water resource management. The CaBA process in the Wear, facilitated by strong championing leadership that helps open up management processes to new forms of knowledge, is arguably enacting some of the recognition required. The management process is still utilising a centralised, discursive mode of knowledge sharing, but recognising that there are multiple ways, times and spaces in which contributions can be made.

Shared understanding builds relationships

As much as understanding between stakeholders can be facilitated by an acceptance of difference of knowledge, some relationships are built through a shared knowledge and a shared language. The individuals who seem to cross boundaries might be seen as intermediaries who create links between different groups. A representative of the EA describes a situation in which an angler at an event used a different language to that normally used by anglers in the experience of the EA representative to indicate his knowledge of the technical aspects of river biology:

> *Occasionally, and it's a breath of fresh air, when you do come across the anglers who will understand the catchment and the catchment approach. […] The anglers were talking about eutrophication and succession, macrophytes abundance; terminology that you would not normally associate with anglers, he knew his stuff and was interested and he had taken it that stage further. That's rare. That's very rare. […] He understood the problems that he was trying to address and he was bouncing ideas off me. (Stakeholder #11)*

The use of a shared language through technical terminology allows the angler to connect with the EA officer and begin a dialogue that includes the development of ideas. The surprise of the EA representative demonstrates the expectation that the translation of knowledge across the boundary of their stakeholder groups should be difficult. Certain individuals who are able to cross boundaries and meet the expectations of another group in terms of their knowledge have the potential to facilitate good links within a catchment network.

Learning, experimentation and the pursuit of knowledge

The process of learning within the catchment system is likely to play a part in affecting the functionality of the network, as processes of knowledge acquisition have the potential to change action and activities, both individually and collectively.

Within the Wear catchment there is an acknowledgement and an underlying driver amongst stakeholders of knowledge acquisition, of better understanding, and of creating a clearer picture in order that action can be better informed. The sharing of knowledge in order to create understanding is key. The focus on learning itself as a process is not explicit within the language used by stakeholders, perhaps because of their lack of need to reflect overtly on the process. Where learning is emphasised, there is a focus on changing practice. For example, a farmer reported that they were learning from people around them all the time, particularly people such as the WRT and their partners within the agricultural diffuse pollution project. The farmer claimed that they needed to be pitched ideas for new ways of working or for new initiatives to manage the water on the farm otherwise the options available would never be known. He described a situation in which a suggestion about habitat creation alongside flow management in drainage ditches was initially rejected by him but after a process of reflection, exemplification and discussion, it became feasible. Foundational understandings of learning (e.g. Kolb, 1984) describe learning as facilitated by reflection upon experiences, which then inform a decision to apply concepts or ideas through active experimentation. This process of learning can be referred to as single-loop learning as the farmer has adapted his actions and understanding on an individual level. This type of learning is occurring regularly within the Wear catchment network and is facilitated by the different types of exchanges and spaces of interaction that are represented by a network structure, particularly influenced by the CaBA process. The types of learning facilitated affect the functionality of the network as a whole in relation to the satisfaction and experiences of the stakeholders themselves.

Social learning is also a factor enabled within the networked system and is also an enabler of functionality. Social learning is often claimed to occur in collective or collaborative management situations and can be argued to be a process that contributes towards positive environmental change through the facilitation of social change through learning from others (Pahl-Wostl *et al.*, 2007). Social learning may be effective where a change in understanding occurs, where that change is situated in the wider social community or network and is a result of social interaction (Reed *et* *al.*, 2010). Social learning may result in the change of collective norms and behaviours and may be able to be observed as structural change in interactions and relationships. Arguably within the Wear catchment social learning has occurred through the process of CaBA, where the stakeholders have identified a specific growth in knowledge (section 5.3.2.1). The occurrence of similar changes in behaviour across stakeholder groups and in different situations (growth of collective meetings, partnerships, intermediary roles and collaborative projects) may demonstrate that changes have occurred across the wider social community. Keen *et al.* (2005:6) have defined social learning as "the collective action and reflection that takes place amongst both individuals and groups when they work to improve the management of the interrelationships between social and ecological systems." Social learning offer the chance to learn about and act to improve situations (Ison *et al.*, 2007; Collins and Ison, 2010). Processes of learning can therefore affect and be affected by the changes in network structures that produce and represent the efforts to improve interrelations.

6.3.2.3. Power relations and resource allocation

The exchanges of knowledge, data and funding within a network are influenced by the power relations that exist in the catchment and that play out within a governance process. Although power has always been a difficult concept to define, it is arguably representative of abilities or capabilities (Morriss, 2006) and is facilitated by social relations. Power defined as ability is also associated with power over others, which refers to the power of people to influence others (Boonstra, 2016:22). It has been theorised that the power to influence can only exist within socially structured systems in which indirect dependence of actors means that people shape the conditions under which other people interact (Pansardi, 2012; Elias, 2012 [1970]). Power within the system can be associated with ability of certain groups to make decisions that affect the ability and opportunity of others to act to fulfil their own as well as collective agendas. Certain actors may create situations in which the power imbalance is evident, acting to enable or block certain processes or practices. The power dynamics likely affect the nature of relations between stakeholders and therefore affect the functioning of a networked system and reflect on the functionality of the collaborative governance process.

Key themes emerged from the empirical data and will be discussed and exemplified in the following section detailing powerful positions in the system and the influence of money on power relations.

Powerful positions in the system

From the view of the catchment management system as a network the most centralised actors can be seen as the most powerful (Newig *et al.*, 2010). The EA are associated with a strongly centralised position in the Wear catchment network, which is arguably a reflection of their position of power. Stakeholders within the Wear catchment talk of the importance of the EA based on their ability to influence and the level of support that they offer. For example one stakeholders describes the EA's role in the catchment:

> *the EA has a lot of, not necessarily power, which obviously they do, but they have a lot of influence with what happens with the partnerships because if they decide that they are not going to support the coordinators in the same way [then…]. Or a lot of the partnerships rely on that EA support at the moment, not all of them, maybe not the ones that are more established, but certainly over here in the North East they are playing a really important role. (Stakeholder #23)*

The stakeholder shows that she believes that it is important to label the EA as influential. In the absence of the direct label of powerful, despite the acknowledgement of its existence, the influence the EA have over the direction and action within the partnerships is described as important and a way to differentiate the EA's role from other groups. Equally, the EA's supporting role is described as central to their level of influence, with the unnamed consequences of withdrawing support deemed an important signal of the possible negativity associated with absence. The stakeholder's allusion to other catchments is an acknowledgement that each process of catchment management is different, where different histories of collaboration or different lengths of time working together can affect the level of influence certain actors have within the system.

Despite their influential position the EA are rarely criticised directly by other stakeholders but are recognised as different from the role of other groups, even those that are also centralised within the catchment network. For example a representative of the WRT, an organisation also identified as central to the catchment network in the Wear, reflects on the role of the EA in terms of decision-making ability:

> *I don't feel like we as a Trust, it's not up to us what decisions are made, it does still lie with the EA and DEFRA and that is because they are appointed to do that work and that's fine as long as they are taking into account people's views.* (Stakeholder #4)

The stakeholder acknowledges that the wider system of governance has assigned responsibility (and thus, power) to the EA to make decisions, which is acceptable, likely because it is the norm for governments and government-led bodies to set agendas and make decisions. However the fundamental recognition of governance processes is that they include both state and non-state actors and act to facilitate power sharing, particularly where collaboration is part of the agenda Governance can, however, be seen (or critiqued) as being the way that government gets its work done (Frederickson 2005: 296) and the lack of ability to deal with the complexity of changing governance practice involving overlapping of existing democratic and political institutions and practices may mean that governments still hold power and ability to steer practice.. The condition placed on the acceptance of the EA as a powerful decision-maker in the Wear catchment is the accountability of the views of other groups through the decision-making process, which allows some change to be felt in the balance of power by beginning to influence the outcome of the decisions made by the EA: a process that is arguably one of the aims of the CaBA.

Power can also be understood as the ability of actors to influence outcomes (Boonstra, 2016). The acknowledgement of the lack of power by other stakeholders can reflect a dismissal of the legitimacy of certain groups and a reason for exclusion from a network. For example, a land agent within the Wear catchment described a situation in which forested land that he was responsible for managing as part of an estate in the catchment became the site of conflict when some of the trees were required to be cut down as part of the management requested by the land owner. The felling was opposed by a local group concerned about the potentially significant habitat loss. The group were reported to have tried to stop the felling going ahead, but lost out as the land agent had obtained a legal license to cut down the trees and had gone through the relevant checks and procedures to ensure minimum damage, and therefore the action could not be affected. The land agent felt frustration with the conservation group and their attempts to stop the works organised by himself and stated that the groups:

> *Call themselves environmental groups, and they have no powers, and they are just self-named. (Stakeholder #2)*

The lack of legitimacy given to the group at the time was influenced by the way in which the interactions took place. The land agent claimed that the environmental group did not use the correct consultation channels to communicate their thoughts about the actions, therefore were labelled as illegitimate. This acknowledgement of correct or normative channels of contact and communication shows that power is essentially created by legitimate structures of interaction, and that the structure is facilitated by more powerful groups at particular times. Thus the power dynamics between stakeholders influence and are influenced by the relationships in existence in a network.

The influence of money on power relations

The powerful groups in the catchment are defined by their ability to affect decisions, action and change. Money is arguably one of the strongest influences or reflections of power in relation to catchment management as it is an enabler of action. Therefore a lack of money is a barrier to action. The winning of funding is one of the core legitimisation processes amongst the actors associated with water management and all stakeholders in some way struggle with the sourcing of funding and strive to win funding to further their own, as well as collective agendas. Some stakeholders have the ability to fund others and therefore exercise power in their decisions about who to fund and when to share funding. One stakeholder recognises that money is a dominant influence in the catchment management process, despite her opinion that it may not be ideal:

> *It shouldn't be about power because it should be [about] recognising that different stakeholders have different things to offer, and then what makes it about power is about money at the moment (Stakeholder #23)*

There is a clear recognition that money is at the root of some of the power dynamics at play in the catchment. The stakeholder also implies that the dominance of money means that certain aspects of stakeholder's skills, abilities and priorities may go unrecognised because of this dominance.

Within CaBA, the dominant source of funding (the Catchment Restoration Fund, at the time of research) is officially associated with meeting WFD priorities and is administered by the EA as the body responsible for the implementation of the WFD. This is not the only form of funding administered by the EA and the association of the EA with funding and thus power, is widely recognised amongst the stakeholders, as demonstrated by the same stakeholder representing NWL:

> *the EA are incredibly powerful because if you are not in with the EA you don't have that route to WFD funding, so if there was some other funding route that we know we could come through, […] partners would be able to judge the power balance better. (Stakeholder #23)*

There is a recognition that the power of the EA is related very strongly to their ability to fund projects and that this skews the power balance within the system. The recognition of the need for other sources of funding may show that the network is too centralised and perhaps overly reliant on that WFD funding sources as a catalyst for action.

Barriers to functioning of a governance network can be affected by other groups associated with funding. As has previously been noted, NWL are recognised as a powerful actor because of their access to monetary resources and ability to effect change in water infrastructure in the catchment. NWL's relationship with the WCP, for example, includes the allocation of £9,000 to fund activities in the catchment, alongside other financial commitments to projects or activities. However, complexities within NWL associated with its private business status mean there are restrictions on the way in which money can be spent and allocated to certain projects, including the WCP and associated activities. Such restrictions mean that barriers and difficulties are faced within the management system that affect the way in which relationships (links) within a network form and change.

First, NWL sees financial contribution to the catchment-management process as investment and therefore requires evidence of effective returns in order to justify the grant. As such, for example, the financial support given to the catchment partnership was conditional, as one stakeholder states:

> *We [NWL] asked them [the WCP] to come up with, a maximum of five issues that they hoped they would solve for us, or help us to resolve within the partnership, so that would be of use to us, but showing us that they are spending that money in a way that we get benefit from. (Stakeholder #7)*

It was acknowledged that this requirement was restrictive in terms of setting priorities for action within the catchment partnerships due to the focus required on certain activities that meet the needs of NWL, which may not align with other organisations' priorities:

> *I find it a bit divisive that it is a catchment partnership but then the hosts have got to do stuff for us [NWL], which is sort of separate to what the partnership should be doing. [The partnership…] is crossing the wide range of bodies that [are] involved […], whereas that bit of money [is] just for working on NWL type projects. It's still going to hopefully help with water-quality issues and all that sort of thing, but I thought it was not really in the spirit of what the partnership was about, but that's what the director said and we have to go with that." (Stakeholder #7)*

The presence of the funding from a private organisation that is able to set the agenda for the projects that are funded is impactful on the functioning of the governance network. Particularly impactful is the decision making of the director of organisations such as NWL, who may have the ability to adjust funding priorities and expectations.

Secondly, the mismatched scales over which decision-making and funding allocation occur in the catchment-management process and within NWL can cause barriers to functionality. For example NWL plan the allocation of funding within their business in five year cycles, culminating in an Asset Management Plan (AMP) each cycle. The five-yearly cycle is often referred to as problematic due to its mismatch with timescales over which processes like catchment management operate. The mismatch has resulted in a difficulty of NWL committing to or taking advantage of opportunities to allocate funding to projects or schemes devised by the WCP, and has resulted in the need for significant communication, contact and discussion between NWL and partners such as AONB, WRT and EA in order to ensure the most effective balance of funding in future AMP cycles. One stakeholder representing NWL describes the mismatch:

> *We didn't budget for it [the allocation of funds to the catchment partnership], […], which causes some tensions, because it's coming out of money that was earmarked to do something else. […] I think it would be a lot easier for us if we had written it in our business plan but at that time, working between 2011 and 2013 submitted in December, we'd only put our reps in place in summer of 2013 or something, so some of them were earlier, and it was too late to be in the business plan" (Stakeholder #7)*

The mismatch highlights that the pace of change in the business could not account for the pace of change in the catchment management process meaning the funding from NWL lags the needs identified in the catchment. This mismatch may be associated with the newness of the CaBA and the difficulty faced by NWL in incorporating new priorities and ways of working. The slow change in practice is reflected in the lag in or lack of funding, as well as the change of behaviour of some of the other stakeholders in the catchment to accommodate for the delays (such as waiting, implementing interim fixes, looking elsewhere for funding and organising strategy meetings with NWL to affect future budget allocation).

Issues of funding and associated power can also drive the functioning of a networked system by encouraging collaborative behaviours that pull organisations together and strengthen relationships and links. For example an NE stakeholder reported that through partnership working they would seek to work with other organisations who had skills and expertise in searching for and applying for funding opportunities, making the most of their own skills alongside the skills and experience of the other organisation to win joint project funding for collaborative work. Equally, a stakeholder from the WRT claimed that part of the driver for creating strong, open communication with other organisations within the catchment, through structures such as the partnerships, was so that they would know about work going on in the catchment and be able to apply for funding for projects to fill the gaps in action and priorities as well as make requests for match-funding. Both examples demonstrate the ability of the availability of funding to play a part in encouraging the strengthening of relationships and therefore the functioning of a networked system.

6.3.2.4. Trust and uncertainty

Trust is a central concept in the process of collaboration and its presence or absence in multiple forms is likely to underpin the relationships within a governance network. Trust has long been defined as important within collaborative NRM through its recognised role in driving collaboration, conflict resolution and learning (Ostrom, 1990; Pretty and Ward, 2001). Uncertainty plays a significant role in creating conditions in which there is a need and opportunity for trust (Rousseau *et al.*, 1998). Under conditions of uncertainty it can never be fully known if the trustee will fulfil the expectations of the trustor nor if the context is likely to affect the fulfilment of expectations adversely. Different types of trust exist (Sharp *et al.*, 2013) and the presence of trust as an attitude that deems someone or something trustworthy, and the act of deciding to rely on that entity (Castelfranchi and Falcone, 2010; Sharp *et al.*, 2013) might encourage certain behaviours. Behaviours could include compliance, sharing, collaborating, engagement, constructive debate and participation.

Key ideas emerge from the empirical data outlined in the following sub-sections covering ideas of trust manifested in good relationships and exploring the consequences of lack of trust, uncertainty and weak relationships.

Trust manifested in good relationships

In the Wear catchment the presence of trust is implicit in stakeholder action and reaction to one another and the environment. The presence of 'good relationships', which usually consist of sharing and collaborating to the extent that the parties involved are satisfied that their expectations are being met, is likely to indicate higher levels of trust. In the Wear many stakeholders assessed relationships with other organisations as good and working well, which can be seen as stronger ties in a network and are likely to be where there is more trust. Such trust could be built and created in a number of ways including through personal or professional history, cultural norms, cognitive or emotional assessment, perceptions of legitimacy or evaluation of information, which are then affected by context and power dynamics to produce the resultant behaviours (Stern and Coleman, 2015).

Lack of trust, uncertainty and weak relationships

A lack of trust and the presence of distrust are more visible within a networked system as stakeholders often pick up on the times and places where lack of trust is problematic, such as around the exchange of data, legitimisation of knowledge or assignment of funding. Behaviours associated with lack of trust may be avoidance of decision making, dropping out, apathy or damaged performance (Noteboom, 2002; Ohno *et al.*, 2010; Smith *et al.*, 2013). Often the uncertainty in a situation is more articulated than the lack of trust associated with it. For example, a representative of NWL reflects on the reasons why they have been reluctant to commit to soft water management projects within the CaBA:

> *So we might be better to spend money upstream of our assets, but it's trying to make sure that that will work long term […]. If we put that bit of plant in we will be running it, we know how to make it work and we know what will be coming out of the end of the pipe, whereas the softer type approach might work, but if the farmer changes and he's going to revert back to putting a lot more fertilisers on […], it might not lead to a long-term solution" (Stakeholder #7)*

The NWL representative implies that there is a mistrust of farmers as actors within the system, based on the lack of certainty around predicting the consistency of their behaviour in relation to reducing fertiliser application, the expected outcome. The decision-makers in NWL have calculated that the risk of adverse effects on their own company if the farmers behave unpredictably are too large to take the step to trust the farmers (trust as a belief) in order to invest in the projects associated with upstream solutions to water pollution. This behaviour is likely to be a combination of a lack of different types of trust ranging from a mistrust in the individual farmers in this context (dispositional), to a mistrust of the procedures associated with the solution to decrease the vulnerability to NWL (procedural). The resultant inaction of NWL is also associated with a predicted lack of evidence and data to prove effectiveness of the upstream solutions, which adds to the perceived uncertainty. Both the actors and the situation are deemed untrustworthy and therefore the step cannot be taken to trust and therefore build the links and structures associated with a new way of working.

New ways of working that bring stakeholders into joint projects do not always indicate the presence of trusting relationships, therefore particular patterns of interaction are not necessarily productive if other factors that affect trust are not addressed. For example, a group of anglers involved in a stakeholder meeting to discuss the issues on a watercourse in the Wear, facilitated by the WRT as part of an initiative derived from the WCP discussions, claimed that:

> *They split us into four groups and we had to write it [ideas] on post-its, they are asking for you to think about it and then pinching your ideas" (Stakeholder #10)*

The opinion of the stakeholder that their ideas are being stolen rather than contributing to a priority setting process shows that there may be a lack of procedural trust in the system to bring benefits to the stakeholders in the future. This mistrust is perhaps based in previous experience of interaction or in an imagined future process that is unfamiliar and therefore risky and uncertain for the anglers. It is not an explicit mistrust of the WRT as a lead organisation, as the same stakeholders talked of their positive relationship with the staff members of the WRT. Therefore the process may be the source of the mistrust. The lack of trust may mean that the relationship within the structural interactions is weak and may be vulnerable to breaking, causing loss of network function. If the process and the outcomes for the stakeholders involved was more certain, the trust of the stakeholders might be stronger.

Overall, trust, associated with uncertainty and risk is a factor that is likely to affect most relationships within a catchment management process and therefore play a significant role in the functionality of a networked governance system. The presence of certain behaviours around sharing, interaction and openness that are evident when issues of data, expertise, legitimacy, knowledge and power are considered can be seen to be rooted in the presence or absence of different types of trust (procedural, dispositional) and the assessment of actors as trustworthy. The individual dispositions of the actors and their organisational behaviours, as well as contextual and cultural norms and rules affect the trustworthiness of other groups, and the decisions and opportunities to act on feelings of trust build relationships and network structures of interaction.

Overall at the interactional level

The interactional level of functionality is an important scale to consider in a networked system as it is the site at which relationships play out and become evident. Factors that are central to the understanding of networks at this scale are associated with the legitimacy of data and evidence as a driver for the formation of relationships, as well as the understanding of the expertise of others and the creation or ownership of knowledge. Learning is seen to play a role in driving changes in relationships and structure. The dynamics of power often underpin interactions and are evident through exchange of resources such as money. The types and levels of trust between stakeholders and of particular situations and processes, strongly associated with ideas of uncertainty and risk, can equally be seen to be significantly involved in the production of patterns of relations within the catchment-management process.

6.4. The individual and organisational level of functionality

Understanding how different groups relate to the environment and are motivated to act at the individual and organisational levels are important parts of the catchment-management process and relate closely to understanding the dynamics evident at the interactional level. Although the evidence for dynamics at this level is less detailed, the interconnections between the individual and the interactional distinctly affect the overall system. A better understanding of how factors inform certain decisions to act, interact, share, exchange, trust, mistrust, or participate is important when considering the networked system as being fundamentally structured through decisions. Inasmuch as each stakeholder is influenced by factors such as motivation, sense of responsibility, goals and social and organisational norms, each stakeholder is affected by the way they understand other stakeholders' motivations and perceptions, which may influence desires to change or align behaviour, or to learn from and accommodate others through collaborative processes.

6.4.1. Factors affecting functionality

6.4.1.1. Perception of the river environment

Pahl-Wostl (2002b) claims that every decision made in NRM (and any other field) is based on subjective perceptions of the world. Such subjective perceptions make up a mental model held by each stakeholder about the way a system such as a catchment management works. Perceptions may be held about the system based on experience, access to data, cultural and social practices, personal values or institutional expectations. Mental models may be shared amongst stakeholders through collaborative relationships and may be combined to co-create new collective perceptions and mental models (Manring, 2007). In some cases mental models and therefore perspectives can be changed through process of interaction with other stakeholders. Processes such as social learning have sought to explain the way in which mental models and the decisions facilitated through mental models and stakeholder perceptions can be changed through the interaction of stakeholders. In the Wear catchment there are many different ways in which the catchment-management system is perceived and understood due to the many different stakeholders that are involved. Some interactions within the networked catchment system can be seen to be influenced by the recognition of differences in mental models due to the range of perceptions. Some stakeholders see a need to change and align perceptions in order to fulfil the overall aims of the management process and such a recognition is often the driver of collaborative approaches, such as CaBA. Perceptions that are recognised as needing to be changed or aligned are both associated with stakeholders' understanding of the quality of the natural environment and with their perception and understanding of their own role. Such perceptions can be seen to be formative of other individual factors such as motivation to act, a sense of responsibility or a specific goal to achieve.

Key points emerged from empirical analysis covered in the following section under themes exploring perceptions and mental models, the influence of trusting relationships and the multiplicity of perceptions.

Some stakeholders picked up on moments where a difference in perception was recognised alongside a desire to change the perception or mental model, leading to new interactions that could be seen as part of the structure of a networked system of management. For example a representative of the AONB stated that:

> *It is not always very obvious to communities in the North Pennines that there is an issue with contamination because the rivers run clear, if they haven't lived here for very long they wouldn't have noticed that there is not many fish or invertebrates, and in fact sometimes there are fish so it seems to be a functioning river, and they have always seen the adits pouring out water and it doesn't seem to be an issue, so there is quite an explanation role there" (Stakeholder #16)*

The difference in perception of the problem associated with river water quality in the area is recognised through the understanding that communities may only be able to visually assess the river water quality, which may not lead to the same perception of the problem as AONB staff who have access to other forms of knowledge and evidence, as well as perhaps different expectations of the characteristics of the river as a resource. In recognising the difference the AONB representative implies that the perceptions and the likely mental models of the members of the community might lead to a certain level of apathy and inaction if there is not perceived to be a problem needing action. The AONB therefore see their role as the organisation who explains and communicates the different forms of evidence in support of the particular problem definition understood by those associated with management. The communication is hoped to influence a change in the perceptions of the community and encourage a change in behaviour in relation to their role in the management process. Such changes in perception are facilitated by links and structures in a governance network such as meetings or events or moments of communication. Therefore the understanding of the difference in perceptions and mental models is a driver for particular structures in a network that may lead to stronger relationships and connections.

The mental models adopted by stakeholders can cause barriers to the functionality of a catchment management system. For example, a representative of the Angling Trust describes the difficulty in getting the farming community involved in efforts to manage water quality. He specifies that there has often been a lack of acknowledgement that the activities and behaviours of farmers might be contributing to the problem of diffuse pollution. He attributes the particular perception as community-wide and due to the refusal of senior managers in agricultural support organisations to acknowledge the problem:

> *Having NFU [National Farmers Union] and CLA [Country Land and Business Association] accept that there is an impact has been challenging, and that probably reflects down the chain.* (Stakeholder #5)

His implication in the reflection down the chain is that farmers' perceptions are affected by the models of problem-perception used by these influential organisations. As such the stakeholder demonstrates that perceptions and mental models can influence the decision to ignore communication from other stakeholders, causing breaks or blocks in the system as a network, perhaps then influencing the structures that are sought in order to overcome the barriers to functionality. For example the use of intermediaries to communicate and collaborate with farmers, as is done in the Wear catchment.

6.4.1.2. Social and institutional norms

Social norms can be defined as shared understandings or rules in relation to actions that are permitted, obligatory or, conversely, unacceptable (Crawford and Ostrom, 2013). They are seen to underpin the behaviour of people in collective situations, including NRM (Minato *et al.*, 2010). Different individuals have varying strengths of conformance to social norms, which affect the way in which they behave in relation to the behaviour of others in the same situation. Within the catchment management system it is likely that adherence to social norms, as well as to institutional and organisational norms, affect the way in which stakeholders interact with others and make decisions about courses of action and therefore the formation of links and structures of interaction within a network. Both the norms themselves and the adherence to the norms can be enablers or barriers to functionality. Within the Wear catchment the role of social norms is implied through the way that the changes in stakeholder behaviour have emerged or have been resisted.

Key points emerged from empirical analysis covered in the following section under themes exploring cultural behaviour, change in practice and change in institutional norms, the role of spaces and places of interaction and the influence CaBA on social and institutional norms.
Social norms can influence the success of projects within the catchment and influence the way in which those stakeholders planning projects attempt to connect with others. For example a representative of DWT reported that the normalisation of flytipping amongst local communities caused a barrier to success in achieving aims of a stream-cleaning projects:

> *I think we really improved it [Herrington Burn] and I think that we made a difference and we got through to some people but not on the scale [that was needed], not when everyone has been flytipping, when they have grown up flytipping in that river, they don't see it as a river. (Stakeholder #20)*

The strength and longevity of flytipping as a social norm is seen as a difficulty faced when attempting to make a difference through project work to decrease the impact of pollution on a significant scale in the sub-catchment. The DWT representative implies that the acceptability of the flytipping behaviour amongst the community through processes of learning and imitation means that it is very difficult to change behaviour through projects. The difficulty posed by strong social norms means the partners may not be easy to get on board. The stakeholder goes on to state that the planning of projects that aim to act to change social norms amongst communities "*take a lot of time trying [for example] to get the council on board",* but have got "*nowhere",* partly attributed to a lack of funding over the long term, which would be required to change patterns of social behaviour. Therefore factors such as social norms act within the complex system to shape the network that emerges.

Institutional norms can also pose a barrier to functionality within the catchment-management process. For example, an NWL representative reflects on the role of culture and the influence of a 'mentality' within the business:

> *In terms of the catchment partnership working, there needs to be a culture change throughout the business particularly information sharing, […] we want to protect our reputation and traditionally we are very private, we do what we do and we do it ourselves, we have to work with others, but we do it ourselves. That mentality, there is an awareness that [it] needs to change, but actually having that change, it's going to be really difficult to actually effect that, and traditionally there is still that [self-reliant] mentality. (Stakeholder #23)*

The strength of the mentality and the normative practices of self-reliance that result are seen as problematic when change in behaviour is expected or required. The normality of a particular attitude and particular patterns of decision making are formative of the resultant relationships and actions that make up a network. Therefore the type of interactions that are sought are affected by the knowledge of the embedded nature of the normative practice in the business. The creation of an intermediary role (Stakeholder #23), sitting within NWL but associated with the WCP, is a reflection of the need to build trust within the business in a new way of working so that new norms of behaviour can become embedded.

Interactions and structures with the network are shaped by an understanding of social norms and may represent an opportunity to provide the spaces in which new norms are created and new behaviours justified and made acceptable. For example a representative of the farming community stated that in the Wear catchment the farmers are very competitive and don't often communicate knowledge or information to one another. The agricultural diffuse pollution project set up by the WRT organised a meeting in which farmers from the catchment could meet, get to know one another, share knowledge and learn from groups such as WRT, Durham University and FWAG (Farming and Wildlife Advisory Group). This meeting recognised that there was a culture or normative behaviour amongst the farming community that meant they were competitive and potentially isolated as a group rather than open to collaborate or work with others. The presence of time and space to interact and learn from one another was aimed to begin to change the norms of behaviour. The representative of the farming community claimed that the meetings were good for getting to know people and one of the only opportunities to do so. The project and its meetings therefore provided a chance to change the normative behaviour of the farming community in relation to water management. The value and function of the network structure is evident in the positive assessment of the outcomes given by the farmer.

Across the whole catchment the CaBA has been influential in changing social and institutional norms, and is evident in the way that stakeholder talk of the emergence of their roles or of certain structures and interactions. For example, where there has been roles of catchment coordinators created in organisations such as AONB or NWL, the stakeholders imply that the creation was influenced by the behaviour and working patterns of others within the catchment, where their own roles were created in order to match and fit in with the new norms of interaction around water management. Equally, the existence of internal group meetings in the DCC or EA were implied to have emerged from a need to change behaviour to match the new norms and the new accepted way of working. The emergence of such structures show the potential sensitivity of the actors to changes in social norms and the need to fit in with the new way of working, and therefore a desire to change. This awareness is an important enabler of the evolution of the CaBA in the catchment and the formation of a distinct network as a result.

6.4.1.3. Motivation and goals

Each stakeholder is motivated at different times for different reasons to act or interact with others in the catchment as part of the catchment management process. The goals, priorities and expectations of each of the stakeholders also influence the decisions that are made in relation to the motivation felt.

Key points emerged from empirical analysis covered in the following section under themes describing differing goals and priorities, the value of shared goals and an open attitude, and the role of passion, persistence and persuasion.

In the Wear catchment all stakeholders interviewed talked of different priorities for their own activity in relation to water management, including delivering legislation, maintaining economically profitable environments, reducing particular pollutant levels, monitoring pollution sources, working with partners, educating children, achieving good status, meeting other targets, improving efficiency, managing data sharing, encouraging community ownership, affecting national strategies, complying with regulation, and maintaining habitats, among others. Rarely are the key priorities amongst stakeholders exactly the same. Such variation demonstrates the complexity of the situation and relates to the need for interaction that allows for the identification of which priorities are shared and when, acknowledging that new co-created priorities might also need to be created to unite the groups.

The need for interaction is particularly the case when priorities are perceived as mismatched. For example in the Wear catchment there is a difference of priorities between the EA and anglers. As such there can be a lack of trust, which affects the strength of the relationship between the organisations and may be representative of a weaker link in a network. A representative of the EA states:

> *We are not about fish or a species of fish, we are about the environment and we work on the basis that if we protect the environment then the knock on impacts will be a benefit to everything else, so we don't become very focused. […] I accept that stakeholders don't agree with me on that […] and I know that particularly the angling community feel particularly that we don't listen. (Stakeholder #14)*

The EA stakeholder recognises that their priority to protect the environment more generally might seem mismatched to the anglers' more specific priority to enhance the population of a certain species of fish. The mismatch is acknowledged as leading to a feeling of not being listened to, which can be symbolic of a lack of trust. It is known that the relationship between some anglers and the EA is mistrusting and therefore problematic. Such relationships may be influenced by the perception of mismatched goals and priorities, which may influence the way in which the interaction between anglers and the EA is shaped, particularly in organised management, where the proactive creation of spaces of deliberation and the maintenance of communicative relationships can offer opportunities to build trust.

Where there is an alignment of priorities between stakeholders the relationships are strengthened and the network more functional at the times and places where strength is needed. For example a group of anglers in the Wear who have a good working relationship with the EA, which they claim is based on a mutual respect and ability to help one another, state that they understand the need to work with broader priorities:

> *We wouldn't raise a problem if it was [just based on our own interests], it's not just 'oh you're trying to make everything better for the angling', we are not, they [the EA] know that. I mean [the work we do on] Twizell Burn, Cong Burn, Stanley Burn, it's got nothing to do with fishing, it's for the people of Stanley. (Stakeholder #10a)*

The claim that the anglers are motivated by the belief that their work and projects will bring benefits for the whole community is seemingly aligned better with the priorities claimed to be held by the EA. This alignment and understanding of the need for prioritisation outside of their own interests allows the anglers to be open to more joint projects and collaborative work, which this particular group are involved in. Thus the understanding of and adjusting of priorities to match other stakeholders is formative of productive and strengthened relationships, which may be foundational to a networked system.

Motivations that drive the prioritisation of decisions and actions are also varied throughout the stakeholders involved. Some motivations are implicit in the words and actions of the stakeholders. Often it is clear that stakeholders are motivated by a passionate concern for natural resources. Sometimes this emerges through the commitment to the fulfilment of a professional role and other times through the drive to be involved voluntarily in managing the water resources. Evidence of motivations and strong motivation may also therefore be apparent in the persistence or commitment of individual stakeholders. For example, a number of stakeholders in the Wear catchment described times when, in relation to achieving their priority goals, they were required to consistently ask for an action to be undertaken by another group, or information to be passed on, or funding to be given. The need for persistence indicates that there are places and times of resistance within the catchment management network, but that the commitment and motivation of stakeholders to fulfil a particular agenda allows the resistance to be sometimes overcome and for resources to be exchanged or an action completed. The motivation of groups to achieve the action and the willingness of other groups to respond is foundational to the emergent effect. An example of this persistence and motivation is an NE officer reporting that he persuaded the EA and NWL to be involved in a project to solve a point source pollution problem:

> B*asically [the problems got solved by] me ringing up [NWL] all that time and making complaints, wringing their necks, get the EA involved as well so they didn't have any choice but to just crack on. (Stakeholder #15).*

The persistence stemmed from his motivation to fulfil the goal of improving the water quality of the burn in the area of land he was responsible for managing. He used his professional status and formal channels of communication to give evidence of negative effects of the pollution that NWL would have to respond. The involvement of the EA is a demonstration of the stakeholder's strategic use of the power dynamic between the EA and NWL, through the EA being an actor able to enforce legislation, make decisions and work collaboratively with NWL. The motivation of the stakeholder played a significant role in inducing activity and creating action based on relationships and communication.

Another example is the persistence with which some anglers attempt to win funding for projects to improve the river and streams. For example, one angler states that:

> *We are not shy, we are not afraid to go knocking on doors begging for money off different [groups], the EA and things like that. (Stakeholder #12)*

The persistence shown is a reflection of the motivation of the angling group. This particular behaviour was claimed by the anglers to contribute to their reputation as confident and knowledgeable about processes within the catchment management process. As such they reported becoming a desirable contact for other angling clubs who wanted to carry out similar actions. Their motivation to persist created links and built a network of other similar stakeholders around them. Angling groups also claimed that "*the vast majority of people who come on the bank […] have a deep, deep passion for the river and everything*" (Stakeholder #10), which could be argued as the basis for the motivation to act persistently in terms of the winning of funding from the EA. However, there may also be other interpersonal reasons for such persistence (McCreary *et al.*, 2012) including satisfaction in winning funds, recognition by other groups as successful, status, promotion of the angling club, or enjoyment. Although the root of the behaviour may not be able to be fully known, the effect of persistence driven by specific motivations builds aspects of a catchment-management network, and is a particularly important enabler where resistance to the expected change or action exists.

6.4.1.4. Sense of responsibility or ownership

A sense of responsibility can be a driver of action within a catchment-management system. Responsibility can result from a personal sense of morality or duty, but is often also officially assigned and normalised at an organisational level through institutional practice and governance decisions.

Key points emerged from empirical analysis covered in the following section under themes exploring the presence and absence of official responsibility, informality, the roles of communication, negotiation and persuasion, and the creation of new senses of responsibility.

In the Wear catchment it is generally acknowledged that there are core organisations who have responsibility for significant issues, as described by a WRT representative in the Wear catchment:

> *There is also the different responsibility things, so NWL are responsible for the sewage network and the CSOs, and then the council are responsible for what is now ordinary water courses, and any sort of consents along those, then the EA have the main river responsibility, and then there is us [WRT] that have different projects and want to kind of build in or add value to what is being done. (Stakeholder #4)*

There is a clear-cut responsibility assigned to organisations such as NWL, EA and the DCC, which are the organisations that are seen as the most central and powerful in decision-making (EA and NWL) in a catchment network.. The official responsibility may affect the relationships built as other stakeholders recognise the responsibility other groups hold and may pursue connections or share knowledge in order to induce action. The recognition of the WRT as being more flexible in terms of action, due to a lack of official responsibility, is a reflection of its charity status and its ability to vary project focus based on need. The WRT is also seen to be a central actor in the configuration of the governance network in the Wear, which may also be associated with its ability to build relationships and projects with a wide variety of organisations.

A sense of personal responsibility is also evident in a number of the actors in the Wear catchment and is seen to inform some of the drive behind the decisions that they make. This sense may be manifested in professional roles, for example, one representative of the EA states:

> *I do actually have a responsibility and I actually have the authority to make big changes and it can be frustrating when I come up [against] obstacles […] [I think] 'for goodness sake, we have just worked so hard with so many different people. (Stakeholder #17)*

This stakeholder's sense of responsibility facilitates a need to overcome obstacles, and can be seen as part of the root of her motivation to act in a situation in which there is a setback or problem. Her motivation and responsibility may mean she is more likely to persist to a solution, utilising the relationships she describes as part of a network

A sense of responsibility is also felt by stakeholders who do not have a professional role, but are voluntarily involved with water resource management. For example, a representative of an environmental community group stated:

> *I do like the idea of the WRT where they get the community people involved and we do this monitoring, it's our area, we should be looking after it and that is part of our responsibility, not a lot of people want to do it but I think it's a necessity especially if we want our streams and rivers to stay clean and healthy. (Stakeholder # 18)*

The stakeholder acknowledges the sense of responsibility associated with an ownership of the area as a local resident, informed by a desire for clean and healthy rivers. She notes the role of the WRT in providing an opportunity to act on the sense of responsibility and monitor the water quality of the rivers and streams (in this case in reference to the Riverfly project). In contrast to the responsibility felt by the EA, the community group may not be able to act effectively through that sense of responsibility and therefore need the support and interaction with the WRT in order to participate in effective action. Therefore the formation of the network is facilitated by the WRT acting to create new structures of interaction, which functions due to the sense of responsibility felt by the community group members who respond and participate with enthusiasm, motivated by a desire to conserve their local area. The alignment of the desires of the WRT and the community group also aid in the functioning of the relationship.

Where there is a lack of responsibility or confusion about who should be acting in a particular situation there may be a lack of effective action or a change in the triggers for action. For example, one stakeholder describes the existence of a lack of responsibility for mineral pollution in the Wear catchment and the effect on activity:

> *The difference I guess between the lead and the mineral exploitation and the coal is that nobody holds responsibility for the minerals and the mine water, whereas there is an institution with a pinned-on responsibility for managing the water from the coal mines […]. [Therefore, only] if something happens someone intervenes, […] so events rather than intent [drive action]. (Stakeholder #5)*

The lack of legal responsibility for mineral minewater contamination is suggested to affect the way in which action is initiated, being reactionary rather than precautionary. Where responsibility is assigned there is an assumption that there is more likely to be activity that helps to prevent future problems, which is part of the role of groups such as the WCP. The lack of responsibility also drives others to try and fill that gap and the CaBA is formative in facilitating collaborative responsibility where there is no official responsibility. For example, a representative of the AONB reported to be talking to the CA and the EA and WRT about the issue of lead and zinc pollution, with the possibility of coming up with joint projects and beginning research projects. The lack of official responsibility therefore creates a void in which collaborative responsibility can be taken up through the networked structures of the catchment management system.

A lack of the uptake of perceived official responsibility can also be a catalyst for relationships and action. For example, an angling groups in the Wear reported that the NWL had sometimes (they believe, purposefully) ignored their communication about water pollution in the water courses and not acted to solve the perceived problems. The anglers believed that it should have been the responsibility of NWL to respond to the problems and therefore acted to induce action through persistent communication with the NWL:

> *A lot of the time they either don't know it's there [the water pollution problem] or they are trying to sweep it under the carpet, so if they don't know it's there we tell them, if they are trying to sweep it under the carpet, we tell them twice, three times, four times, five times. (Stakeholder #12)*

The persistent action of the angling group, alongside being driven by the motivation of the anglers, is also likely to be affected by the perceived lack of uptake of the responsibility of NWL. The barrier to action exists where the expected outworking of that responsibility is mismatched with the actual reaction. There are also likely to be other factors involved in the patterns and timings of interactions, such as the potential reluctance of NWL to act based in their assessment of the legitimacy of the evidence from the anglers related to the power of NWL and the historical interaction with the group. The angler implied that the persistence was effective in inducing NWL to react to the problem, which may indicate the way in which responsibility is also associated with demand for the responsibility to be fulfilled in particular ways in relation to other group's understanding of the outworking of responsibility. These complex factors combine to create the resultant network of interactions and may affect the way in which NWL may act out its responsibility in the future.

As a lack of responsibility can influence the types of structures and relationships that are built, the interactions and exchanges that result can also change or induce a new sense of responsibility through learning and acceptability of new behaviour. For example a stakeholder in the Wear stated that a change in responsibility of local communities had resulted from collaborative action in the Twizell Burn sub-catchment:

> *People's attitude to pollution isn't necessarily 'oh my goodness look at that pollution I must tell someone', they will walk past and go 'mmm it's always like that' and that's something that through the weeks of action and getting other organisations involved we are really hoping to [continue to] change […]. If for example when a CSO is discharging when it shouldn't be, members of the public do report it now because they know that it's not acceptable, so it is gradually changing people's perceptions. (Stakeholder #17)*

The change in a sense of responsibility to report a pollution event, underpinned by a change in perception is claimed to be influenced by the collaborative action in the area, facilitated by the involvement of the EA and other groups. A change in the social norms of reporting of incidents means that the EA is more likely to carry out further action in the sub-catchment and create more projects and encourage collaborative relationships, which builds a more functional network of catchment management.

6.5. The contextual and policy level of functionality

6.5.1. Factors affecting functionality

6.5.1.1. The driving force of policy and regulation

The central driver of CaBA and the formation of new structures and interactions within catchments in the UK is the WFD. The dominance of the policy is purveyed by most of the stakeholders in the Wear catchment, particularly those who have a professional responsibility to help deliver the targets set for each waterbody. Those groups less involved are affected by decisions influenced by the policy such as project funding or prioritisation of actions or the set-up of collaborative projects. The dominance of the WFD is also balanced against the influence of other policies, regulations, management plans and legislation, which are also particularly influential on priority setting and goal definition for individual stakeholders. Some examples include: agricultural stewardship schemes, Catchment Sensitive Farming, Nitrates Directive, Floods Directive, Flood Management Plans, Sites of Special Scientific Interest, Special Areas of Conservation, OFWAT regulations, Asset Management Plan, County Durham Plan, Surface Water Management Plan and National Nature Reserve management plan. These represent other drivers of action and each stakeholder is affected differently by the combination of influences that both constrain and enable actions and decisions.

Key points emerged from empirical analysis and are covered in the following section under themes exploring the driving force of the WFD, the challenges of balancing priorities, modes of affecting WFD statuses, the restrictive nature of goals and sustainable links beyond legislative context.

Necessarily the actions of the EA are most influenced by the WFD. The goal of achieving good ecological status for the waterbodies is clear in the decisions that are made and the relationships that are sought by the EA across the Wear catchment. For example, one representative of the EA stated:

> *The biggest priority at present in the EA business is the WFD, we eat sleep and breathe the WFD, we have got 100 priority waterbodies in the Wear that we are all trying to fix and get to good status as soon as we can, so that generates a lot of work, which might entail walkovers and investigations, identifying solutions, working with partners to get the outcome we want. (Stakeholder #11)*

The central prioritisation of the achievement of the WFD goals directs the actions of the EA in relation to the work they do and the partnerships they pursue. By claiming ownership of the outcomes ("outcomes we want"), the stakeholder shows that the responsibility to meet the targets is felt by the EA and that partnerships are seen as facilitators of the centralised WFD goals. The strength of relationships and the pattern of the network that emerges as a result is therefore shaped by the priorities of the WFD. This centralisation of the WFD does not prevent the formation of relationships not directly associated with the WFD, but the nature of the interactions are still affected by the goals. For example, the same EA stakeholder states:

> *We still have stakeholder engagement with angling clubs to a lesser extent so that would be working on projects, so habitat improvements, […] angler access, bolted on to that there is a vein of WFD that may well run through that, particularly working with the WRT, they have been one of the key deliverers of WFD projects. (Stakeholder #11)*

The instrumental nature of the relationship between the EA and the WRT is evident, as is the value of the WRT as an intermediary able to work between the anglers and the EA in order to translate the action and goals of the WFD into a variety of contexts. The relationships built with the angling community are also influenced by WFD, directly from the relationship with the EA and through the intermediary role of the WRT, perhaps often without knowledge of the influence of the policy. Similarly, a land agent in the Wear talked of the potentially hidden influence of the WFD:

> *Obviously we are beginning to see the WFD rearing its head more and more, although if you were to ask people they would probably have no knowledge that it is the WFD behind it. (Stakeholder #9)*

The hidden nature of the influence demonstrates that the power of legislation in the actions and activities is distanced from the original source, and that the power is thus wide ranging.

Where the influence of the WFD is more obvious is where it is negotiated at the points of interaction within the networked system amongst stakeholders who are working in collaboration. For example, the relationship between the EA and NWL, facilitated through the WCP, involves debates around prioritisation of action, where the ability to meet the WFD targets features highly as an enabler of action. For example, a representative of NWL states:

> *[I've been] looking at the medium-term plan with the EA and trying to pick out the waterbodies where we want to concentrate funding and projects because we know those are ones that we can possibly get them up to good status […] they are also ones where we [NWL] are spending money, it makes sense to target the same waterbodies, [particularly where there is] the best chance of getting up to good [status]. (Stakeholder #7)*

The strong emphasis on the achievement of good status within the waterbodies is a driver for the decisions that NWL are making in relation to prioritisation of actions, which affect the funding available and the relationships and exchanges possible. Deliberation between EA and NWL highlights the shared influence of the WFD and its ability to unite them around a common purpose. The willingness of the two organisations to work together to negotiate where actions and priorities cross over is influential in creating a strong working relationship, which the stakeholders talk of as being an important outcome.. Therefore the combination of the dominance of the WFD and the willingness of organisations to work together (enhanced and encouraged by CaBA) creates the network structure.

The dominance of the WFD can also be seen as less positive by blocking activity based on wider priorities. For example, a representative of NWL states:

> *I mean I don't think we have got to a stage where we have expanded beyond the WFD priorities yet [in the catchment partnership], I don't think we have still got enough community-led projects where people come in and say I'd like to see this happen, so it's not so much bottom-up as top-down from the EA saying this is where we need, [but] I think that will come in time. (Stakeholder #7)*

The stakeholder identifies that the WFD is a top-down driver of actions and may not give space for the more equitable priority setting that he sees as necessary to partnership working. The acknowledgement that the change in priorities may come in time signifies the ability of the catchment management process to change and evolve in relation to different drivers. The stakeholder may be expressing confidence in the sustainability of the networked system and the established relationships within the CaBA.

Barriers are also faced when WFD targets are prioritised, therefore affecting action and funding for water courses that are difficult to improve. For example, a representative of NE claims:

> *It is too easy for them [the EA] to write water courses off, say for example that can't ever retain good status because it's too heavily modified and I've seen that used to basically remove water courses out, which is bad. (Stakeholder #15)*

The stakeholder is referring to situations outside of the Wear catchment, but demonstrates the decisions that can be made to deprioritise particular water courses if they are too heavily modified and cannot achieve the required ecological functions needed to obtain good status under the WFD. This approach is described as "bad" by the stakeholder, perhaps referring to the negative consequences of focusing funding and action away from water courses that have very poor environmental quality, therefore likely poor habitats, recreational options, flow or biology. The ability of the prioritisation to shift the focus of activities affects the nature and extent of relationships and structures that can be created and sustained in that area. There may be groups who feel passionately about the water courses that are de-prioritised and who are then detached from the network and the wider governance process due to lack of funding for joint projects or research.

While the influence of the WFD as a driver of decision-making is clear there are elements of negotiation and manipulation that happen within the WFD assessment and implementation that allow for a flexibility. The WFD status of each waterbody, set and administered by the EA, arguably drive the action and inaction in the catchment, where failing waterbodies often become a priority for funding. The statuses are set based on evidence collected by the EA. Stakeholders, particularly within the EA, can change the status of a waterbody strategically by harnessing the legitimacy of their evidence and making changes to data collection strategies, to take advantage of the power of the WFD as a driver for action. For example, a representative of the EA states:

> *We [are] constantly reviewing WFD, we tweak where we are not comfortable with a fish failure, or conversely we move some of the [data-collection] sites to make the waterbody fail. Say for example a sample site may be below an obstruction and it passes and we might challenge that and say that if you put the survey data above, we have tested that and found that the waterbody would fail and then we'd go,*

> *well, that's more representative, well the reason for failure is that obstruction and it gives us then a driver to fix it with the WFD." (Stakeholder #11)*

The stakeholder recognises the authority of the WFD; that if the waterbody fails or achieves a lower status, with a clearly defined reason for failure, there will be opportunities to gain funding and resources to work on the water course. The ability of the stakeholder to challenge the status of the waterbody and adjust the sampling points based on their personal assessment and experience of the site is representative of the power dynamics in the catchment, where the EA have the ability, capability and legitimacy to influence the status, but where experiential, local knowledge is key to harnessing that ability. The harnessing of the WFD means that the relationships are affected through the ability to gain funding for projects otherwise unjustified. The ability to manipulate evidence affects the functioning of the governance network, mixing the influence of the contextual policy level with the power dynamic of evidence and legitimacy that exist at the interactional level.

6.5.1.2. Funding and budget cuts

At the time when this PhD research was carried out, the UK was undergoing a number of cuts to public sector budgets under the 2010 – 2015 Coalition Government's austerity plan. The cuts extended to the EA, local councils and water companies and affected the ability of certain actors to fulfil certain expected functions at the expected times, such as capacity to respond to requests and offers, ability to deliver projects, ability to support others and ability to collect detailed data.

Key points emerged from empirical analysis covered in the following section under themes exploring resource availability and capacity to adapt.

Table 6.1 shows a number of examples when cuts to budgets have affected possible actions and had an impact on personal and relational levels within the catchment.

Table 6.1 *Some examples of the effect of budget cuts on activities in the Wear catchment alongside details of how the stakeholders reacted or overcame the barriers posed.*

Stake-holder	Details of budget cut	Effect on activity	Reaction / counter action
#23	*so OFWAT came out with a plan to cut the spending by 20%*	*that increases the pressure within the business to deliver what we need to deliver, much, much more cheaply than we ever thought that we would need to do it,*	*means that we are just not doing things that we ought to be doing because we can't justify the spending*
#3	*the EA is being cut to the bone*	*hasn't got the analytical capacity, doesn't have the consistency,*	
#15	*again the EA, the people that you are dealing with are so under resourced*	*the asks have just ended up falling into the abyss and not being picked up again*	*We have got the evidence now and we can try and [square that up] as part of the partnership project.*
#4	*EA, they are strapped for resources*	*they can't sample really, really high spatial density and really frequently*	*so that's why it is important to have the Riverfly volunteers because you can see the difference of the different tributaries and up and down the river and get that overview, so it is really useful to know*
#20	The councils are overstretched	They don't come out and don't have the time to visit	Take responsibility for actions ourselves and through local volunteers
#11	*[We have] had another 10% cut in GIA [government Grant In Aid] or rod licensing income has gone down*	*as money has got tighter and the business has got smaller we are probably not out hand-holding [helping manage problems] as much as we used [to be]*	*trying to manage their expectations*
#18	*I think they have cut down on staffing levels to do with the environment [at Sunderland City Council]*	*there are only a couple of people in Sunderland City authority who I can liaise with and they are so busy that we ask them questions sometimes and they forget and they don't reply and I think that's a bad thing*	*I'm just going to keep doing the same thing, they need to liaise with the volunteer groups and with the schools*

In reaction to the barriers faced by the inability to deliver, support or respond because of the cuts to budgets, stakeholders changed their behaviour in order to adapt. This change included using new structures of interaction, such as partnerships and collaborative initiatives like Riverfly, to fulfil functions that could not otherwise be fulfilled. Other reactions included relying on volunteers to deliver on-the-ground changes. The organisations affected themselves used strategies of communication to inform of the inability or attempt to manage expectations. The ability of stakeholders to cope with the barriers in existence is formative of a functioning governance system. Particularly important are the existence of the network structures of partnerships and the ability to rely on collaborative projects and volunteer run initiatives that give the network flexibility to cope with changes that may involve the change in function of the most powerful actors in the network.

6.6. Implications for the system of catchment governance: multiple levels of influence on functionality

Short (2015) describes that the level at which intra- and inter-organisational networks form and at which collective action and integrated working play out (the micro-level) is the level at which most integrated catchment management is situated. McAreavey (2006) states that knowledge, power, trust, perceptions, understanding, social networks and values make up the micro (interactional) level. This level is also implicitly linked to the individual levels at which goals, motivations, perceptions and expectations influence the interactions and actions that become exchanges of knowledge or trusting relationships, influenced by power dynamics. Such systems are bounded and influenced by the contextual factors of funding, policy and regulation that affect the scope of actions and interaction and feedback to influence goals and motivation as well as systems of power and authority, legitimacy and trust. It is therefore significant to reflect on the dynamics that are evident in the Wear catchment across levels to connect the management decision-making, dynamic interactions and influences on behaviour to the wider system of catchment governance in place through the CaBA.

The interactional level is one at which the most changes might appear to have happened in relation to water management. From the effects and activities in the Wear catchment CaBA has made a significant impact on the way stakeholders interact and form structures of interaction. The power dynamics that have shifted because of CaBA through the emergence of new network structures of partnership working, collaboration and communication, have meant that there have been new forms of knowledge, evidence and data legitimised alongside the groups associated with the different forms of knowledge. This means there is space within structures of interaction for the influence of multiple forms of knowledge to inform, if indirectly, the prioritisation of action in the catchment. The presence of intermediary groups and individuals who can communicate effectively across boundaries between traditionally and practically different groups is foundational to the functioning of the system. Equally valuable are spaces and times of deliberation and communication to maintain links even if there is a lack of trust. It is likely that the power of individual actions alongside the power of network structures and events contributes to the functionality of the system as seen as the operationalisation of a governance approach (Boonstra, 2016).

Evidence from the Wear catchment has also highlighted that there are barriers that exist in terms of functionality, including a mismatch of timescales, mismatched expectations, and a reluctance to trust where there is unfamiliarity or uncertainty. The processes and situations in which mistrust may lead to lack of action or difficult relationships are not often explicitly reflected on and could be addressed more openly to help overcome significant barriers to the water-management process. This reflection may be valuable in a system of water management that is based heavily on evidence and proof, as the system of CaBA in this case study appears to be, when defining problems and legitimising action and where data and evidence is often contested or hard won. Therefore even when there is a process of collaborative governance implemented involving networked systems that appear to facilitate change, there can barriers to the management actions within that system that affect its functioning.

The network structures identified in the Wear catchment (Chapter 5) could be argued to be representative of the power dynamics and the funding systems present in the catchment, where those with the most ability to enable or cause barriers to action through legitimisation of knowledge and data or funding for projects being the most connected. The link between network structure and function is therefore evident and may reveal something of the governance processes associated with networked interactions but is not direct. A closer examination of interactional level factors has shown that there are intricacies such as lack of trust or understanding or legitimacy that complicate relations, even where seemingly persistent links exist. Other factors are likely to play a role in understanding how dynamics play out within the network, including individual as well as contextual factors particularly combining with power dynamics or concepts of trust and legitimacy to form the resultant systems and tangible structures and relationships.

Institutional change is a factor that is central to the CaBA approach and arguably where it has been effective to date, despite the need for continued change. The Wear catchment shows that there have been clear changes in the general behaviour of professional organisations (at certain points in time) as a result of being involved in the CaBA process. The identification of institutional change as a continuing barrier to improved functionality of the overall governance approach is an important factor.

Where motivation and passion are harnessed, sometimes in a professional role (as an intermediary) or through volunteer positions and groups, a change in normative behaviour can be encouraged and has been shown to be effective at times in the Wear. The recognition of the drive and motivation of groups has been recognised through new network structures and by individual champions and intermediaries. Where motivation and a sense of responsibility are able to be harnessed, through projects and collaborative work, there is the possibility of better relationships and more effective delivery of action in the future. The ability of stakeholders to overcome barriers and points of resistance in the catchment system mean that a network emerges indicating where there has been effective persuasion or a change in attitude. Sites of negotiation and exchange are important within the networked system to facilitate such changes. It may be that recognition of the passion and enthusiasm be more of a focus for directing action that will be successful. This action, however will be affected by the context in which it is set and the overall legislative and funding influences on priorities, affecting the ability of certain actors to act and react in ways other than to achieve the overarching central goals. Power relations therefore affect the emergence of certain individual and organisational influences on networks and functionality by creating more dominant actors and priorities. This dominance of certain agendas and goals is clear when a whole system approach is taken, and although individual stakeholders do not always recognise the influence, the patterns of interaction are affected.

It is likely that there will always be variety in the factors associated with stakeholder decision-making at the individual and organisational level but that with an openness to understanding the perspectives of others and an opportunity to create and participate in a variety of interactions and actions (building relational capital of actors), the inevitable barriers can be more easily overcome. It is likely that the processes of learning and social learning offered in more collaborative and partnership working, such as through the CaBA in the Wear catchment, can influence changes in motivation, responsibility, and normative behaviour.

The processes of change within the Wear catchment are clearly bounded and directed by the dominance of the WFD, which is known and acknowledged as a driver of the water management process in the UK, attributed to the original purpose of the CaBA initiative to facilitate the local delivery of the WFD at the catchment scale. Stakeholders do acknowledge the need to go beyond the WFD in order to ensure water management is more closely defined by local need. Wider priority-setting may be something that is possible in the future, particularly in a post-Brexit context, supported by the motivation of stakeholders to take into account multiple priorities. The need to go beyond the WFD is an issue that was identified through the pilot phase of the CaBA by stakeholders in the Wear catchment and was envisioned to be a future phase of the process, yet is still present as a concern five years later. There are processes of negotiation, dialogue and collaboration that merge and attempt to integrate the WFD goals with other needs and actions in the catchment, evidencing a process of governance involving multiple actors in priority setting, but the continuing claim by stakeholders to diversify focus and funding might show the restrictive influence of the dominant legislation and a need for even more change in the way that the collaborative governance approach is operationalised.

There is an acknowledgement that the centrality of the WFD is sometimes problematic, but at other times beneficial as the values cross-cut many of the stakeholder groups and often combine with the goals that stakeholders attempt to achieve individually. The centrality also allows for funding to be utilised, and particularly functions where there is a close connection between the need for change in the water course and the WFD priorities. The ability of the EA to change the status of waterbodies under the WFD is a significant mode of local exploitation of the centrality of the policy for providing funds. Issues of legitimacy and validity of evidence, however, also play into the negotiation of statuses. In relation to the critiques of some of the processes of legitimisation and the subsequent power dynamics, the continuing collaboration of the EA with other partner organisations to affect the labelling of watercourses may have potential to change dynamics and decentralise the application (if not the priority) of the WFD.

Economic influences are also significant for the water-management process as the system relies so heavily on funded project work, facilitated by resources from fairly restricted sources of funding. Whilst the specific funding sources and structures have not been documented through this research it is evidence that the cuts to budgets through the wider economic situation is significant, particularly where the sources of funding are mainly central government administered, or private businesses also regulated by government bodies. Cuts to availability of resources have posed barriers to action, particularly where expectations are mismatched to ability to deliver. However, the motivation, connections and relations amongst stakeholders, sometimes facilitated by structures of collaborative working, have demonstrated a flexibility to cope with changes to funding and to persist or seek new projects, partners or modes of communication to pursue the goals for the water resources. The networked system lends itself to innovation, and despite some difficulties and barriers in existence, may have the potential to work with the cuts.

The governance approach therefore functions as a result of a combination of enabling factors at multiple levels that facilitate particular management decisions and actions and that underpin the maintenance of a networked governance system. Where there are barriers and difficulties and complexities in achieving desired outcomes and relationships, functionality is affected. The combination of the configuration of the governance approach through a networked structure of interactions and the mechanisms of management within the catchment system represent the context for functionality and the changing enablers and barriers affect the social and environmental outcomes from the system.

6.7. Conclusion

This chapter has detailed the potential factors that might influence the functionality of a catchment-governance system through the effect on stakeholder behaviours and management mechanisms, the formation of a network of interactions, which facilitate a set of particular outcomes. Factors are seen to be evident at three conceptual levels: the individual, interactional and contextual. The balance of factors cannot be prescriptive or provide a blueprint for other or future management practice, but could be used to better understand the types of issues that might need to be considered if practice were to be improved to better facilitate collaborative governance. An understanding of the interplay might also help stakeholders to better understand their own capacity and agency within the system and realise where they have the ability to make changes.

The study of the factors that might affect the functionality of the system in a networked context also raises questions about the way that such factors might play out in particular situations and interconnect with changes in the physical environment. The use of simulation modelling can offer a mode to explore the dynamics of the factors identified in this chapter in relation to stakeholder behaviour and decision-making, which feeds into an understanding of management activities as constitutive of action within the catchment system and of the operationalisation of a governance approach through the emergent networked structures and related interactions.

Chapter Seven

Exploring catchment-management behaviour through ABM

7.1. Chapter overview

In Chapters 5 and 6 the mechanisms and drivers of patterns of stakeholder interaction have been explored through a network-based analysis and in-depth exploration of empirical data. Each mode of analysis has given an insight into the system and has relied on the words, descriptions, opinions and observations of stakeholders that produce a snap-shot of the case-study system. In order to add an extra level of understanding and to think more dynamically about the way that certain elements of a catchment system may function in relation to the management actions and the wider context and networked structure of collaborative governance, agent-based modelling has been employed to explore stakeholder behaviour.

The value of the modelling process lies in its power as a heuristic device to help explore the dynamics and mechanisms through which certain outcomes might be produced. It is also to experiment with different behaviours to observe potential changes in outcomes (within the bounds of a hypothesised system) if such behaviour were to be enacted (generative and consequential modes of ABM respectively: (Millington and Wainwright, 2016)). Conclusions and outputs are then able to act as discursive material about the system and about future changes, acting as a starting-point (rather than the answer) to deliberations.

In this research the modelling process focuses on representing the reactions and interactions of stakeholders to a pollution event caused by a point-source release of polluting material into a water course over a relatively short timescale. This scenario approach aims to be exploratory of some of the dynamics of a system rather aiming to give a holistic view, using the short time scale as a potential proxy for wider dynamics. Such a representation combines empirically based knowledge of the patterns of interaction between the stakeholders in a networked catchment system, gained from the analysis reported, with accounts from stakeholders about their own and others' possible reactions to the problem. The modelling process uniquely allows exploration of the influence and combination of certain behaviours and strategies of stakeholders, influenced by networks, motivations, resource availability and structures, on a water course and its related pollution levels, given the goals of stakeholders to reduce pollution levels and maintain healthy water quality. Outcomes of the model allow comments to be made about behavioural assumptions and knowledge of the functioning of elements of the catchment system. The specific identification of minewater pollution as a scenario for the stakeholders to deal with is a context-based choice, as it resonated with many of the stakeholders in the Wear catchment as a familiar problem, given the history of mining in the catchment. Its specificity has an effect on the particular outcomes and dynamics of the system, which allow a reflection on the possible differences and similarities to understanding and exploration of reactions and interactions more widely and across other similar problems.

7.2. Behaviour and problem solving in catchment management

A key element of the ABM philosophy is that individual actions are seen as the basis of complexity in a system. Such understandings relate to ideas of a generative social science in which larger scale structures are believed to be observed as emergent from smaller scale interactions (Epstein, 1999). Whether such assumptions are acceptable as logical or useful understandings of social systems is a subject of debate (O'Sullivan and Haklay, 2000), but have important implications for understanding power and ability to transform a system (Boonstra, 2016). In a context such as the Wear catchment, effects portrayed in a model are attributed to the actions or behaviours of groups and institutions as well as individuals, whilst also being constrained and influenced by past events and the contextual effect of wider social system.

Using a scenario approach, the ABM in this research attempts to represent the specific behaviours of agents in a problem solving situation. It is the culmination of decisions (behaviour) at the smaller micro-scale, and the effect of larger scale macro systems acting as constraints or enablers of that behaviour. Problem-solving is a key element of the process of catchment management across spatial and temporal scales. Through the use of empirical data from the stakeholders in the Wear and discussions of the specific minewater pollution event, problem-solving strategies are drawn up for each of the stakeholders, which are seen to represent their behaviours in relation to the specific problem. The following section details the process of abstraction of stakeholder strategies from the empirical data.

7.2.1. Stakeholder strategies

One of the core reasons for using a modelling approach is to explore the possible effects of the combination of multiple stakeholder strategies to a particular problem. In the River Wear context the interview process and general discussions of water management informed understanding of stakeholders' strategies and reactions to a particular event . The stakeholders' answers revealed that in tackling a problem such as a point-source event the response is likely to be multi-stakeholder and that there would be a high level of communication and even collaboration among groups in order to solve the problem. This process is concomitant with the understanding of the catchment-management system as a whole, in which there is a significant level of partnership working and communication amongst the (core) stakeholders.

The differences between the stakeholders reveal their individual capacities and strategies, and mostly can be argued to result from the difference in the balancing of priorities within the organisations. Factors influencing decisions include motivation and goals, perception of the river environment and the severity of the problem, the influence of policy, responsibility for dealing with the issue, access to data, access to available resources, and trust of others.

Table 7.1 shows some example quotes used to compile the strategies of the stakeholders. Each of the stakeholder's responses can be loosely categorised as referring to; 1) the way that they might communicate or be motivated to communicate when the pollution is identified, 2) the way that they or others might be involved in directly trying to reduce the pollution in the short term and, 3) the way that the might be involved or encourage others to be involved in actions in the long term. These categories are derived from the direct answers given in relation to the scenario during interviews, which was also supplemented with ideas and practices discussed at other times in the interview to create fuller hypotheses.

The detail of reactions varies with each stakeholders group, with those groups more experienced at dealing strategically with incidents able to be more explicit with the suggestions for possible action. Some groups refer to action they or others have undertaken in the past, and others imagine action based on their role and their knowledge of possible opportunities and options. The translation from the direct comments into agent action within the model was informed by a number of factors mentioned by the stakeholders who helped create the context and content of the interacting system and set up the differences between the stakeholders and their strategies, including:

- Whom the stakeholder mentioned as connecting with and when, which helped to create an understanding of the networks created.
- How much capacity and willingness each stakeholder had to get involved in mitigating actions, which helped to create an understanding of the impact and the possible delays or problems with action.
- How and when stakeholders might seek out resources, skills or input to supplement their own, which helped create an understanding of where collaboration might emerge.

Table 7.1 *Direct quotes from stakeholders (italics) in relation to the minewater scenario that have informed the creation of agent strategies in the ABM. Individual people's responses have been pooled with colleagues from the same organisation if more than one person was interviewed from that group.*

Stakeholder	Communicating	Shorter term strategies	Longer term strategies
EA	• *"Would be talking to the Coal Authority to try and understand if their pumping regime has suddenly changed and we have got outbreaks in the area"* • *"I would be speaking to the groundwater and contaminated land team to try and understand what groundwater levels we have got in the area"* • *"Try and get the message out probably on social media to try and let people know what is going on [...]Things like angling clubs and fishing clubs, we would be contacting them to let them know, to make sure that they knew that this had happened and that we were involved in investigating"* • *"We would be the interface perhaps with the Wildlife Trusts, NE and people like that as well."*	• *"If possible I guess we would try and see how we can mitigate the impacts of the minewater depending on how bad it is, [...] try and contain spills if it was a contamination or chemical spill, they could be damming off bits of the river and over pumping bits of the river and I'm not sure what they could do in this instance aside from block it up and if it is a long terms thing whether or not there could be any form of settlement and treatment before it gets into the river"* • *"We are going to have to treat and mitigate, so we deal with it"* • *"UK Coal basically have a scheme in the Black Dene Burn and that will clean up the Black Dene Burn and the transition would be quite quick."*	• *"[There might be] longer term monitoring to see how it had affected t* [redacted] *waterbodies, maybe the formation of a project group"* • *I think the Coal Authority have an obligation, I think it falls under the* [redacted] *remit of their duty of care, so it would be working with them, they cou* [redacted] *prioritise their list based on environmental risk so we would be feedi* [redacted] *information into them to try and get it moved up the list to get some measur* [redacted] *in place to treat it"* • *"We work with Coal Authority to put it in schemes as appropriate to mak* [redacted] *sure that it meets RQO (river quality objectives) and WFD for whatev* [redacted] *metal, predominantly iron"* • *Working with landowners or Coal Authority or people to try and put som* [redacted] *sort of treatment in"* • *Saltburn Gill which was a huge minewater input, which now [...] has lar* [redacted] *infrastructure treatment, so we kind of deal with it as and when"*
NWL	• *"I mean we would have to talk to the EA about it"* • *"It depends what assets we have got in the area"* • *"I'm not saying that it doesn't matter, but [how] far does it impact on us as far as our activities [are concerned], potentially not.* • *"Generally it's not something to do with us, we would be happy to help but it's not something which [we would get involved in], it's in the EA remit to resolve and the Coal Authority has powers to do it"*	• *"There is a question of whether we could take it out through our outfall which we have got there, which would take it out to sea and we have the capacity to do that, so there might be situations where we have got extra capacity, we could maybe take it in even on a temporary basis"* • *[We might do] whatever we could to assist in any investigations if it was an uncertain source"*	• *[We] certainly [would be] interested and we would be looking to make be* [redacted] *use of that because it can be of use the iron, because at the moment we a* [redacted] *using raw materials for taking out phosphorous, [...]so if we can use th* [redacted] *material to do the same job, so there might be economic reasons for us to u* [redacted] *it"*
Anglers	• *"Our role as volunteers is to bring it to the attention of the people who can fix it"* • *"I hope [I would] report that to the EA"*	• Get involved in action around the water course if possible	• *"Trying to filter out the iron ochre by constructing reed beds, we have done th* [redacted] *in several areas"* • *"Coal Authority are involved because there is going to be a massive project do* [redacted] *at Cocken in about the next year and a half, a humungous five hectare re* [redacted] *bed to take off the minewater, which actually runs from Kimblesworth"*

NE	• *"First thing would be to report it to the EA"*	• *"Do whatever is necessary to sort it out so we would physically and practically work with the [EA] to do what we could, so if we had to get pumps on the job, we have got machines"*	• *"Yeah I would look to the [EA] to lead, but working with them obviou*[redacted] *we know the area better so they might say we need to do this and we might* [redacted] *well the way to do that would be to put a pump there"*
Land Agent	• *"The first reaction is that you would get the EA in and try to find the source of the pollution and try to stop it."* • *"Have an awareness that a discoloured watercourse is cause for picking up the phone and bringing it to someone else's attention."* • *"[I would be] trying to keep everyone informed as well as myself"*	• Not likely to get directly involved in a shorter term solution	• May be involved in encouraging action to be carried out by farme[redacted] on their land or may be involved in the planning of larger scale lar[redacted] changes if they are well connected to groups such as WRT.
Community Group	• *"I actually took photographs [of a previous incident] and sent it to the EA"*	• *"You can play a part and you can do little bits of work, you can monitor the area, to me I would want to get physically involved in some aspect"*	• *"Someone like WRT and EA [would be involved] and I think they do wo*[redacted] *together quite a lot but I think that they would need to come together with* [redacted] *as] volunteers"* • *"Town Council here, we would want to get them involved and use some of* [redacted] *resources that they have got to help contain that"* • *"I wouldn't have minded applying for funding but I would need guidan*[redacted] *because it's not something that I'm an expert at so I would need somebody* [redacted] *look at that area with me and say what could be done and how they co*[redacted] *help, so then you could say would there be an expert at DWT is there* [redacted] *expert at the WRT, would they work with us in a project of this nature to* [redacted] *it and create a filter bed in that area to try and stop it from getting into* [redacted] *stream"*
Farmer	• *"The streams in my land are orange all the time anyway."*	• *"The ochre has an effect of blocking the drains because it's sediment, so best to keep on top of it"*	• May take part in schemes or activities if invited by trusted partne[redacted] in the long term
WRT	• *"I would have load of people ringing me up saying 'the river's orange what are you going to about it'"*	• *"[An option] is try and divert if it's seeping out of this spring above the level of the water rather than straight in a base flow, you can divert it into reed beds and things"*	• *"The Chester le Street [reedbed] the angling club were involved because* [redacted] *directly affected their fishing waters and the council paid for it and they work*[redacted] *together".*
Coal Authority	• Regularly in contact with the EA through regional meetings	• Liaise with the EA and work out if there is anything that could be done	• May be the possibility of co-treatment schemes on the larger sca[redacted] Relies on getting partners, such as the EA and NWL on boa[redacted] which requires arranging meetings.
AONB	• In contact with stakeholders about minewater issues all the time. Contact with landowners and local communities is more difficult than statutory organisations	• "*Some issues are dealt with as they come up*". Very involved with minewater remediation schemes already happening.	• May be possible to begin a new scheme working with local partne[redacted] Previously involved in the building of Green Infrastructure project. Ha[redacted] knowledge and facility to appeal to higher level organisations to resol[redacted] long standing issues through discussions and changes to practice.

Table 7.2 shows the core differences in the overall hypothesised strategies of stakeholder agents based on the evidence given in Table 7.1 and supplementary information from the interviews. The strategies can be broken down into a number of stages that cross the stakeholders including: observing the environment, communicating with others, action to reduce pollution, seeking to work with others, acting together with others and involvement over the longer term. Each stage is fulfilled slightly differently by the different agents. Core variations include differences in the capacity to observe the environment before the pollution event is known; differences in the decision to contact certain groups before others when reacting to the pollution, or equally, waiting for others to contact them before any action is induced; differences in the ability to carry out action without the need of resources and skills of others; and differences in the capacity or willingness to be involved in any longer term action such as a project group. At this level of simplification a number of agents may have the same approaches at certain stages (such as communicating straight away with their working partners once a pollution event is identified), which may signify a similarity in attitude (if not specific action) between the stakeholders. The difference then comes within the model through the differential times that those stakeholders may find out about the pollution event and the differential network of working-partners to which they connect when communicating.

The data have been translated into a conceptualisation of the agents in the system and their behaviours. At each level of abstraction there are assumptions contained in the decisions made as the strategies of stakeholders are solidified. The assumptions form the basis of the modelled system but also act as hypotheses to be tested and explored through the model process.

Table 7.2 *An outline of the core features of each of the stakeholders hypothesised strategies.*

	Observing	Communicating	Initial attempt to reduce pollution	Collaborating or working with others	Acting together with partners	Longer term
EA	Fairly high capacity to observe	Immediately communicates with all working-partners	Able to implement action for longer	Attempts to collaborate with those with higher official responsibility first then asks wider partners	Continues to act while searching for new partners	If pollution is still a problem will create a project group
NWL	Rely on others for certain specific WQ information	Don't actively inform others (unless the pollution is very severe)	Waits to be contacted by others before acting	Respond to requests to become involved from trusted partners	Act only when a number of trusted partners have requested action	Will continue to act for a time and then are willing to become involved in the project group
WRT	Fairly low capacity to observe alone (rely more on partners)	Communicate with EA as a priority, then inform other working partners	Able to act for a short amount of time with own resources	Investigates working more closely with all working partners	Acts together with others for an amount of time	Lets the EA know that they are looking to commit to a long term project
Farmer	Fairly high capacity to observe pollution (familiar with own land)	Don't actively inform others straight away	Act to reduce pollution alone after pollution exceeds a threshold	If pollution is still a problem, inform working partners	Agrees to work together when trusted partners have requested action	Act for a certain amount of time
Angler	High capacity to observe	Inform EA first until EA responds to confirm their action. Then inform other partners.	Only act when pollution reaches a threshold. Act for a short time.	Sends requests to all working partners	Act in partnership for a time if pollution is problematic	Have helped to create longer term options that continue to be effective
CommEnvi	Fairly high capacity to observe	Inform all working partners straight away	Wait for replies from others – unable to act alone	Send requests of support to all partners	When collaboration agreed act together for a time	
AONB	Rely on others for certain specific WQ information	Inform all working partners straight away	Act for a short amount of time with own resource	Send requests to work more closely to all partners	Act together if pollution is still high and action is needed	Willing to participate in the project group
LandAgent	Rely on others for WQ information	Informs EA first then other working partners	Doesn't directly act to reduce pollution	Waits for request from others (WRT) to work together	After a time informs farmer of need for action	Not closely involved in long term efforts
NE	Fairly high capacity to observe	Inform the EA first then other working partners	Act for a short amount	Send requests to work more	Act in partnership for a time if	

			of time with own resource	closely to all partners	pollution is problematic	
Coal Authority	Rely on others for certain specific WQ information	Don't actively inform	Doesn't directly act in the short-term	Request to work more closely with EA. Respond when linked to trusted partners	Act in partnership for a time then seek wider partner	Will continue to act for a time and then are willing to become involved in the project group

7.3. Components of the model

7.3.1. Model premise and questions

The premise of the modelling process is to investigate and explore the possibilities and effects of multi-stakeholder action over a short time scale around a water course affected by a minewater pollution event. The key questions aimed to be addressed by the model are:

- How might individual stakeholder strategies for dealing with a pollution event combine to form a management approach?
- What might be the effect of combined strategies on the pollution levels in a water course during efforts to reduce the pollution?
- What might affect the successfulness of combined stakeholder efforts?

7.3.2. Overview, design concepts and details (ODD)

ODD is a protocol used to describe the details and concepts of an ABM, and the following sections will use the components of the ODD process (section 4.2.4.1) to describe the elements of the model created based on the strategies given by the stakeholders in the Wear catchment. Where elements are referred to in `courier`, they are representative of names or elements of code directly included in the model.

7.3.2.1. Entities, state variables and scales

Agents

The agents in the model are based on the key stakeholders in the Wear catchment and could be representative of stakeholder groups likely to be present in other catchments across the UK. Each represents a stakeholder organisation or group as a whole, not a single individual person. The representation of the agent as a group is representative of their power as a collective, and is reflective of the conceptual level often used by stakeholders (section 5.2.1.1). The agents include (and are referred to in the model as): The Environment Agency (EA), Northumbrian Water (`NWL`), the Coal Authority (`CoalAuth`), anglers as represented by an angling club (`Angler`), North Pennines Area of Natural Beauty (`AONB`), Wear Rivers Trust (`WRT`), farmers (`Farmer`), volunteer community environmental group (`CommEnvi`), land agents (`LandAgent`) and Natural England (`NE`). Hereafter these agents are referred to as stakeholders, agents or actors interchangeably (the actors in the system are stakeholders, who are represented as agents in the model).

Each of the agents are assumed to have a number of variables representing their characteristics and abilities. The same characteristics are shared amongst the stakeholders but represented at different strengths by each group (see Appendix C for fuller description). The characteristics include:

- The capacity of the stakeholders to focus attention and financial resources on point-source pollution.
- Access to data within an organisation on the quality of the water course.
- The proximity to water environments on a regular basis, based on regular knowledge of the day to day changes in one water course, compared to a broader knowledge of the water courses across the catchment but less in-depth.
- The ability of the stakeholders to make physical changes to the water environment.
- The specific ability to know about and control the sources of minewater pollution.
- Statutory responsibility for maintaining water quality.
- The sense of responsibility that organisations may feel, from a professional sense of duty and/ or a personal care for their local environment and a drive to see environmental improvements.

Each of the characteristics is scored out of 10 to give an indication of strength and are assigned relatively amongst the actors rather than being quantitatively representative of any absolute measure. The scores for each of the agents in each of the measures are collated into an `effectiveness` measure, which is used to represent the capacity or ability of the stakeholder group to carry out action when tackling the pollution problem. The measure assumes that the characteristics directly and equally contribute to the ability of the stakeholder group to put effort into acting to solve pollution problems.

The agents in the model also have a selection of groups that they have a working relationship with and with whom they are willing to interact (`working-partners`). The presence of working partners represents the existence of relationships and practices of interaction that have built up through previous action. The number and type of working partners that an organisation has reflects their position in the networked catchment management system. The `working-partners` of an organisation do not necessarily represent trusting relationships, because, as has been shown previously (section 6.3.1.4), trust is context-dependent and can change over time. The `working-partners` represents the presence of potential for the organisations to be linked because of shared goals or physical environments. The strategies and behaviours of the organisations through those links is then representative of trust or lack of trust in that situation.

The stakeholder agents in the model also have the ability to create links with one another to form networks. There are two different types of links: `communication` (representing the flow of information and knowledge between agents) and `collaboration` (symbolic of the mutual agreement needed between organisations as they enter into a deeper sharing, exchange or action). Each link is created between an agent and one other agent. Agents can hold an unlimited number of links (within the context of the model, where the maximum links possible is limited by the number of agents in the model) but their acceptance or seeking of links depends on each stakeholder's individual strategies and behaviours:

- `Communication` links are directed (one-way, with a sender and receiver: the receiver has the power to accept or ignore the existence of the link).Each stakeholder agent can choose to create communication links with others and through the links can send messages and pass information to the receiving agents. The links might be representative of physical face-to-face interactions between the stakeholders in the location of the pollution; they may be representative of meetings that happen away from the water course; or they may be representative of phone calls or email communication; or of a combination of communication types. Regardless of type, the communication is perceived to be mostly instigated in reaction to the pollution event but does not exclude structures that might also symbolise the routine communications that happen between the agents anyway.

- `Collaboration` links are undirected (two-way, meaning that once they are created both organisations hold the link equally), symbolic of the mutual agreement needed between organisations. Collaborative links are symbolic of processes through which stakeholders share resources, ideas, skills or data. They are symbolic of a commitment to work together towards a shared goal and go beyond the fleeting communication and sharing of information to represent a more constructive set of interactions. In the model, the communication links exists between two agents (not as a collective of more than two agents), which is because there is no structure of joint meetings (which may encourage more collective collaboration) in this scenario (a feature not included in this model due to the temporal scale of the scenario). Most agents in the model, therefore, desire to enter into collaborative relationships with one or more of their `working-partners` as all agents are active in their desire to reduce the pollution and aware of the ability of the closer sharing relationships (represented through the collaborative links) to provide skills, knowledge, resources and capacity beyond their own.

Environment

The model represents two parallel systems, one spatial and one non-spatial (Figure 7.1). The non-spatial system represents the interactions of the stakeholder agents in reaction to the water environment through the creation of links (as described in the previous section), which form a visual network of connected stakeholders. The spatial system consists of a very basic representation of a water course at the sub-catchment scale with surrounding riparian land. The stakeholder agents can sense the state of the water environment and respond through the connections and communications they make as well as the direct action they take to reduce the pollution, but do not move through or occupy space in the physical environmental system. Consequently the water environment responds to actions and changes accordingly.

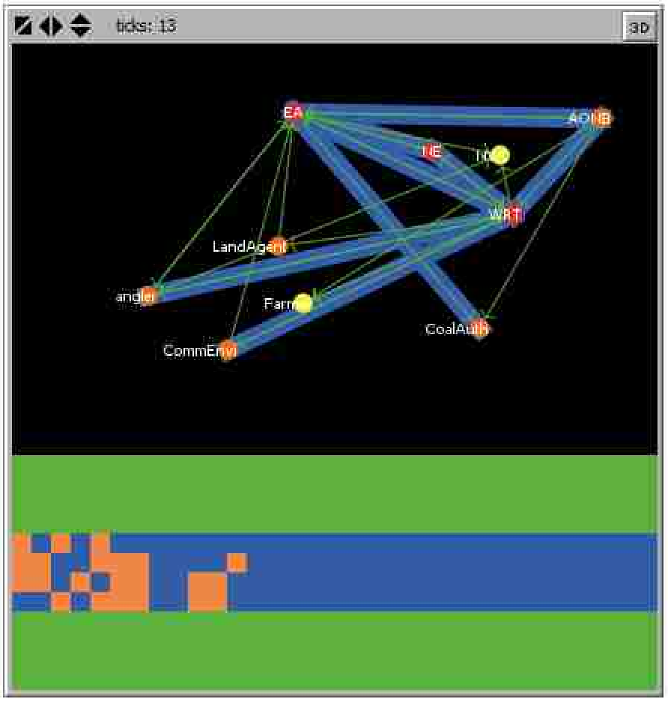


Figure 7.1 *Depiction of part of the model interface in NetLogo representing the modelled 'world'. The non-spatial system representing the network of agents is shown in the top of the window (black background), and the spatial system representing the water course (showing some pollution represented by the orange patches) is depicted in the lower section of the window.*

The water course represents a basic environment that changes through time as a pollution event occurs, representing the propagation and decay of pollutants (see Appendix C for details). It does not represent characteristics of a real river system, but is symbolic of a changing environment. Such a simple river environment is justified through the acknowledgement that the exact mechanisms of pollution propagation, the effect of channel form or hydrological connectivity on resulting pollution levels are not the focus of the model nor the research as a whole and therefore do not need to be represented in exact form in an abstracted model. There is also a global variable (applied to and is available to all agents in the system), `pollution-extent`, which refers to the number of polluted patches in the water environment.

Temporal scales

Each model time step (tick) represents one day, and the model tends to run for 40-50 runs, representing a period of 6-7 weeks. This temporal scale is based on the system-level phenomena of a pollution event that would be likely to last in the order of days or weeks, with the decisions made by the stakeholders at the agent-level happening daily in response.

7.3.2.2. Process, overview and scheduling

As stakeholders undertake their strategies for reacting to the pollution event, they undertake actions and communicate with one another. The model uses the BDI and FIPA messaging systems (section 4.2.4.3), meaning that the agents add and execute 'intentions' (commands) throughout their strategies as well as passing and responding to messages. Figure 7.2 shows the basic stages that the stakeholders go through following on from their initial intention when running through the model process (see Appendix C for full description). Each of the stages is scheduled and implemented differently for each agent type but the broad pattern is similar (Table 7.2). The stages have been suggested as follows:

- **Observing:** This process of surveying the environment may represent the formal collection of water-quality data or the visual observation of the watercourse. Some stakeholders have good access to data and others rely on other groups to inform them of pollution events.
- **Communicating:** Stakeholders may choose to communicate with others to inform them of the problem or discuss details of observations. This may be with their trusted partners or with those who they believe have the responsibility and ability to fix the problem.
- **Acting to reduce pollution:** This stage is representative of an immediate attempt of organisations to enact some form of direct action to reduce pollution, which may result directly from reaction to observations or from requests or information from others. The effectiveness of their actions can be set within the model and each stakeholder has thresholds (relating to problem-perception) at which they might begin action.
- **Working with others:** If there is still pollution present in the water course, stakeholders might turn to the creation of more collaborative relationships in order to share knowledge, resources and skills to plan joint action, with the desire to be more effective in reducing the pollution levels. The presence of collaborative links is suggested as affecting the ability of each stakeholder to enact effective action, based on the way in which resources, skills and knowledge are transferred and co-created during collaboration. Two theories are explored: the first relating to collaboration that results in the best skills and knowledge of both groups combining (`best-effectiveness`), and the second relating to collaboration that leads to compromise (`average-effectiveness`).

- **Longer-term strategies:** If the pollution continues and the previous actions have been ineffective, certain groups have strategies to take an extra step. The EA have the capacity to begin a project-group, which appears as an alternative agent in the model and to which stakeholders can connect to enact collaborative decision-making and action that is potentially more effective.

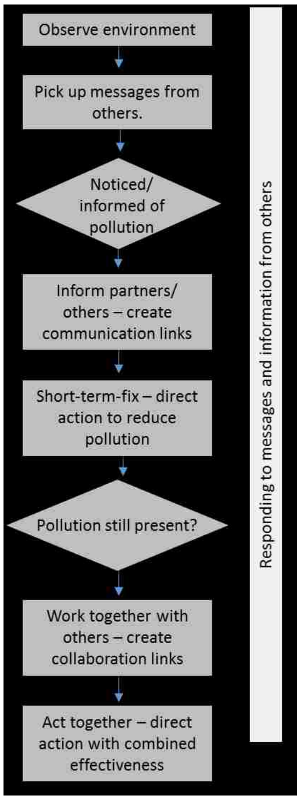


Figure 7.2

Overview of the broad stages that stakeholders may go through during their strategies for dealing with the pollution incident. (Diamond boxed indicate decision points)

Overview of a schedule

Each of the stakeholders have their own strategies and processes to be followed in the model (see Appendix E). Figure 7.3 is an example of the schedule followed by the WRT agent. The diagram gives a broad understanding of the decisions and processes followed by the WRT agent but is not a portrayal of the exact model schedule. However, the details of the processes can be found in the code with notes and descriptions within the coding itself (see Appendix F). Figure 7.3 shows that there are a number of decision-points within the WRT agent's schedule (diamond boxes) the results of which affect the actions that are taken. Each agent has a default 'intention' (as part of the BDI structure), which in most cases is to `check-messages`, portrayed in Figure 7.3 in the rounded-edge boxes. This is an intention that is returned to if all other options have been completed.

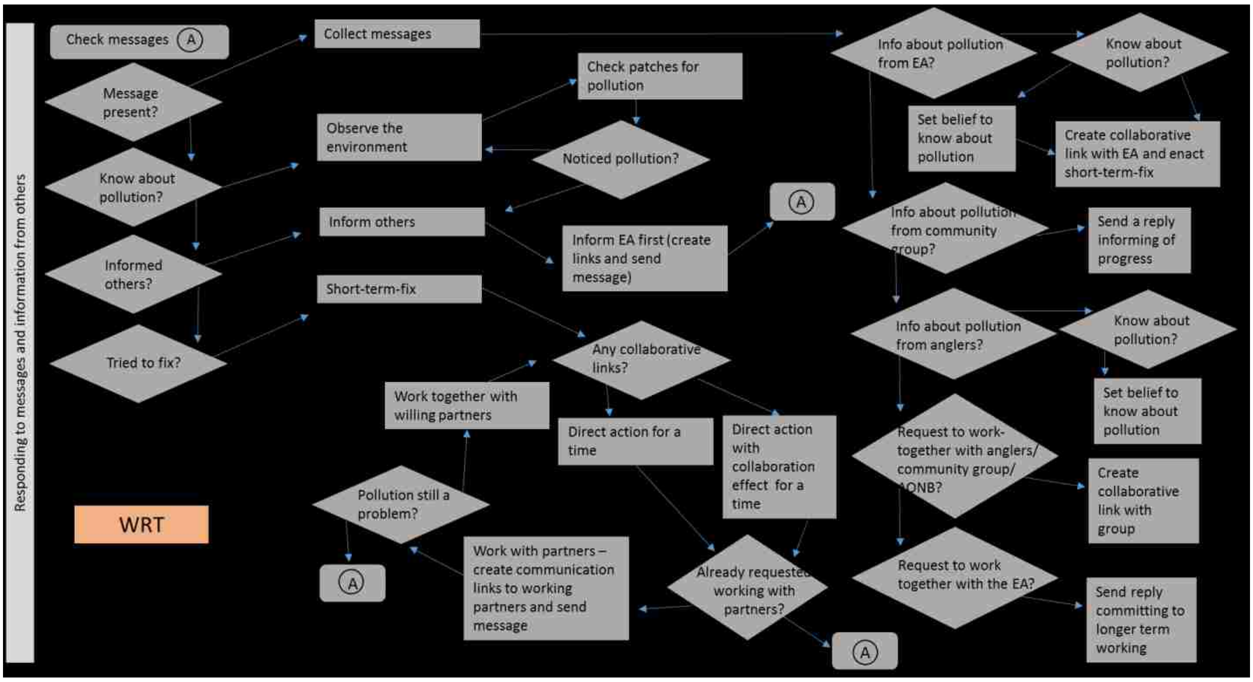


Figure 7.3 *Informal schedule for the WRT agent. Diamond boxes indicate decision points, round –edge boxes indicate default intention and rectangular boxes indicate procedures or multiple procedures. Arrows indicate the flow of logic.*

7.3.2.3. Design concepts

Emergence: The key patterns that result from the model include the number of polluted patches (`pollution-extent`) and the change in pollution through the simulation, as well as the time it takes for the pollution to be reduced. The order in which stakeholders begin to collaborate and acquire new effectiveness is emergent from the combination of their individual strategies.

Adaptive behaviour: Much of the behaviour of the agents in the model is based on indirect-objective-seeking, where choices are programmed to be enacted at certain decision-points in order to reproduce the types of behaviour seen in the real system, rather than the agents choosing among alternatives to meet a specific goal. The adaption comes as agents react to one another's requests and messages as well as the change in the environment; their overall strategies do not change but the timing of certain aspects might be affected by the actions of others.

Objectives: The implicit objective of the agents is to reduce the pollution levels in the water course. The objective is implicit, rather than explicit, because the agents do not actively calculate which actions would best achieve the objective, but rather run a set of actions when pollution is judged to be present that are likely to work towards the goal.

Learning: In the basic version of the model the agents do not learn as none of their behaviours are based on previous events in the model. The agents do have a very basic form of memory, however, that allows them to try new actions if the problem still persists having already enacted previous actions.

Sensing: During processes of observation, the agents sense the quality of the water environment as they 'look' at the river patches. It is assumed that each of the stakeholders can sense the quality of the water equally, and are only differentiated in their spatial frequency of 'looking'. Such an assumption means that some of the dynamics and problems that arise through lack of or differences in access to data and the validity of data are excluded and therefore to be considered when reinterpreting the model. Once the pollution has been noticed by the agents, all the agents are then able to sense the full extent of the pollution event for the rest of the simulation. The assumption of full knowledge of the pollution extent is symbolic of the way in which information about the pollution tends to be shared amongst the stakeholders, particularly if the event is at the sub-catchment scale, alongside the tendency of organisations to hone in on the polluted area once the pollution is known, potentially intensify their monitoring, whether formal or informal, as well as the fact that the type of pollution simulated in this case is visual and able to be gauged fairly easily without specialist equipment once identified. The agents can also sense the characteristics of their `collaboration-neighbours`, who are the agents joined to them through a collaborative link. This sensing is symbolic of the processes of sharing and exchange that happen when groups agree to work together. It is assumed that they can fully know the characteristics of their neighbours and can learn from them (to affect their own `effectiveness` score, for example). The full knowledge of characteristics however does not take into account the ability of stakeholders to hold back information at chosen times or the difficulty in communicating knowledge if there is a lack of trust. Such dynamics are, however, partly symbolised in other ways in the model.

Interaction: The agents interact only with their `working-partners`. The interaction, therefore is not organic within the model but based on the patterns of interactions demonstrated by the Wear stakeholders. Therefore the process of interaction in the model focuses on the choice of when to connect, who to connect with first, who to respond to and how. The form of interaction is through message-passing. The stakeholders can respond by sending replies or further messages, creating links, or beginning action.

Stochasticity: Variability in the model is achieved through the use of (uniform distribution) random numbers to generate probabilities. Variability is built into the effectiveness of the action undertaken by the stakeholders in reducing pollution and accounts for the potential changes in conditions within the natural environment that might affect the success of any given mitigation effort. The actual mechanisms of natural variability have not been focused on in this model as it is the reaction of the agents to changes in the environment that are significant, rather than the exact processes and drivers of change in the environment. Other random processes include the propagation and reduction of polluted patches in the water environment.

7.3.2.4. Initialisation

The starting conditions for the agents include setting the stakeholders `working-partners`, `spatial-sampling-frequency` and characteristic measures that make up the `effectiveness` score, as well as the values for the characteristics of each of the stakeholder agents that define their skills, knowledge and abilities. Thresholds are also set for controlling when actors take up action or collaboration. (See Appendix G for details of initial conditions). The initial conditions are based on the dynamics observed in the Wear catchment and represent a version of current practice.

7.4. Sensitivity analysis and variability

Sensitivity analysis is an important part of the modelling process to foster better understanding of the model and its potential contribution (Thiele *et al.*, 2014). The analysis that follows describes changes in parameter values and the resultant changes in the dynamics of the model in order to test theoretical understandings of the components of the modelled system. The analysis was carried out using the Behaviour Space feature of NetLogo.

7.4.1. Pollution-extent and changes in action and communication

One of the key numerical outputs of the model is the change in the `pollution-extent` (the number of polluted patches in existence), which is associated with the level at which the agents react to and act to mitigate the pollution. The changes in pollution levels that emerge aid an understanding of the potential for stakeholder reactions to collectively affect the environment at particular times, through particular interactive patterns. The exact patterns of change in the pollution-extent are therefore unimportant in the absolute, but the changes and balances in the relative sense can highlight the potential shape of processes. The higher the `pollution-extent` the more problematic the pollution in the water course. The higher extents could either be a result of an intensive pollution event (fast expansion) or a consequence of a lack of effective (enough) combined action from the stakeholders. There exists a natural decay of pollution in the model throughout each run, and therefore regardless of the efforts of the stakeholders the pollution will always be reduced through time (to simulate a dilution process).

Due to the elements of stochasticity in the model, each run is slightly different, meaning that there is a variability in the model output. Understanding the variability helps to situate where the behaviours of the agents are balanced against the random elements of the model and equally where patterns emerge despite variability. Figure 7.4 shows the pattern of change in pollution-extent over the length of a model run (measured in ticks (time-steps), in NetLogo language), where the agents share `effectiveness` (their capacity to act and interact) through the best-`effectiveness` system (collaboration equivalent to best-practice and when stakeholders agree to work together through a collaborative or closer partnership, they take on the knowledge or skills of others where they themselves are lacking) and where other conditions are fixed as listed in Figure 7.4. The change in pollution-extent is shown as an average over 50 runs with error bars representing one standard deviation away from the average. Figure 7.4 shows that there is a significant amount of variability between approximately 20 and 40 ticks (roughly equal to days), which may be the point at which stakeholders begin to form meaningful collaborations and therefore represent the variety in the timings of the collaborations and actions of the agents in the system in relation to the reactions throughout the run. There is less variability at the beginning of the model run, which is likely due to the lack of action or communication from the agents to affect the pollution levels differently meaning they fit the programmed rules for the propagation of the pollution event at the beginning.

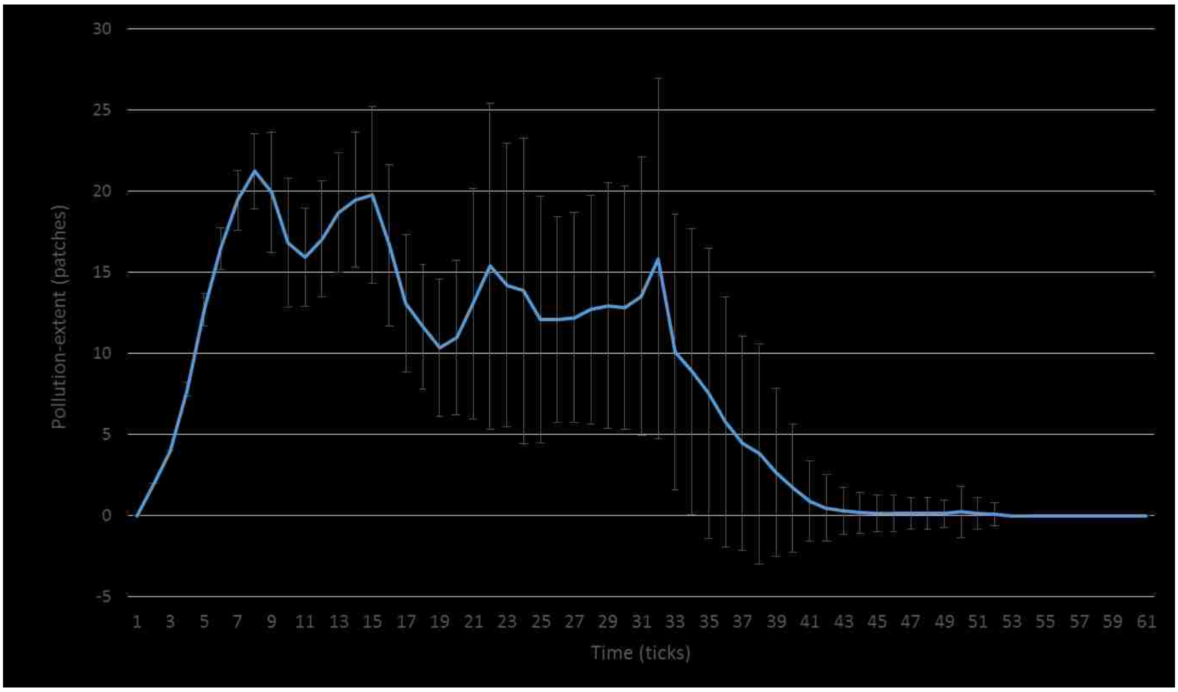


Figure 7.4 *Line graph showing the change in pollution-extent over time using the best-effectiveness strategy for agent collaboration. The graph shows an average of 50 runs with error bars showing one standard deviation. Conditions for the model run include the variables set to the following values, each of which is relatively chosen rather than absolutely: ["pollution-propagation-rate" set to 1 (the rate at which pollution travels through a water course, variable [1,5])] ["pollution-fix-memory" set to 1 (length of time a river patch stays unpolluted after it has been cleared of pollution by the action of stakeholders before pollution may diffuse into it again, variable [0,20])] ["max-random-effectiveness" set to 0.3 (the maximum proportion of the effectiveness value of the agents that can be used to reduce the pollution levels, variable [0,1.5])] ["available-resources" set to 1 (the proportion of resources available to each agent, variable [0,1])].*

Figure 7.5 gives an overview of the changes that happen (such as communication, collaboration or actions) within one run in relation to communication and action of the agents, which helps to explain the trajectory of the average change in pollution-extent over one run. Figure 7.5 shows that as the pollution increases at the beginning of the run, the number of agents noticing the pollution also increases, a little after the agents begin to notice the pollution the number of communication links begins to increase sharply. Soon after, agents begin communicating via messages, which then feeds into agents undertaking direct action. Communication and action appear to slightly mirror one another in terms of numbers, for example there are less agents communicating when there are more directly acting, which reflects the nature of the ability of the agents to be in only one state at once. As the agents start to act the pollution levels broadly decrease. The relationship between the number of agents acting and the way in which the pollution levels are affected, however, is not direct as the record shown in Figure 7.5 does not take into account the effectiveness of the agents. The collaborative links begin to increase at the same time as the action and communication begin. The pollution level appears to rise again in the middle of the run, which perhaps indicates the point at which agents generally change from a strategy of directly acting to reduce the pollution if they can, to concentrating on working with others to share data and resources in order to enact more effective action together. Once collaborative links have been made then the actors are able to continue to reduce the pollution levels again until a point at which they can no longer continue indefinitely (causing the pollution to increase again). At this point the project-group is triggered and project links begin to appear. As the project begins to produce joint-action the pollution decreases significantly (due to the higher levels of effectiveness associated with project-group action). The rapid decrease in pollution at the end of the run is likely also affected by the effect of the dilution of the pollution. The variability shown in Figure 7.5 is indicative of the changes in the balances of acting, communicating and linking between the agents and relative effects of a change in order or timing, as well as the stochastic factors included in the model.

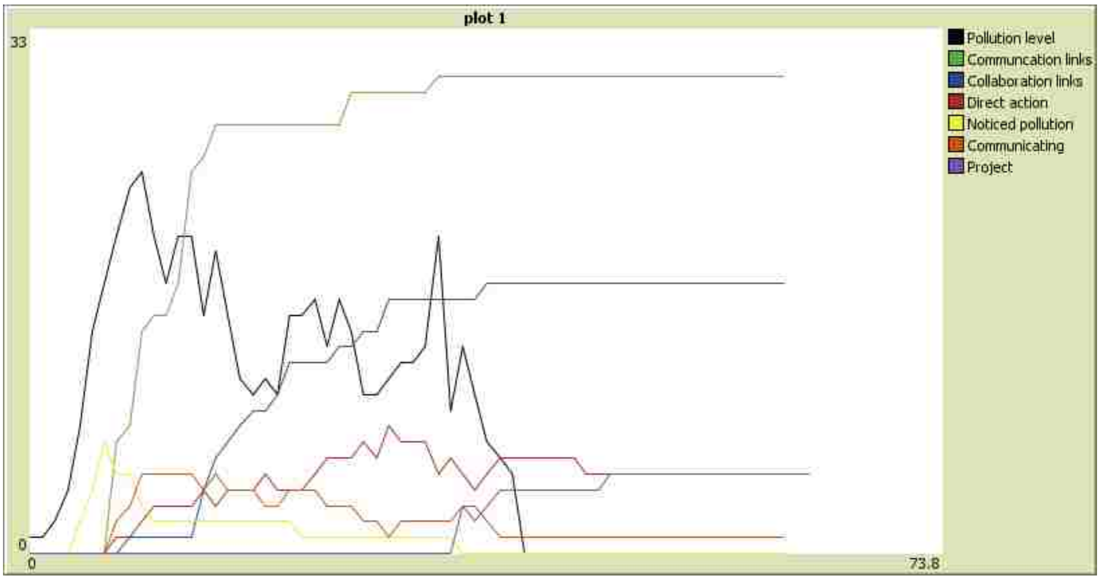


Figure 7.5 *Netlogo output from one model run depicting the change in agent actions and communications. Lines represent numbers of agents or numbers of links (or numbers of patches, in relation to the pollution-extent). Conditions for the model run include: ["pollution-propagation-rate" 1] ["pollution-fix-memory" 1] ["max-random-effectiveness" 0.3] ["available-resources" 1] and the use of the best-effectiveness collaboration strategy.*

When the `average-effectiveness` strategy is used in the model the average pattern of pollution change is slightly different. The `average-effectiveness` model involves the averaging of characteristics between collaborating agents rather than the acquiring of the best score (as for `best-effectiveness`) (see Appendix D under 'working with others' for explanation of mechanisms of sharing). Figure 7.6 shows a comparable graph to Figure 7.4, using the same conditions and number of runs, but with a change in the way that stakeholders 'share' information at the point of collaboration The pollution-extent reaches much higher values (between 50 and 60 patches at the maximum) compared to the best-effectiveness strategy (just over 20) and takes much longer to reduce completely. Such a difference is indicative of the known outcome that by averaging scores when collaborating the agents end up with lower effectiveness levels, which give them less power to affect the pollution levels in the water course and hence the higher pollution-extent. Figure 7.6 shows that on average the efforts of the stakeholders do not result in significantly reducing pollution levels for the first 30 ticks, only slowing the general increasing trend. The sharp decrease that can be seen after 30 ticks is again associated with the appearance of the project-group and the effect of the joint-action. The decrease in pollution levels is similarly steep in both scenarios as the project-group uses the same mode of sharing both times.

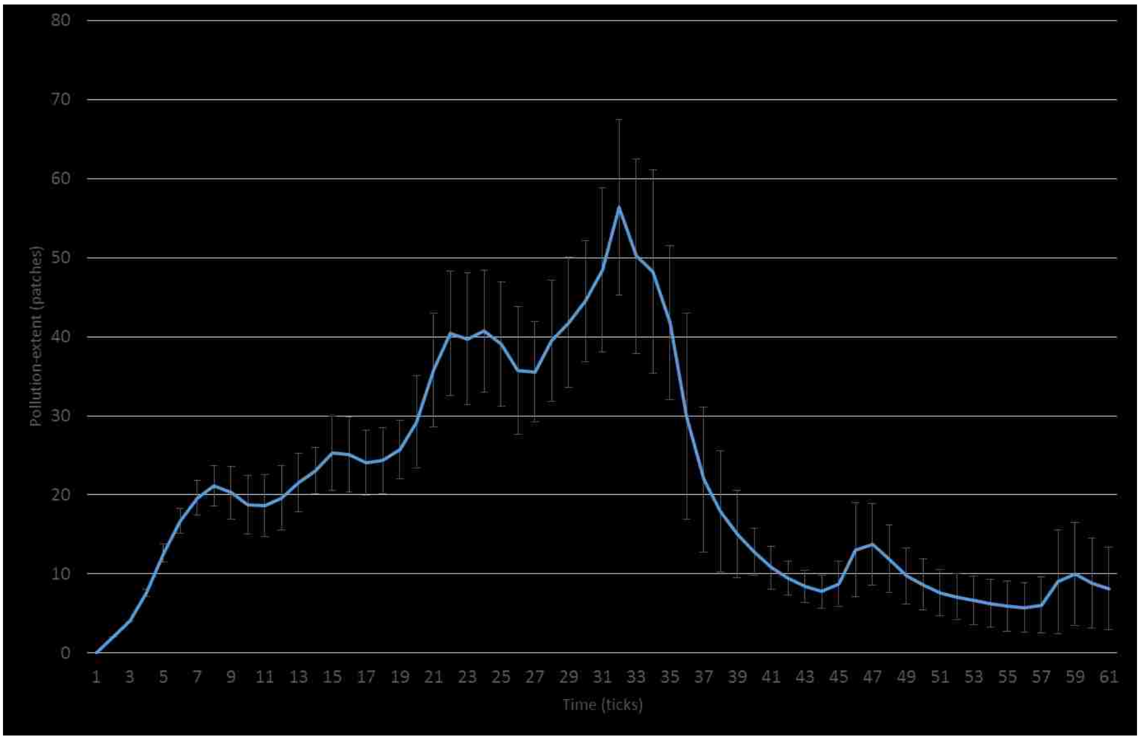


Figure 7.6 *Line graph showing the change in pollution-extent over time using the average-effectiveness strategy for agent collaboration. The graph shows an average of 50 runs with error bars showing one standard deviation. Conditions for the model run include ["pollution-propagation-rate" 1] ["pollution-fix-memory" 1] ["max-random-effectiveness" 0.3] ["available-resources" 1].*

Variability in the values of pollution-extent (indicated by the error bars representing one standard deviation on Figure 7.6 and 7.4) is broadly similar in magnitude between the two scenarios (Figure 7.7). Both scenarios show increasing variability in pollution-extent towards the middle of the run at the point between 30 and 40 ticks where the pollution-extent usually peaks, showing that the maximum pollution-extent is the most changeable element. The `average-effectiveness` scenario gives more variability at that point than the `best-effectiveness` scenario, as well as towards the end of the run, perhaps indicating the variability in the time that the pollution is reduced when using `average-effectiveness`, compared to a more certain end using `best-effectiveness`. The consequence of the variability is that with any changes in other conditions of the model or in other scenarios, it may be difficult to discern the effects (particularly when pollution is at its peak values). This difficulty is reflective of any real life situation in which a natural variability in the environment means that it is difficult to know when behaviour change is having a significant effect on the water courses, a factor that a number of the stakeholders in the Wear catchment were aware of.

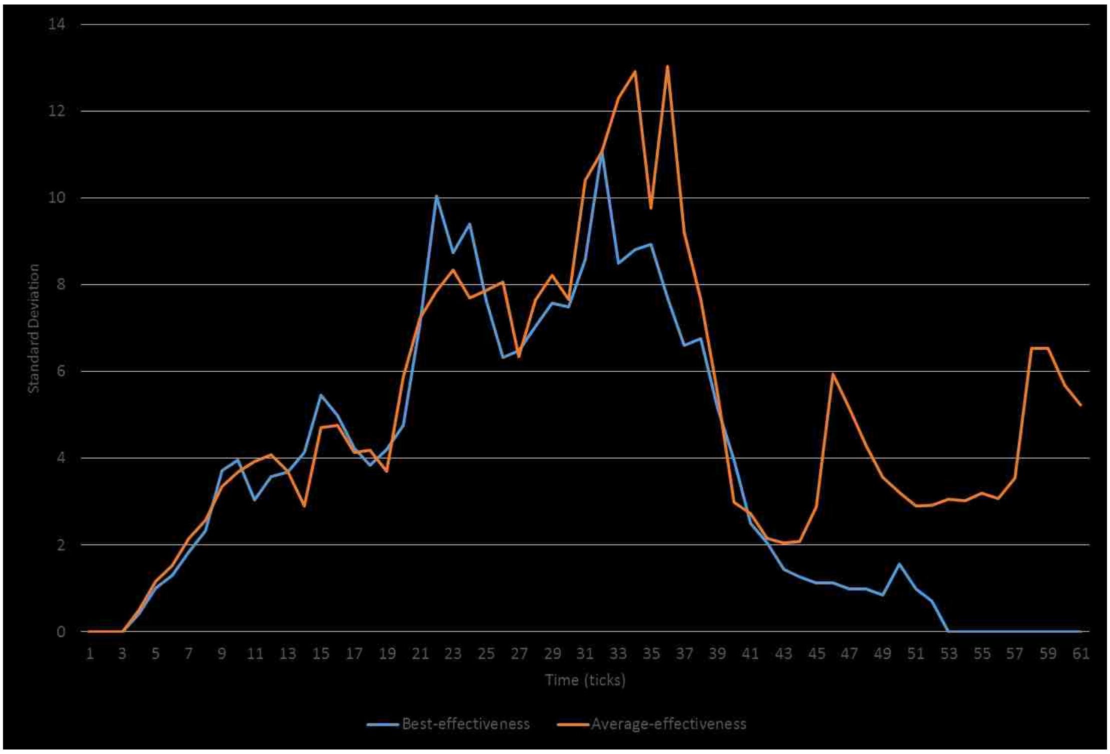


Figure 7.7 *Line graph showing the change in standard deviation of the values of pollution-extent over the period of a model run, comparing best-effectiveness runs and average-effectiveness runs. Pollution-extent values are based on the average of 50 runs. Conditions for the model run include ["pollution-propagation-rate" 1] ["pollution-fix-memory" 1] ["max-random-effectiveness" 0.3] ["available-resources" 1].*

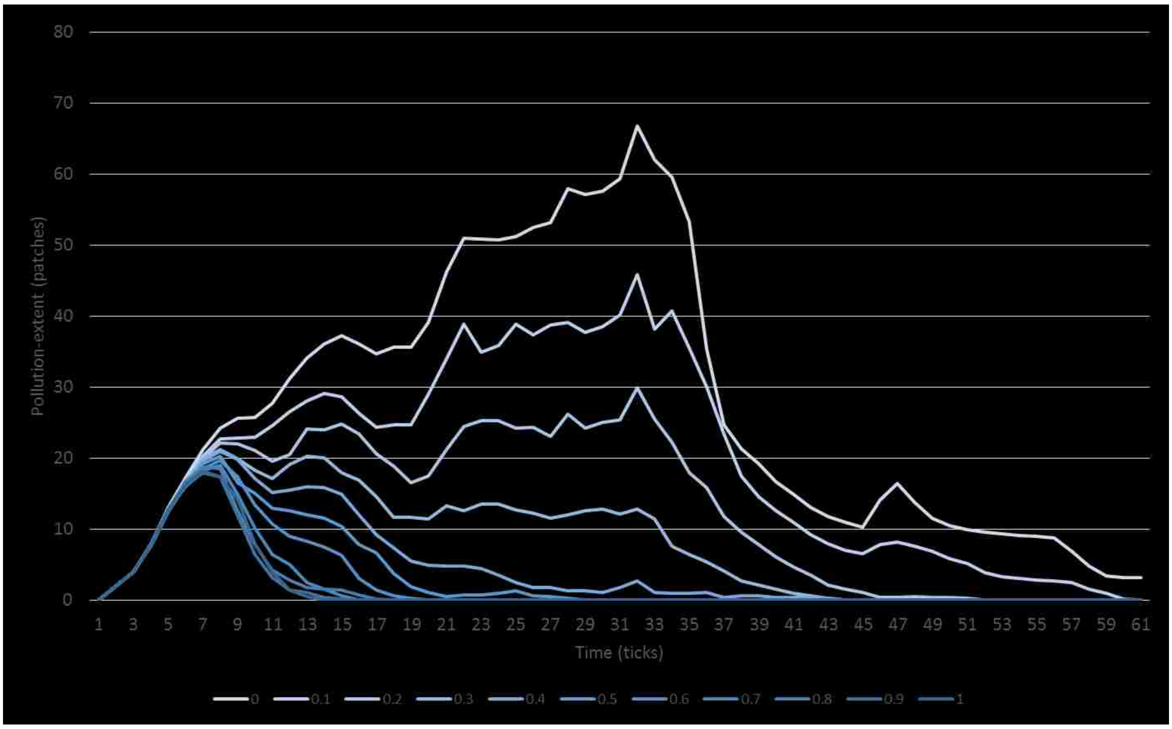
In addition to the variability in the pollution-extent through the stochasticity of the model, change in model parameters also create changes in the pollution-extent and therefore help to explore the potential mechanisms that lie behind the assumptions in the parameters. The first parameter that can be changed in the model is `max-random-effectiveness`, which changes the maximum proportion of the effectiveness score of each agent that is applied when the agents are directly acting to reduce pollution. Figure 7.8a shows the average change in pollution-extent through variation in the parameter (over 20 runs for each parameter value). The change in parameter makes a significant effect on the pattern of pollution. The higher the `max-random-effectiveness` proportion the lower the pollution-extent and the faster the pollution is reduced. The model is particularly sensitive to the changes in this parameter, which indicates the centrality in the model of the effectiveness value and the application of that value to efforts to reduce the pollution. Conceptually the focus on effectiveness is significant for reflecting on how stakeholders behave, as success or progress is an important measure for stakeholders when reflecting on problem-solving and management action. The significance of using the effectiveness concept in the model may help to highlight the potential modes of change that could be thought about in terms of changing effectiveness.

In terms of how effectiveness is understood, there is an assumption in the model that the resources each stakeholder has access to (financial, physical, knowledge-related) contribute to the effectiveness measure. Therefore changes in the levels of resources available should have an effect on the outputs of the model in terms of the pollution-extent if there is a link between effectiveness and pollution. Figure 7.8b shows the changes in pollution-extent that occur when the `available-resources` parameter is changed at the start of each run (compiled as an average of 20 runs for each parameter value). There is a noticeable reduction in the severity of the pollution extent as the available resources are increased, particularly at the peak of the `pollution-extent`. There is also a reduction in the time taken for the pollution to be reduced as the resources increase. The link between available resources and pollution extent is not unexpected given the direct influence of the amount of resources on the `effectiveness` scores and their transfer to direct action. Figure 7.8b shows that the model is sensitive to the change (albeit in a small way) and therefore verifies the assumed processes conceptualised about the system.

The nature of the pollution event itself can also be hypothesised to have an effect on the outputs of the model. The parameter `pollution-fix-memory` relates to the ease with which the pollution can be reduced (perhaps symbolising a variability in the type of substance causing the pollution). Higher values of `pollution-fix-memory` equate to longer lengths of time a river patch stays unpolluted after it has been cleared of pollution by the action of stakeholders before pollution may diffuse into it again. Figure 7.9a shows the effect of a change in this parameter on pollution-extent (again, compiled as an average of 20 runs for each parameter value). Figure 7.9a shows that the higher the `pollution-fix-memory` the quicker the pollution is reduced and the less fluctuating the `pollution-extent` throughout the run. Again these changes are not unexpected given the effect of the `pollution-fix-memory` on reducing the physical number of patches that can be polluted and therefore enhancing the effect of any action. The consequence of the verification of the effect gives opportunity to experiment with the nature of the pollution event within the model.

Equally, the parameter `pollution-propagation-rate` can be changed to affect the output of pollution-extent. A higher propagation rate attempts to symbolise changes in the intensity of a pollution event, whether through the release of pollutants or through a change in river flow. Higher propagation rates symbolise pollution that moves quickly to pollute the water course. Figure 7.9b shows the results on pollution-extent of a change in the propagation rate (again, compiled as an average of 20 replicates for each parameter value). There is some change evident, particularly at the beginning of the run, where, expectedly, the maximum pollution-extent is larger when propagation rates are faster, as agents do not react in time to keep the pollution-extent low. The effect of the different propagation rates (above 1) then begin to assimilate and make little difference beyond 20 ticks. The exception is a propagation rate of 1, which allows the pollution to be tackled more successfully by the agents in the model. Above a value of 1 the pollution-extent fluctuates, as it gradually decreases, indicating that the agents' actions are less effective. Such a pattern may be the result of the programming of agents to be fairly un-adaptive in terms of dealing with a much larger or aggressive event, in which they do not have the strategies to change their communication or action patterns. Although this lack of adaptability could be changed in the model, it highlights the difficulties in creating agents that can deal with such changes, that they would need a wide range of strategies and options to deal with larger than expected problems. These processes of sensitivity analysis or verification of the models mechanisms and reactions highlight the value of the process of modelling itself to identify concepts and ideas that may be important for application to real situations.

a)



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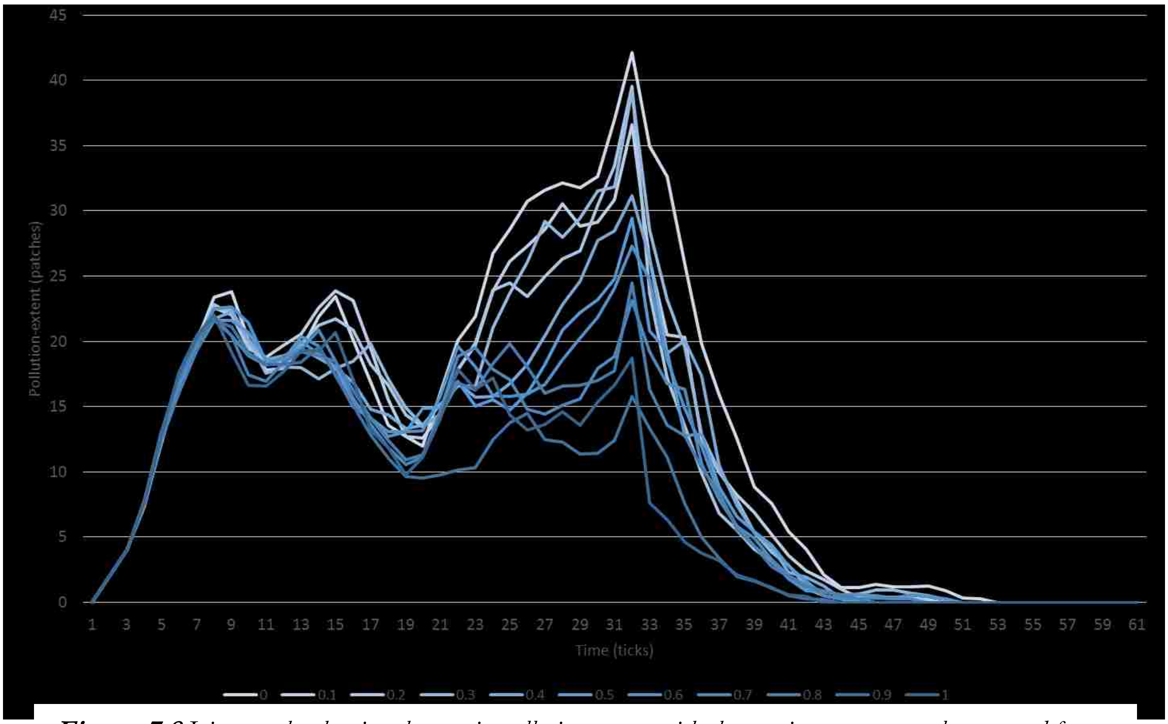
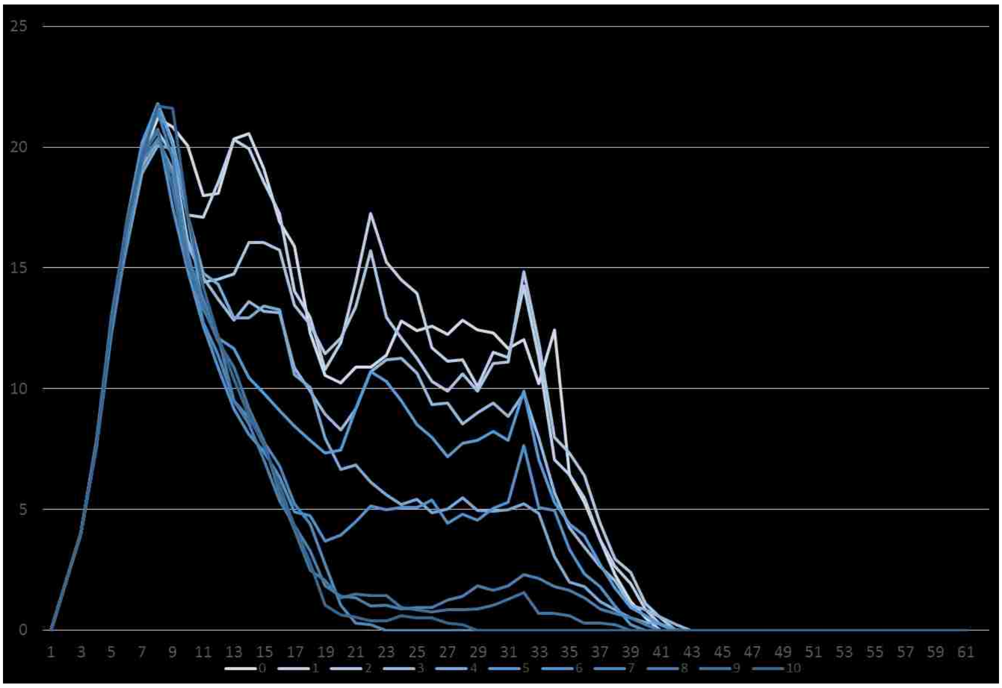


Figure 7.8 *Line graphs showing changes in pollution-extent with changes in parameter values created from an average of 20 runs for each parameter value. A) Changes in max-random-effectiveness. B) Changes in available-resources. Conditions for the model runs include ["pollution-propagation-rate" 1] ["pollution-fix-memory" 1] ["max-random-effectiveness" 0.3 (in graph B)] ["available-resources" 1(in graph A].*

a)



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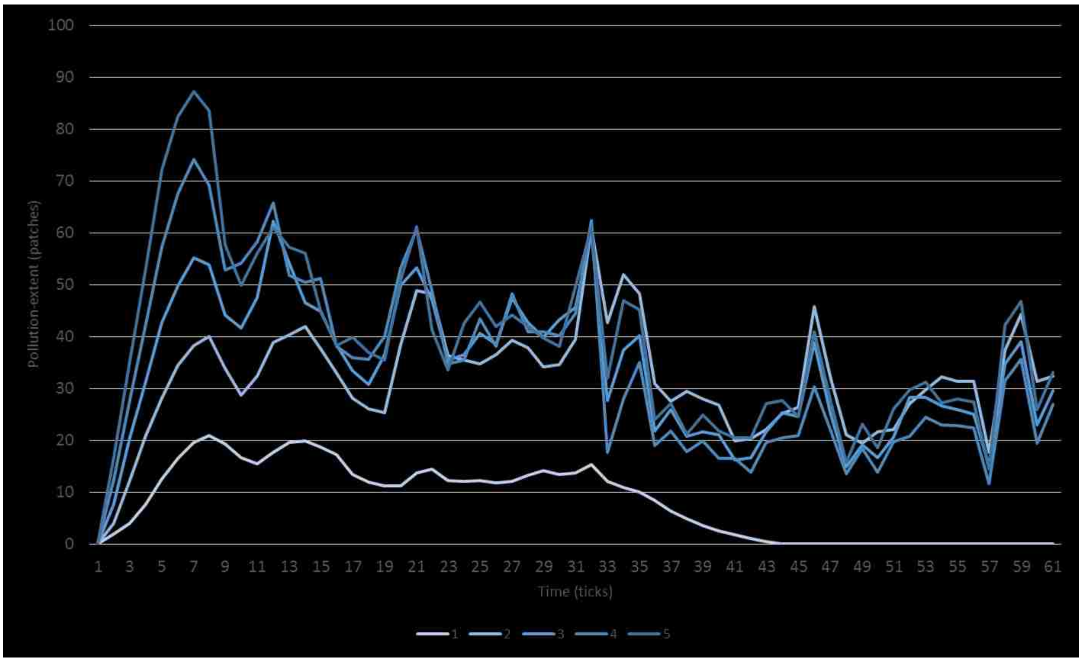


Figure 7.9 *Line graphs showing changes in pollution-extent with changes in parameter values created from an average of 20 runs for each parameter value. A) Changes in pollution-fix-memory. B) Changes inpollution-propagation-rate. Conditions for the model runs include ["pollution-propagation-rate" 1 (in graph A)] ["pollution-fix-memory" 1 (in graph B)] ["max-random-effectiveness" 0.3] ["available-resources" 1].*

An additional output of the model is a record of the change in effectiveness for the agents, which is a measure that changes based on the number and type of links an agent forms through decisions to collaborate with others. Such a measure is a proxy for the agents' levels of, and decisions about, collaboration. The `best-effectiveness` and `average-effectiveness` strategies for sharing information and resources when collaborating produce different results (Figure 7.10). The `best-effectiveness` strategy (Figure 7.10a) means that agents converge their `effectiveness` score towards an ultimate high-level effectiveness that represents the best scores of those with which they have created closer working relationships. Each time the agent acts when they have `collaborative-links` with other agents, their effectiveness score changes, picking up the highest scoring elements of the agents they are connected to, who in turn have picked up the highest scoring elements of their own `link-neighbours` (other stakeholders they are working with or in communication with in a network). Those who directly act more often or who have more collaborative links may change their score the most. The agents ultimately converge towards a very narrow range of scores, with some agents ending up with the same score because they are linked to one another or one another's partners (the network is connected). Differences in the end effectiveness score between agents perhaps indicate where there are breaks or clusters in the network (those with similar scores have worked in the same sub-network). Those acting with others first in the simulation may change their score in smaller increments than those who act last, the latter of whom benefit from the sharing that has already happened within the network that has pushed up the effectiveness score of their `link-neighbours`.

For the `average-effectiveness` strategy (Figure 7.10b) the agents converge towards a small range of effectiveness scores towards the end of the run but do not converge to a single value. The change in effectiveness that happens over the run can sometimes mean a higher than original end-effectiveness for some agents but a lower than original for others. Agents tend to change their effectiveness throughout the run and fluctuate values depending on who they are working with at the time that they undertake direct action. The range of values at the end of the run is not representative of the average of all the agents in the model, but a feature of who has worked with who and at which points they acted together. There is a process of the creation of multiple mini-networks of agents within the network. It is the intermediaries and the brokers who bridge the mini-networks and act to connect the whole network. The constant change in values demonstrates the constant change in the balance of actors working together throughout the run. The `average-effectiveness` run demonstrates positive and negative changes in effectiveness, which may be representative of the inconsistency of action with different partners.

a)

b)

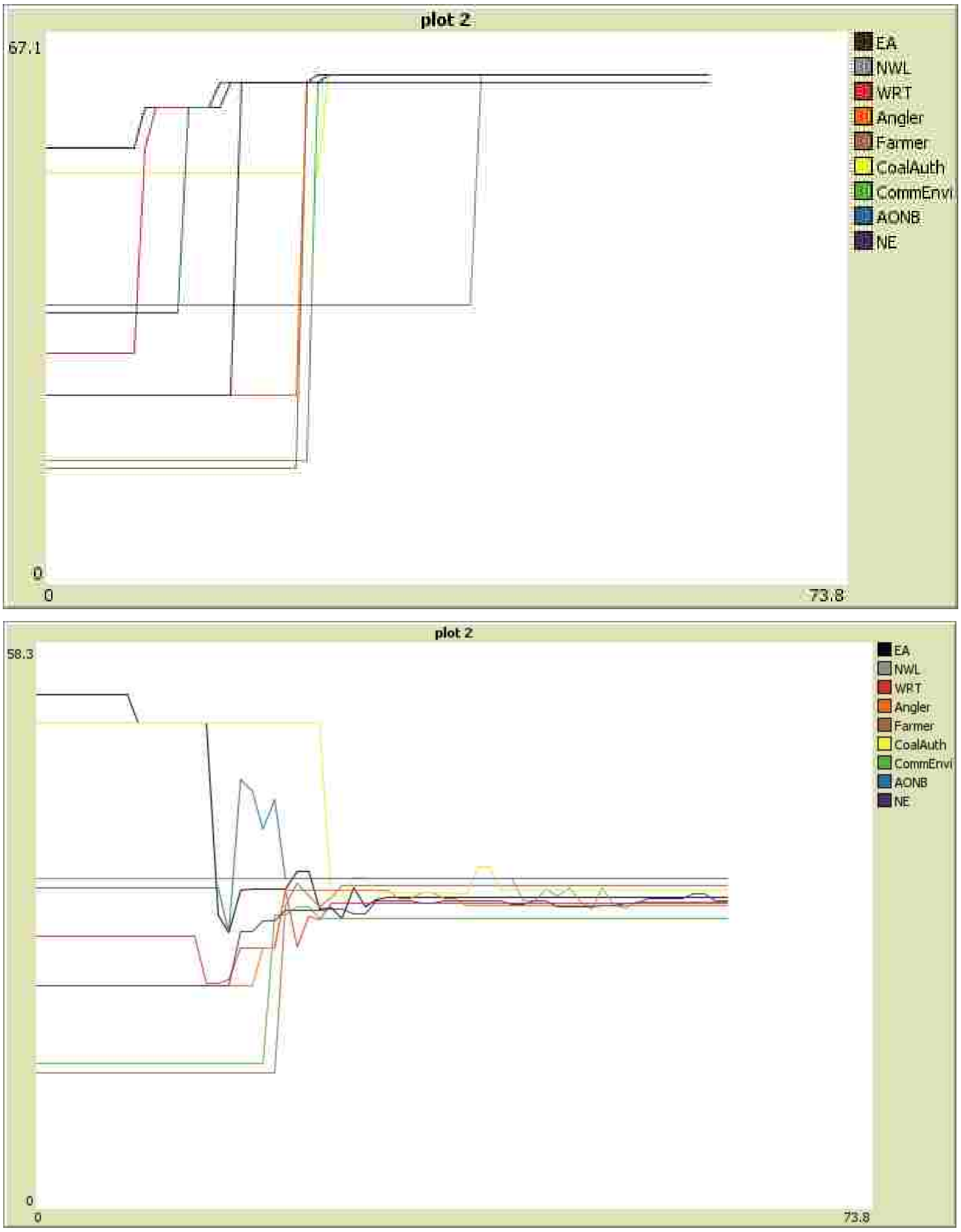
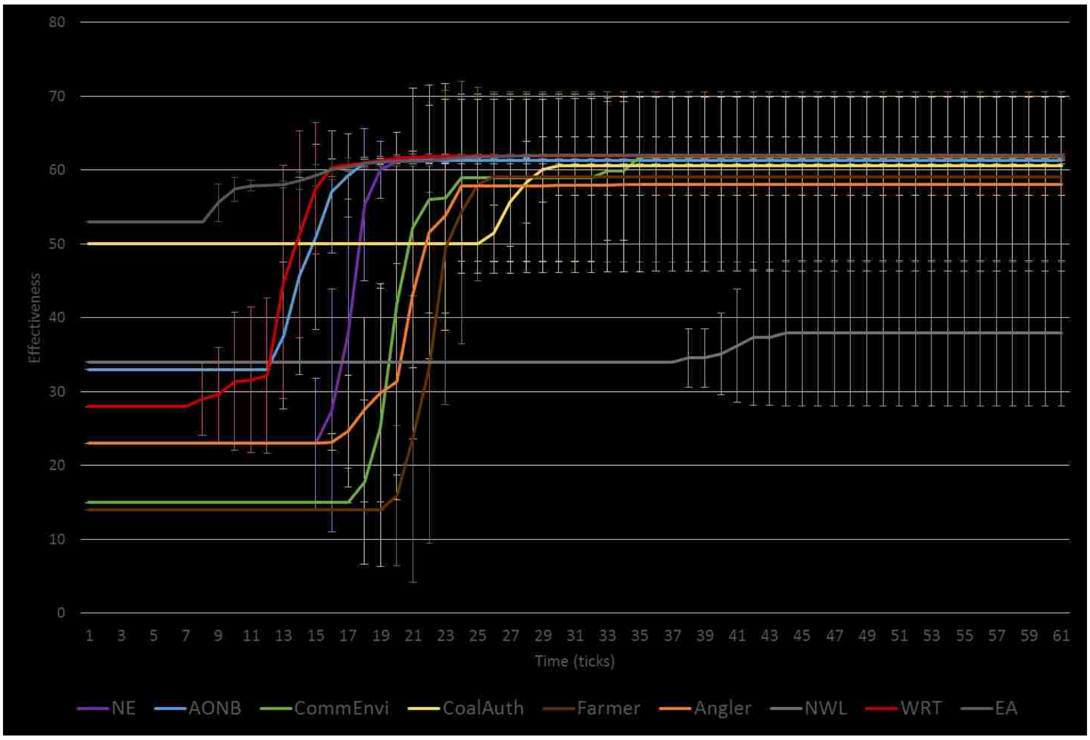


Figure 7.10 *Output graphs directly from NetLogo interface showing the change in effectiveness for a) one run using the best-effectiveness sharing strategy and b) one run using the average-effectiveness strategy. Conditions for the model run include ["pollution-propagation-rate" 1] ["pollution-fix-memory" 1] ["max-random-effectiveness" 0.3] ["available-resources" 1].*

As with the changes in pollution-extent there is a natural variability caused by the stochastic elements of the model that means that each run produces slightly different results. Equally, the order in which the actors begin to act with other partners as well as the pattern of change throughout the run are variable factors of the model. Figure 7.11 shows the variability in the trajectories of each of the agents in both the `best-effectiveness` and `average-effectiveness` strategies (compiled from the average of 50 runs). Figure 7.11a shows the average change in effectiveness for the `best-effectiveness` strategy. It shows that most actors have begun to act with others before 20 ticks, and undertake a fairly large jump in effectiveness to meet the levels of the highest scoring agent as the best scores are shared. In most cases each agent continues to change throughout the run as they act together with more partners, others may only change once. There is a large variability shown for some of the agents towards the end of the run, which accounts for the fact that sometimes they may not act with others therefore creating a large difference in effectiveness between the times when they act and when they do not become involved. The EA is shown to be one of the first agents to act with partners and therefore the others who follow will pick up the scores of the EA, if they or their partners are connected to the EA (particularly as the EA is a central agent, who becomes connected to a large proportion of the agents in the model). Figure 7.11a shows that despite the variability in the values of effectiveness there are consistent times after which the agents get involved in joint action. For example, the EA and WRT have the shortest times before they are involved, followed by AONB, Anglers, CommEnvi, Farmer, CoalAuth and finally the NWL. This order may not always be the same, but is emergent from the combination of the individual agent strategies and is broadly representative of the opportunities, attitude, resources and responsibilities of the agents. The validation of this strategy in the emergent output of the model can give more strength to any experiments for which the model is used.

In Figure 7.11b, showing the change in effectiveness using the `average-effectiveness` strategy (average for each agents compiled from 50 runs), the average order of involvement, as represented by joint action with others, is broadly similar to the best-effectiveness strategy (EA and WRT, AONB, NE, Anglers, CommEnvi, Farmer, CoalAuth and NWL). The presence of a point before which there is no variation for each agent, and therefore after which they are likely to be working jointly with others, gives the impression that (within a certain set of conditions) there is a consistency to the action of the agents. This consistency is a feature of the way the agents have been programmed and may also represent the behaviour of agents in a real system who might have the same trigger points when faced with the same conditions as a previous case (something that could be questioned as a strategy). Some agents can be seen to have larger variability than others in the way that their effectiveness changes throughout the run. This variability could be a result of working with a number of others with variable effectiveness scores and contributing factors, who change the effectiveness score often as new partners are added. High variability is associated with agents such as WRT, which could link to the position of the WRT in the network, as an intermediary between disparate groups, meaning the WRT's action is more variable each time due to the range of other stakeholders they link to and the more possibility that the order or timing may change amongst those stakeholder agents each run. Overall the variability in the agents' effectiveness for both strategies demonstrates the potential for reactive difference, yet the consistencies show the overall control of some of the elements of the stakeholders' strategies.

a)



b)

Figure 7.11 Line graphs showing the change in effectiveness scores for multiple agents over a model run (as an average compiled from 50 model runs) with error bars showing one standard deviation for each agent's trajectory a) for best-effectiveness and b) average-effectiveness scenarios. Conditions for the model run include ["pollution-propagation-rate" 1] ["pollution-fix-memory" 1] ["max-random-effectiveness" 0.3] ["available-resources" 1].

7.5. Experimentation

Simple experiments can involve changing the modes of control at decision points for the agents, not in order that they might make different decisions but that processes may be quicker or slower or more or less significant and may subtly affect the outcomes. Such experiments can make use of the model without extending or changing the structure. The experimentation is a simple way of highlighting the existence of possible points at which changes to behaviour could be made and bringing to light the reflection on the possible existence of such decision points in a real system.

7.5.1. Experiment 1: Reaction to other agents

As a translation of issues of trust and legitimacy some of the agents in the model do not react straight away to any messages or requests for partnership from other agents. The delays may symbolise a process of internal checking of evidence through lack of trust of external data, the weighing up of priorities or a process of meetings and discussions. To experiment with the importance of the existence of such delays the timings can be changed. The first experiment therefore imagines a system in which stakeholders immediately react to one another and are in close contact constantly. Such a system may be created in reality through increasing the contact between agents through meetings, or other forms of communication, which could be facilitated by a system of catchment partnership, such as the WCP in the Wear catchment and those that have been set up within catchments across England and Wales.

Figure 7.12 shows the results of the changes to agents' behaviour (reacting immediately to requests and collecting messages consistently throughout the run) on pollution-extent (assumed to be the key measure of success/ change in this model) using a best-effectiveness strategy compared to the results on pollution-extent previously found using the unaltered model. Other model conditions have been kept the same for comparison. Figure 7.12 shows that there is a small decrease in the magnitude of the average pollution-extent between 20 and 35 ticks. This small, but potentially significant, decrease in magnitude could be a result of the agents being more reactive in the second half of the run as they begin to work together, therefore reacting more quickly to any increase in pollution and reducing its magnitude.

As an extension to the experiment it is possible to change the behaviours of a number of the agents in the model to mean that they react to the first agent to contact them to influence their behaviour rather than waiting for the reaction or request of two or three others before acting. For example, to represent the behaviour of a farmer who might be reluctant to take individual action if there is a difference in problem perception between themselves and other organisations, the original model hypothesised that a farmer might only react once they had heard from two trusted partner organisations (the AONB and Land Agent) to represent a longer process of change. In the extension to the experiment the need for triangulation of information can be reduced and the farmer, for example, might react when they are initially contacted by either one of their trusted partners. The same behaviour can be changed in other organisations such as the Coal Authority and NWL. The EA can change their behaviour by reducing the number of repeated messages they need to receive from the angling community to react to their request, which is a mechanism in the original model. With the delay in reaction in the original model the lack of trust or priority for angler's information by the EA was represented.

Figure 7.13 shows the change in average pollution-extent for the original model and the adjusted model and shows that the trajectory of change is similar, but there is a small increase in the pollution levels between 25 and 32 ticks compared to the original model; an indication of action happening prior to more collaborative links being made and therefore the individual effectiveness of the agents being lower when they act (as the best-practice scenario is being used to demonstrate the impacts). The difference to the average levels of pollution in the two parts of the experiment might indicate that when thinking about reaction to others within the context of a water pollution issue in this specific modelled environment, having open communication and reacting quickly is likely positive until it reduces the capacity of actors to build up connections before jointly acting together. The margins of change for both parts of the experiment are small, however, which may also indicate that the change is not significant in this modelled system, but that therefore the modelled system may not be simulating dynamics at a subtle enough level. It does, however highlight that there may be a choice to be made about how quickly a stakeholder reacts to their partners (if it can be attributed to choice rather than other circumstances, pressures, processes or mechanisms within the catchment management network).

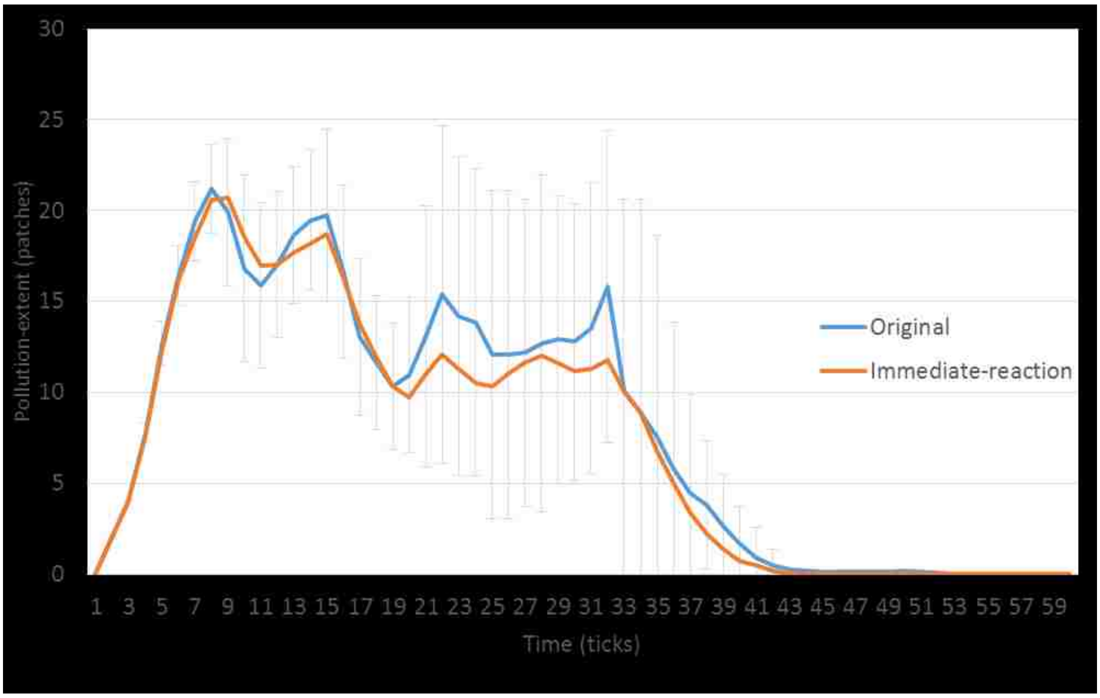


Figure 7.12 *Average pollution extent over 50 model runs for the original configuration and the experiment in which the reactions are faster and the picking up of messages is more frequent. Error bars represent one standard deviation for the original set of model runs. Conditions for the model run include ["pollution-propagation-rate" 1] ["pollution-fix-memory" 1] ["max-random-effectiveness" 0.3] ["available-resources" 1].*

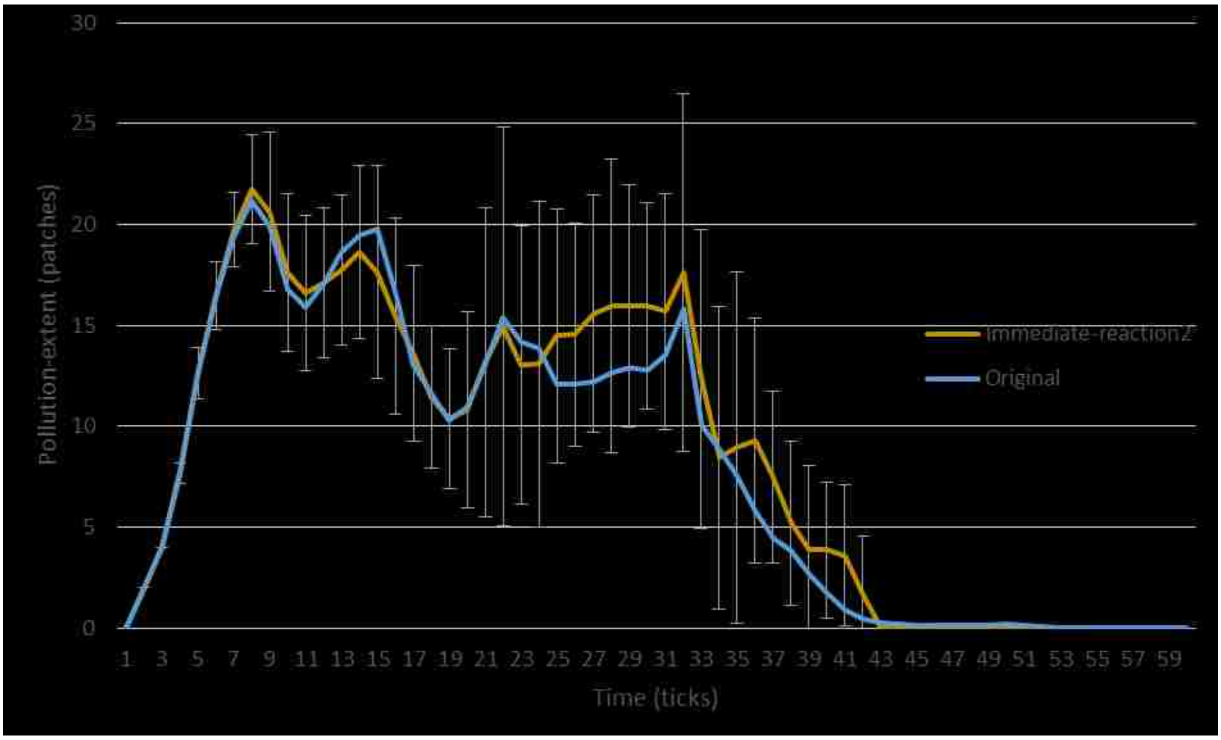


Figure 7.13 *Average pollution extent over 50 model runs for the original configuration and the experiment in which the reactions are faster. Error bars represent one standard deviation for the original set of model runs. Conditions for the model run include ["pollution-propagation-rate" 1] ["pollution-fix-memory" 1] ["max-random-effectiveness" 0.3] ["available-resources" 1].*

7.5.2. Experiment 2: Pollution-thresholds for action

Within the original model most of the stakeholders are represented as being aware of the extent of the pollution problem throughout the run and use their awareness of the problem to judge when and how to act. Most stakeholders are willing to act even when the pollution extent is small, reflecting a sense of responsibility and a desire to reduce damage to the environments they use and manage. Some stakeholders use larger pollution level thresholds to govern when to directly act alone, contact wider partners or act jointly with others to actively reduce the pollution levels. Where stakeholders use higher pollution thresholds it is reflective of a lack of resources to tackle the pollution themselves, meaning that their preferred strategy is to tell others with more responsibility and resource about the problem and ask and encourage them to act. However, if the pollution gets to a larger extent, therefore indicating that others have not been able to solve the problem, those stakeholders who have not previously acted feel they should do something to fulfil their sense of responsibility. The action may be to engage with wider partners or to try and act alone despite their initial restrictions. In the second experiment within the model it can be imagined that each stakeholder has enough resource to act immediately when they perceive the pollution problem and that any action is not governed by the size of the pollution problem. This scenario may represent a very reactive and highly resourced and agile set of stakeholders, where each feels a sense of individual responsibility that might persuade them to act quickly and pursue a number of options more rapidly than if any thresholds for certain action were used.

Figure 7.14 shows the change in average pollution-extent when changes to the behaviours of stakeholders involving pollution thresholds have been changed (in the experimental model no thresholds exist apart from the existence of pollution as a trigger for action). The change in average-pollution extent compared to the original model is not significant and likely due to the small change in thresholds that occur from the original model to the model used. In the original model the thresholds are generally fairly low as most stakeholders are keen to get involved even when the pollution levels are small. The existence of a slight difference in pollution-extent indicates that the small change in behaviour could be having a subtle effect. For example there is a reduction in the average peak pollution level between 10 and 15 ticks, which could be attributed to the agents acting when they previously would have been waiting for pollution to reach a higher threshold, therefore are able to reduce the pollution levels more than previously. There is also a faster reduction in pollution between 22 and 30 ticks, resulting in a lower level of pollution-extent compared to the original model, which could account for the same process of acting when some stakeholders may not have done previously. The effect of the extra action is to maintain a lower than original pollution-extent until the pollution begins to be fixed consistently each run after 44 ticks.

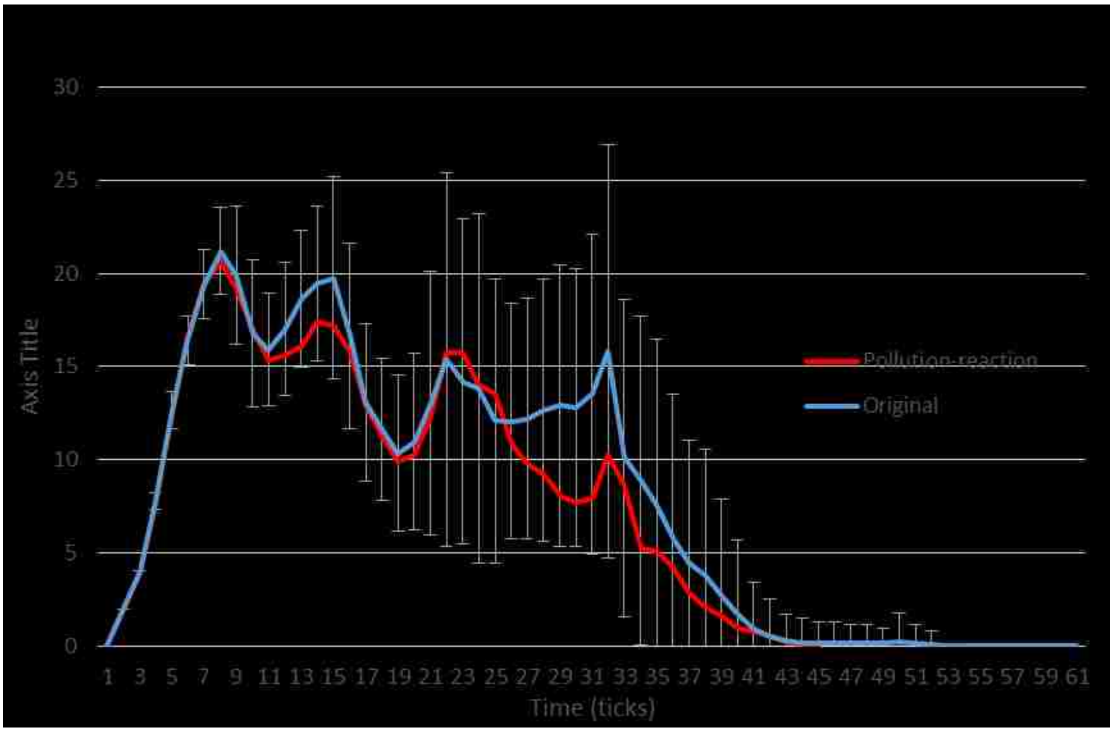


Figure 7.14 *Average pollution extent over 50 model runs for the original configuration and Experiment 2 in which there are lower pollution-extent thresholds for triggering certain actions in the stakeholder strategies. Error bars represent one standard deviation for the original set of model runs. Conditions for the model run include ["pollution-propagation-rate" 1] ["pollution-fix-memory" 1] ["max-random-effectiveness" 0.3] ["available-resources" 1].*

7.5.3. Experiment 3: Joint-action

Within the model stakeholders are hypothesised to both act within their own capacity as an organisation and in joint capacity with others. Each stakeholder enacts the action and joint-action differently and over different time scales as a reflection of their own resources, goals and responsibilities. The length of time that each agent enacts each stage may be influential on the levels of pollution, therefore in the third experiment it can be imagined that each of the stakeholders minimise the length of time they spend reacting to pollution in their own capacity and maximise the time spent acting together with the partner organisations they have contacted or responded to over the course of the pollution event. In the original model the ability of organisations to work with others is clearly represented (and was based on the real capacity and willingness that organisations showed in a real system) but the experiment plays with the idea of maintaining such capacity for longer. In an imagined future management system the maintenance may come from support structures such as funding for short-term 'quick-win' projects with the ability to experiment without need to demonstrate benefits before funding is won, or a tighter system of collaboration among groups when working on a joint project through the concentration of personnel.

Figure 7.15 shows the change in average pollution-extent over model runs showing the difference between the original model and the model adjusted for Experiment 3. For the version of the model used for Experiment 3 the `timeout_expired` function for each round of `direct-action` (see Appendix G) was adjusted to a maximum of 1 for the times when agents were acting in their own capacity or at the beginning of the action process, and at a rate of double their original length of time for the periods where agents were acting together with their partner organisations. The difference in the relative capacity of stakeholders for joint action is therefore still represented in the model, but the absolute capacity is increased. Figure 7.15 shows that the changes in average pollution-extent are noticeable and perhaps more significant than the previous experiments. The changes are evident at a number of stages in the model run including between 8 and 16 ticks, where the experimental model shows a higher pollution-extent and a lesser decrease from the peak pollution-extent than the original model. In general the pollution decreases after the first 7-8 ticks as the agents begin to react and act to reduce the pollution after it has been noticed, in the experimental model the agents are acting for a shorter time and therefore may not be able to act to reduce the pollution as far as in the original model, allowing it to decrease less and increase more at that point. The clearest difference is evident between 20 and 28 ticks where the pollution-extent associated with the model for Experiment 3 is lower and flatter and does not reach a peak as the pollution-extent in the original model does. This stage of the run is likely where the agents are acting together and perhaps due to the extra consistency of their action (double the length of time compared to the original model) can maintain a more consistent pollution level rather than allow it to rise as a number of agents run out of capacity to act together. The final difference in comparison to the original model is after 32 ticks when the pollution begins to decreases rapidly a little later in the experimental model than the original. This difference could be attributed to the fact that within the experimental model the appearance of the project-group is likely later than the original model, due to the fact that the EA, who instigate the project-group, are acting with their partners longer and only begin to think about creating a group once the smaller scale joint action has been enacted, thus delaying the larger decrease that occurs with the enhanced effectiveness of the project-group. Experiment 3 therefore shows that with a fairly large change in behaviour (double action times, for example) there can be a noticeable change in the average pollution level change. The change may show that there is a sensitivity in the model to the processes of joint-action of the agents, which may represent a sensitivity in a real system of the effect of joint-action on the environmental outcomes.

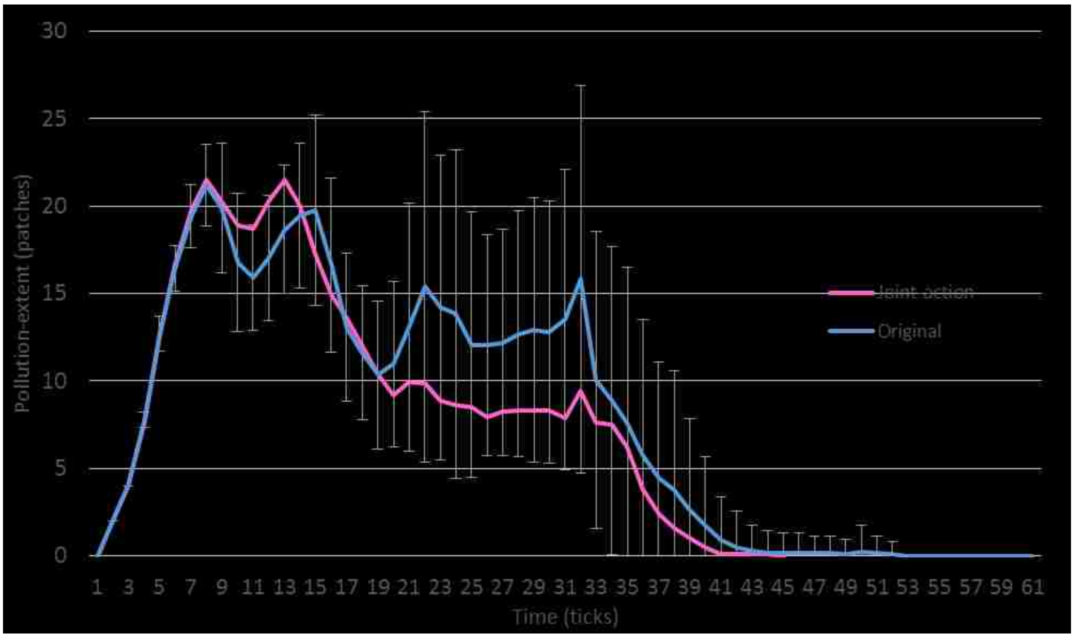


Figure 7.15 *Average pollution extent over 50 model runs for the original configuration and Experiment 3 in which joint-action is enacted for double the original time and individual action just once for each stakeholder. Error bars represent one standard deviation for the original set of model runs. Conditions for the model run include ["pollution-propagation-rate" 1] ["pollution-fix-memory" 1] ["max-random-effectiveness" 0.3] ["available-resources" 1].*

7.5.4. Experiment 4: Central point of sharing

For a number of the stakeholders in the Wear catchment one of the key issues was the sharing of information. A few stakeholders mentioned the desire to have a centralised point into which information about the catchment could be fed and therefore easily accessed by any interested stakeholder. The desire arose from frustrations with access to data, particularly data held by groups seen to have more authority within the catchment and which were sometimes less accessible. In the Wear catchment the structure of the Catchment Partnership allows for data sharing amongst a number of key stakeholders (although not without difficulties due to permissions and technicalities), but some smaller organisations and actors are not included in the strategic partnership meetings and therefore expressed a desire for sharing that could be centralised for wider stakeholders and smaller action groups in addition to those at the strategic level. Experiment 4 draws on the ideal practice of sharing information centrally within the catchment network.

Experiment 4 imagines a system in which agents can share information through a central point (`SharePoint`). All agents feed information about the existence of a pollution event to the central point and all agents are aware of and able to access the information from the central point. The experimental model assumes that all agents feed in the same type of information and can access information equally from the central point at any time. Agents 'check' the sharing point whilst observing the environment or checking their messaging system, meaning that they may come across information at different times. It is hypothesised that agents would gain in effectiveness through their increased access to data, therefore in the experimental model all agents have an increased `data-on-water-qual` variable (all at maximum 10). The access to more information about the existence of pollution may allow the stakeholders to react faster to the event and to reduce pollution more effectively.

Figure 7.16 shows the average changes to pollution-extent when agents share information via a share point compared to the original model. Figure 7.16 shows a small difference in extent of pollution throughout the model runs, which is likely representative of the increase in effectiveness of each of the agents due to the higher data access score. The overall pattern of change is similar to the original model; the speed of the overall solution is the same and does not indicate that the sharing of information at the beginning has any significant effect on the following behaviour of the agents and therefore the pollution-extent.

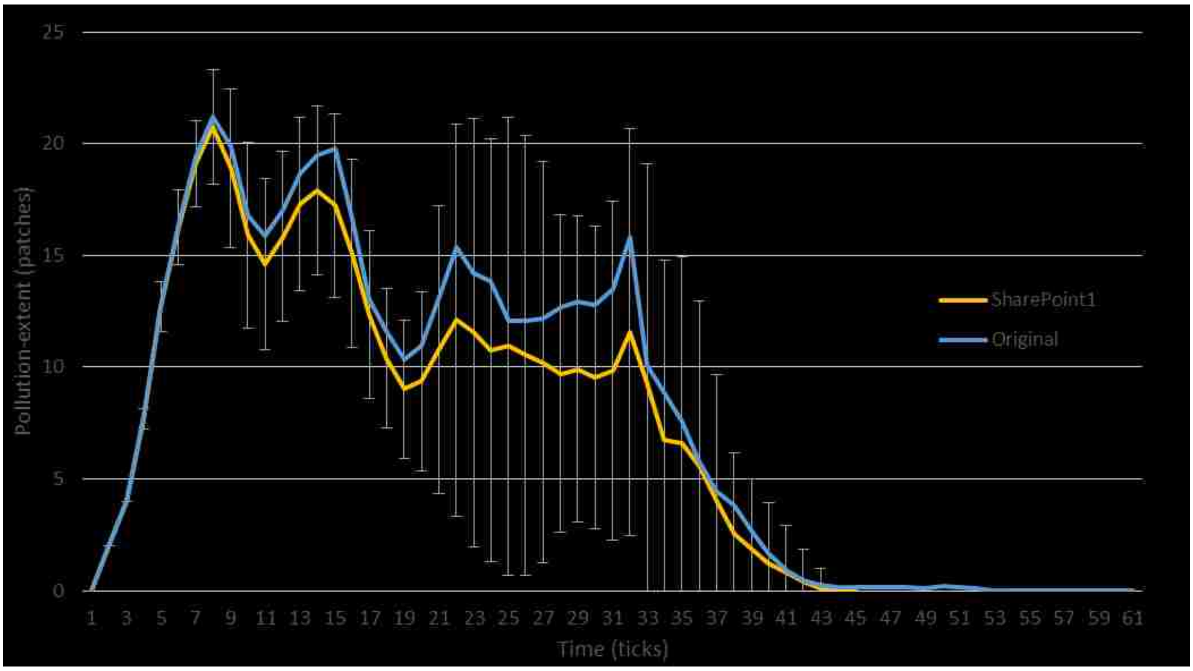


Figure 7.16 *Average pollution extent over 50 model runs for the original configuration and Experiment 4 in which agents share information with a central point and have an increased access to data score. Error bars represent one standard deviation for the original set of model runs. Conditions for the model run include ["pollution-propagation-rate" 1] ["pollution-fix-memory" 1] ["max-random-effectiveness" 0.3] ["available-resources" 1].*

The effect of a central sharing point may be less when the agents only share information about the existence of a pollution event. If the agents were to share information about their own activity, ideas and goals then it may be possible for other agents to align their own action with that already being enacted by others or create joint-action where there may not have been previous opportunity. However, it is very difficult to speculate the extent to which such sharing would offer opportunities for changes in behaviour or strategies, as outcomes would be very dependent on the type of data that was shared and the timings of such sharing. It would equally still be reliant on a strong network of contacts within the catchment who would be willing to be available and reactive to the ideas of others based on the information in the central sharing point. There would still need to be contact made with groups and still need to be individual collaborations agreed (as is simulated in the original model). The central sharing point may offer an easier way to contact groups outside of stakeholder's normal working-partners and therefore act as an intermediary in the catchment network, shortening paths between agents and facilitating trust (if all stakeholders used the system with the same willingness and openness), perhaps meaning that the ultimate joint-action is more satisfactory to stakeholders and potentially more effective at reducing pollution (although not guaranteed). Given the levels of abstraction and assumptions within the current ABM model, adding specific elements of data sharing practice would be expanding the model into a layer of detail too speculative to be useful at this point. A larger extension to experiment 4 could therefore incorporate more detailed sharing strategies using a central point of access and the possible effects on decisions to undertake joint-action as a result of having access to the share-point.

7.6. Discussion of modelling outcomes

The process of modelling the interaction between stakeholders within the context of a water-pollution event has offered the chance to explore the empirical observations from the River Wear catchment in a new and different way. It has allowed the interrogation of the descriptions and opinions of the stakeholders grounded in the empirical data alongside the ability to use the ABM as a "computational petri-dish" (Miller and Page, 2007) to explore a potential scenario and projected behaviours within that scenario. The process of modelling has served to help formalise ideas about the influences on and structures of stakeholder behaviour and decision-making (Chapters 5 and 6). The ideas presented in the modelling example characterise the system of interaction at the event-scale, and therefore outcomes of the modelling process are not designed to provide answers or predict future changes in the system. The process can help to hypothesise dynamics about the behaviour of stakeholders that would not otherwise have been able to be identified. Such observations and new questions have implications for analysing the broader system of catchment management more critically, particularly if the event-scale is seen to inform the interactions and actions at the wider scale.

7.6.1. Processes of decision-making

The process of formulating an ABM has allowed an understanding of the processes stakeholders may go through when reacting to a pollution incident to emerge, giving insight into the capacity of stakeholders to act within a system. As part of the stakeholder strategies for the model it was hypothesised that each stakeholder enact a number of stages as part of the process. Although each of the stages of such strategies is not new or unknown, the identification of mechanisms that might happen in each stage and the identification of the influences on and relative importance of each stage for different outcomes, is potentially significant. Themes identified as important for understanding the functioning of governance approaches can be seen to be important at each stage and were included in the conception of the rules for each stakeholders at each stage:

- Observing the environment: access to data, legitimacy of data-collection processes, expertise, roles and responsibilities, connection to others who have access to data, motivation to pursue data in relation to a problem.
- Informing others: Previous relationships and working patterns, position in a networked system, trust, sense of responsibility, perception of problem, influence of policy and regulation.
- Action to mitigate pollution: Access to resources, perception and motivation, skills and expertise, sense of responsibility, institutional norms.
- Seeking partners: Position in network, role and responsibility, trust and trustworthiness, legitimacy of evidence, goals, motivation, problem-perception, institutional norms.
- Working with others: structure and availability of spaces of interaction, exchange of knowledge and data, trust, access to resources, sense of responsibility, and adaptability of goals.

Knowledge of the various stages could help to identify where intervention might be most significant given the processes involved in each stage and the potential for changes in behaviour to change the outcomes of action and activity. The identification of similar stages for most of the stakeholder groups (with the acknowledgement that each of the stages might look very different for each of the stakeholders) means that there can be questions raised about universality of the response to pollution problems. New questions emerging as a result could be, for example, could each of the stages be identified by stakeholder groups and standard practices be agreed upon at each stage that may make a difference across the catchment (should there be a requirement for a wider change in behaviour)? Equally, could comparisons be more easily made between disparate groups if they identified the points at which their strategies intersect or at times when they might be pursuing similar goals through each stage? Such questions might help reflect on current approaches to catchment management and would not have been possible to reflect upon in such detail without the process of model creation to facilitate the hypothesis creation.

7.6.2. Importance of personal sub-networks

Part of the value of the model created for this research is the ability to examine and reflect on the way each stakeholder's effectiveness (as a conceptualisation of their capacity to act) was adapted and changed through processes of collaboration (dependent on the particular theoretical collaboration strategy). The influence of the number and type of links (based on a network of working-partners) each stakeholder had was seen to influence the resultant effectiveness of joint-action. The change in the effectiveness can be seen as an indication of change in the network structure at the personal sub-network level. The model facilitates a hypothesis that the overall effect on pollution is a result of the configuration and activity of the small-scale networks in the catchment as stakeholders interact with one another. Each stakeholder is affected by a unique combination of factors that affect their ability to act and interact which affects their own personal sub-network. Whilst at the scale of the model (the event-scale) such networks affect the immediate action and effect on the water environment, at the interactional scale such networks are affected by the opportunities open to stakeholders to build a set of diverse relationships through participation and inclusion in collaborative structures that either build trusting relationships, make stakeholders aware of the role of others in the catchment or provide opportunities to share, exchange and co-create knowledge about the catchment. Such effects have been reported in the Wear catchment facilitated by the CaBA approach. The potential link between the longer time-scale strategic action context of a process like CaBA and the event-scale (represented in the model) is the building of personal sub-networks for each stakeholder that they might 'wake up' links in reaction to observations of pollution, for example. Moreover, there is likely to be a formative link between the event-scale and the strategic management scale in that action and interaction facilitated in reaction to sudden environmental change builds opportunity for joint-action such as project work, as well as motivation and evidence to feed into wider priority setting in collaborative groups. The trust or legitimacy built at the event-scale may be learned from (through processes of social learning) in terms of creating sustainable links between groups, which then inform and strengthen the connectivity across the whole network. Such ideas of capacity at the personal sub-network level relate to ideas of relational capital, where capacity is seen to be built through relation to others. Experiment 1 in this research suggests that there is value in stakeholders taking advantage of multiple links when looking to carry out joint action, as action with minimal partners could be suggested to be less effective, at least at the event-scale. The process of modelling has opened up the consideration of the importance of stakeholder-centred capacity in relation to the networks built through actions and activities across scales within the system.

7.6.3. Communication and ability to react

A potential change in frequency of communication and reaction times of each stakeholder was seen to have an impact on the reduction in pollution levels (a proxy for effective action) in the modelled environment. Within the Wear catchment communication is facilitated in multiple ways within the stakeholders groups. One of the methods apparent and mentioned by a number of stakeholders is the creation of, or dedication of time to, the role of a catchment-coordinator or officer for individual organisations. In relation to an event-scale system it could be hypothesised that it is agents such as these intermediaries that would take responsibility for communication and have some influence on ability to react quickly (although constrained by other factors such as institutional norms, responsibility, policy, resource access and motivation). Such roles have been, or are newly in existence in larger organisations such as the EA, the AONB, Coal Authority and NWL, where the dedicated officer can be a point of contact and focus time and effort in building relationships. The stakeholders mentioned the benefits of having such a role and the growing tendency of the organisations to create and support such roles. The creation of more intermediary roles such as these may be able to facilitate a component of the behaviour change imagined in Experiment 1, perhaps leading to more effective environmental change at the event-scale (as well as at other scales). However, such roles were also mentioned as difficult to maintain due to the need to balance dedicated communication and decision-making about the collaborative catchment efforts with other duties and other priorities for the organisation. Equally, where groups do not have the capacity for a separate intermediary a constant balance has to be maintained in order to give the time to communication and to building the relationships needed to be reactive to catchment issues. More empirical evidence is needed to discern the link between such behaviour change and outcome such as improved water quality (at the event and longer term scale).

Alongside the existence of time and people to facilitate communication and exchange, should organisations wish to change the way they communicate and interact with other groups there needs to be an infrastructure in place to allow that to happen. For example, as part of the work of the WCP, the WRT organised stakeholder-meetings (such as the Old Durham Beck meetings) to discuss particular problems. Such meetings put groups into close contact and offer the chance for communication and sharing of ideas and resources, therefore, it might be theorised that more meetings (or similar spaces and places of communication and interaction) would enable the kind of increased contact and closeness that Experiment 1 imagined. However, it has been shown that such meetings do not always engender positive outcomes or build trust depending on the attitude of those taking part and the modes and subjects of discussion. The comments from stakeholders in the Wear catchment have highlighted that regular contact with other groups (particularly those with whom there may have been a lack of trust previously) in a variety of situations that suit both groups, often outside of organised meeting spaces, can build stronger relationships that can become reliable working relationships (the idea that feeds into the concept of working-partners in the ABM), in which communication is easier and more effective as the attitude of both groups is open and trusting. However, equally those relationships only exist between certain individuals and for certain problems and issues (trust is transient). When a different issue occurs, for example an event that needs action and cooperation on a different scale, the relationships may need to be remade with new individuals or through new mechanisms. The strength of relationships (and the need for diverse personal sub-networks) is important for creating opportunities for communication to cope with new situations. Therefore Experiment 1 suggests that the way in which close relationships are built, maintained and facilitated is likely to be an important part of understanding response and effectiveness of a decision process.

7.6.4. Roles, responsibility and action

Experiment 2 suggested that with an increased propensity to react quickly there was a small reduction in the extent of pollution (representative of a more effective ability to tackle the problem). In relation to the real situation in the Wear catchment, if stakeholders were to be able to react more quickly to problems they would have to take on a level of responsibility (sometimes over and above their perceived responsibility), have the resources and skills available, or the knowledge of who else has the knowledge and skills, to deal with the problem, and perceive the problem to be significant enough to react. In the Wear catchment those stakeholders involved in water management currently have a high sense of responsibility or official responsibility. Where reactions to problems might be lacking is where problem-perception differs or where belief in their ability to be part of the solution is low. However, there are examples within the Wear catchment case of opinions (and therefore reactions) to pollution being changed. For example, a farmer reported that through contact with groups such as the WRT and their partner organisations they were persuaded to change their behaviour in relation to water courses on their land, where previously they had thought the issue unproblematic or were lacking in the opportunity to create a solution. Such actions show that it is possible for activity of others to change the perception, opportunity and activities of others in relation to specific problems. The conditions for the change in attitude were based on the presence of trusted relationships built up over time and through shared understanding and experience, influencing the ability of those trusted groups to influence the preferences and options of the farmer. Zellner *et al.* (2014) state that the capabilities of agents to influence the positions, preferences, or opinions of other agents is vital in a collective-decision making system (such as a catchment management system). Where the ability is also facilitated is through the availability of resource to equip, for example the farmers, with the tools and materials to carry out actions, which is a result of a funding structure that support joint-projects, for example such as the Agricultural Diffuse Pollution project in the Wear catchment. To influence and change reactions of agents requires a complex mix of factors and an alignment of understandings. The results of Experiment 2 highlight the potential to identify where reactions or abilities of stakeholders to react (either at the event-scale or other scales) is lacking and the kinds of actions, structures and processes that might be involved to change those aspects. It is important to note that the experiment not be interpreted as suggesting that all agents should play the same role in reacting to a pollution incident, which would go against the diversity of groups involved, but to asses where the capacity of the groups might be lacking in reacting in an expected or better (agreed) way.

7.6.5. Preparedness and ability to enact joint action

Experiment 3 touched on the possibility of increased time spent conducting joint action, and demonstrated the largest change in the pollution-extent based on changes in behaviour of the agents in the model. The hypothesised ideal of longer action, however, is perhaps over-generalised and did not take into account the type of projects that might be run or the need that they might be fulfilling, and therefore the fact that not every project would be more effective if simply extended. The model, however could also be symbolising an extended emphasis on joint-working rather than the exact time-frame of the projects, which could mean that each group invested more time and resource in working with others when specific problems appear. Such preparedness could be a result of forward planning for unknown events or by being aware of and linked to others more consistently or sustainably and therefore more able to work together when needed. The experiment also highlights the need for a support system for such activity, which would likely involve more and more easily available funding for small-scale projects. Again, although the model results cannot give exacting conclusions about the need for or utility of more joint-action, it can raise questions about the factors that contribute to the production and maintenance of joint action and begin to question the structures and support systems in existence.

7.6.6. Consideration of new modes of sharing

The existence of sharing point was hypothesised to change the structure of the communication network within the catchment and thus act as a connection between perhaps disparate groups. The process of thinking through the mechanisms that would need to change and how they would change to accommodate the new structure also highlighted that, although a useful conduit for sharing data, a sharing point would likely still encounter problems of trust, access, lack of resources and structures to support joint-action after data had been shared. Examples of the use of 'share points' in other catchments have shown that they can be an important addition for creating more successful funding applications or for allowing in depth modelling of the system, but that their benefits are sometimes less clear (as yet) (CaBA, 2016). The overall consensus seemed to be optimistic for the utility of data sharing and therefore highlights the need for further investigation. As an extension to the current ABM it could be insightful to talk to stakeholders about their data sharing mechanisms and use such data to experiment with the existence of a sharing system in a catchment system.

7.6.7. Adaptable and agile agents

The modelling process, in combination with the analysis of networks and enabling factors, has highlighted that there are sets of relations, attitudes, capacities and decisions that might affect the way that stakeholders respond and act. In terms of viewing the system as a complex, adaptive system, such observations about the potential effectiveness of increased agility of stakeholder agents highlights the importance of adaptability to functional catchment management and the importance of reflecting on factors, structures and processes that might allow the development of an adaptability. The value of modelling in contributing to an understanding of the need for adaptability and agility can lead to more unique discussions about future change.

7.6.8 Insights from modelling about network structure and functionality

The modelling process has helped analyse the system of catchment management in relation to the concepts and ideas of network structure and functionality of the system. The networked nature of the system is seen to be an important part of collaborative catchment governance and the modelling process has helped to experiment with the way that networks might operate given changes in different factors that might affect the functionality of relationships. The design of the model translated the idea that networks can be understood at the stakeholder level with each actor central to their own network of others, where network connections are important in relation to capacity, opportunity and access to resources. The model assumed that the emergence of effectiveness of a networked system would come from the combination of stakeholder actions situated within and bounded by their interlinking networks, the combination of which formed the networked system. Where the previous chapters have identified the nature of network structure, its changes and outcomes (Chapter 5), and the multiple influential factors on functionality of a management system, situated within a particular governance approach (Chapter 6), the modelling process allowed experimentation with the way that the network structure and related influences on functionality of relationships for example might affect decision-making around a particular management problem (minewater pollution of a watercourse). The value lies in the opportunity to use knowledge already gained about how a networked system is enacted and the various ways that relationships can be enabled or restricted to identify potential leverage points in the system to improve effectiveness.

The model concentrated on an event-scale context that involved management decisions about action, communication and collaboration taken by individual stakeholders, which have been analysed throughout the thesis to be the fundamental point at which governance approaches and processes are operationalised. The event-scale is seen to be an example of one time-frame that the system can be conceived at, but one that might reveal association between day to day decision making and the formation of elements of governance systems that become more embedded and visible across time (such as formal and informal institutions). As such the model concentrated on relationships between stakeholders rather than the connections to network structures such as partnerships or schemes, although a project group structure is used to represent the beginning of processes that form more embedded structured interaction around a specific problem. The model therefore translates the idea that stakeholders' decisions in a management context are formed by and form networks. Although the model was restricted to analysing just one understanding of effectiveness (reduction in pollution), it translates the ideas that effective practice or outcomes are affected through the nature of the interactions within the networks and whilst creating new connections, which is influenced by factors at the individual, interactional and contextual level (alongside the broader structural context, power relations and institutions operating in a particular context) discussed in Chapter 6.

The modelling processes has shown that network structure is something that can be fluid at the event-scale and at any one time there is a different set of sub-networks operating depending on varying operation of communication, action and collaborative interactions. Factors such as access to resources, responsibility, communication and trust influence the nature of communication and collaboration as modes of connection to form sub-networks (partly bounded by the existence of more embedded relations). Where these are varied there are seen to be changes in the effectiveness of the system of management in relation to one particular output (change in environmental condition). The experiments run within the model give an indication of the relevance of various factors in the system to functionality in relation to effective outcomes, both through analysis of the factors directly represented in the model and of those that are implicit in the nature of the decision making strategies programmed into the agents within the model (based on the observations and analysis within the Wear catchment). Certain factors were seen to have more effect than others, for example increased access to resources and an increased investment in partnership working through changes in commitment, responsibility and collaboration, which implicitly relate to social and institutional norms, motivation, relations of trust, legitimacy and power dynamics as well as contextual effects. The model allowed the experimentation with changes in factors influencing functionality and the resultant analysis, and the link back to possible realities in a catchment situation confound the heuristic purpose of the model.

The modelling processes also gave insight into network structure and functionality across timescales. The event-scale was not one that was studies empirically in this research but one which the modelling process could compare to the longer timescale view given by a more generalised overview of the system because of its virtual and simulation opportunities. As such the model helped to reveal that network structure is relatable between event-scale and longer time scale through the repeated nature of new links building trusted relations that become more embedded to form a networked system. Whilst the model did not generate these patterns as only one event was modelled, the chance to experiment with the decision patterns of the stakeholders and the observation of changes in sub-networks, alongside analysis of the experiences of stakeholders through the empirical data, indicates the likely role of small scale events creating opportunity for interaction that builds trust that then becomes a more permanent pattern of interaction.

The results of the experiments also gave insight into the potential importance of agents who can communicate across groups, due to the increase in effectiveness of the system when communication was increased between stakeholder agents in the model. This is related to the idea of brokers and intermediaries within a networked system and show that they may be important at multiple scales for acting as a point of contact between groups. Whilst this can be a group or organisation, it can also be an individual within a group who acts as a point of contact with other groups. This reflection through the model results gives insights into the type and form of network that may be effective and gives insight into the potential leverage points within a real system that could improve effectiveness.

The ability for agents to act quickly was also found in the modelling experiments to give a small reduction in the extent of pollution and this is associated with factors affecting the networked interactions through a sense of responsibility and ability and willingness to act. These factors are represented in the model and also implicitly tied to the trusted relationships and a funding structure that support joint-projects. Although the project level aspects of a network structure were not included in the modelled system the observation about the potential influence of particular factors on the nature of the relationships (which were implicitly structured in the model based on relations as represented in the Wear catchment influenced by its collaborative network structure) helps underpin understandings of functionality when projects are part of the system being studied. The insights from the model are therefore important for underpinning understandings of the full networked system by experimenting with dynamics of a particular management decision context.

The modelling process also gave insights into the way that network structure itself could be changed and its potential effect on outcomes. The experiment to add a new structure for sharing information amongst the stakeholders allowed an experimentation with the processes of data and information transfer (which were based on empirical understandings). The effects on outcomes within the modelled system were small and as such showed that a change in structure in this way may be less effective within the bounds of current influences of the functionality of the relationships. The model therefore gave insights into the nature of network structure change and helped raise questions about the way in which better relations could be facilitated through networked changes. The link between the model results and the analysis of the way that network structure can be operationalised in relation to functionality of that system in relation to outcomes was important for learning more about the system of catchment scale water management.

7.6.9. Limitations of the modelling process

The modelling process is not without limitation and the model assumptions and restrictions mean the conclusions and questions that emerge should be taken in context of the process through which they were created. The use of NetLogo language and systems such as BDI nominally restrict the way the system can be conceptualised and often means that a rigidity is applied to rules and interactions that may not be clear in the qualitative data. The act of assigning numerical values to aspects of the system that cannot ordinarily be quantified is also a significant limitation to interpretation (Yang and Gilbert, 2008). Such limitations mean that the agents' ways of acting in the modelled system are distinctly unrealistic in relation to the cognition of human agents. As long as this recognition is acknowledged in interpretation of results such limitations can be accommodated, however the difficulty comes in the decision about when the representation is 'good enough' to be usefully interpreted (Wilensky and Rand, 2015).

7.6.9.1 A non-participatory process

In relation to the model in this research the way that outcomes have been interpreted have been cautious, in relation to realism. This caution is because validation of the behaviours in the system as 'good enough' have relied only on reference to observational data, and the modeller's own theoretical expectations (Oreskes *et al.*, 1994). It is widely agreed that it is important to have feedback from stakeholders about the rules and decision processes implemented in an ABM as part of the validation process (Barreteau *et al.*, 2003). As a consequence it would be ideal, given more time, to involve stakeholders more closely in the checking and design of an ABM model. Such a validation process, would allow the restrictions of the process and software to be somewhat overcome if usefulness was universally agreed.

Overall the approach to the modelling in this thesis has been non-participatory, which was a purposeful choice due to the circumstances of the project. Hare (2011) states that in order to implement a successful participatory modelling process skills are needed in facilitation and the technical process of modelling in order to confidently engage stakeholders and competently involve them in a modelling processes that will be useful for its particular designed purpose (e.g. social learning or decision-support). At the beginning of the project it was decided that the technical skills and knowledge of the processes of modelling was not sufficient enough to support a full participatory approach that would bring benefit to all involved, specifically where the involvement would have been most beneficial from early stages of the research. Moreover, it was justified as a moral and ethical decision where it was seen as unjust to request voluntary time and energy of participants when the process of modelling was also unknown to the researcher. As this was not a fully participatory research project, where the research questions and methods would be co-designed, the experimentation and uncertainty required to develop, implement and test the model would have been frustrating and potentially irrelevant for participants. As such it means that the model produced was for a very different purpose. In its current form the model has been used as a learning tool for the researcher (which was its purpose in this project), which has brought benefits to the reflection on the conceptualisation of the catchment management system and governance processes. Through this purpose the model is acknowledged to be less widely applicable than a model validated through stakeholder involvement and is restricted in the conclusions that it can make about the system This was balanced in relation to the harm reduced to potential participants had they been involved with an unfulfilling participatory process, or the risk of a failed participatory process. Improvement to the research process would however be to bring stakeholders in to later stages of the modelling process in order to test assumptions. More in-depth involvement of stakeholders in the design and experimentation with an ABM system would allow the ABM process to act as a learning tool for a much wider audience and to be a source of dialogical material to begin conversations within and between both academic and practical spheres.

7.6.9.2 Stochasticity

The model is recognised to have fairly high levels of stochasticity, which have been designed into the model in order to represent the uncertainty in aspects of the natural environment and in effectiveness of actions on the river environment. This variability can produce interesting analyses in itself (Bruch and Atwell, 2015), but means that it is difficult to interpret small change in output based on changes in parameter values when variability is high. The stochasticity in the model has been addressed through the aggregation of the results of multiple model runs before analysis. However it is recognised as a limitation to interpretation and a reason that the results of the experimentations should be seen as starting points for further understanding of the system rather than any stronger association with potential mechanisms of change.

7.7. Conclusion

This chapter has focused on the presentation of an ABM modelling process designed to facilitate the further exploration and understanding of stakeholder interactions and decisions in a catchment management context. The model focuses on hypothesising patterns of interaction around a small-scale pollution event, asking how stakeholder strategies might combine to produce an effect on the environment, and to experiment with changes in stakeholder behaviour and their possible effect on outcomes. The modelling process incorporates qualitative empirical data from stakeholders about their specific imagined behaviour in the particular scenario combined with more general understandings and hypotheses of stakeholder behaviour within a networked system. The process has begun to highlight questions about dynamics as well as beginning to be able to comment on times and spaces where the stakeholders may have some control over aspects of the decision processes (Zellner *et al.*, 2014) and where considering these elements more closely might help lead to better or more efficient processes of management.

The heuristic purpose of the modelling process has been its key value in this research. The patterns that emerge are interpreted as mimicking emergence in the real system rather than directly relating to any process that might happen (Clifford, 2008). Consequently, it is the interpretation of the outcomes that adds value to the research process. From the process of model building and the experimentation with changes to the behaviour of stakeholder a number of observations or possible understandings of dynamics can be mentioned as a focus of ongoing interpretation, and can be applied to ideas of future change in the catchment system:

- The universal stages of response shared amongst stakeholders to pollution problems could be a useful way into focus on reform or reallocation of resources when searching for new ways to adjust response or behaviour.

- There is likely a link between the patterns of interaction at the event-scale and at longer scales where collaborative working is more formalised and vice versa. Therefore the way in which close relationships are built, maintained and facilitated is likely to be an important part of understanding response and effectiveness of a decision process at multiple scales.
- The process of modelling has opened up the consideration of the importance of stakeholder-centred capacity in relation to the networks built through actions and activities across scales within the catchment management system.
- In order to increase the effectiveness of joint-action across a collaborative network there is likely needed to be changes in the attitude, opportunity and available resources. It might be observed that wider structures of support for small-scale joint action might increase such factors. Again, this would need to be contextualised through further study.
- The modelling process suggests the value of the adaptability and agility of agents in reacting to small-scale events may be an important factor in facilitating more effective environmental improvement, which link to capacity built up through actions and interactions at multiple scales within a management system.
- There are significant limitations of a modelling process that mean the utility of the suggestions from the model outputs need to be part of a discursive process in which ideas are used to begin discussions rather than as immediate suggestions for any real change in practice (Millington and Wainwright, 2016).

It is noted that the conclusions from the modelling process in this chapter should be considered in context of other forms of analysis about the system of catchment management, such as an understanding of the networked system (Chapter 5) and an understanding of the complexity of factors affecting stakeholder actions and interactions (Chapter 6). The following chapter will reflect on the system as a whole and discuss the implications of the processes and outcomes of each form of analysis in the context of catchment management and an understanding of complex, networked, social-ecological systems of collaborative NRM.

Chapter Eight

Discussion

8.1 Chapter overview

This chapter analyses the core themes of the thesis across Chapters 5, 6 and 7. It first discusses the relation of key themes of complexity and emergence to the findings and explores their relevance and implications for water governance and management research. The chapter then evaluates the findings in relation to understanding structure and functionality through a network perspective, a systematic understanding of the barriers and enablers to functionality and exploring the mechanisms of interaction and action for stakeholders in the catchment management process. The evaluations can be seen to relate to understanding the character of catchment governance system and process of management. The chapter concludes with reflection and evaluation of the implications of the research for catchment management practice in the Wear catchment and reflections on processes of catchment governance.

8.2 Understanding network structure and functionality: reflecting on a collaborative catchment governance system

Each of the modes of exploration of the catchment-management actions and interactions in the catchment governance process in this research has given insights into the system. Using a network perspective has added to an understanding of how network structure might be conceptualised in order to characterise a governance approach, and is supplemented with in-depth analysis and modelling to add an understanding of how functionality might be affected. The following sections discuss aspects of each mode of exploration, in relation to the original aims and research questions for the research, referring to the outcomes of the research analysis and the consequences of the methodological approaches.

8.2.1 A network perspective: characterising the practice of catchment management and operationalisation of catchment governance

Fligstein and McAdam (2012:6) suggested that "there is very little elaboration of how actors enact structure and the role they play in sustaining or changing these structures over time". As such the research aimed to conceptualise the network structural relationships within the catchment system. The first stage of analysis in this research project focused on utilising a network perspective to identify the characteristics of the system in the River Wear catchment. The approach was influenced by both social as well as social-ecological network analysis, and aimed to better understand the system and practices within the system as shaped by the CaBA, fuelled by questions about the shape, pattern, utility and sustainability of the new form of collaborative catchment management within the application of collaborative water-resource governance. Network analysis has been proven valuable for making existing network structures in systems such as catchment management more visible and for analysing the positions, contexts and interaction of individual actors and the collective networks underpinning catchment scale governance (Stein *et al.*, 2011). Parker (2007) has highlighted that not all networks arrangements can be described as governance networks and that there should be the presence of steering and coordinating feature for the network to represent a governance network (itself not necessarily representative of governance structures). The approach in this research has been successful in identifying some of the key components of the network, exploring an understanding of the roles of different groups in relation to their conceptualised position in the network, identifying changes in network structure as changes in practice, and the way in which changing practice through network change is perceived as positive or needing improvement. The roles, changes and outcomes have indicated coordination and cooperation amongst the stakeholders and therefore can be seen to be indicate the presence of a governance network, which reveals something about the operationalisation of water resource governance. The process of network analysis has helped conceptualise the system in a way that reveals a new perspective on the operationalisation of a governance approach and helped build an understanding of how catchment management can be conceptualised as being structured in relation to its networked features, and how stakeholders interact and act to facilitate practice. It has also raised questions about the nature of the networked governance system and highlighted complexities and intricacies that add to the understanding of the system as complex.

One of the key outcomes of a networked approach is the development of knowledge about the components of the management system and the configuration of a catchment governance network. Traditional social network analysis focuses on the individual and organisational entities in a network and this study has identified the wide variety of organisations linked to management of water issues in the Wear catchment. This research has also identified additional nodes representing spaces and places of interaction, including meetings, partnerships, schemes, projects and actions that are important for the conceptualisation of the management network. Studies such as Janssen *et al.* (2006) have also identified the importance of elements such as projects in the conceptualisation of a social-ecological network. For example, Janssen *et al.* (2006) identified that a project to manage flooded meadows in the Kristianstads Vittenrike, Stockholm, brought together multiple actors from a variety of networks, and therefore needed to be included in the conceptualisation of the network in order to recognise the matching of social and ecological processes. In the Wear catchment the identification of additional nodes in the network helps recognise the link between strategic decision-making and on-the-ground, physical actions, through the transference and solidifying of collaborative interaction in projects and schemes (for short and long term implementation respectively). Such additional nodes help conceptualise the system as dynamic and made up of multiple elements that each facilitate and support processes of change over different spatial and temporal scales.

The particular pattern of alternative nodes within the catchment system indicates the characteristics of the CaBA approach. For example, when considering betweenness centrality in relation to the network conceptualised for the Wear catchment, the inclusion of spaces and places meant that the moments, structures, interventions and planned actions could be evaluated for their role in the network despite not normally being included when using network metrics. For example, elements such as new partnerships, (such as the Coastal Streams Partnership) were identified as potentially important for bringing new groups into relationship who had not previously worked together (shown through the betweenness measure), which was different to the role suggested by the measure of the established WCP that acted to connect many groups but those group already had close relations with each other. The use of network metrics to help expose particular roles and important elements of the system arguably stretches the concept away from its application to traditional SNA, but the use of the logic underpinning the idea of centrality and its combination with the qualitative interpretation of the system allowed the comparison of heterogeneous elements to be an advantage rather than a confusion, to better expose the multi-layered nature of a network. Such an evaluation may be useful in analysing and reviewing particular network structures which might open up discussions about the balance of meetings, projects, schemes and partnerships in a collaborative approach like CaBA.

In addition to the identification of network structures, the network perspective can help the identification of changes to interactions within the system. Stakeholders in the Wear picked up on changes in network structure that relate to the creation of new meeting structures, new communication practices, new intermediary roles, new projects, new strategic partnerships and new responsibilities. Such changes could be seen as representative of institutional change facilitated through the CaBA. If institutions can be understood as the 'rules of the game' (North, 1990) institutional change involves changes in the modes of exchange and practice of interaction and action. It is generally agreed that the initial formation of a partnership can be seen as a process of institutionalisation (based on, for example, much work by Barbara Gray e.g. Gray and Wood, 1991; Gray and Stites, 2013) as such structures have now become relatively stable in their existence (if not their membership) in the network. The high centrality measure of the WCP in the network structure showed that the WCP played a central role, acting to connect a high number of stakeholders, demonstrating the embeddedness of the network structure within stakeholder systems. The fact that catchment partnerships are supported and facilitated in a top-down system from DEFRA with the specific purpose of fulfilling the WFD, means they have a regulatory framework, which Pahl-Wostl *et al.* (2007) argue provides long-term stability for new structures to become institutionalised. The positive acceptance of the WCP as a system of decision-making was clear amongst the stakeholders in the Wear and therefore is an important indication of the potential sustainability of the management approach and of that mode of operation of the catchment governance process. The formal and informal institutionalisation of aspects of a system considered collaborative or participatory, such as a catchment partnership structure, arguably indicate the presence of governance networks (Newig *et al.*, 2010). CaBA can therefore be considered an example of a governance network in which there are relatively stable horizontal interactions (between stakeholders through institutionalised partnerships) within regulative and normative frameworks (CaBA and the WFD), that are self-regulating (adaptive to changes) and contribute to a public purpose such as water-quality management (Torfing, 2005). The use of a network perspective has facilitated the identification of the nature and existence of governance networks in relation to approaches to catchment-scale water-quality improvement , and can be better understood through a conceptualisation of the way that interactions are seen to have changed matched against a time of change in governance practice.

Alongside the structural centrality of more stable features such as the WCP, the smaller scale changes in practice described by the stakeholders and interpreted in this research as changes in network structure (such as new intermediary roles, new projects, new smaller scale partnerships and new responsibilities) could be argued to represent the way that the institutionalisation is playing out beyond the expected and standard (across all catchments) catchment partnership. The changes might indicate informal or partial institutionalisation that represents a more flexible and fluid system within the governance pattern in which learning and adaption are important. For example, the presence of new collaborative projects arise in reaction to particular problems and priorities, which can change and be reformed as knowledge or opinion changes or new co-produced knowledge emerges, equally meaning that new projects are created and reform to match changing need or priorities as well as the structure of meetings or interactions. The projects and meetings themselves are not institutionalised but the relationships that make decisions about and support projects may be solidified in their existence rather than their form. Similarly, new intermediary roles created within the larger groups such as NWL, EA and NP AONB, to deal with catchment-scale issues have been created in order to begin to change the culture of their own organisations and integrate their agenda with the collective agenda set by the catchment partnership. The roles themselves are not institutionalised (because they are open to change and temporality) but the essence of the relationship that is being created between groups is part of the wider, more permanent change (CaBA and the WCP). The use of the network approach in this research has allowed these changes to be highlighted and therefore a better understanding of the development of both formal and informal institutionalisation processes in the catchment-management approach.

The network approach also allows a better understanding of the potential roles and positions of groups within the networked system and their likely influence on changing practice and the process of institutionalisation. This is in recognition of the restrictions of a network perspective in the difficulty of revealing hierarchical relationships that might more fairly describe the agency or influence of the groups. The network approach acted to begin to highlight where the importance was placed in the system and thus begin to reveal something of power if not the exact mechanisms or wider structures that might contribute. The three most central actors identified were the EA, NWL and WRT, who all play a leading role in the catchment management processes. The EA is the most central actor, attributed to their regulatory function and cross-cutting interaction with a wide range of groups. Arguably their centrality is related in some way to their power in the network (Newig *et al.*, 2010) and thus may be seen to support the analysis that the CaBA process is negatively affected by power imbalance based on the centralised influence of the state in the catchment partnerships (Watson, 2014). However, this claim cannot be made specifically in the Wear catchment, particularly only using network analysis as a basis for deduction as without additional interpretation the structure of a network, particularly enhanced by the use of metrics that symmetrically compare components, may confuse the influences of power dynamics on relations and outcomes. Their centrality, however, is an indication of their importance and relevance for the process of catchment management, perhaps obviously so when the origins of CaBA are reflected on, particularly the level of responsibility held at the state level for delivery of the WFD and therefore the interest the EA has in involvement and maintenance of particular agendas. The interesting balance shown by the network approach is the centrality of other actors alongside the EA to almost equal measure, which although may not be indicative of the power of the groups, may be indicative of their presence as agents and actors in the system.

The WRT was also identified as highly centralised, particularly having a high betweenness centrality. Their role is unique in the catchment as lead organisation in the WCP (following on from a joint leadership with the EA held previously) and as facilitator and implementer of on-the-ground action via strategic planning, joint-working and grant applications. As a lead organisation and one of the most central intermediary and brokers in the catchment system, the WRT represent both a point of strength and a point of weakness in the catchment management network because they have the ability to bring groups together and to facilitate co-produced agendas and collaborative action, and without their presence the network would be weakened. Fliervoet *et al.* (2016) attribute vulnerability in a network of organisations working to manage Dutch floodplains to the loss of a central group who coordinated much of the action in the network. The central organisation lost funding from the government and was abolished in 2015 leaving a lack of structural integration in the management network, disconnecting disparate groups and reducing their participation in decision-making. Their network analysis also identified other relationships and links in the system that may have been able to adapt and change to cope with the loss of the centralised group. As such, Fliervoet *et al.* (2016) were able to make suggestions as to candidates for the coordinating role as well as identify potential positive links to enhance after the abolition of the central group. Although there are no immediate parallels in the Wear catchment to the situation in the Dutch floodplain-management system in terms of vulnerability of central actors such as the WRT (aside from the precarity of charitably funded organisations, reliant upon grant funding from limited sources), there are similarities in the potential use of network analysis to identify strengths and weaknesses in the catchment system. For example, the WRT generally create strength in the network through the strong links they facilitate however, the vulnerability of the network should they be unable to fulfil their role is clear. Therefore it is pertinent to be aware of the alternative links and structures that might exists within the network that support the resilience of the system.

Resilience of networks is an important consideration and a theme that is prominent in network studies as well as the conceptualisation of social-ecological systems and adaptive systems, in particular in accounting for uncertainty within complex systems. Bodin and Norberg (2005) argued that adaptive capacity of a system is linked to the network structure by the ability of actors to enact institutional integration in order to organise and reorganise in relation to environmental and social change. As a result of the analysis in this study it can be argued that the nature, volume and diversity of links are important for understanding the resilience of the ideal of collaborative catchment scale management as they portray a diversity across the whole network but a consistency of connection. For example, in the Wear catchment although some actors and entities are more centralised than others, the whole network is not highly centralised, meaning each actor is connected to a number of diverse others and where they are not, and only have one link to one group, it is likely to indicate a lack of ability within the study to gain knowledge about that group and therefore an inability to close or bound the network. From the observation of multiple connections for each actor and entity (which is built on through the modelling of the system and the decision spheres of stakeholders), it is possible to understand each actor as possessing their own network. Within each network is a number of options and opportunities to collaborate, exchange and interact that facilitate the ability to act in certain ways that are productive for the state of the water resources and the overall success of a management approach.

Of equal contribution to the resilience of the governance network, is the presence of mini-hubs or centres of activity and action, where new ideas and directions can be set separately but not disconnected from the central institutionalised point of the WCP. For example the responsibility for individual localities in the Wear catchment had been transferred to separate structures such as in the Twizell Burn or Old Durham Beck. For the Twizell catchment, GWNE coordinated and facilitated a number of meetings involving multiple stakeholders with the purpose of co-creating a Green Infrastructure Plan for the sub-catchment. Such a process could be seen as a separate network of organisations, meetings, schemes and actions within the wider catchment network that acted to grow the collaborative approach through connection to localities in the catchment. Equally, the creation of the Coastal Streams Partnership helps to transfer power and decision-making away from a centralised system. Additionally, one of the key changes in structure observed by the stakeholders in the Wear relates to the growth of internal meeting in large organisations focusing on catchment-specific issues. Such a change in organisational culture is another demonstration of the diversification of the decision-making structure and the growth of sub-networks. Each mode of sub-network diversifies the overall governance network and arguably acts to strengthen and embed the approach, enacting integrated practice and contributing to the resilience of the system.

In relation to an overall understanding of the adaptive capacity of the networked system, the more diverse sub-networks there are, the more opportunity the stakeholders have to be part of multiple modes of networked management, and therefore the more likely sustainability of links. This means stakeholders are more likely to feel connected within the network, which is important in relation to ideal and future developments of the system. The ideal of open and easy communication between actors as well as the ease of knowledge and information sharing was an important part of future management. The study of the nature of the current network allows reflection on the possibility of where future connections and links might be encouraged and through what variety of structures. A future in which the larger network and the sub-networks were considered alongside the positions and roles of stakeholders might allow stakeholders to have a better understanding of how their own skills and knowledge could integrate with others in order to achieve shared goals, and importantly who to connect to, how and when in order to react and be pro-active in dealing with issues.

The evaluation of the system by stakeholders gives an indication of the link between particular structures or structural changes in the configuration of network governance and success. In the Wear catchment there were a number of positives that were identified, including the tangible and measurable improvement of water quality as well as intangible positives such as good relationships, access to resources, delivering across scales, and improved understanding. It was possible to attribute some positive effects to particular patterns of interaction or systems of management, such as the reduction in litter in Hetton Burn due to a targeted interaction between a conservation group and NWL, or an increased access to resources, data and knowledge attributable directly to the attendance of partnership meetings. However the exact mechanisms leading to the positive experiences or evaluations were not always explainable or tangible, often clouded by complexity, and equally where seemingly similar interaction or structures were in place differing evaluations arose.

Where a network perspective is limited is in its ability to begin to explain emergence, beyond the observation that network structures and positive evaluation of institutional change occur. This lack of explanatory power is where the network perspective needed to be supplemented with a more in-depth analysis of the drivers and barriers to successes in the system (see Chapter 6). Prell *et al.* (2009) in a study of social networks in the Peak District National Park, also conclude that the use of social network analysis should be in conjunction with other approaches to avoid simplistic conclusions.

Scott (2015) also outlines the difficulties with using a network approach to analyse social connections. In light of such critique, the network analysis and its outputs in terms of conclusions and diagrams need to be interpreted carefully through a reflection on context and a realisation that the results should act only as a heuristic to help further analysis and begin discussions (Prell *et al.*, 2009) rather than act as a guide or a blueprint for future management, and particularly for future participation. Equally, that although there are networks represented these might not be constitutive of network governance and in particular may not be constitutive of the structures of governance associated with water resource governance, which need to be analysed in context of the wider structures and hierarchical systems of power relations to better understand the complexity of the system and the production of outcomes. This follows ideas of Law and Urry (2004) around the performativity of methods. The alternative perspective is that the network is conceptualised as a static, co-created depiction of a system,that is truly messy and dynamic on-the-ground (Scott, 2015) and that the network analysis helps to make suggestions about part of the complexity, not the whole. This role of network analysis is one that is recognised in this research, but is accepted alongside the use of other modes of exploration to counter the critiques of using a network perspective alone.

8.2.2 A systematic understanding of enablers and barriers to functionality: catchment management in practice

When considering how the patterns of interaction and action within the networked system of catchment management could be better understood, multiple factors were considered at three interlinking levels. The individual, interactional and contextual levels were considered to be influential on the actions, interactions and decisions of stakeholders that would then form networked structures which would lead to particular outcomes. The analysis goes some way to revealing the processes of operationalisation of a governance approach to water resource management and the inequalities and complexities also help to begin to analyse the power dynamics and how wider contexts and histories might affect the actions and behaviours that then go on to form network structres. A number of studies (Patterson *et al.*, 2013; Patterson *et al.*, 2015; Patterson, 2016) have explored enabling capacities in relation to practical action and regional responses within collective-action approaches to catchment management in Australia. Their conclusions concur with some of the suggestions from this PhD research. For example Patterson *et al.* (2015:493) state that “it is vital to generate diverse enabling capacities at both the local catchment level, as well as at broader regional policy and governance levels”. Importantly, Patterson *et al.* (2015:493) also suggest that the interconnectivity of factors at multiple scales is important. They state that “it was not just the presence of capacities but also their interplay that was important, implying that it would not be possible to view the capacities separately or deterministically, because what is most important is their combined and interactive effect in any particular place." Such observations of the combined effect of capacities relates to ideas of the combination of factors from different levels that affect the functionality of the catchment management system in the Wear catchment. Capacities such as prior experience, institutional arrangements, collaboration, engagement, vision, knowledge brokerage, resourcing, leadership and adaption are seen by Patterson (2016) to help facilitate outcomes, both environmental and social-institutional, through collective action. This research agrees with Patterson in the range of enabling factors found to be important and strongly agrees that there is a distinct, contextual balance of factors in each case, where each factor has the potential to affect feedbacks and links to other factors. This research has been able to expand understanding of factors affecting collaborative management for a UK context in order to describe the way in which they play out in a networked catchment governance process and how their complexities can mean barriers exist to particular outcomes.

Equally, the unique identification of a different scale-breakdown to understand the factors supplements other scales of understanding, including the spatial scales of catchment, regional and national or wider (Patterson *et al.*, 2013) and micro- (local networks and action), meso- (procedures and programme design) and macro- (formal external rules and legislations) institutional scales (Short, 2015). The scales of individual, interactional and contextual relate to the influences on stakeholders agency within the system, all of which combine at multiple spatial and temporal scales.

Factors at each of the levels of influence appear to be important for facilitating particular aspects of the system of catchment management in the Wear catchment, and it is important to reflect upon their value for understanding complexities within the system. Patterson *et al.* (2015) argues that processes of management emerge from enabling capacities and their interactions, which must be generated within particular situations. If the concept of emergence is to be accepted within this research, then the factors within the individual, interactional and contextual levels of a catchment management system could act as a starting point to understand where circumstances could be created in order for a collaborative approach to water quality management to be facilitated.

Questions around emergence relate to agency and the point at which creation of circumstances ends and emergence begins (section 2.3.6). There will always be a level of complexity through non-linearity of association between factors, actions, network structures and outcomes that mean it is very difficult to identify at which point intervention could be most effective. There is therefore a recognition that the analysis of factors contributing to the functionality of the system and network is not a tool-kit. In addition, although suggestions may be able to be made about the utility and positivity of particular aspects, the study has allowed an evaluation of the fact that it is difficult to then provide answers about how to recreate or engineer a successful approach.

8.2.2.1 Scales of functional factors

The analysis is able to give an impression of the enablers and barriers to stakeholder agency in order to gain a better understanding of some of the dynamics of a networked system of management. Many of the factors identified in the Wear catchment are issues and understandings that are already seen as important for NRM but their exact nature may have been previously unexplored in the particular context of CaBA.

At the interactional level: the issue of legitimacy around data and data sharing and the association to legitimacy of certain groups is a significant issue and appears to be part of a number of the difficulties in the catchment. Illegitimacy results from a lack of trust of stakeholder groups or the processes associated with sharing and exchange. However, the Wear case study has offered examples of ways in which legitimacy has been built and facilitated. Sandström *et al.* (2014:61) suggest that legitimacy can be conceptualised as an outcome of collaboration and collaborative processes, and considers co-management as a facilitator of deliberation and articulation of different interests, helping to foster understandings, common agreements and, finally, acceptance. However building legitimacy is not a straightforward process and as, Sandström *et al.* (2014) argue, is affected by past and the present institutional landscape, the role of formal government actors and efforts to reframe the process. In the Wear catchment for example, legitimacy of volunteer data on water quality is built through the Riverfly project and facilitated by an intermediary group (the WRT) who broker knowledge between the groups to enhance legitimacy, despite data shared having little power beyond triggering a process of official data collection by the EA. The legitimacy is therefore dependent on the structure of the institution of the WCP utilising the relationship between the EA, WRT and volunteers to create functionality. There is still some dissatisfaction about the legitimacy and trust given to volunteers to be fully able to contribute with their own data to formal processes such as the change in WFD status of the waterbodies.

Where other issues occur around data sharing and legitimacy, changes in the structure of interactions through the creation of catchment coordinator roles within the business may act to help translate a need for a reframing of processes and identify the need for formal agreements around data sharing. Such changes then open doors for acceptance and the ability to act differently under the same circumstances. The structures of collaboration in existence through the networked system can be seen as both a result of and constitutive of the effects of legitimacy. However it is also recognised that attitudes and norms of practice, as well as the context are all drivers of action and inform processes of legitimisation and inclusion. The combination of understanding of the different levels of influence on each stakeholder helps to highlight this level of complexity.

At the individual level of influence on the system it has been suggested that there is a number of features associated with individuals and individual organisations that interact with the factors at the interactional and contextual scale to enable and cause barriers to action and interaction. The main observation of factors at the individual scale is the multiplicity of each and the uniqueness associated with each stakeholder group. Much of the suggestion around practice associated with features seen as effective in the Wear catchment was where the multiplicity was recognised by other actors or where alignment was enacted through collaborative actions. Equally important in recognising where change and action happened in the catchment was the recognition that certain individuals with strong motivation, sense of responsibility or particular problem-perception were active in encouraging, asking for or implementing action. The role of personality and personal drive (even if built in a professional capacity) has been previously assessed in relation to leaders (environmental champions) in NRM, where factors such as enthusiasm and confidence, persisting under adversity and propensity to openness are seen as important (Taylor, 2008). Although not all individuals who influence action in the catchment network could be considered as leaders, they might be considered as agents of change who use their positions to influence others. It was also noted, however, that there needed to be the norms, context, acceptance and willingness of others to change or to cooperate in order for change to happen.

Particularly relevant for the continuation of the CaBA approach in the Wear was an acknowledgement of the importance of organisational culture change for the adaption of larger organisations to a new way of working. One of the most significant changes in the catchment was the changing role of the NWL, particularly in becoming more strategically involved in the WCP and the planning process, having been recognised as a powerful actor in the catchment. At the time of research NWL were at the beginning of a process of culture change in which the first stages were to introduce catchment coordinators to mediate between the catchment-management process and the business. There were negative assessments of the speed of progress in terms of change but a clear acknowledgement from those involved for its need. The difficulty came when trying to prioritise such changes with decision-makers in the business of NWL when the CaBA process involved so much uncertainty and experimentation. The complexity therefore of a change in behaviour was evident within a large scale business, even if there was the enthusiasm and motivation of individual officers. The slowness of the organisational culture change had been seen to cause some tensions and barriers to action in relation to other stakeholders and was something that was hoped would continue to change as the process progressed. However the challenges faced represent the tensions that exist in the process of integration where cultural norms between the new institutional practice and normative behaviour of an organisation do not (initially) align. Although some aspects at the individual level cannot easily be subject to planned intervention, others such as institutional and organisational norms can be actively reflected on and changed, as shown by evidence from the Wear catchment process.

At the contextual level the dominance of the WFD is a key consideration and although it is seen as a strong driver of positive change in many cases, there are issues with the centrality and restrictive nature of the legislation. The dominance of policy and government agendas in terms of targets sets the boundaries of the CaBA process, giving it a fairly narrow frame. Such boundedness raises questions about the nature of the governance process. Watson (2014) questioned whether the pilot process of CaBA was truly collaborative given the dominance of the government in driving the agenda (based on the centrality of the WFD policy). From analysis of the Wear catchment as a study of a catchment that has moved into the implementation phase of the process away from the pilot phase (that was arguably more orchestrated by the EA), it offers the observation that the government agenda still remains central, but the process of delivery of that agenda is (broadly) collaborative (influenced by a co-produced action plan and facilitated through joint meetings and discussions), particularly through the structure and network of the WCP. The frustration arises when, for stakeholders connected to the process through the network of structures emerging around the WCP, only small parts of an organisation's goals align with the WFD agenda or where there is restricted funding for areas with waterbodies not prioritised as able or needing to meet targets. A number of stakeholders acknowledged a desire for more broadly defined funding. Most of the projects organised centrally through the WCP have been funded through the DEFRA Catchment Restoration Fund, which was active between 2012 and 2015, designed as a grant scheme to support the delivery of projects to improve water quality in order to meet the objectives of the River Basin Management Plans. The fund was amalgamated with the Catchment Partnership Fund (2013-2015), which supported the establishment and maintenance of catchment partnerships, to create the Catchment Partnership Action Fund, which supported projects within the catchment partnership structure (expecting partnerships to find 20% match funding for projects) (Defra, 2016). Funding is a significant part of a governance approach and the nature of funding can affect changes in governance structures, action and activities.. However, while the agenda of the governance process is focused on the delivery of policy objectives, the funding structure will continue to be reflective of those centralised aims.

Other funding available equates to small scale grants from various sources, which are pursued by individual organisations or partnerships and which appear to be available but difficult and time consuming to 'win', as well as short term and therefore precarious. The context of austerity was also a defining restriction and a source of precarity in relation to funding availability (as well as time and staff). Austerity consequently influenced behaviour change in order to cope with the lack of funding, harnessing the motivation, sense of ownership and goals of stakeholders to fill the gaps. Such adaption alludes to an adaptive capacity of the system exercised through the ability to form different relationships and plan and deliver new actions to cope with change.

An analysis of the interconnections of the factors affecting functionality helps identify the capacity of the system as a whole to be adaptive. Concepts such as relational capital and social capital have been useful (if not uncontested) in highlighting the potential of collective management systems to facilitate positive outcomes and positive relationships (Armitage, 2005; Bodin *et al.*, 2006), if such capacities are balanced against processes of social learning. The multitude of factors explored in this research (in relation to influence on action and interaction of the stakeholders)form the building-blocks of a successful approach, however the reality is that there are mismatches in the way the factors influence and play out in each stakeholder's context at particular times that might affect their ability to make certain decisions, leading to lack of achievement of individual or collective goals. The configuration of factors at any one time is arguably unknowable and a feature of the complexity of a system (if conceptualised so). The ability of the systems perspective to be useful is therefore in identifying where the small changes are able to be made to behaviour or manipulation of factors at different scales to make enough of a change to affect the system outcomes in line with desirable goals set by expectations of the stakeholders and wider goals set by management plans, action plans and policy targets. Simulation modelling offers a mode though which the configurations of factors and context can be experimented with and explored in relation to building a better understanding, and beginning conversations about the potential changes that might be able to be suggested for a system of catchment management.

8.2.3 Modelling decision-making: exploring the mechanisms of interaction and action for stakeholders in catchment management

The process of modelling the interactions and decisions of stakeholders around a specific event-scale pollution problem in the context of a catchment management system has helped to unravel some of the complexity involved in the specific natural resource-management system (Rammel *et al.*, 2007). It has highlighted the ways that some of the functions and networks, hypothesised to be important for conceptualising the system of management in relation to stakeholders, might play out more dynamically and form and reform between scales and events. The modelling process has also supported analysis of current practice and raised questions about possible future changes in behaviour. The role of the modelling process is firmly seen as heuristic in this PhD. Consequentially, the process has inspired reflection on the system of catchment management as a whole and asks questions about the conceptualisations of a system of management and the role and agency of stakeholders.

The ABM produced for this research focuses on a water-pollution scenario, examining the interactions of stakeholders informed by processes and patterns of action and interaction happening in a collaborative catchment-management context. The model is similar in some respects to other ABMs of water and NRM, in relation to the inclusion of multiple stakeholders, a changing natural environment and feedback and communication between the agents. The context of the model is also one in which new systems of decentralisation are in existence, which is a common theme across ABMs of water management (see section 2.5.5.3). Where it differs is in the specific focus on a minewater pollution event, where few models of water management focus on the event-scale (with the exception of for example, Zechman (2007)). The model therefore can make a contribution to exploration of the dynamics of stakeholder interaction, particularly as the understanding of the event-scale appears to be closely interconnected to stakeholder behaviour and interaction at the wider temporal and hierarchical scales, and therefore relevant for wider reflection on collaborative management processes. From analyses of the ABM outputs and experiments it has been suggested (Chapter 7) that it is helpful to conceptualise an iterative feedback between the action of stakeholders at the event-scale, the relationships formed through the emergent network structure, and the patterns of interaction in longer-term collective processes. It could be conceptualised that each is a palimpsest of the other. The event-scale is therefore valuable as a basis for modelling behaviour that might be relevant for understanding the system dynamics in a broader sense, if only through raising questions about relationships and interaction.

The interrelationship between different scales is an important consideration in the analysis of the value and place of the ABM in the research process and its contribution to theoretical ideas around behaviour and practice. The bottom-up assumptions in generative social science that underpin the philosophy of ABM, presume that macro-level dynamics can be understood through the study of individual-level behaviour. Ideas about the role of behaviour at the micro-level and its influence on macro-level structures, and the influence of macro-level structures on individual behaviour have been a constant feature of discussions of social dynamics and network studies (Tasselli *et al.*, 2015). Arguably debates have moved away the idea that systems are just bottom-up and instead take into account the effect of strucutres and aggregate behaviours (O'Sullivan and Haklay, 2000). This also reflects critiques of network perspectives that only consider actors to have power and agency without recognsing the wider structral context. In this PhD study the ABM process focussed on the micro-level behaviours and decisions in order to understand the system, but concepts of wider contextual structures and aggregate behaviours shaped decision-rules. There has been a recognition that although the contextual structure itself does not have agency (section 2.3.3), the contextual factors through which structure emerges prevent certain opportunities and behaviours. Therefore, where suggestions and questions were raised in the model results around stakeholder-behaviour change in relation to improved processes of environmental improvement careful balance has been struck between suggesting that responsibility for change rests with individual stakeholders, and suggesting that potential for change also exists in relation to wider contextual factors at other hierarchical scales, that will enable change at the individual level. This also helps to overcome critiques of network approaches that do not consider hierarchical influences ofn power dynamics. The utilisation of a scenario at the event-scale in the context of management system operating across scales helps to highlight such dynamics and allows reflection on the use of model analysis to inform questions about behaviour change.

The use of model analysis is also taken in context of limitations to the composition of the model as a representation (if highly abstracted) of a real system. There is a recognition in modelling that all models are incomplete in some way (Clifford, 2008). Simandan (2010) argues that this means they are open to critique relating to the decisions made by each modeller to exclude particular elements from their model that may have been crucial for understanding the dynamics of the system. Whilst Millington and Wainwright (2013) recognise that it is the utility, agreed amongst users, of the model that matters, rather than the completeness or complexity, it is still pertinent to reflect on the elements that have not been included in order to justify their exclusion and identify potential for future exploration.

As such, it could be argued that important elements had been omitted that should receive further analysis. For example assumptions were made about the processes of collaboration, sharing and exchange, particularly in relation to the smaller-scale mechanisms needed to produce the particular sharing methods hypothesised when stakeholders form collaborative links. For example for stakeholders to pass on best-practice effectively there are likely to be process of meetings and exchange that are conducive to effective learning and sharing (for example as explored through Bohensky (2014) in relation to processes of learning in a water-management system). It is assumed in the current model that these processes can and do happen, but are not detailed in the coding. In a more detailed version of the model it would be pertinent to think through and represent the processes involved in the sharing, in order to discern the difference between sharing and exchange that result in the most effective best-practice being shared and therefore having an advantageous effect on the efforts of the stakeholders, compared to systems where the exchange was not always effective and resulted in compromise (as symbolised with the average-effectiveness scenarios).

The model also assumes that, by representing pollution-extent as a key outcome, the effect of stakeholder action on the water resource is the way in which success is measured in a system. This singular mode of analysing success is not the case in a real system, where the satisfaction of stakeholders through meeting expectations or fulfilling personal, professional and management goals is equally as important to the sustainability of management systems, alongside other factors, which may be different depending on the views of each stakeholder.

The outcomes from the modelling process reported in this chapter acknowledge the limitations of the process and therefore the caution needed in interpretation. A key recognition is that the ABM is not a black box and there is a process of design involved. Sometimes such transparency can be seen as instrumentalism (Clifford, 2008) where the ABM is furthering agendas already set or knowledge already claimed as truth. As counter to this, the recognition that the ABM is part of an ongoing research process is important, where outputs are treated as the beginning of conversations rather than the end and are balanced against other forms of analysis (as they are in this thesis). Equally the accusation of over-simplification of real-life situations through abstraction via a modelling process can be countered by the argument that using disposable 'fast-and-frugal' models will result in more rapid learning than using highly detailed models (Carpenter, 2003). This continuing iteration between analysis, modelling, questioning, analysis and modelling underpins the philosophy for the model in this research. Despite the restrictions on the opportunity to enact more than one iteration of the modelling process in this research (such as is done for more participatory modelling processes: (e.g.Gurung *et al.*, 2006)) it demonstrates the potential of modelling to contribute to the understanding of catchment systems as part of an ongoing learning process (Pahl-Wostl, 2002c) and opens up opportunities for future application of models to related issues.

8.3 Core themes of the research: catchment governance and processes of catchment management as a complex system

This research has brought together three modes of analysis, in order to reflect on the practice of collaborative catchment-scale water governance. A systems perspective has been used to conceptualise the processes and practices, drawing on ideas of social-ecological and complex systems. Such perspectives have drawn attention to the component parts of a system, the networked nature of such parts, the factors that affect the nature of the functionality in the networked system, and the way in which dynamics of functionality might play out in relation to stakeholder behaviour and decision-making.

8.3.1 Frameworks for understanding catchment governance and processes of catchment management as a complex system

The combination of three perspectives builds insights into the system and offers a layered approach to understand its network structure and functionality, which are important in order to reflect on enabling more successful management and for the modes of maintaining and facilitating a collaborative governance approach. The focus on network structure allows the operationalisation of the governance processes to be explored, where governance is understood as inherently networked but where the focus on collaboration gives high importance to understanding the configuration of relationships and institutions.

The value of the combination of three modes of exploration of the catchment system is in their ability to highlight the components and dynamics of a complex system. Firstly that the entities and their relationships are important, secondly that the relationships and resulting outcomes and functions are affected dynamically, and that thirdly, those insights can be used to reflect on the points at which there may be space for change.

Figure 8.1 gives an overview of the relations between elements of a complex system around water resource management and governance using the concepts of network structure and functionality. It shows the multiple influences on network structure through structural context, governance processes and the operationalisation of a governance approach (such as CaBA), from agents decisions and interactions influenced by management approaches, through particular patterns of networks and subnetworks across time and through processes of formal and informal institutionalisation. Network structure can therefore reveal something about network governance and stakeholder decision making in the system. The link to functionality is iterative and shows that functionality is a result of the operationalisation processes and can reveal distributions of power and influence. Its features and focus include multiple levels of factors that influence functionality (interactional, individual and contextual). Functionality leads to barriers and opportunities within the system, which produces particular outcomes across the social-ecological system. The outcomes are linked through processes of learning and adaption to agents' decision-making and to processes of governance, which in turn ae associated with the broader context. The diagram hypothesises the associations between elements in a system of resource management and highlights that by focusing on such elements an understanding of patterns and drivers of change, as well as challenges and success may be revealed. If something is known about each element in the system then the overall functioning can be better understood.

The diagram also shows how the elements have been explored through the approaches in this research, which have each been able to focus on particular combinations of elements. Each mode of exploration reveals something about part of the system, which together helps to develop an in depth picture of a complex system around catchment management and governance. From these hypotheses of relations between elements of a system comes a way of thinking about natural resource management and governance that may be helpful or revealing in other contexts. Figures 8.2 and 8.3 detail frameworks for thinking about stakeholder decision-making, and the elements associated with a complex system of water resource management, such as catchment management. They are simplified ways of understanding key elements that have been discussed throughout the thesis and detailed in diagrams such as 8.1 and 6.2. The following sections discuss the key themes of the research in relation the system including, complexity, emergence and the concepts of network structure and functionality. Section 8.3.5 returns to the frameworks to explain their value in relation to the core themes.

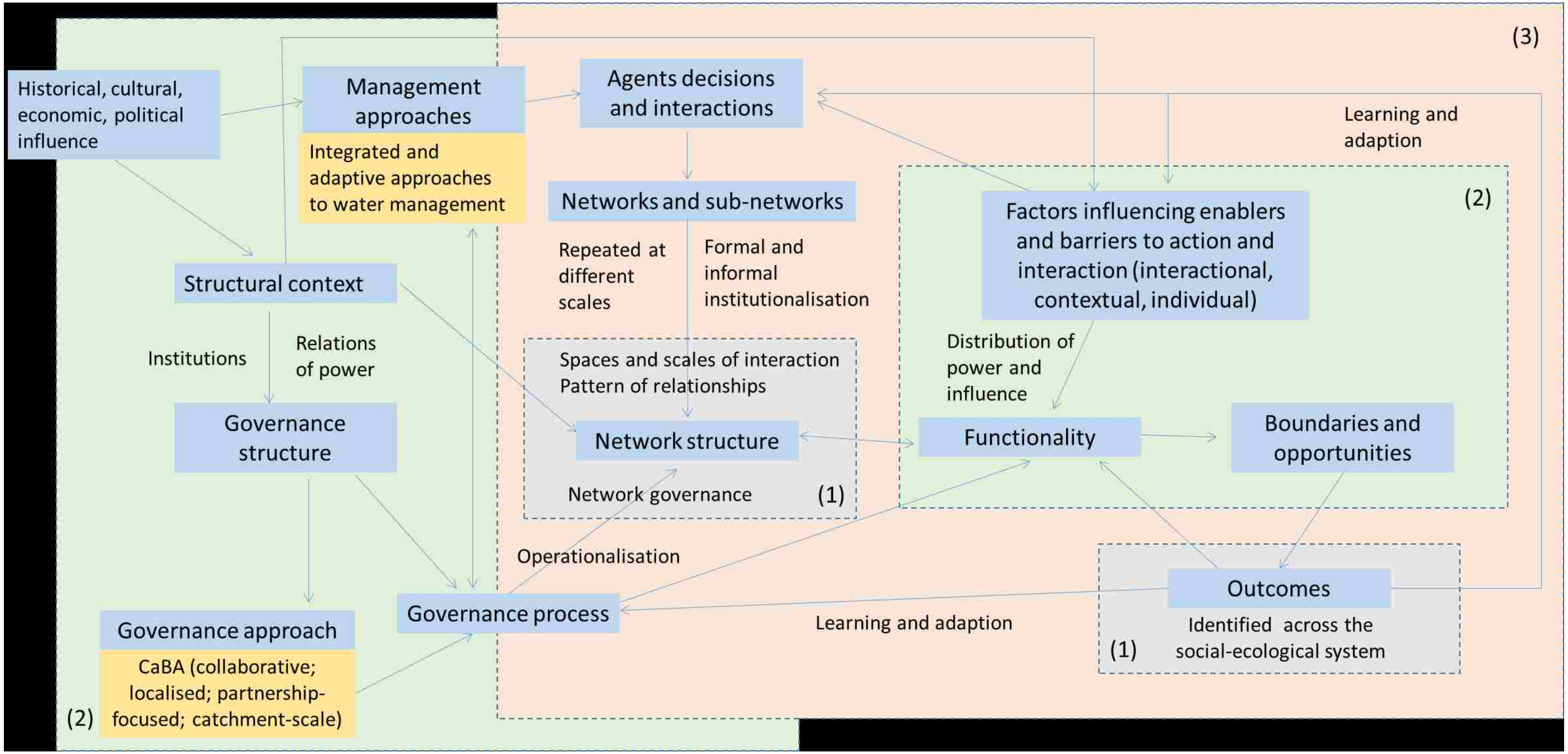


Figure 8.1 *Relations between elements of a complex system using concepts of network structure and functionality in relation to water resource management and governance. Arrows indicate influence. (1) Grey boxes relate to elements that were the focus of a network structure exploration in this thesis. (2) Green boxes relate to elements understood through qualitative exploration in relation to the concept of functionality in relation to networked interactions. (3) Pink boxes relate to elements influencing the ABM model in this thesis (which were applied at a particular scale).*

Figure 8.2 *Framework for thinking about stakeholder decision-making.*

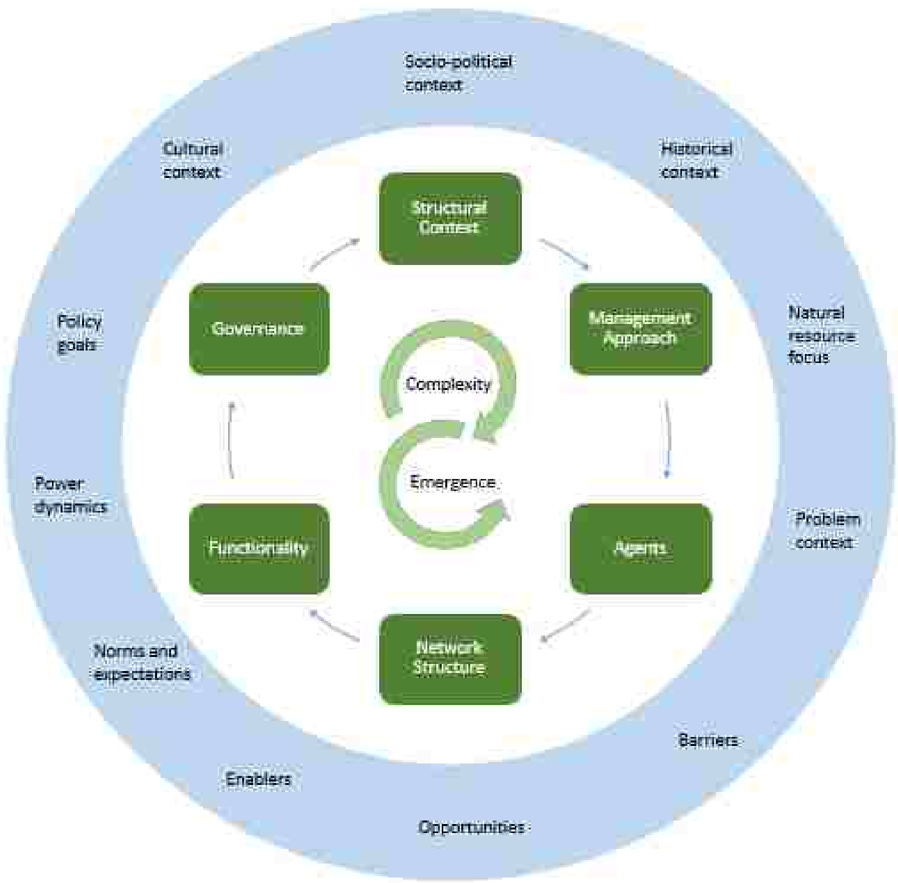


Figure 8.3 *Framework for thinking about a system of resource management and governance incorporating themes of network structure and functionality and centring from the principles of complexity and emergence.*

8.3.2 Complexity

Complexity is a concept familiar to the understanding of catchments and catchment-management processes, particularly in relation to the presence of multiple and competing actors and values, uncertainty and interconnectivity in multiple ecosystems, social systems and action arenas (Bellamy *et al.*, 2002; Hirsch, 2006; Ison *et al.*, 2007; Pahl-Wostl *et al.*, 2010; Patterson, 2016). The growth of collaborative governance approaches and specific interpretations such as CaBA reflect the need to embrace and manage for complexity through governance practices (Pahl-Wostl *et al.*, 2012). Patterson *et al.* (2013) claim that looking at any particular outcome or measure alone will not provide a full picture, particularly in light of nonlinear change and time lags inherent to social-ecological processes within catchments. As such, in order to conceive complexity in systems in the UK CaBA context, this research attempted to look at multiple aspects of a system in order to better understand the character of complexity.

Based on the combination of findings and analyses, in relation to the CaBA approach to water management, complexity is evident and dealt with in a number of ways. When considering the catchment system as a network, complexity is evident based on the multiplicity of stakeholders, spaces and places of interactions and multiplicity of relationships (links) between the components of the network. The complexity is managed and understood through the presence of a collaborative management structure such as the WCP, which acts to cut through the complexity by pulling together priorities, creating spaces in which multiple knowledges could be generated; facilitating actions and projects that created points of connection between disparate actors; bridging gaps between complex demands from physical water issues, environmental goals, stakeholder perceptions and policy agendas. Understandings of institutional complexity have argued that complexity can be increased with the creation of multiple institutions (Wallis and Ison, 2011) and this is true in the Wear catchment, where the presence of multiple meetings, partnerships, management agendas and data sources arguably adds to an already complex situation. The stakeholders, in this study manage multiple demands and complexities by building relationships within the network and capitalising on the opportunities to learn from others through collaborative structures. Such understandings of complexity might indicate that although there are multiple components of a networked catchment management system the functioning of the system (on the whole) contributes to the ability of stakeholders to cope with the complexity through processes of learning, which could be understood as social learning (Pahl-Wostl, 2002c).

Complexity as conceived at the level of functionality is evident by the multiplicity of levels at which the stakeholders' actions and interactions can be affected. It is likely that the combination of factors at any one point in time and for any one or any collection of stakeholders lead non-linearly to a functionality of the system. It is likely that the combination of factors changes over time and space and with each context, each one malleable and iteratively connected to others. For example where notions of trust are linked to legitimacy, they are also associated with power dynamics, the role of policy, availability of data, social and institutional norms. In turn these factors link to perceptions, mental models and motivations, which are all situated in relation to the space, place and issue that the stakeholder is dealing with. Where these aspects of complexity are recognised is in the way that stakeholders negotiate their position and make decisions about actions and interactions. Stakeholders are aware of the opportunities to harness aspects of responsibility, build trust or change perceptions, for example by changing the way that they behave. Equally, changes in structures and modes of interaction facilitated at a collective scale show an awareness of the need to harness or bring together multiple factors to take some control of the outcomes that emerge. Complexity is also evident where there are difficulties and barriers, where factors have combined in unpredictable ways to create difficulties that are problematic to negotiate in themselves because of the tangle of factors affecting the desired outcome in non-linear ways. This is also a recognition that the wider structural context, institutional settings and social and political power dynamics affect outcomes. Recognition of the components of complexity (such as an identification of the factors affecting functionality) could provide a way in to negotiating overcoming barriers, and is where this PhD hopes to contribute knowledge in relation to the factors that might be likely to be affecting other stakeholders.

Complexity through modelling is demonstrated at first in the difficulty of creating a model that symbolises (even part of) the system, based on the knowledge and evidence of the multitude of mechanisms and concepts needed to conceive the dynamics. The creation of a model helps to capture some of the complexity and isolate parts in order to better observe hypothesised dynamics. The non-linearity of the complex system is evident in the emergence of unexpected outcomes, in terms of the pollution patterns and the patterns of interactions and involvement amongst the agents. The ability to experiment with aspects of the complex system highlighted the possible modes by which stakeholders could manage complexity, particularly in terms of building networks of connections and becoming agile and adaptable agents. The combination of ideas of complexity and adaptability are important for understanding the successful implementation of polices such as the WFD (e.g. Fritch, 2017), particularly in relation to the creation of complex adaptive systems, in which there is the adaption of sub-systems to emergence at smaller scales (such as new management regimes, varying communication opportunities or organisational change) (Rammel *et al.*, 2007). The ability to characterise and observe complexity in the system of catchment governance and associated management practices in the Wear catchment through multiple methods and perspectives in this thesis is formative of an understanding that allows reflection in the ability of stakeholders to cope with change and to facilitate functional change in relation to changing systems and problems.

8.3.3 Emergence

The concept of emergence is closely tied to the concept of complexity and although emergence is various in its interpretation and definition (section 2.3.6) it is important for conceptualising and understanding complexity, particularly in social-ecological systems. In the context of integrated catchment management (ICM), Collins and Ison (2010:12) associate emergence "with new patterns arising from a set of interrelationships between the constituent and diverse elements of a system, these patterns or characteristics not being reducible to individual elements." Taking such a definition, emergent patterns in the Wear can be seen as the network structure able to be conceptualised through a network perspective (Chapter 5) and of the configuration of network governance, as well as the functionality of thate network in relation to management actions and interactions within the context of the governance process (Chapter 6). The presence of the WCP, meetings and projects and the particular structure of actors in the networked system in relation to their positions, power and connections can be seen as emergent. The notion of weak emergence (Bedau, 1997), in the sense of a recognition of the link (if non-deterministically) between relationships and structures, is seen through such conceptualisations. The structures and patterns of interaction in the Wear catchment have been argued to represent both informal and formal modes of institutionalisation. McCay (2002) argues that governance institutions can be seen as emergent phenomena from the management of commons resources. She conceptualises that ways of understanding processes of emergence involve understanding the position and capacity of stakeholders to make particular choices in particular contexts. McCay (2002) states that factors such as awareness of the problem, conviction to act, resources available to act, perception of benefits of action, priorities and goals that affect decisions to act, contexts and opportunities to act as well as political and economic contexts and histories, affect the action of stakeholders in a system and thus affect the emergence of institutions. Through the study of factors that affect the functionality of networked systems in a catchment governance context, this PhD study has highlighted the areas for consideration in better understanding the way that new institutional arrangements emerge in a process of collaborative catchment management.

Equally, other less tangible phenomena can be seen to emerge from a process of interaction, which refers to a conceptualisation by Collins and Ison (2010) of emergence as constitutive of a successful approach. Within the Wear catchment elements such as learning, understanding, positive relationships and improved water quality were described as evident in relation to, but sometimes not directly attributable to single elements of new forms of interaction and relationships built within the catchment system. Equally, where there were barriers to action that could be argued to have emerged from the complex combination of factors, sometimes unpredictably, and arguably represent a breakdown in the delivery of a successful approach. The concept of emergence helps to understand the relationship between a complex system and outcomes, and therefore a consideration of the possible mechanisms that might influence functionality.

The modelling process in this research utilised the concept of emergence in relation to the assumption that the combination of behaviours and decisions of stakeholders might produce emergent effects in terms of patterns of reduction in pollution in the water course. Causation was not directly assumed and the modelled process incorporated elements of stochasticity to represent non-linearity in the complex system and utilised inputs such as networks and relationships of trust and mistrust to observe the potential effects on the emergent outcomes. The concept of emergence therefore is influential in the way in which the results of a modelling process can be interpreted. For example where the model helps inform recommendations about the potential identification of areas that could constitute behaviour change in agents at the practical level, no definitive link to outcomes can be assured, due to the complexity of the system and the non-linearity of emergent phenomena in relation to the relations and interactions of the constituent parts. A recognition of that non-definitive link is important for realising that management processes in particular may appear to 'fail' to achieve expected outcomes, but equally, may produce unexpected benefits or influences. Some parts of the management processes to date have been expectant of certain outcomes produced through prescriptive steps, which has led to frustrations when the expected outcomes have not been achieved.

Collins and Ison (2010) recommend that in management processes a certain level of trust in the process of (weak) emergence is needed. This trust is needed in order to encourage concentration on the practice and processes of a catchment management approach, trusting that outcomes will emerge, rather than a prescriptive focus on outcome-oriented behaviour. Such an approach also emphasises the need to recognise the unpredictability of the emergent outcomes and to focus on practice and processes that can deal with that uncertainty. The results of the modelling process have alluded to the potential need to focus on characteristics such as agility and adaptability of agents in creating an approach that can deal with a number and variety of changes. Theoretical understandings of emergence (e.g. McCay, 2002) suggest that such focuses on the process and practice cannot be taken without consideration of the complexities that might in turn affect the effectiveness of the adaptability in itself, therefore being aware that adaptive capacity is also emergent and reliant in (sometimes) non-linear ways on a combination of factors that constitute complexity.

Therefore the concept of emergence in a system such as a catchment-management system, as Collins and Ison (2010) have found, can offer an alternative way to conceptualise the management process. When elements such as improvement of water quality, learning or new forms of institutions are perceived as emergent properties rather than individual elements that exist and can be deterministically manipulated, a new emphasis on process and practice is raised. This is particularly reflective on the relationships between the governance process, emergent governance network and management actions. Such understandings, do not, however, provide clear answers for the transformation of practice in relation to prescriptive targets such as those set by the WFD, nor does it provide answers in terms of who should take responsibility for change and at what level in relation to improving operationalisation of collaborative catchment governance, or help understand dynamics of power that might affect those decisions about responsibility. There have been discussions around the utility of the concept of emergence and the fact that it may be used to deny responsibility for outcomes or to confuse mismatched expectations and outcomes with an unknowable process of change (Corning, 2002). The concept of emergence therefore should be taken into account alongside the understanding of a system as complex and although helpful when applied through forms of analysis such as network analysis and ABM, needs careful consideration when used as a basis for recommendations. This consideration raises questions about the translatability of such abstract concepts from academia to practice.

8.3.4 Insights into collaborative catchment-scale governance and management using the concepts of network structure and functionality of a system

Using the concepts of network structure and functionality has provided a way to understand the system of catchment-scale governance and management in a detailed, as well as holistic, way. The detail relates to a breakdown of the constitution of the governance and management system and a detailed exploration of how multiple factors at different levels are important and influence behaviour. The holism comes from combining the multiple stakeholder experiences of the system and then multiple expressions of the processes, effects, influences and dynamics that form a broader understanding of connectivity and influence in relation to management and governance outcomes. It is also only in combination of the study of network structure and of functionality that a broader picture of a complex system can be built. The study of the two concepts brings to life the idea of emergence (e.g. what can emerge, how and when) and also help to frame complexity (as detailed in the previous sections). Figure 8.1 demonstrates that the concepts of network structure and functionality cannot be taken in isolation and are associated with governance, agent decision-making, processes of operationalisation, management approaches, processes of earning and adaption, the outcomes, wider governance and structural context and iteratively associated with one another. Network structure and functionality should be understood as windows in to particular aspects of a system that is itself interconnected across spatial and temporal scales and political and social hierarchies.

In relation to the concept of network structure, insights about the nature and character of ties or links in a catchment network have been given, as well as the processes by which a structure (a persistent pattern of relations) could be formed through informal institutionalisation and embedding of certain network structures in practice. These elements help to reflect on how a catchment-based approach is constituted and how the governance approach is operationalised. As there has been little direct study of these processes and patterns in the UK context this research offers an insight into the new governance system. It has also allowed an understanding of the way the structure of interactions might influence actors by both providing opportunities for and barriers to action (Wasserman and Faust 1994, 4; Scott 2000: 2-3).

The modelling process helps build up knowledge gained about the network structure and outcomes as well as the functionality and wider context of the system of management and governance (see Figure 8.1) by utilising theories and hypotheses about the influence of network structure on outcomes. It has allowed deeper thinking about the way in which network structure develops and the way that small scale interactions can turn into more embedded structures. Although this is not shown in the model, it is a hypothesis that has arisen from the modelling process and part of the value of the exploratory and experimental mode of analysis that ABM offers. The modelling process has also allowed reflection on the link between event-scale and longer timescale notions of networks. It has shown that the network interactions are dynamic at the event-scale and that sub-networks change and evolve as actors enact action and adjust their needs in relation to a given problem. The influence of the presence of trusted links and working relationships representative of the more embedded network structure are also seen to be influential on behaviours of agents. Within networks there is assumed to be interdependence between actors based on resources, where control is exercised and where there may be gains to be had by pooling resources (Powell, 1990). Such interdependencies play out in the various forms of networked interactions across the management processes, and the modelling process has allowed experimentation with the processes of exchange of resources (e.g. knowledge and funds) and the exercise of control (when actors actively choose to control who they interact with and how they interact through decision-making).

The notion of networks and functionality in the research process allowed the results of the model to be interpreted in context of the qualitative understanding and to produce insights into the potential mechanisms of the operationalisation of a catchment-based approach to water management in relation to the pattern of relations between actors in the system. Equally the modelling process allowed reflection on the link between network structure, functionality and management decisions (as influenced by, and part of, governance processes). Where stakeholders face decision-making about water environment they are hypothesised as being constrained and enabled by their connections, but recognised as needing to be adaptable and agile to create new sub-networks. Such reflection uses the themes of emergence to understand the resultant effects of combination of decision-making strategies and uses the concepts of network structure and functionality to explain and adapt the way that stakeholders act in the system (at a particular scale). The concepts therefore frame the insights about management decision making.

It is important to reflect that the insights from using the concept of network structure rely on its distinction from wider governance structure. Network structure is not thought to be representative of governance structure but part of the way in which a picture of a governance system can be built and a way in to ask questions about the nature of relationships and exchanges whilst also interrogating the power dynamics and contextual influences. It is usually applied with a metric understanding of the structures, which associates characteristics with particular functionalities, including learning (Newig et al., 2010) In this research it is acknowledged that while metrics can give some insight into the nature of the networked system, they cannot give the full picture of a governance network. For example the position of actors and entities in the network can reveal something about the likely role of that group or entity in that networked system, but its symmetrical treatment of all elements needs to be supplemented with an understanding of power relations and historical context to overcome the limitations.

Despite some critiques of network perspectives that need to be taken into account, it has been argued that the more is known about networks, the more can be understood about governance dynamics due to the growing association of implementation of governance practice with networks

(Montenegro and Bulgacov (2014;111). In particular, in the UK context, a governance network approach has been facilitated through the aims of CaBA, which supports the creation of networks of actors within catchments through the presence of partnerships where the stakeholders are expected to self-organise to deliver agreed elements. The presence of a governance network is associated with certain benefits in relation to management, for example Lubell and Fulton (2008) investigated three social mechanisms in which governance networks may be important for effective management and implementation of policies: (1) networks may be a means whereby policy and management innovations are diffused; (2) networks represent an investment in social capital, important in the case of collective action within a decentralized multi-actor social system; and (3) networks can provide pathways for cultural change through processes of social learning. The positivity that many of the stakeholders in the Wear catchment associated with outcomes of the new mode of governing the water environment in the catchment (collaborative, partnership-based) is perhaps support for the benefits of governing in this way, which is revealed through an understanding of the emergent outcomes from a networked system. It is particularly shown in the Wear catchment that processes of learning in relation to cultural change at the institutional level have been important and facilitated by new structures of interaction including partnerships, which change the way that organisations exchange knowledge and resources.

The concept of functionality encourages reflection on the effectiveness of networked governance processes. Functionality relates to a notion of effectiveness, in relation to the ability to produce the desired result or the ability to reach the organisational objectives (Sandström, 2008). In this thesis it relates to notions of stakeholder satisfaction and approval of processes, and to universally understood conceptualisations of success in natural resource management and governance. Where network structure may indicate positive configuration, the use of the concept of functionality facilitates a more detailed look at how the relationships might actually be functioning based on a combination of factors and analysed in the light of stakeholder assessments and norms of environmental management processes.

A focus on functionality also draws on the notion of power dynamics and the influence of wider social structure on the functioning of a governance process. Ezzamel and Reed (2008: 600) recognise that the regulative practice and form of governance is always mediated through particular socio-historical and spatial contexts. By understanding the different layers of influence on stakeholder behaviours within a networked system, some of the inequalities in the system and influences of wider contexts become clearer. For example the dominance of the EU legislation within the delivery of the CaBA and the ultimate authority of the government actor (EA) in decision-making; and the restrictive nature of prioritisation of action (against easy wins within the

WFD); barriers created through funding structures related to the status of businesses in the wider governance structure; global market systems and the commodification of natural resources that put pressures on actors to make certain decisions; and the historical understanding of citizen participation and legitimacy of knowledge, are all important for understanding the system of management, but rely on a contextual focus, which the study of functionality can bring. Where network structure has been used as an indicator of or explanation for processes, it has often been acknowledged that power structures and hierarchies associated with wider context are ignored (Kahler, 2009; Scott 2015). For example Scott (2015) claims that "the prevailing functionalist/connectionist ontology 'privileging harmonious social networks' dis- places how connectivity does not necessarily induce communication and consensus (Mackinnon and Derickson, 2013: 259)". The combination of the concepts of network structure and functionality therefore counter the difficulties of relying on network structures to reveal the complexity of a system and supplement the knowledge of its entities and relationships with an understanding of how such relationships can be affected and produced by social, political and wider structural contexts that form privileged or unjust relations or, equally, fair and beneficial relations. Moreover the combination of the approaches has allowed the factors that have utilised or adapted power structures successfully to enact collaborative processes of governance (through partnerships or through formal relationships) that have been effective in building trust and enacting planning and implementation actions from which positive outcomes have emerged.

8.3.5 The value of a framework for understanding a complex system of catchment management and governance

In light of the themes of complexity, emergence and network structure and functionality of the system, the value of the frameworks outlined in Figures 8.2 and 8.3 for thinking about management and governance is in their ability to help understand how the system might fit together. Figure 8.2 shows the iterative feedbacks between network structure and functionality and decision-making, influenced by context, individual drivers and interactional dynamics. In this thesis stakeholders and observation of stakeholder behaviour are understood as an important ways to understand a system (through the concept of agents). To acknowledge that their role is complex and complexly affected by a number of factors helps to understand where the restrictions on their action and interaction might be and what factors might enable them to better navigate network structures. Understanding of the associated power relations and contexts for actions and interactions gives an insight into elements where perhaps they do not have the power to influence but can affect the functionality of the system. Thinking about each stakeholder and the variety of opportunities and barriers they face can be helped by the framework to focus on the different scales of influence and to think about the link to network structure and functionality, particularly when they are acting within a network governance system. The feedback between functionality and network structure and the factors affecting behaviour encourages an understanding of the wider complexities of influence and to interrogate the reasons behind certain decisions and their link to particular sets of relations that produce certain network structures. The framework may also help to think about the configuration and behaviour of agents in a modelled system of resource management where actor decisions have to be made in a management context, which is relevant in relation to the growth of modelling techniques and the growing use of agent-based modelling to analyse natural resource management issues.

Figure 8.3 helps to highlight the important aspects to consider when thinking about a resource management system such as in a catchment management context. The themes of complexity and emergence sit at the centre in order to contextualise the approach. Each of the elements in the inner and outer layers of the diagram can be understood through the concept of emergence and are better understood in association to other elements when thinking about a complex system that is non-linear and self-organising. Such fundamental underpinnings means that the framework encourages an open and variable understanding of the system of interest but one where the dynamics can be recognised in the context of complexity thinking. The elements in the inner circle connected by arrows represent the important aspects of the system to consider, with the framework suggesting that the associations between each is important. The elements in the outer circle interact with the elements in the inner circle to affect the relations between each element and the resultant outcomes. The cyclical aspect indicates that an understanding of feedback loops is important for associating elements, as well as representing processes of learning and adaption. Structural context is placed at the top of the diagram as an overarching influence, affected by cultural, socio-political and historical context, which also affect all other elements. It can be linked to management approaches through wider social systems and expected behaviours, bounded by the natural resource focus and the problem context. Management approaches are conceived, mediated and enacted through agents as actors in the system, based on their decision-making. Agents and their associated formal and informal institutions make up the networks in the system based on their interactions, and the repetition of such networks based in trust and exchange through institutionalisation become embedded to form an observable (but arguably transient) network structure. Network structure is complexly linked to functionality considering the influence of the factors on the outer circle producing barriers, enablers and opportunities, assessed in relation to power dynamics and norms and expectation of outcomes from a given system. Functionality is linked to the processes of governance in relation to policy goals and the wider context in which a governance approach emerges from wider governance structures and social and political contexts, also intimately associated with power relations. Governance is therefore able to be linked to structural context through processes of learning and social change.

Each of the elements provide an understanding of dynamics in a complex system and when considered in combination can be ways in to thinking about change in approach or opportunities to get a better understanding of dynamics.

The consequence of using the framework is to address critiques of studies that only consider network structure to be relevant to understanding a system and goes some way to helping interrogate how a system is configured based on important influences of context, power and governance. Thinking in this way helps to reveal the dynamics involved in a particular system of operationalisation of governance in relation to how it is enacted and how it functions. Such a framework is relevant for thinking about contexts in which network governance is happening. This includes the CaBA in relation to water quality management in the UK and such thinking in this research has helped to reveal a detailed understanding of the operationalisation of a collaborative approach in which multiple stakeholders are involved in decision-making at multiple levels within the catchment system and in which new relationships have formed to facilitate the governance and management agendas and which have been seen to produce positive outcomes, but are complexly affected by barriers and difficulties of the wider system. It is a context in which complexity is evident and emergence is a helpful way to think about the variety of outcomes. The framework may be helpful in thinking about other CaBA implementations across the UK in other catchments when assessing their functionality and configuration, particularly as there are comparable stages of implementation of CaBA geographically. Equally, it might be applicable more widely to other contexts in which multiple stakeholders organise into networks in order to deliver management in relation to natural resources in which 'wicked' problems and multi-level institutional arrangements create complex contexts in order to both broaden and focus the study of a complex system.

8.4. Lessons for catchment-management practice in the Wear Catchment and beyond

Utilising multiple perspectives to analyse the system of catchment management in the Wear catchment has allowed an in depth picture to be built of the complexities and intricacies unique to the catchment. The study has created a snapshot of the network structures and dynamics making up the CaBA in one catchment. The research has been able to highlight aspects of the dynamics of the system that could be more closely considered in relation to reflection on practice in the Wear catchment and its applicability beyond.

Knowledge of the components of the network is useful for conceptualising where the energy is focused in a CaBA approaches and can relate to an assessment of progress or particular character of a system at one time. For example the Wear catchment is much further along the process of CaBA than other catchments who did not take part in the pilot between 2011 and 2013. Therefore the network and balance of factors might look very different in the Wear catchment from other catchments. The stakeholders in the Tees catchment, which is a neighbouring watershed, were still looking to put together a steering group at the time of research, compared to the Wear who had an established catchment partnership group, steering group, meeting structure and project delivery processes. The network perspective therefore could be a method by which the differing stages of CaBA be documented and compared.

The network perspective has been influential in reflecting upon the role of certain groups within the system and their individual positions. The notion of a personal network and an awareness of each organisations potential or current role in the networked system could be formative of helping to think about the nature of interventions or planned behaviour change. A relevant idea in relation to the potential roles and positions of stakeholders in a network is the concept of power. Swyngedouw *et al.* (2002) observed that decentralisation of decisions and management in water management and NRM can be considered to simply aim to reduce the burden on governments and not to fundamentally change the power dynamics in which decisions and actions happen. This view is a restrictive view of the potential importance of the emergent structures of interaction following the CaBA approach, which has allowed the development of the personal networks of the individual stakeholders, which is constitutive of options and abilities to act differently. This observation of behaviour change has revealed how a network might be configured via stakeholders action and interaction, and which has been seen to represent a governance network because of the intentionality and cooperation of the actors, which itself goes some way to revealing processes of operationalisation of a water resource governance approach,

Equally, however there are elements of the process that are restrictive and highlight the strong central role of government and the power of legislation as the central driver for the process. There is recognition amongst stakeholders of a need to go beyond WFD, for example, if the collaborative process is to be more equitable. In the current policy context, it seems unlikely that the funding and data structures will move beyond meeting WFD targets. However, the opportunities offered within the networked structure to develop new relationships and new interactions in order to more collaboratively deliver the collective aims and goals within the context of the overall purpose of CaBA, to deliver centrally derived targets for water-quality improvement, alongside more general aims, are evident.

8.4 Summary

This chapter has presented analysis of the core research findings from across the three empirical chapters of this thesis, summarising, evaluating and explaining the ideas around the system as a networked system, around the factors contributing to functionality at multiple scales and the use of ABM to experiment and explore dynamics of a system of management based on interaction of stakeholders. The core themes of this thesis in relation to understanding the catchment management process as a system relate to complexity and emergence. Complexity is apparent in the water-management system through the multiple components of the networked system and in the (sometimes) non-linear interconnection of factors contributing to functionality of the system. Knowledge of complexity and positionality within a connected system might allow barriers to be identified and overcome. Equally, emergence has been shown to be a concept that is potentially useful for reconceptualising the management system. Emergent properties of a complex system were understood as network structures in the form of new institutional formal and informal relationships as well as intangible functions such as good relationships and improved understanding, alongside water quality improvements. The encouragement to 'manage for emergence' (Collins and Ison, 2010) could mean a positive focus on process and practice rather than prescriptive outcomes (which result in difficulties when expectations are not met). However, the lack of utility of the concept to influence interventions and management practice due to confusion over agency means the value needs to be carefully considered.

Each of the empirical chapters contributes to an understanding of complexity and emergence through the presentation and analysis of aspects of network structure and functionality of the catchment system. The network approach has highlighted the characteristics of the network structure of a catchment management approach, which is indicative of the operationalisation of a governance approach through mechanisms of network governance; the in-depth analysis has revealed the potential factors at multiple scales that act to affect the functionality of a system; and an ABM processes has helped to test the assumptions and provide a heuristic tool to explore changes in behaviour and system practice in relation to functions. The combination of modes of exploration through an interdisciplinary approach has brought benefits through the ability to build layers of understanding. The frameworks laid out in Figures 8.2 and 8.3 offer a way to think about complex system of resource management using the core concepts in this thesis of network structure and functionality in relation to underpinning through complexity and emergence and in association with wider management and governance approaches and contextual influences on power dynamics. The results of the analysis of data through multiple modes of exploration are able to reveal characteristics of one catchment-based management approach, are relevant to reflect on practice in the Wear catchment, but are likely applicable more widely for other CaBA catchments. Equally the themes are more broadly relevant to perceptions of other forms of NRM as the complexity of collaborative management efforts is considered.

Chapter Nine

Conclusions: understanding complexity, network structure and functionality in a system of catchment management

9.1 Chapter overview

This chapter offers some final reflections on the research and research process. It includes a summary of the research premise and key findings in relation to the three research questions posed in Chapter 1, as well as analysis of the potential contributions of the research, recommendations that arise from lessons learned, and an exploration of avenues for future research.

9.2 Summary of research premise

The initial motivation for this research was to explore the intricacies, reasoning, processes and experiences of the stakeholders involved in a catchment-based approach to water-quality management, in order to better understand the processes and practice of the new governance approach. An understanding of the system of catchment management and the operationalisation of collaborative governance as complex and constitutive of messy, multi-stakeholder contexts, in which wicked problems prevent simple solutions to issues of water-quality management, provided the background in which to situate a study that attempted to represent and interrogate those complexities. Stein *et al.* (2011:1085) argue that the development of "analytical tools and methodologies that can capture and translate such complexity" has driven the application of multiple modes of exploration within this research in order to contribute to the investigation of "effective methods to analyse complex water governance arrangements, in particular the social dimension". The combination of methods has led to analysis of the intricacies of the CaBA system of governance in a UK catchment and has allowed a reflection on ideas of complexity, emergence, agency and intervention, contributing to scholarship on NRM and on means of understanding systems.

The core research questions focused on facilitating explanation of the network structure and function of the system and were as follows:

- What characterises the network structure of the catchment-management system and the collaborative catchment governance approach in the Wear catchment?
- What factors are important for understanding the functioning of a catchment-management system and the associated collaborative catchment governance processes?
- How can ABM help to better understand the structures and functioning of catchment-management processes in relation to stakeholder behaviours?

The questions were approached through interview conversations with stakeholders involved in management of water resources in the river Wear catchment in North East England. It was vital that the research be derived from the ideas and experience of stakeholders, as a fundamental underlying principle of the research related to the centrality of stakeholders as agents, where actions and interactions based on stakeholder's decisions represented and formed the network structures and functioning of the system. Equally, where sustainability, equality and best-practice rely on individuals acting in certain ways, no other data could act to represent or value individual perspectives better. The interview conversations were used as a basis for analysis in relation to the research questions and formed the basis of a network analysis, as well as informed rules and understandings of dynamics for the ABM process.

9.3 Key findings

Each of the stages of analysis and exploration in this project have contributed a different form of understanding, situated within the conceptualisation of the catchment as a system. They have explicitly contributed to an understanding of the social and relational aspects of a system of management, exploring network structures and dynamics not previously a focus of such in-depth study. In relation to each of the research questions the findings can be summarised under the following themes: 1) Structure, networks and governance change; 2) understanding functionality at multiple scales; and 3) modelling as exploration of stakeholder behaviour.

9.3.1 Research question 1: structure, networks and governance change

The concept of structure is closely interconnected with the idea of networks and networked systems. This research has emphasised that network structure is an emergent property of a system based on the actions and interactions of stakeholders facilitated through spaces and places of interaction. The system of catchment management was conceptualised as a governance network which was identified "as a set of relatively stable relationships of communication between actors or organisations involved in resource management, and based on degrees of mutual trust, reciprocity and cooperation" (Chaffin *et al.*, 2016:114 also Torfing, 2005; Newig *et al.*,2010). The interesting aspect of the study of the governance network in the Wear catchment in relation to the CaBA was the ability to highlight the new features of interaction (and thus changes in network structure) observed by stakeholders as occurring through the new governance approach. Equally, the opportunity to identify the potential positive effects of the changes or features of the current approach to management offered a chance to comment on the tractability of such changes in interaction for the improvement of practice. Key findings are as follows:

A networked system of collaborative catchment management is made up of multiple nodes of interaction, including meetings, partnerships, schemes, projects and actions. Each of the spaces and places of interaction act to connect stakeholders in different ways and represent the link between strategic decision-making and on-the-ground, physical actions. The conceptualisation of such spaces as part of a networked system in the Wear catchment, particularly when they have been identified as having functions within the network (such as projects connecting disparate actors), is an important observation about the complicated nature of a multi-layered system. The reflection on the network structure of the system (in relation to research question 1) is that the network structure of a catchment management system within the wider governance approach is not only conceived as stakeholders and their links, but the modes through which they are linked as important sites of agency and change.

There are many ways that the stakeholders connect to one another, and the association of certain spaces and places with a new collaborative way of working, characterises the CaBA in the Wear catchment. Processes of institutionalisation occur to solidify new relationships through a new governance approach and represent a change in structure of the network. It is likely that the configuration of nodes, and the various levels of institutionalisation are symbolic of the stage of management and could be compared to other times in the same catchment, or other places at the same time to compare configurations.

CaBA is facilitating institutional changes in network structure that can be identified as new relationships and patterns of interaction. Where new structures have been identified as part of the networked system based on the influence of the CaBA, such as new intermediary roles, new projects, new smaller scale partnerships and new responsibilities, there is a recognition of processes of institutionalisation, which are also seen to constitute the operationalisation of a new governance approach. Features such as sub-networks and devolution of decision-making act to embed the changes beyond the main catchment partnership. This embedding of new relationships and the formation of new network structures at smaller scales acts to strengthen the approach, enacting integrated practice and contributing to the resilience of the system. Such observations come alongside the understanding of the roles of different stakeholders at different times and at different points in the network. The network approach has identified the connected nature of the system as a whole and the role of each stakeholder in facilitating their own network connections.

The network approach has also highlighted the transitory nature of some aspects of some of the network structures. For example whilst the WCP stays relatively stable and embedded, other structures such as meetings and schemes and projects act on a shorter timescale. Ultimately a reflection on the network structures and changes in the Wear catchment has meant that the CaBA approach could be conceptualised in its form and in its facilitation. The principles of the method, if not the in-depth nature of the method itself, could be replicated in other catchments or for other collaborative resource management effort to characterise the components of a complex system.

Positive outcomes likely emerge from a system of catchment management in non-linear ways. The positive aspects of the changes in management practice seen through the structural changes in the networked system in the Wear related to the tangible and measurable improvement of water-quality as well as intangible positives such as good relationships, access to resources, delivering across scales, and improved understanding. Such positives relate to concepts of "good governance" (Montgomery *et al.*, 2016) and can be seen to show the effectiveness of governance change through the CaBA and through the related management actions. As such, positives are seen to emerge in non-linear ways as a function of the complexity of the system. The concept of weak emergence is seen to be appropriate, whereby particular practices create a successful approach but that there are also unexpected truths (Bedau, 1997).

9.3.2 Research question 2: understanding functionality at multiple scales

This research has conceptualised that barriers and enabling factors are associated with the patterns of action and interaction that form the structure of a networked system; forming the functionality of network governance practices. The key observation is that there are multiple scales at which factors that affect the functionality play out, including the interactional, individual and contextual. Figure 9.1 summarises the constitution of each of the scales and the relationship of the factors to stakeholders, their decisions, their actions and interactions and the emergent network structure and outcomes, taking into account the wider contextual influence of the social structure and structures of governance on power dynamics and institutions that also affect network structure and outcomes. This diagram represents a key finding of the research and can be seen to be representative of knowledge about the complex system of catchment management. It has the potential to be relevant for other contexts in which collaborative governance is being enacted. However, the factors were derived from a very particular context and therefore may not transfer.

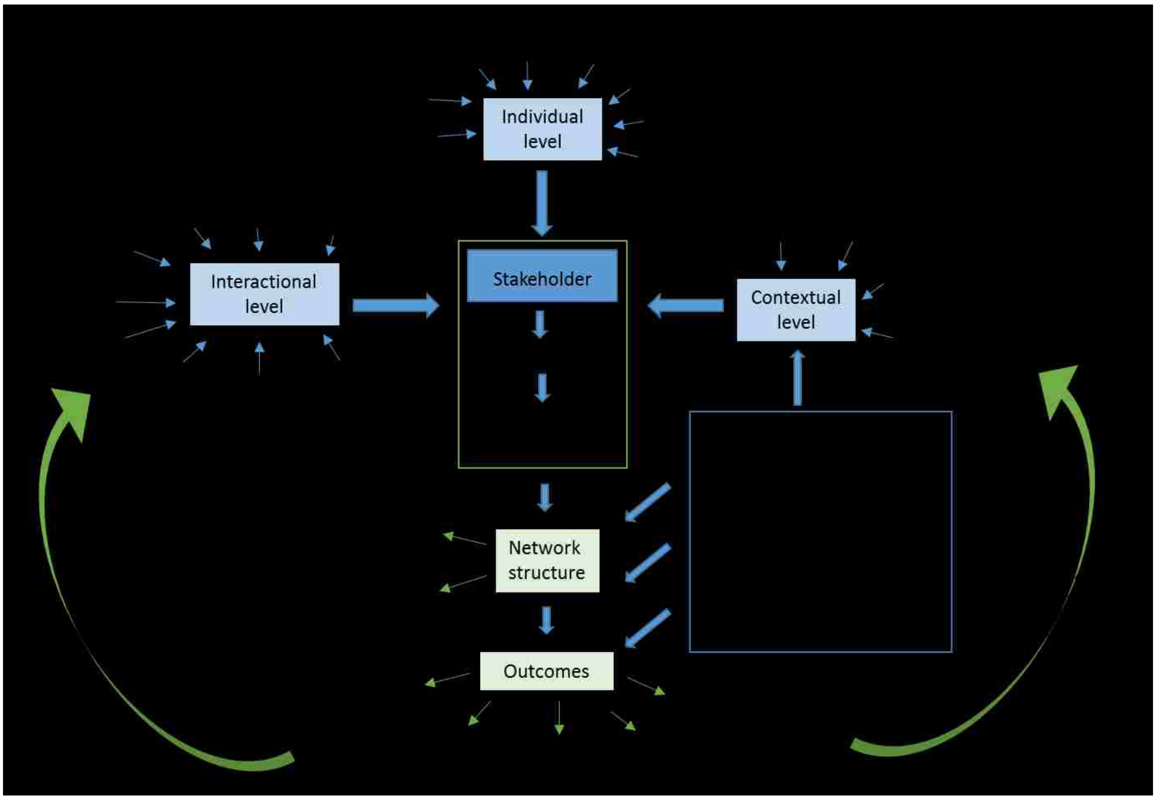


***Figure 9.1** Theoretical associations between the factors contributing to functionality of the system and the network structure and outcomes of the system. The stakeholders act as agents of change and are influenced by individual, interactional and contextual factors to make certain decisions at certain times that lead to actions and interactions, which can be understood as constituting a network with outcomes that then influence the factors that influence the stakeholders.*

The combined effect of factors relates to the functioning of the catchment management system at any one time. It is the combination of factors from multiple scales that affect the ability of stakeholders to make particular decisions that lead to particular practices within, or forming, particular network structures and the emergence of outcomes. No one scale of factors alone is relevant to understand or evaluate the processes and practices of management and the related system of governance. At the interactional level issues of legitimacy, data sharing and learning affect the way that stakeholders are able to, or are invited to participate and form relationships. Issues of trust are seen to be related to procedures as well as groups and can fluctuate through time and contexts. Such factors are related to individual level factors such as motivation, goals and sense of responsibility that drive stakeholders to act or make changes, and cultural norms that might enable or restrict certain change from happening. Such factors cannot be separated from the contextual factors that drive goals such as legislation, policy, economic and political circumstances and regulation. As such, the levels of contributing factors are artificially demarcated because they are constitutive of one another and iterative in their influence. However the recognition of the multiplicity of factors that might enable or restrict the action and interaction of stakeholders in a networked system is an important finding of this research. It can offer a mode by which the most important trade-offs are identified within the system in terms of tensions or in terms of beneficial practices. In the Wear a number of combinations of factors were identified as causing barriers such as around legitimisation of data, availability of funding, difficulty in changing institutional norms and dominance of WFD to name a few. Equally, there were areas that were identified as functioning well including the WCP, leadership and good partnership working affected by trust, personalities, participatory attitudes and proactive change.

The impact of identifying multiple scales of factors affecting functionality is the ability to breakdown the complexity of the system. Even, if it is also acknowledged that the best combinations of factors might be ultimately unknowable, the understanding of the possible ways the system can be changed and influenced might be productive in reflecting on where and how to change practice in the future. Ideas of scales of influence might be productive when applied to other catchments or other resource management contexts in order to help identify where problems or positive combination might exist. The concept of emergence is again important for the interpretation of this finding as the combination of factors may not always produce the same effect due to the complex interactions within the system affecting the processes and practices. Therefore the process of modelling (Chapter 7) can help to experiment with some of the factors and some of the unknowable mechanisms (alongside understandings of connectivity and network structure) to reflect on the process of management and to more widely associate those processes to the governance context.

9.3.3 Research question 3: modelling as exploration of stakeholder behaviour

The ABM aspect of this research project was the most experimental, which was reflected in the nature of the research question: "How can ABM help to better understand the network structures and functioning of catchment management processes in relation to stakeholder behaviours?" A key finding of the research is that modelling can offer an alternative method through which management and the operationalisation of governance processes can be better understood.

The process of ABM identifies assumptions and theories about behaviour in the catchment management system that can be further investigated. Both the process of creation and the process of analysis in an ABM are useful for identifying assumptions and theories about behaviour. Batty *et al.* (2012) state that it is the process of modelling itself that becomes part of the theory. The process of creating an ABM is also a process of reflection on the knowledge already gathered about a system and the assumptions already held about the way in which interactions happen and relationships play out in relation to decision-making and behaviour. Therefore it offers the opportunity to solidify such assumptions, identifying both what is certain and uncertain, which can be valuable in opening up the system and better understanding complexities. In relation to the process of developing a water-pollution scenario of ABM in this research, the assumptions about centrality of particular actors and the composition of individual networks of connections based on the network analysis in this study were applied to the model rules, as well as the balance of factors affecting them at particular decision-points in the management process. The results of the experimentations then gave an opportunity to identify some theories about the behaviour of stakeholders including the possible connection between the behaviour of stakeholders at the event-scale and their behaviour within a networked system at the longer-term scale in relation to the likely influence of one on the other to build patterns of behaviour and levels of trust. Equally, theories emerged around the positivity of agents who behaved (and were able to behave) in agile ways to adapt to changes in approach, through sharing and trust and new norms of interaction, and to smaller-scale demand, potentially through the strength of their links to others.

Experimentation within ABM can reveal where the system might be open to change. The ABM process in this research identified that improvement in the effectiveness of joint-action might be facilitated through changes in the attitude, preparedness, responsibility, opportunity to interact and available resources. It might be observed that wider structures of support for small-scale joint action might increase such factors. The process of experimentation had utility in itself, as a number of the experiments contain elements inspired by suggestions for ideal management given by stakeholders in the Wear catchment. It therefore offers a "computational petri-dish" (Miller and Page, 2007) to explore a potential scenario and projected behaviours relevant and conceptualised by the people directly involved in current practice. Although the process in this research was not participatory, there are obvious opportunities to apply such a modelling process more closely with those involved in practice in order to inspire direct dialogue about the assumptions and the traction of potential solutions. As such in this research, the outcomes provide the foundation for further investigation or discussion about the possibility or utility of changing such factors at different scale and for different problem contexts. The results are not definitive but inspirational for further work.

9.4 Contribution to water-management research

The contribution of this thesis to water-management research is two-fold: conceptual and methodological. In addition it also makes an empirical contribution to understanding the specific case study of CaBA in a UK catchment. Overall it has represented a drawing-together of multiple areas of knowledge and research about water management and NRM in relation to the social and governance processes involved and the core ideals and theories related to water management. This thesis has attempted to find a pathway through multiple aspects of the water management field including demands for reflection on the practice of a new governance approach in the UK and a need to evaluate progress, the need to be able to understand complexity in NRM in order to produce adaptive and resilient systems (e.g. Rammel *et al.*, 2007; Duit and Galaz, 2008; Booher and Innes, 2010; Cilliers *et al.*, 2013; Chaffin and Gunderson, 2016), the growing utility of ABM for answering and exploring questions of resource governance, behaviour and decision-making (e.g. Costanza *et al.*, 1993; Pahl-Wostl, 2002a; Bousquet and Le Page, 2004; Grimm *et al.*, 2005; Miller and Page, 2007; Bohensky, 2014), and an awareness that water resource management is of growing concern as land use, climate, extreme events and population pressures appear to become more visible, in consequence with the pressure of meeting policy targets for good quality water environments.

9.4.1 Conceptual contribution

The core conceptual contributions of this thesis are through its reflection on complexity and the breakdown of complexity into the concepts of network structure and functionality. Such an approach is unique in the study of water-quality management in this way. Network structural understandings of systems through the concept of complexity can help conceptualise the character of the management and governance processes and understand changes over time, alongside processes of institutionalisation that might accompany governance change. Functional understandings can help identify the successes and problems with an approach in a particular context and help to focus understanding, in relation to practical action and interaction, of the application of concepts often associated with water management and NRM (including social learning, trust, legitimacy, cultural norms, decision-making and participation). The use of the concept of functionality allows studies to be critical of processes and practices but able to have a holistic view of the critique in relation to the complexity of the system.

Both the network structural and functional perspectives can relate to ideas of integration, which is a key theme for water management research (Margerum, 1999; Biswas, 2004; Lubell and Lippert, 2011; Hering and Ingold, 2012) increasingly so as efficiency and complexity are considered in legislation and governance approaches. Knowledge of the practical application of integration is arguably lacking (Lubell and Edelenbos, 2013) and a study of the structural features and functionality of a governance approach goes some way to evidencing the processes of integration, such as the creation of new positions or the informal institutionalisation of interactions such as partnerships as shown to be evident in the Wear catchment. The process of modelling could help to contribute to the questions and explorations of how integration could be facilitated via network governance (Pahl-Wostl *et al.*, 2007) in relation to water management. Equally, there could be particular value in a multi-method approach to help understand integration in relation to concepts of participation, equitable access and managing demand, which Fritsch and Benson (2013) have identified as priorities for research, and that require multi-perspective and analyses to understand.

There is still some doubt and questioning of the appropriateness of the CaBA style of governance for solving water-management issues due to the organisational effort involved and the lack of evidence at such an early stage in the governance approach about its effectiveness in achieving water management goals as well as equitable and truly inclusive management. Other countries focused on delivering the WFD such as Scotland are considering the CaBA as a governance option in future water management and therefore studies that help to identify the character and functionality of the approach, may be relevant in discussions and future research into the feasibility or the processes of evaluation of such collaborative approaches. The role of this research might be to begin to identify the components and character of such a governance approach that elements of it can be looked at in more detail to contribute to ongoing conversations in academia and practice about the approach, its link to stakeholders' actions and interactions and its link to policies and contexts that drive agendas.

Another conceptual contribution of the thesis is in relation to the concept of emergence, which has not been a focus of water-management studies previously, (with the exception of Collins and Ison, 2010). The concept is suggested as relevant for understanding the formation of network structure in a catchment management system, and the development of outcomes and functionality related in (sometimes) non-linear ways to processes and practices. The proposal to "manage for emergence" (Collins and Ison, 2010) could continue to have utility if facilitating the interpretation that there needs to be a removal of the expectation of prescriptive outcomes within systems and a concentration on process and practice. Such a claim however also highlights another important conceptual question raised by the research in relation to the level at which agency is held within a system. Where conclusions can be made about the factors affecting functionality, or ideas proposed from the modelling process about potential areas to investigate around behaviour change, there still remains a question over the degree to which such observations can be practically interpreted in relation to interventions or behaviour change.

The idea of complexity is relevant for understanding the difficulty in identifying where and how definitive action could change outcomes based on new understandings of network structure and functionality. This could be used to conclude that there is no way of understanding how outcomes are arrived at and therefore no way to reform activities, however this is not the case as there were clearly links made by stakeholders between action, change in interactions and practices and positives or challenges that arose. There is, therefore, some ability for the findings of the research to contribute to debates around, for example, the WFD as a driving force for CaBA, via funding and setting expectation in terms of deliverables and targets (affecting aspects of motivation, goals, legitimacy, data sharing and trust within the system). It is beyond the scope of this research to comment politically but some of the challenges and power dynamics within the system in the Wear catchment are important for identifying where the current issues and challenges lie. A reflection on such challenges and the broader role of policy such as WFD as a driving force for water management could be more broadly considered in further study, particularly as there is likely to be opportunity for change in the UK as Brexit unfolds and an increasing recognition that water quality management could be more broadly interlinked with priorities for water use from communities, and with management actions around Flood-Risk Management, with which there is currently little cross over.

9.4.2 Methodological contribution

The methodological contribution of the thesis to water management is evident through the utility of both a network perspective and qualitatively informed ABM for the exploration of complexity in collaborative management contexts. Where governance conducted in networks is seen as desirable for enhancing collective learning and facilitating functioning environmental management practice (Newig *et al.*, 2010), the ability to characterise its structure in relation to networks, and experiment with its functioning through modelling behavioural rules are arguably valuable, and this thesis demonstrates their application. The utilisation of a network perspective relates the thesis to studies that conceptualise catchments as social-ecological systems (e.g. Stein *et al.*, 2011) and that advocate (as well as critique) the use of SNA in NRM (e.g. Scott, 2015). It builds on those studies to add ways of recording and conceptualising structural relationships, as well as address difficulties with traditional SNA, such as the lack of consideration of dynamics, to create new understandings of network characterisation. The application of such network analyses more widely than this one case however may be difficult as the process is intensive (although not as intensive as SNA), and not quickly replicated. The concept of analysing structural relationships and interactions could, however, be done fairly easily based on a number of interviews with key practitioners. Therefore there is potential for similar methods to be applied, potentially through practice focused evaluations, or within other academic studies in other catchments and other contexts.

The ABM process is a novel and little-applied method for studying collaborative water management and the study sits in a unique position focusing on event-scale collaborative interactions to solve water pollution problems. Currently there are few similar studies and therefore this study may demonstrate how ABM can be relevant to collaborative water management issues. The methodological approach has similarities to other studies looking into alternative management strategies for water management (e.g. Schlüter and Pahl-Wostl, 2007; Kock, 2008) but makes tentative suggestions for behaviour change instead of investigating systemic change in practice. Other iterations of the model could experiment with options for future management practice and act as a decision-support tool (which was outside the remit of this project, but could be a feasible application of the approach). The obvious difficulties of applying ABM to other contexts include time intensity, and skills of the researcher. Where there is the availability of skills and time to create a model it can be a useful methodological approach to better understand systems of water management. However, its utility is balanced against its limitations and difficulties of representation of complexity, alongside the role that it plays in the research process. The space, skills and justification for modelling need to be in place for it to offer the most benefits. Equally, where processes of validation through those represented can be sought the value increases. The study has shown that there is potential for ABM to be used in other water-management contexts, particularly where there are uncertainties, interactions between spatial and non-spatial scales, feedbacks, communication and decision-making, as it promotes an intensity of evaluation of holistic and individual level dynamics that would not be induced by other methods of analysis and are valuable for understanding complexity in natural resource-management systems.

9.5 Recommendations: Implications for research and practice

There are a number of recommendations that arise from the research in relation to water management in the Wear catchment and in the UK more widely, and for the application of network perspectives and modelling as methods of investigation in a research process around water management. These recommendations represent some of the lessons that may be relevant in further consideration of the implication of the research:

For water management in the Wear catchment and beyond:

- The positive experiences of many of the stakeholders in the Wear catchment in relation to CaBA is indicative of practice that is on the whole, functional, and the Wear catchment could be used as an example of good collaborative practice.
- Good practice relates to building a network of well-connected stakeholders that build relationships through shared experiences and chances to meet and discuss issues across multiple spaces and places of interaction.
- Careful consideration needs to be given to creating procedural trust not just personal trusting relationships in order to build stronger connections.
- Significant importance is placed on the role of the WRT in connecting the network and facilitating the WCP as a strong centralised point that is becoming institutionalised in practice.
- Projects and partnerships are the points at which disparate stakeholders can come together through connecting or intermediary roles in a network. The experiences derived from joint project work form the foundation of relationships that continue into the future and act as options to deal with future change or new demands.
- Good practice is likely driven by passionate and dedicated individuals that know their role, place, ability and connectivity within the networked system.
- Each stakeholder should be aware of their position in a networked system and the opportunities and challenges they face in changing their behaviour to better fulfil their own and collective agendas.
- Institutional and organisational change is vital for the integration of practice, in order to overcome barriers to data sharing, resource sharing or decision-making.
- The inclusion of powerful actors in partnership decision-making may act to encourage cultural change, particularly where intermediary roles are created within organisations.
- If collaboration can be seen as successful in relation to water management in the Wear catchment, there may be opportunity to facilitate network governance at a basin scale in order to better coordinate across the whole district, equally there may be chance to

incorporate other priorities through deeper integration via a networked system of actions and interaction, for example incorporating priorities in relation to flooding (particularly as the CaBA is biased towards water-quality management).

For the study of network structure and functionaality in water management and NRM:

- The study of network structure and function may be a useful way to understand complexity of water management and other NRM contexts.
- An understanding of network structure should be taken as a step towards, but not fully representative of, an understanding of processes of network governance and should be understood in context of wider social structures and structures of governance. Network structural analysis should be supplemented by study of social, economic, cultural, political and historical contexts that contribute towards an understanding of functionality and of governance practices.
- There may be opportunity to transfer the lessons learned from this PhD research to other sectors of governance that are looking to move towards more collaborative management. The concept of structural and functional networked systems may be helpful in conceptualising an approach that is aware of the mechanisms and interactions necessary for more successful practice.
- There may be a need to incorporate better understanding of the dynamics of resources in relation to the social structures and functionality of practice in other studies of social-ecological systems.
- It is likely that factors affecting functionality of networked management practice are relevant in other catchments and in other NRM contexts, and offer the chance for other studies to add to the knowledge about functionality in order that a more comprehensive understanding of how factors combine to affect outcomes can be created.
- Careful reflection on the relevance of the concept of emergence and an understanding of agency in governance and management practice change is needed in order to better conceive where changes can be made and practice improved.

For the application of network perspectives and ABM to NRM:

- A network perspective can offer new understandings of the character of a system of management.
- A better understanding of the position of stakeholders and inference about their role, as well as an understanding and spaces and places of interaction in the management

approach can result from a network perspective and can be productive in learning how power plays out through relationships and interactions within a network.

- Modelling offers a novel alternative method to explore the dynamics of a networked system.
- Qualitative data can be used successfully to develop an ABM in relation to water governance and offers opportunity for other qualitative data to be collected and used to inform modelling processes around NRM.
- As computational power increases it is likely to become easier to create models quickly which could be used in an iterative process of analysis, feedback and modelling to allow more in depth analysis of contexts and processes and could be capitalised by researchers.
- The purpose of the model needs to be closely tailored to the research process and clearly identified when disseminating results. The use of a model as a heuristic tool is able to contribute to a process of research where validation with stakeholders is not possible.
- Modelling can be balanced with other forms of analysis through a multi-method approach and can be supplementary, adding another dimension and depth of detail to qualitative findings.
- Where there is increasing focus on uncertainty but a need to better plan and deliver water and other NRM systems, an opportunity to experiment with management options and behaviour-change feedbacks through ABM could be vital.

9.6 Future research

This section outlines three further aspects that could form the basis of future research. First, there is an opportunity to apply similar methods across the UK to analyse the CaBA more fully. Secondly, the thesis has raised important questions about agency and the concept of emergence, which could be interrogated further. Thirdly, the thesis has been haunted by the idea of participatory modelling opening up opportunities to apply a more participatory method to questions of management practice.

9.6.1 Further investigation of the trajectory of governance change under the CaBA

As the CaBA continues to evolve and be implemented in the catchments across the UK there is an obvious opportunity to study the different stages of the approach, particularly focusing on the temporal change in relationships. The systems of analysis developed in this PhD research in relation to understanding both the network structure and functional aspects of the system of management have scope to be applied to other catchment contexts in order to compare the changes that have happened and the outcomes that have been observed. Opportunity would exist either to monitor change within each catchment or to utilise the various stages of management progress across the country as indication of change over time. It would be particularly interesting to compare other catchments to the Wear catchment where the experiences have been mostly positive, and where other catchments may encounter different issues and challenges based on their history, context and geography. This comparative study would allow the stages of CaBA to be better characterised, as catchments across the UK are at very different stages. Such a characterisation would contribute to understanding of governance change (e.g. Rijke *et al.*, 2012; Short, 2015), which is a key consideration in NRM drawing on ideas of institutionalisation and behaviour change. Such a study would also allow reflection on the utility of a network perspective and analysis of factors affecting functions, where multiple contexts would provide different inputs and results from the process of analysis. If the factors affecting functionality could be developed through a study of other catchments, there could be a better analysis of possible changes to practice and a better understanding of their combination at particular times and particular places. It would be important to study the development of the CaBA as a contribution to the overall study of governance transformation toward more collaborative and place-based approaches.

9.6.2 Analysis and exploration of emergence and the role of agency in collaborative NRM

An intriguing question and frustration within this PhD research is that there have never been clear answers around the level at which change might best be operationalised because it is not clear to conceptualise where agency ends and emergence begins. As has been said, in a situation that is characterised as complex, with the expectation that there will be non-linear outcomes and unexpected change, it could be easy to dissipate agency away, however for research that is relevant to practice is important to reflect on where change can be operationalised. Through the study of networks and systems a hint at where behaviour change results in positive outcomes has been demonstrated, however as systematic study of agency and ultimately power relationships could shed light on how decisions are influenced and at what scale. It could draw on ideas developed in this thesis of factors affecting functionality, but could incorporate study of past change at multiple levels and the effectiveness of outcomes, perhaps intertwined with discussion with stakeholders about their experiences of change at multiple levels and their own understandings of agency and ability to change practice. Such a study would contribute to understandings of types of governance, where collaborative governance systems could be compared to other forms of governance in relation to the agency of stakeholders at various scales.

9.6.3 Participatory ABM to facilitate collaborative governance

Participatory forms of ABM have been the most prevalent application of ABM to NRM research and offer a unique opportunity to both study and help facilitate processes of collaboration and cooperation. This PhD research has been grounded in a number of the principles around ABM developed through participatory approaches to ABM, including Companion Modelling (e.g. Bousquet *et al.*, 1996; Barreteau *et al.*, 1997; Étienne, 2011) and there is scope to apply a participatory method to collaborative governance contexts. This PhD research has also highlighted the importance of spaces and places of interaction in facilitating strong relationships within a networked governance system. Participatory ABM can be introduced as a way of bringing groups together within a process of collaboration. It could be proposed that a participatory ABM be developed with a working group within a catchment (or other form of governance structure) on an issue of choice relevant to their area and to the agendas within the particular stage of collaborative management. The process of collectively creating the model would facilitate a process of learning about the system, but also an opportunity to apply that learning through iterative discussion to practical decisions and planning in that particular locality. As participatory modelling has not been applied to water management in the UK, and particularly to collaborative forms of water-quality management, the changing governance environment in the UK might offer an interesting study through this method of modelling. The study would forward the exploration of the utility of a participatory ABM approach, but would also allow an observation of its role within collaborative management and as a tool for practice as well as for research. This would represent an important boundary between research and practice and would encourage reflection on the use of modelling and computational simulation in NRM where uncertainty and complexity make traditional decision-making and collaboration difficult.

9.7 To conclude

Finally, this research has opened up an understanding of the complexity of water resource management in the UK through the development and application of a combination of methods applied to facilitate discussion of the processes and practices of collaborative governance and to explore dynamics of network structure and functionality within a system of catchment governance and management. Rooted in the experiences and ideas of stakeholders, the research has explored ways of characterising the network structure of a system of networked governance and of breaking down the functionality of such networks. The study is a conceptual exercise as well as a practical reflection on current practice and is able to speak, in different ways to academic and practical conversations about water management. Significantly the study has identified ideas and processes that may be able to be applied outside the context of water management to broader studies of NRM. Despite significant challenges and limitations of a single case study case and the difficulty in interdisciplinary research, the study has contributed to overcoming major challenges of analysing complex water governance arrangements and contributed to the development of tools and perspectives that attempt to capture and translate complexity. It has ultimately opened up questions for reflection on practice and research in relation to the continuing changes in governance approaches to resource management problems as challenges of environmental change and legislative jurisdiction continue to inspire the need for reflection and evaluation.

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Appendix A

Information sheet and consent form

Durham University

Catchment Connections: New perspectives on the role of stakeholders in catchment-scale management of water resources

E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL

Information Sheet

The Project

The project is an independent research study that aims to explore how people who live and work near the River Wear and in its surrounding landscape, use, manage, protect, benefit from, maintain and make decisions about the River Wear and its tributaries both in personal and professional capacities. The ultimate aim of the research is to identify a new way in which the needs and abilities of stakeholders can be explored and understood in order that they can be better incorporated into management decisions in the future. It aims to help make the water resource management process, as well its ultimate outcomes, more relevant for the wide variety of stakeholders that are affected.

This initial part of the project aims to explore the perspectives and knowledge of local groups and people (mainly those who have close working relationships with the River Wear and land near the river or any of its tributaries, whether that be through farming, land management, fishing, conservation volunteering or management), specifically looking at how connections are made to local environments; and how connections are made between people and organisations when sharing knowledge or making decisions.

In the second stage of the research the knowledge and opinions of the initial stakeholders will be developed into a computer model (using agent-based modelling techniques). The computer model will be used as a device for participants to explore how water management works now; what it might look like in the future by running different scenarios; and how each stakeholder group and network plays a part.

Geographical focus

The study focuses on the River Wear catchment (from source to North Sea) and is interested in discussing processes and experiences from any of the tributary or water course sections (not just those areas focused on for Water Framework Directive failures). The research however does not aim to solve particular localised problems in the short term (and is not a device for mediating between groups) but aims at stepping back and focusing more generally on how issues are tackled and what ideal management strategies might look like.

The model that will be produced will not focus on individual issues or locations (as some other models you may have seen do) but be a more generalised representation of how the whole system works. It will depict relationships and decisions and changes to the physical environment as a result.

The interview

The interview will last between 30 minutes and an hour. It will focus on your experiences as part of the local authority in the Wear area and will allow you to share knowledge about issues you have encountered, current management processes around water resources that you are aware of, and the people and groups you work alongside.

The interview will cover topics such as:

General discussions

- Your top priorities in your professional role
- The key challenges you face achieving your priorities

Water resources

- Importance of water resources for you and the people you encounter through your job
- The varying interests in water resources you have to juggle and the difficulties around that
- How water resources are considered in planning
- Issues you have encountered around water resources in the Wear area
- Your evaluation of the management processes happening at the moment to tackle problems
- Changes you have experienced in the landscape and water resources over time
- The role of policy and its implementation
- The catchment based approach

Partnerships and interactions

- Which organisations and groups you work most closely with
- Why certain relationships are beneficial and helpful to you
- Who you would like to improve relationships with
- Your evaluation about how other groups interact, particularly when dealing with environmental issues
- In an ideal world, how you see water management improving and how you see your involvement changing if at all

Scenarios

- Briefly talk through a hypothetical scenario

Additional information about taking part in the research:

Benefits and risks

Taking part in the interview will help participants reflect on knowledge about water resources and the process of management happening at the moment. It will provide a chance to explore how management might look in the future and an opportunity to share information about the work being done in the area and highlight issues that arise. By sharing expertise participants will help contribute to a more complete picture of how resources are managed in the area.

If participants chose to be involved in the next stages of the research they will learn more about the knowledge and opinions of other stakeholders and might benefit from experimenting with a computer model.

There are no known risks in this study. It should be mentioned that the study does not have any power to change practice directly, but is an independent exploratory study.

Participants' rights

Participants may decide to withdraw from the research study at any time without explanation. Participants have the right to ask that any data supplied up to that point be withdrawn/ destroyed.

Participants have the right to refuse to answer or respond to any question and will also have the opportunity to rephrase any answers given.

Participants have the right to ask any questions about the study and should contact the researcher prior to the study with any queries.

Cost, reimbursement and compensation

Participation in this study will be voluntary, however, refreshments will be provided or the costs covered where appropriate.

Confidentiality/ anonymity

Information given in the interview may be used to develop a computer model that will be shown to other groups. Information will be anonymised and the model generalised so ideas or information will not be traceable back to any individual. The nature of the topics discussed are not meant to be intrusive or personal but participants should be aware that any information discussed may be used to help inform a model that will be shown to multiple other groups, unless you let the researcher know that the information should not be shared.

The sessions will be recorded using a dictaphone but participants can choose not to be recorded if wished. Data recorded using a dictaphone will be downloaded and stored securely in digital format.

Participants will not be identified by name in any written work that is produced and the recordings and notes will not be shared directly. Direct quotes may be used in written work to support analysis and demonstrate the specifics of the situations participants refer to. It should be noted however, that where direct quotes are used in any written work participants might be able to be identified through the specifics of their words, particularly if certain readers are familiar with the context. You have the right to let the researcher know if you do not want certain information to be used directly.

Funding and support for the project

The research is being carried out by Sophie Tindale, a PhD researcher in the Department of Geography, Durham University. It is a 3.5 year project and it is in the 15th month of funding. The project is funded by the Economic and Social Research Council. The project has been approved by Durham University and the Department of Geography Ethics Committee.

It is supervised by Dr Louise Bracken, Professor John Wainwright and Professor Rachel Pain at Durham University.

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March 2015

Catchment Connections: New perspectives on the role of stakeholders in catchment-scale management of water resources

Consent form

This form is to ensure that you have been given information about this project (see information sheet). It is to confirm that you know what the project is about and that you are happy to take part. Please tick the boxes below if you agree.

I know what the project is about and have read and understood the information sheet. Any questions I had have been answered satisfactorily.	☐
I know I have the right to refuse to answer questions during the interview	☐
I know that my participation is voluntary and that I have the right to withdraw at any time	☐
I agree that the session can be recorded	☐
I understand what will happen to the data once it has been collected and I am aware of the possible use of my responses for word for word quotations.	☐
I understand that I will remain totally anonymous in any written work	☐

I would like to take part

Signed ____

Name ____ Date________________________________

I would like to hear about the progress of the project ☐

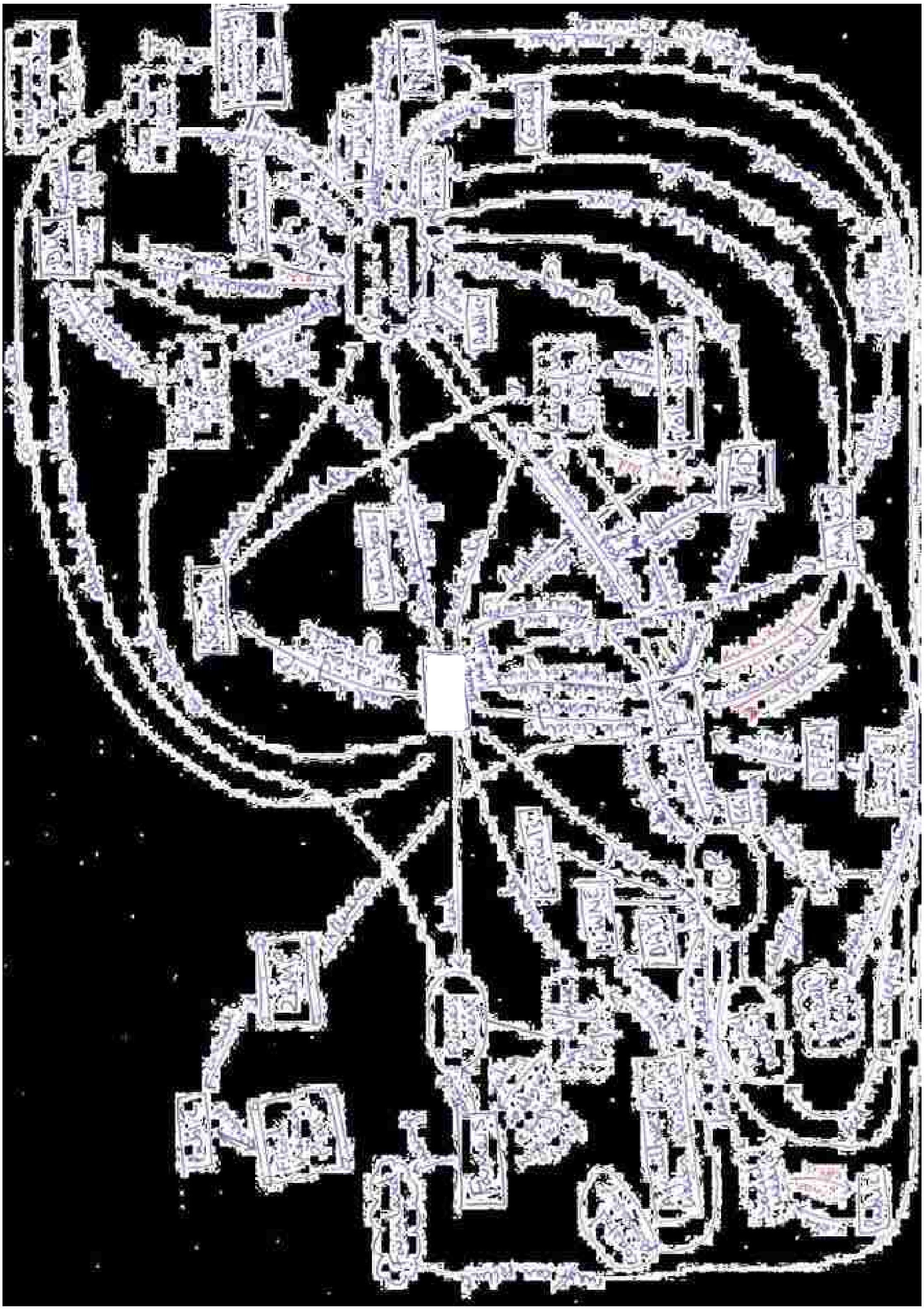
I am happy to be contacted if more information is needed ☐

Email address ____

Appendix B

Example of an ARDI-inspired diagram

ARDI-inspired diagram for an interviewee representing their organisation.



Appendix C

Characteristics of agents and environment

Agent characteristics

Each of the agents are assumed to have a number of variables representing their characteristics and abilities. These include and are listed in the model as:

- `available-resources-to-tackle-minewater` – this measure refers to the capacity of the stakeholders to focus attention and financial resources on a point source pollution issue particularly associated with minewater. A score of 10 would represent a stakeholder who could put the most resource into solving the problem, with descending scores (to 0) representing those with fewer resources available or with other priorities for their resources. The variable `available-resources` allows the amount of resources available throughout the system to be changed globally. It affects the proportion of `available-resources-to-tackle-minewater` that can be used for action and collaborative efforts.
- `data-on-water-qual` – this measure represents the access to data on the quality of the water course in question that the stakeholder may have within their organisation. High scores represent those who have direct access to water sampling processes that happen regularly and are relied upon for decision-making and those with lower scores are those who do not collect data themselves and perhaps rely on others to supply information.
- `eyes-and-ears-on-the-ground` – this measure is taken from the language used by a number of the stakeholders who describe their proximity to water environments on a regular basis. Although most groups have a proximity to the water environment on a regular basis, whether through professional duties or other activities, within this measure scale has been taken into account. Where some groups may have repeated and regular view and knowledge of a particular water course consistently, others may have a broader knowledge of the water courses across the catchment but less in-depth or regular knowledge of the day to day changes in one water course. Within this measure, higher scores represent those whose knowledge is concentrated on a narrower scale and who are in regular (mainly visual) proximity of the same water environment and may be able to spot changes in the colour of the water if a minewater event should occur.
- `ability-to-change-physical-environment-or-infrastructure` – this measure refers to the ability of the stakeholders to make physical changes to the water environment, which often constitute part of the solution to point-source water pollution problems through for example creating a reed-bed,

diverting flow or changing waste water infrastructure. Some stakeholders have a more significant capacity, both financially, practically and legally, to make changes to the environment or infrastructure. Higher score for this measure therefore represent those who have the capacity, either to do the works themselves or to give permission to others, while lower scores represent those who have to rely on others to make changes.

- `capacity-to-identify-and-tackle-source` – this is a specific measure relating to the type of pollution modelled in the specific minewater scenario. There are certain organisations who have a more significant ability to know about and control the sources of minewater pollution, who therefore may be key to solving a problem, both in the long and short term. The scores for this measure would change depending on the nature of the pollution and would be problematic when diffuse pollution is also accounted for. The higher scores for this measure are for those organisations who deal with minewater sources or manage land in which the sources may exist.
- `official-responsibility` – this measure refers to the statutory responsibility that some organisations hold for the maintenance of clean water and for dealing with pollution incidents in particular. Those with a high score are those groups whose responsibility it is to find a solution to the problem, meaning they are likely to be active in the process. Those with a low score are those who have no statutory responsibility (but, which does not necessarily translate to inactivity). This measure goes some way to representing a capacity or power of a group to be part of the problem-solving process.
- `organisational-sense-of-responsibility` – this measure is a representation of the sense of responsibility that organisations may feel, born from either a professional sense of duty (and/) or a personal care for their local environment and a drive to see environmental improvements. This is a measure that is designed to relatively represent the commitment and perseverance of certain groups to find a solution in relation to the specific problem targeted in the model.

Environment
The patches representing the water environment have a number of variables that allow them to become polluted and unpolluted to represent a change in the pollution levels that can affect and be affected by the stakeholders:

- `Pollution-level` – this variable represents the status of a `river-patch`. There are three discreet levels: 0 = no pollution present; 1 = polluted; 2 = previously polluted but currently unpolluted and protected from becoming polluted again for a certain amount of time (regulated by an external timer that sets the number of time steps before the patch can potentially become polluted again). Pollution is represented by an orange colour and is symbolic of the iron ochre sediment that is often associated with minewater pollution. It is assumed that the pollution is distributed evenly across the patch and, as there is no concept of depth in this model, is present only when visible (and therefore at surface level).
- `Countdown –` this variable is representative of the time (in time steps) a patch can be protected from becoming polluted again once it has been remediated by the actions of the stakeholders. It can be set using the slider `pollution-fix-memory,` which represents the positive and cumulative effect of any possible action to reduce the pollution levels made by the stakeholders. For example an attempt to pump away pollution may be effective for a time but will not be a permanent solution. The higher the countdown the longer the patches that have been unpolluted because of the actions of stakeholders stay unpolluted before pollution can again diffuse into that space.
- `Decay –` this variable represents the natural degradation and dilution of the pollution over time. After a specified number of time steps a polluted patch becomes automatically unpolluted.

Appendix D

Stages of agent action

Stages of action

Observing: The first stage is to observe the environment, which involves surveying a proportion of the river environment and checking for pollution (Figure D1). This process of observation may represent the formal collection of water quality data or the visual observation of the watercourse. Equally, some stakeholders rely on others to inform them of any point source pollution, particularly pertaining to minewater, and therefore do not observe the watercourse directly in this case. Those stakeholders rely on receiving a message from other stakeholders about the pollution. Each stakeholder who observes, observes a different proportion of water environment, represented by the variable `spatial-sampling-frequency`, which is directly equivalent to the number of patches that are 'looked at'. The higher the number of patches observed the more likely the stakeholder is to notice the pollution.

```
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

to observe-anglers
a) ->  ask n-of spatial-sampling-frequency river-patches
  [
     if pcolor = 26
b) ->  [ask angler
       [ set color yellow
         set duration-of-pollution-event duration-of-pollution-event + 1
         add-belief create-belief "pollution-event" "requires-action"
       ]
     ]
  ]

end

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
```

Figure D1 Code showing the process of observation for the angler agent. Section a) represents the random choice of a specified number of patches (spatial-sampling-frequency). Section b) asks the angler agent to change their colour, belief and update the duration of the pollution event if any of the selected patches are polluted (have a colour of 26).

Communicating: The observe process usually runs until the stakeholder has noticed the pollution or been informed of the pollution by others. Once the pollution has been noticed (a change in the colour of the water course) the stakeholders either go on to inform others or try and fix the problem themselves. Most organisations are likely to communicate with others who either have more responsibility than themselves for reducing the pollution or who they have a close relationship with and who could be involved in the solution to the problem. Some stakeholders target single organisations first (for example the EA is well known to have responsibility for maintaining water quality and dealing with incidents, and are therefore the first port of call for some groups), others connect with all of their `working-partners` and pass on information to them through the sending of a message. Some groups may then pick up that message and become aware of the pollution before they have noticed the pollution through their own observations.

Figure D2 shows an example of the code used to produce the communication process between the stakeholders. In Figure 6.5 the code in section a) asks the agent to choose one of their `working-partners` (specified at the beginning of the model) and give them the label `new-partner.` Section b) looks at all the other agents in the model and checks whether they match the label of `new-partner.` Section c) asks a link to be created from the agent to the new partner agent.

```
;.....................................................................
to create-communication-links-AONB
ask AONB
[repeat 100
[let new-partner one-of working-partners            <- a)
        ask AONB
          [ ask other turtles                       <- b)
              [
                if label = new-partner
                   [create-communications-from myself]   <- c)
              ]
          ]
]
]
end

;.....................................................................
```

```
;.....................................................................

to send-inform-message

    set color orange
    let msg create-message "inform"
    set msg add-content "pollution-event-AONB-info" msg
    broadcast-to out-communications-neighbors msg
    ask my-out-communication
      [set color green]
end

;.....................................................................
```

Figure D2 *Code showing the creation of communication links and a sending of a message along those links.*

Acting to reduce pollution: Organisations may then attempt to do something about the pollution problem in the short term to reduce its impacts. Some organisations may attempt to do this before having informed others, but most after. The `short-term-fix` function is slightly different for each stakeholder but is representative of an immediate attempt of organisations to enact some form of direct action to reduce pollution such as to divert flow, pump away pollution or tackle the source. Some groups do not have the capacity to do such short term actions alone and may instead begin to ask for help and resources to create longer term solutions through more collaborative relationships or equally continue to inform and encourage action by others. Where stakeholders can carry out `direct-action` it directly transfers to reducing pollution in the water environment. The power of the action is affected by the `effectiveness` score of the agent carrying out the action, which translates into a proportion of polluted patches in the river environment that become unpolluted when the direct action is enacted. There is a level of uncertainty of the effectiveness, represented through the use of a randomly generated number that denotes the proportion of the effectiveness translated on to the watercourse. The uncertainty represents a natural variability of the water course and the likelihood that any attempt to manage the pollution may be ineffective. The variable `max-random-effectiveness`, can be used to set the maximum proportion of the effectiveness of the agents that can be used to reduce the pollution levels. The slider can be set between 0 and 1.5 meaning that the maximum possible effectiveness can be varied from no effect at all to 1.5 times as effective as has been set by the variables for each stakeholder.

The `direct-action` process is often repeated over a number of timesteps as the stakeholders carry out action for a set amount of time. Each stakeholder is able to carry out action for a different length of time dependent on their available resources and capacity to act. Equally, the direct-action may not be triggered for certain groups straight away, based on their interest and sense of responsibility around the problem. Some actors use a `pollution-threshold` to control when they are willing to become involved directly, which refers to there being a certain number of polluted river patches before they will act. The delay is based on the fact that not all organisations feel it is their immediate responsibility to become involved, but will react if the problem becomes a significant one and is seemingly unmanageable by those who take initial responsibility.

Figure D3 shows an example of the `direct-action` Netlogo code (for the AONB agent in this case). Section a) refers to the presence of collaborative links, which modify the way the stakeholder can carry out action; section b) defines the number of patches to be potentially unpolluted dependent upon the effectiveness score (out of a total of 70) and the number of patches actually reduced dependent upon the random number and `max-random-effectiveness`; section c) ensures that the number of patches to reduce does not exceed the number of polluted patches; section d) acts out the reduction of the relevant number of patches, setting the colour to blue and the pollution level to 2 giving the patch immunity from becoming polluted again through the `propagate-pollution` process, set by the variable `pollution-fix-memory;` section e) tells the agents to check for any messages and changes the colour of the agent to red to show that they are acting directly to reduce the pollution levels.

```
;.........................................................................
to direct-action-AONB
[redacted]
    if any? collaborations-neighbors
     [direct-action-collabs-AONB]
[redacted]
  let patches-to-reduce (count river-patches with [pcolor = 26]) * (effectiveness / 70)
  let patches-to-reduce-variable (patches-to-reduce * (0.1 + random-float max-random-effectiveness))

  let max-patches-to-reduce-variable 0
[redacted]
  ifelse patches-to-reduce-variable > count river-patches with [pcolor = 26] ; make sure number is <
    [set max-patches-to-reduce-variable (count river-patches with [pcolor = 26] - 1)]
    [set max-patches-to-reduce-variable patches-to-reduce-variable]
[redacted]
   ask n-of max-patches-to-reduce-variable river-patches with [pcolor = 26]
         [set pcolor blue set pollution-level 3];should there also be a delay in the effect?
[redacted]
   check-messages-AONB
   set color red

end
```

Figure D3 *Code showing the implementation of direct-action for the stakeholder agent AONB. Labels a)-e) refer to explanations for different stages of the process.*

Working with others: When groups have attempted to fix the pollution problem through individual action, if there is still pollution present in the water course, they turn to the creation of more collaborative relationships in order to share knowledge, resources and skills to plan joint action, with the desire to be more effective in reducing the pollution levels. Some organisations set up collaborative links quickly, representing a high level of trust and strong working relationships. Collaborative links can therefore be created in reaction to the initial sharing of information about the pollution event between organisations that trust and work closely together. Other organisations may create closer working relationships only when they have attempted other options first. The creation of `collaboration` links in this case is preceded by the sending of messages requesting that there is a closer relationship. Organisations can chose to react immediately to the request from others or to delay their response (for example if there is an issue of trust or lack of willingness to work together or a lack of resources). Some collaborative relationships are created as soon as the request is sent and some require a request and respond form of communication, representing times when there may have to be meetings set up to agree on how sharing of resources may be done.

Once collaboration links have been set up, the agents may choose to act to try and reduce the pollution again in partnership with other groups, representing the chance to open up the options available and use the skills and resources of others to complement each stakeholder's own. Theory and understanding of partnership and collaborative working in environmental management decision-making has suggested that more effective and acceptable action is likely to result when groups work in partnership and share resources and knowledge. The model works on two conceptualisations of the way in which having collaborative partnerships with other organisations might affect their ability to produce more effective solutions to problems:

- The first is a `best-effectiveness` model in which, when stakeholders agree to work together through a collaborative or closer partnership, they take on the knowledge or skills of others where they themselves are lacking. In terms of the model this means that the collaborating agents compare their seven characteristics that make up their effectiveness score and take on board the values of each characteristic from their collaborative partner that is higher than their own, keeping their own if it is higher than their partner's. This assimilation means that the two collaborating organisations end up with the same, higher value of effectiveness, which they can then apply to their own actions. This model implies that there is equal learning and beneficial exchange of all aspects across both groups and that when they are in collaborative relationship they have an equal ability to act. If a stakeholder has more than one collaboration link and therefore many partner organisations, the sharing continues between all the partners and the first agent ends up with the highest values from all of their partners, creating a high score that is then also shared with their own partners. The process of assimilation means that eventually all those organisations connected through collaborative relationships will gain similar high effectiveness scores if there is a constant process of sharing.

- The second model of sharing is an `average-effectiveness` model that involves the averaging of characteristics between collaborating agents rather than the acquiring of the best score. The average model may represent times when there are compromises involved in the process of sharing and exchange through closer relationships. The compromise may come in terms of having to spend time or resource facilitating a partnership or where translation of data is difficult or lacking in trust. The same process of assimilation across the network of collaborating agents also happens if there continues to be a process of sharing, but the score to which they assimilate is likely to be comparatively lower than the overall scores of the best-effectiveness strategy.

```
to direct-action-collabs-AONB
|
repeat 100
[
[redacted] →  ask one-of collaborations-neighbors
  [
[redacted] →  if (best-effectiveness = true)
   [
    let characteristic1 avialable-resources-to-tackle-minewater
    let characteristic2 first [avialable-resources-to-tackle-minewater] of AONB
    if characteristic1 > characteristic2
    [
      ask AONB
       [ if random-float 1 < positive-collaboration-chance
      [ set avialable-resources-to-tackle-minewater characteristic1
        set color blue]
       ]
    ]
  ]

[redacted] →   if (average-effectiveness = true)
   [
     let characteristic1 avialable-resources-to-tackle-minewater
    let characteristic2 first [avialable-resources-to-tackle-minewater] of AONB

      ask AONB

      [ set avialable-resources-to-tackle-minewater (characteristic1 + characteristic2) / 2
        ]
   ]
]
  ]
```

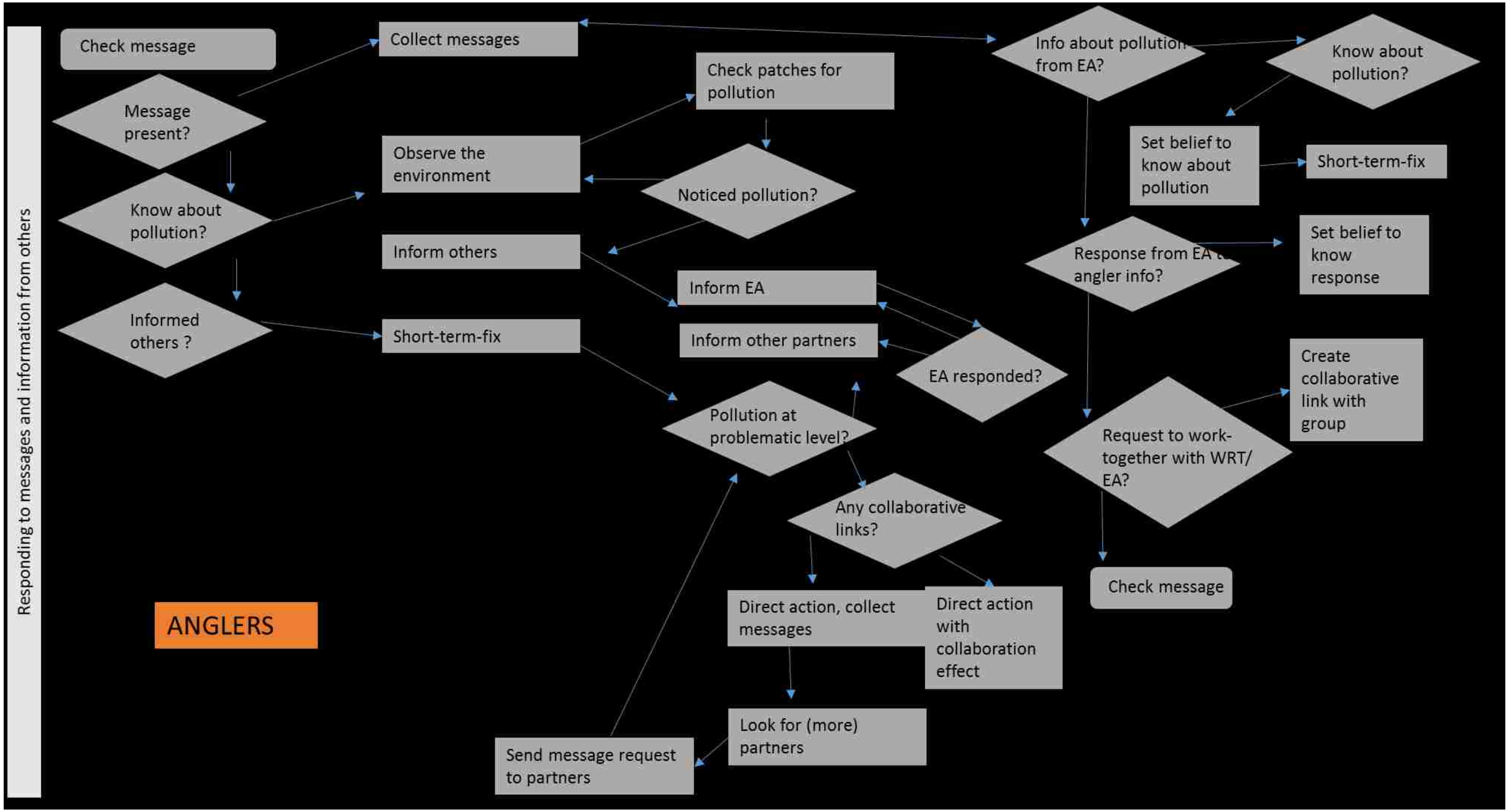
Figure D4 *Code showing the process of sharing when a collaborative link is present whilst a stakeholder enacts the process of direct-action. Shown for the AONB agent. Labels a)-e) refer to explanations for different stages of the process.*

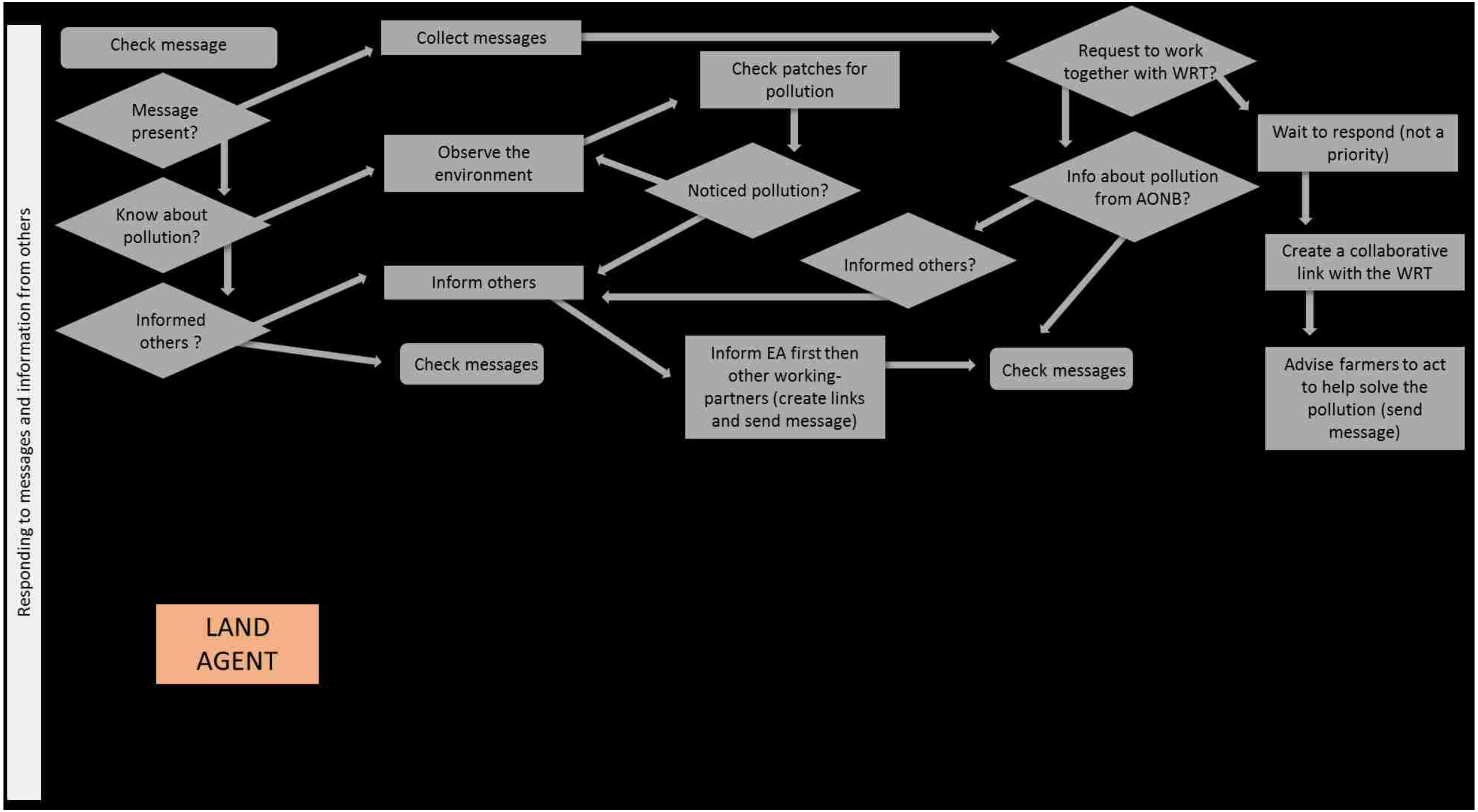
Figure D4 shows an example of the Netlogo code that was used to create the sharing function between collaborating stakeholders. In section a) one of the agent's neighbours (joined through a collaborative link) is asked to run the sharing function detailed in the code below section a), which is then repeated (to ensure that all the neighbours are chosen at least once). Section b) denotes the process that happens if the best-effectiveness switch is on. The relevant characteristics of the neighbour agent and, in this case the AONB agent, are compared and if the neighbour agent's characteristic is a higher value then it is taken on by the AONB. However it is only taken on if a random number (up to 1) is smaller than the variable `positive-collaboration-chance`. This variable represents a possible chance that collaboration might not result in best practice or more effective action, perhaps depending on the nature of the relationship and the interactions. Section c) show the processes that would happen if the `average-effectiveness` switch was on (cannot be on at the same time as the best-practice switch). The two characteristics are identified and the mean value of the two is taken on by the AONB agent. These processes are done for each of the seven characteristics that the agents hold as part of their effectiveness function. Some actors rely on the presence of multiple collaborative links before they will begin to act together with any form of direct action, representing those groups who seek investment, support or other resources from other groups in order to be able to carry out a project. Others will continue to act and adapt their effectiveness as they gain new partners.

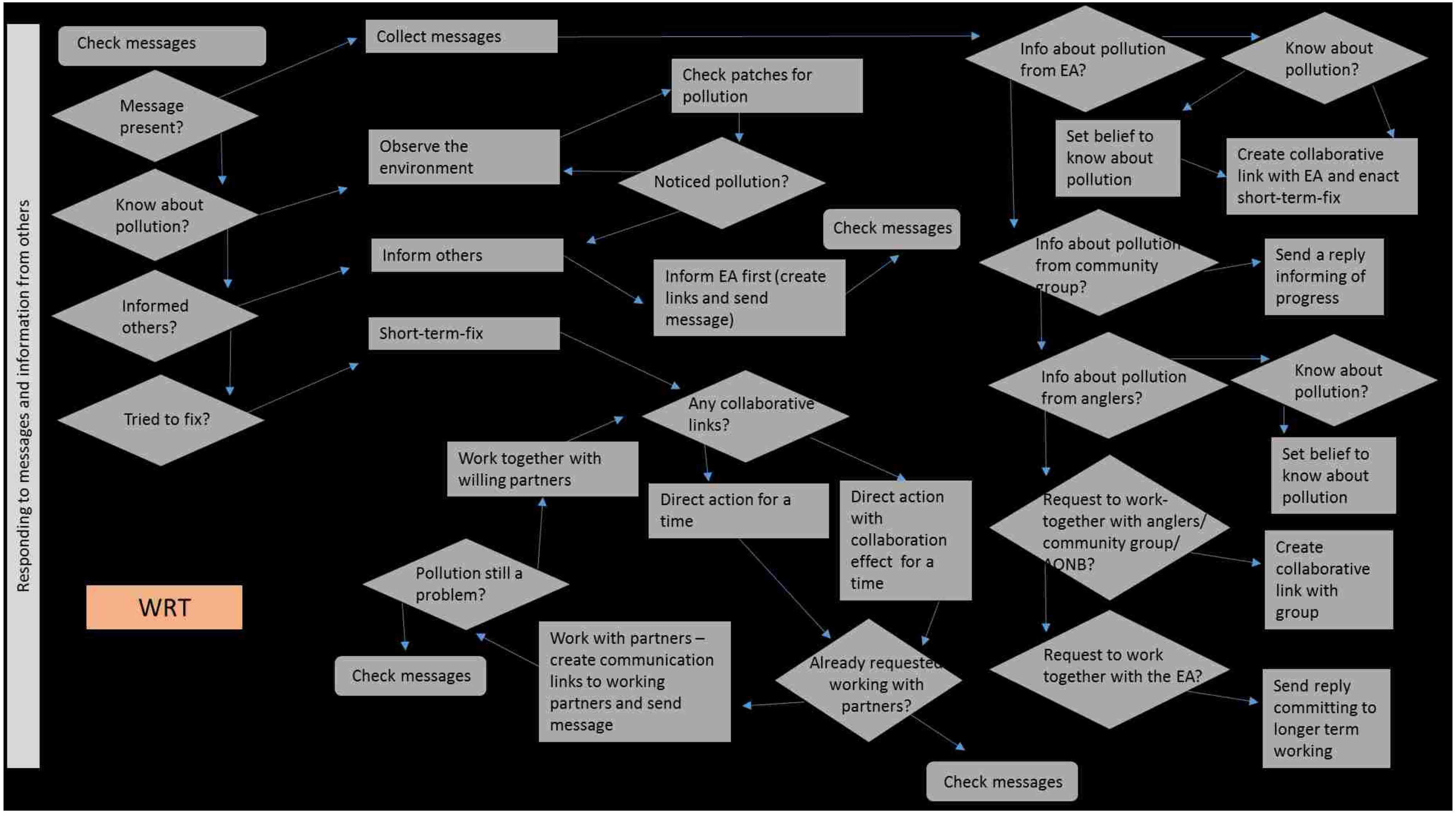
Longer term strategies: If the pollution continues and the previous actions have been ineffective, certain groups have strategies to take an extra step. The EA have the capacity to begin a `project-group`, which appears as an alternative agent in the model. The project-group once formed acts independently of the other stakeholders but is informed by their characteristics and goals if linked. The project-group forms `project-links` with a set of core actors who are likely to be involved in more collaborative, long-term planning. There is an assumption made that the key stakeholders would agree to be involved in the project- group immediately (and therefore no simulation is used to replicate delays in agreement or uptake). This acceptance of membership is one of the key assumptions of the process and may be open to change during experimentation with the model. The sharing of characteristics within the project group happens differently compared to the individual collaboration relationships, in order to represent the ability to share more deeply, to co-create and to go beyond the capacity of the individual groups when involved in processes that may include meetings, formal on-going data sharing, joint grant applications or access to funding. The `effectiveness` measure of the project-group is therefore represented as the total of the effectiveness levels of those linked to the project-group. In contrast to the organisational level collaboration the existence of a project group assumes that there would be an ease of access to the knowledge, skills and time of groups and that the sharing and learning process would create an effectiveness significantly beyond that possible through individual collaborations. Such assumptions lie in the theoretical understanding of collaborative-group management (although are under representative of the possible difficulties associated with larger group decision-making processes such as inertia, data-sharing problems, lack of time, difficulties with inclusion). Through the strategy of the project-group in the current model application of the effectiveness is still modified in the same way as the individual agents through the `max-random-effectiveness` variable, however, it is assumed that the effectiveness of the group might increase over time through a process of learning about the pollution and adapting the capabilities and capacity of organisations to react, as well as the creation of physical infrastructure projects that may increase in effectiveness over time. Therefore the effectiveness of the group increases by a proportion of 0.05 at each time step (starting with max-`random-effectiveness`, then increasing incrementally once any action is enacted by the group). The project-group, when directly affecting the water course may be representative of multiple actions, including the possibility of creating a reedbed treatment system (based on the efforts of some groups in the Wear catchment to create co-treatment works as a long-term solution). Such efforts are represented by a symbol in the model, which is an indication of the project-group's efforts. If such a symbol exists it can be assumed to represent a more permanent change to the water system (such as a reedbed) and continues to have an effect on the water course outwith the direct-action of the project-group. The concept of the model is not to represent fully the exact solutions used or potentially used by the stakeholders but to imagine the broad possible effects of some form of joint-action and potential longer-term changes.

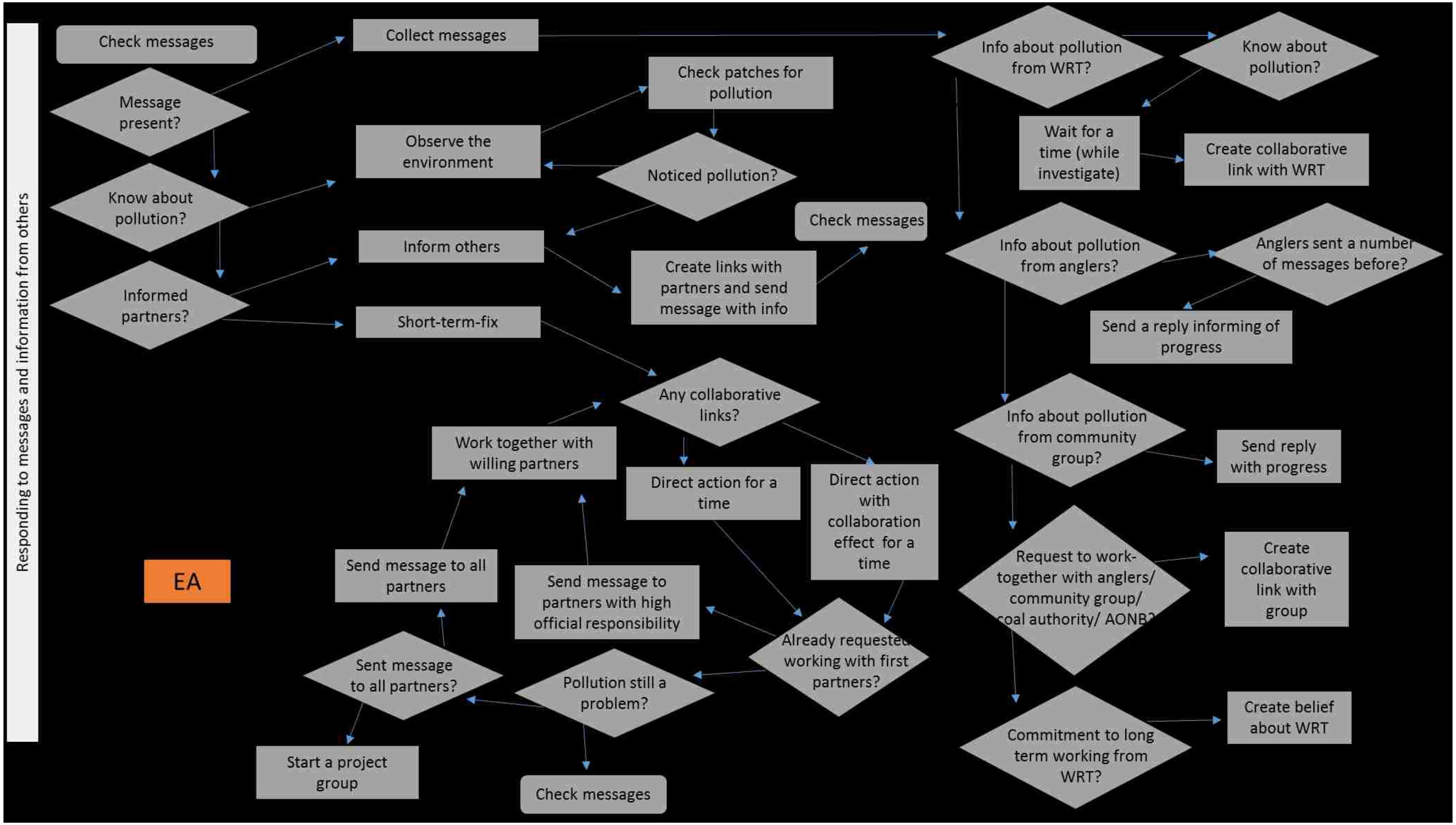
Appendix E

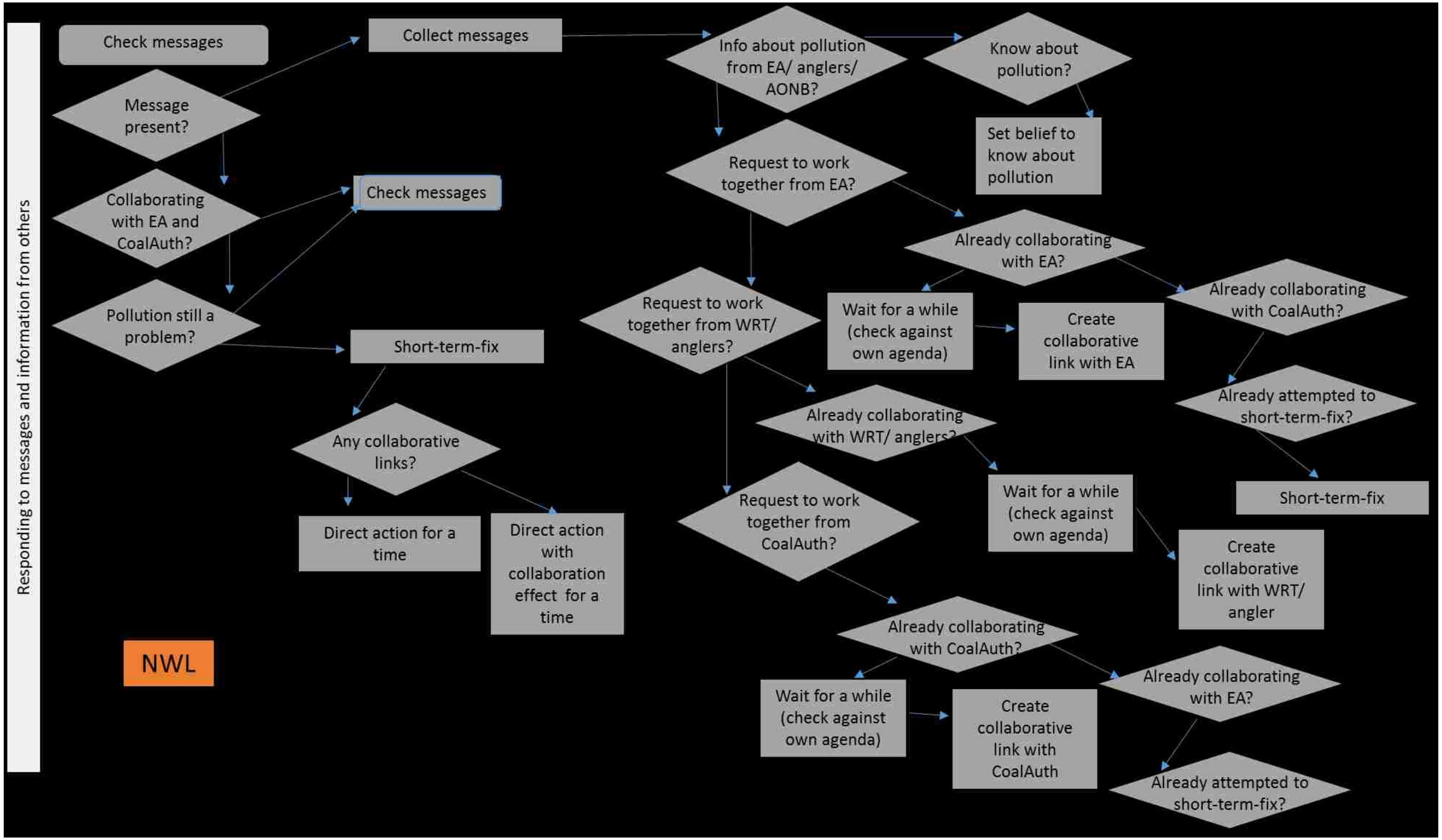
Agent's individual schedules

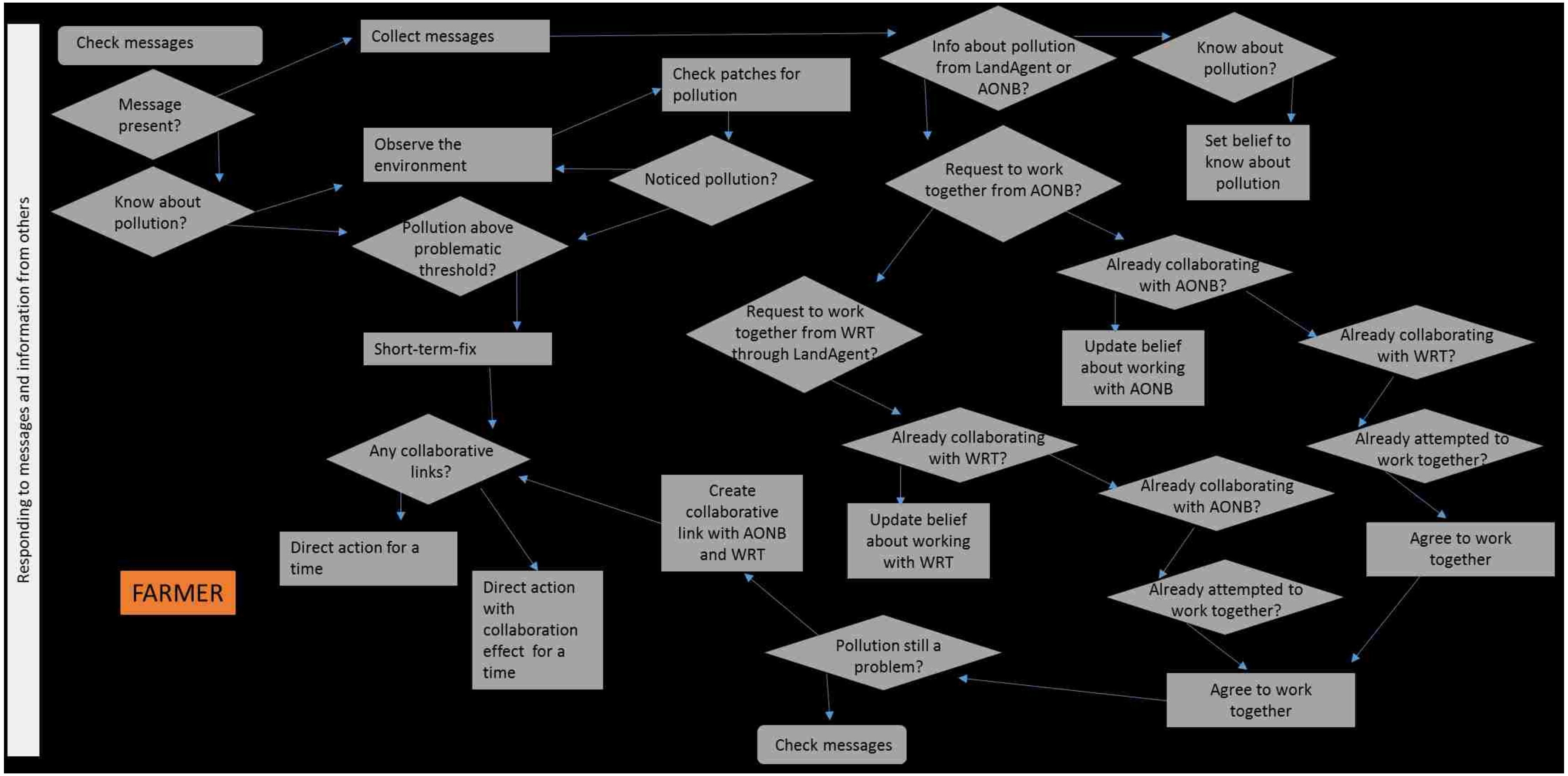

Responding to messages and information from others
Check message
Message present?
Know about pollution?
Informed others ?
Collect messages
Observe the environment
Inform others
Short-term-fix
Check patches for pollution
Noticed pollution?
Inform EA
Inform other partners
EA responded?
Pollution at problematic level?
Any collaborative links?
Direct action, collect messages
Direct action with collaboration effect
Look for (more) partners
Send message request to partners
Info about pollution from EA?
Know about pollution?
Set belief to know about pollution
Short-term-fix
Response from EA to angler info?
Set belief to know response
Create collaborative link with group
Request to work-together with WRT/ EA?
Check message
ANGLERS

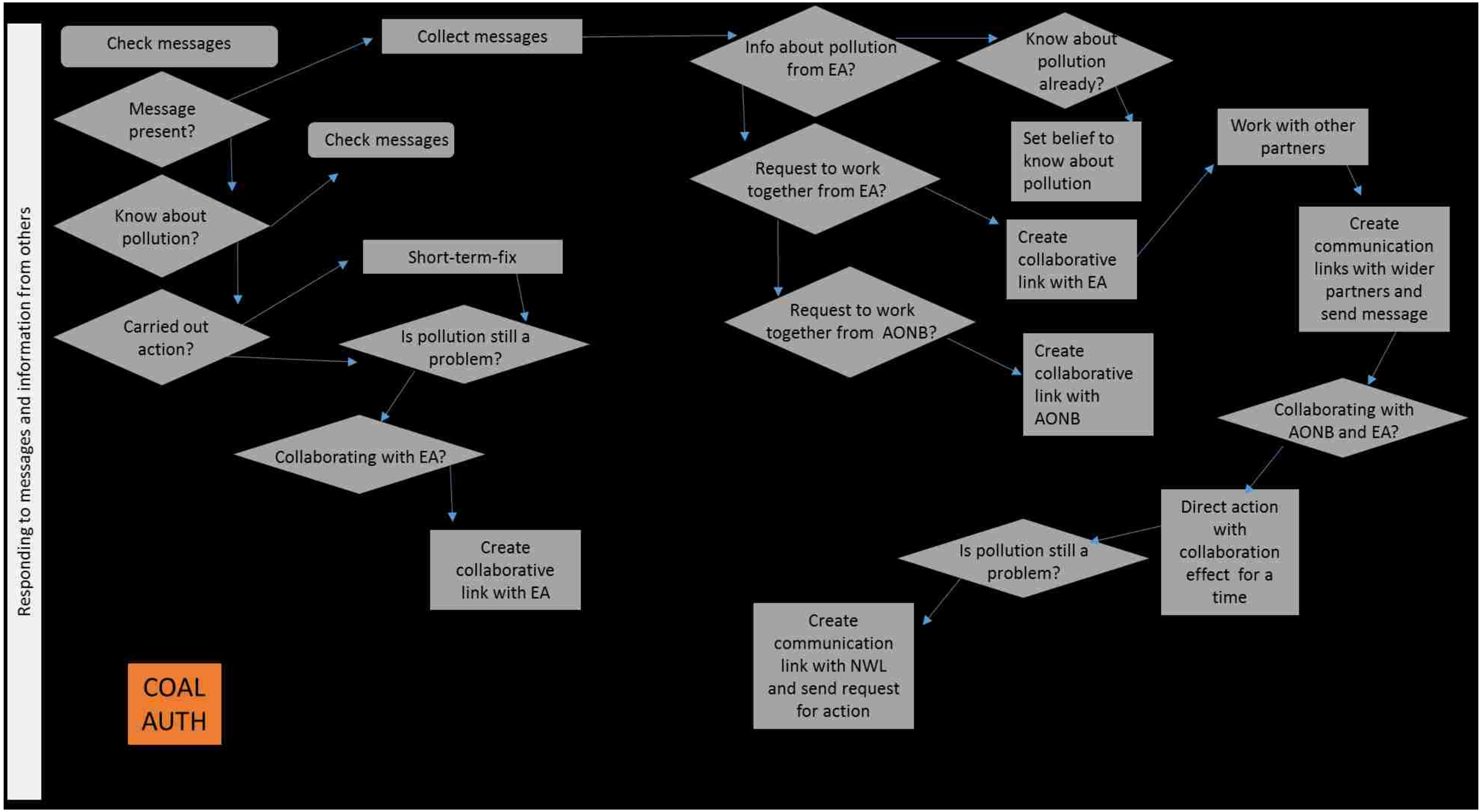

Responding to messages and information from others
Check message
Message present?
Know about pollution?
Informed others ?
Collect messages
Observe the environment
Inform others
Check messages
Check patches for pollution
Noticed pollution?
Inform EA first then other working-partners (create links and send message)
Informed others?
Request to work together with WRT?
Info about pollution from AONB?
Check messages
Wait to respond (not a priority)
Create a collaborative link with the WRT
Advise farmers to act to help solve the pollution (send message)
LAND AGENT

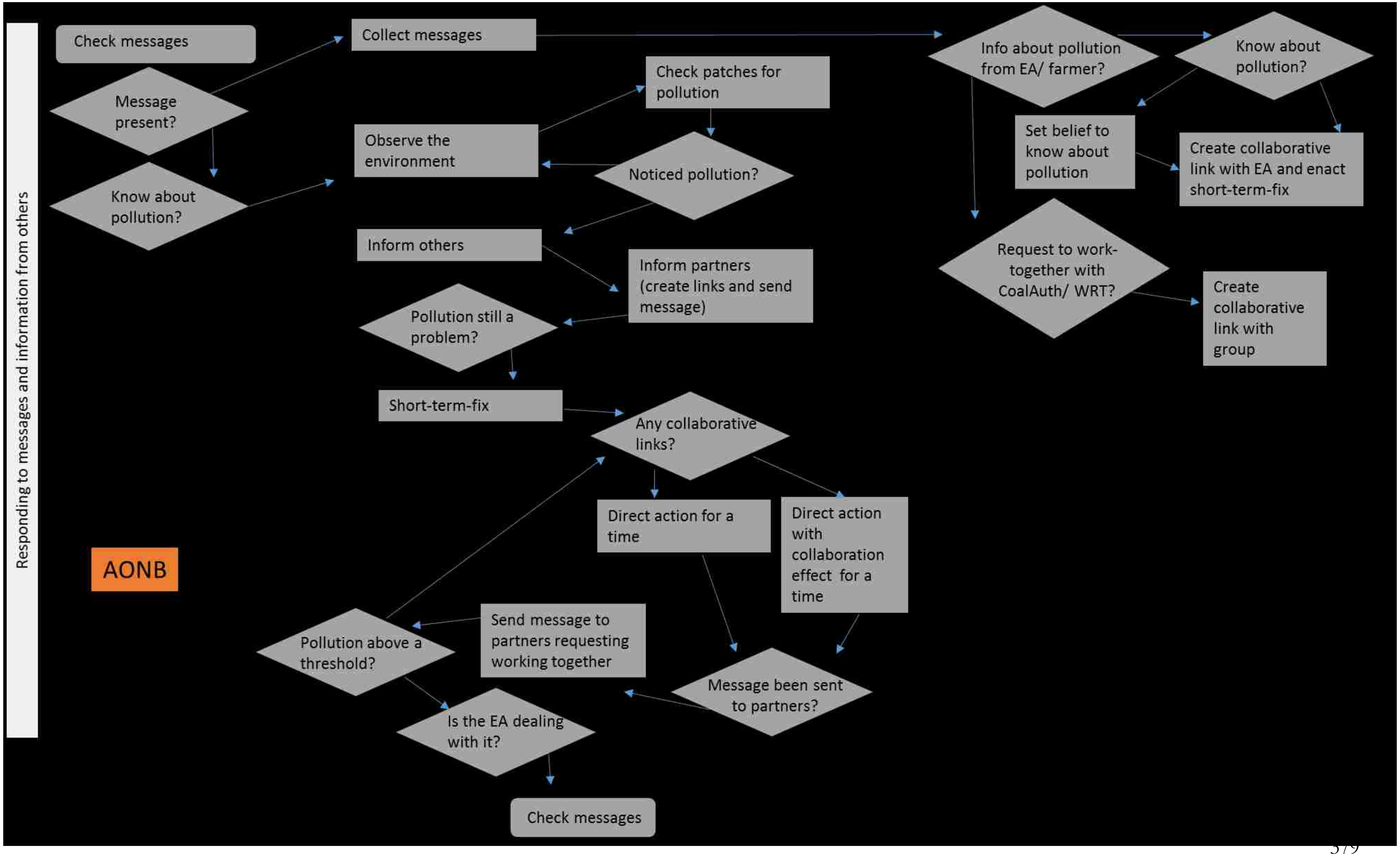

Responding to messages and information from others
Check messages
Message present?
Know about pollution?
Informed others?
Tried to fix?
WRT
Collect messages
Observe the environment
Inform others
Short-term-fix
Check patches for pollution
Noticed pollution?
Check messages
Inform EA first (create links and send message)
Any collaborative links?
Work together with willing partners
Direct action for a time
Direct action with collaboration effect for a time
Pollution still a problem?
Check messages
Work with partners – create communication links to working partners and send message
Already requested working with partners?
Check messages
Info about pollution from EA?
Know about pollution?
Set belief to know about pollution
Create collaborative link with EA and enact short-term-fix
Info about pollution from community group?
Send a reply informing of progress
Info about pollution from anglers?
Know about pollution?
Set belief to know about pollution
Request to work-together with anglers/ community group/ AONB?
Create collaborative link with group
Request to work together with the EA?
Send reply committing to longer term working

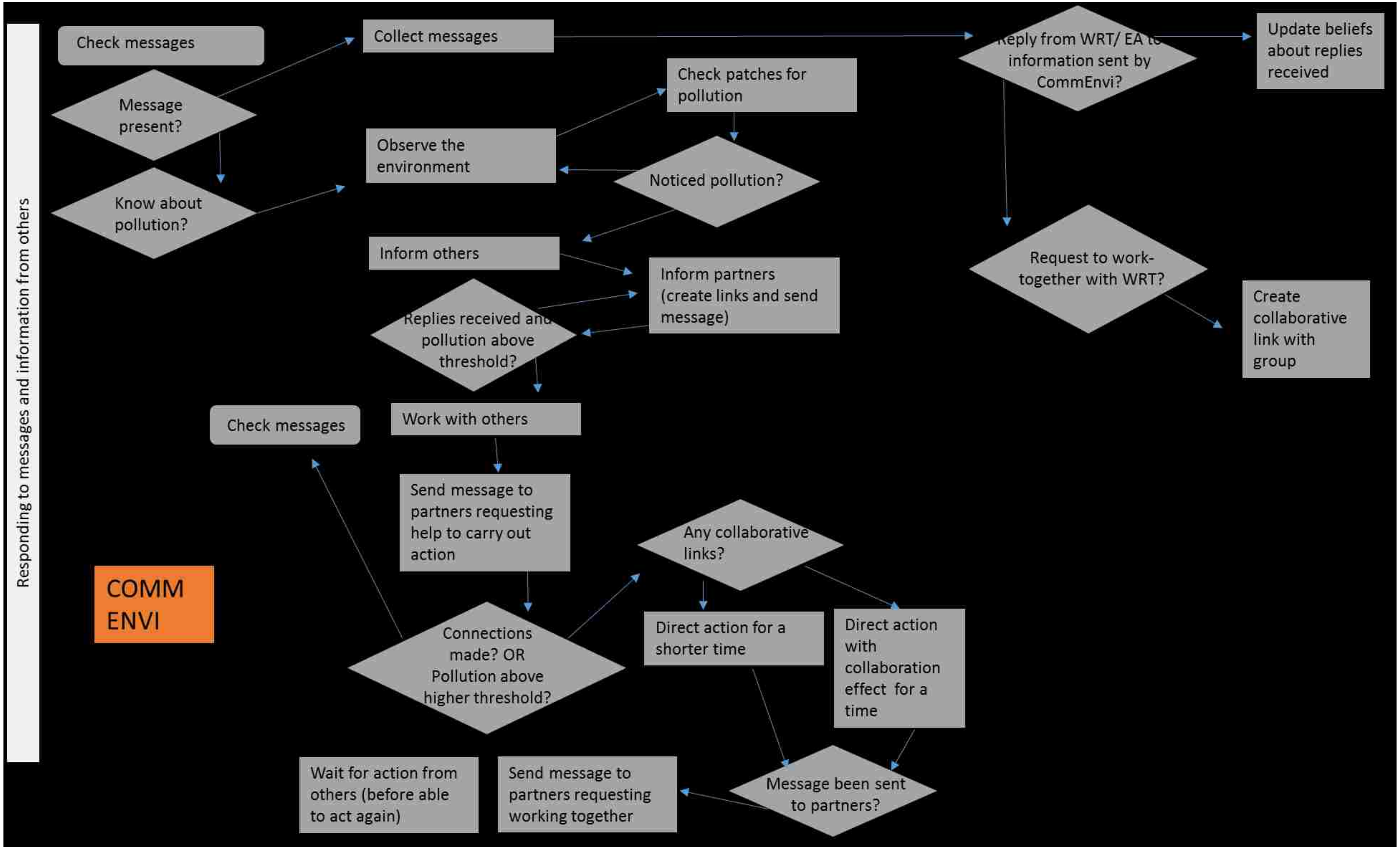

Responding to messages and information from others
Check messages
Message present?
Know about pollution?
Informed partners?
Collect messages
Observe the environment
Inform others
Short-term-fix
Check patches for pollution
Noticed pollution?
Check messages
Create links with partners and send message with info
Any collaborative links?
Work together with willing partners
Direct action for a time
Direct action with collaboration effect for a time
EA
Send message to all partners
Send message to partners with high official responsibility
Already requested working with first partners?
Sent message to all partners?
Pollution still a problem?
Start a project group
Check messages
Info about pollution from WRT?
Know about pollution?
Wait for a time (while investigate)
Create collaborative link with WRT
Info about pollution from anglers?
Anglers sent a number of messages before?
Send a reply informing of progress
Info about pollution from community group?
Send reply with progress
Request to work-together with anglers/ community group/ coal authority/ AONB?
Create collaborative link with group
Commitment to long term working from WRT?
Create belief about WRT

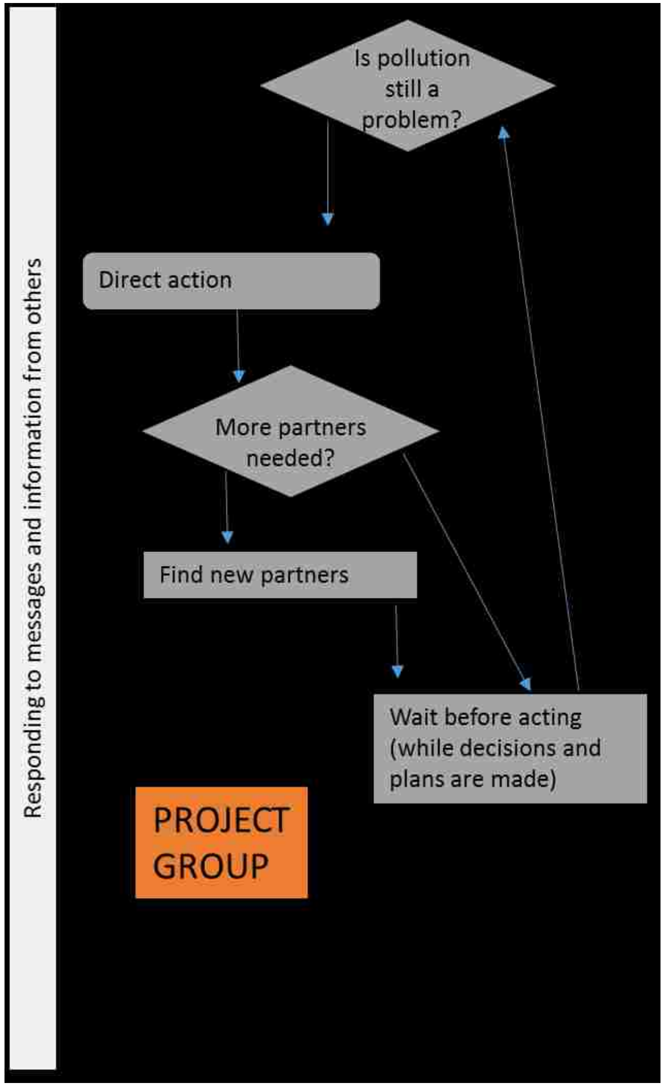

Responding to messages and information from others
Check messages
Message present?
Collaborating with EA and CoalAuth?
Pollution still a problem?
Collect messages
Check messages
Short-term-fix
Any collaborative links?
Direct action for a time
Direct action with collaboration effect for a time
Info about pollution from EA/ anglers/ AONB?
Know about pollution?
Set belief to know about pollution
Request to work together from EA?
Already collaborating with EA?
Request to work together from WRT/ anglers?
Wait for a while (check against own agenda)
Create collaborative link with EA
Already collaborating with CoalAuth?
Already attempted to short-term-fix?
Short-term-fix
Already collaborating with WRT/ anglers?
Wait for a while (check against own agenda)
Create collaborative link with WRT/ angler
Request to work together from CoalAuth?
Already collaborating with CoalAuth?
Already collaborating with EA?
Wait for a while (check against own agenda)
Create collaborative link with CoalAuth
Already attempted to short-term-fix?
NWL

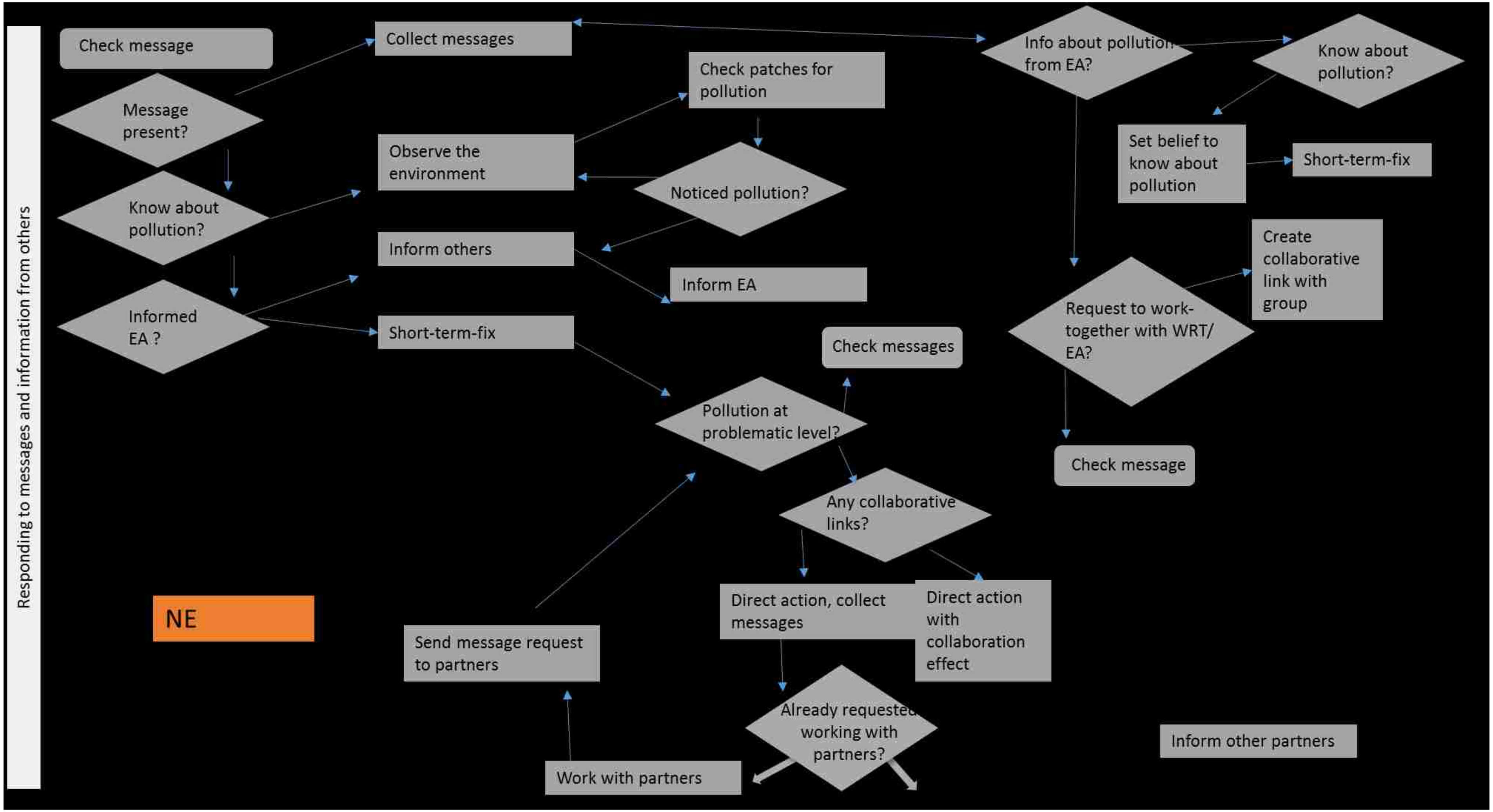

Responding to messages and information from others
Check messages
Message present?
Know about pollution?
Collect messages
Observe the environment
Check patches for pollution
Noticed pollution?
Pollution above problematic threshold?
Short-term-fix
Any collaborative links?
Direct action for a time
Direct action with collaboration effect for a time
Create collaborative link with AONB and WRT
FARMER
Info about pollution from LandAgent or AONB?
Know about pollution?
Set belief to know about pollution
Request to work together from AONB?
Already collaborating with AONB?
Update belief about working with AONB
Already collaborating with WRT?
Already attempted to work together?
Agree to work together
Request to work together from WRT through LandAgent?
Already collaborating with WRT?
Update belief about working with WRT
Already collaborating with AONB?
Already attempted to work together?
Agree to work together
Pollution still a problem?
Check messages


Responding to messages and information from others
Check messages
Message present?
Collect messages
Check messages
Know about pollution?
Short-term-fix
Carried out action?
Is pollution still a problem?
Collaborating with EA?
Create collaborative link with EA
COAL AUTH
Info about pollution from EA?
Know about pollution already?
Set belief to know about pollution
Request to work together from EA?
Create collaborative link with EA
Work with other partners
Create communication links with wider partners and send message
Request to work together from AONB?
Create collaborative link with AONB
Collaborating with AONB and EA?
Direct action with collaboration effect for a time
Is pollution still a problem?
Create communication link with NWL and send request for action


Responding to messages and information from others
AONB
Check messages
Message present?
Know about pollution?
Collect messages
Observe the environment
Check patches for pollution
Noticed pollution?
Inform others
Inform partners (create links and send message)
Pollution still a problem?
Short-term-fix
Any collaborative links?
Direct action for a time
Direct action with collaboration effect for a time
Message been sent to partners?
Send message to partners requesting working together
Pollution above a threshold?
Is the EA dealing with it?
Check messages
Info about pollution from EA/ farmer?
Know about pollution?
Set belief to know about pollution
Create collaborative link with EA and enact short-term-fix
Request to work-together with CoalAuth/ WRT?
Create collaborative link with group


Responding to messages and information from others
Check messages
Message present?
Collect messages
Know about pollution?
Observe the environment
Check patches for pollution
Noticed pollution?
Inform others
Inform partners (create links and send message)
Replies received and pollution above threshold?
Reply from WRT/ EA to information sent by CommEnvi?
Update beliefs about replies received
Request to work-together with WRT?
Create collaborative link with group
Check messages
Work with others
Send message to partners requesting help to carry out action
Any collaborative links?
COMM ENVI
Connections made? OR Pollution above higher threshold?
Direct action for a shorter time
Direct action with collaboration effect for a time
Wait for action from others (before able to act again)
Send message to partners requesting working together
Message been sent to partners?


Responding to messages and information from others
Is pollution still a problem?
Direct action
More partners needed?
Find new partners
Wait before acting (while decisions and plans are made)
PROJECT GROUP


Responding to messages and information from others
Check message
Message present?
Know about pollution?
Informed EA ?
Collect messages
Observe the environment
Inform others
Short-term-fix
Check patches for pollution
Noticed pollution?
Inform EA
Check messages
Pollution at problematic level?
Any collaborative links?
Direct action, collect messages
Direct action with collaboration effect
Already requested working with partners?
Send message request to partners
Work with partners
NE
Info about pollution from EA?
Know about pollution?
Set belief to know about pollution
Short-term-fix
Create collaborative link with group
Request to work-together with WRT/ EA?
Check message
Inform other partners

Appendix F

Sample of Netlogo Code (set-up and go procedures)

```
__includes ["bdi.nls" "communication.nls" "EA-2.nls" "WRT-2.nls"
        "NWL-2.nls" "Anglers-2.nls" "CA.nls" "AONB.nls"
        "Farmer.nls" "CommEnvi.nls" "Project-group.nls"
        "LandAgent.nls" "NE.nls"]


;;;;;;;;;;;;;;;;Globals;;;;;;;;;;;;;;;;;;;;;;;;;;;;
globals [
  river-patches
  north-riparian-patches
  south-riparian-patches
  non-spatial-patches
  pollution-extent
  tick-count


]

;;;;;;;;;;;;Breeds;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
breed [EA]
breed [WRT]
breed [NWL]
breed [angler anglers]
breed [CoalAuth]
;breed [DCC]
breed [LandAgent]
breed [AONB]
breed [NE]
breed [CommEnvi]
breed [Farmer]
breed [DWT]
breed [project-group]
breed [long-term-project]
breed [reedbed]

undirected-link-breed [collaboration collaborations]; transactional and purposeful
exchanges
directed-link-breed [communication communications]; simply informing or requesting
undirected-link-breed [project projects]

;;;;;;;;;;;;;Agents-own variables;;;;;;;;;;;;;;;;;;;;
turtles-own
[
  spatial-sampling-frequency
  ;resources
  incoming-queue
  beliefs
  intentions
  working-partners
  duration-of-pollution-event
  sender1
```

```
  sender2
  effectiveness;
  avialable-resources-to-tackle-minewater
  data-on-water-qual
  eyes-and-ears-on-the-ground
  ability-to-change-physical-environment-or-infrastructure
  capacity-to-identify-and-tackle-source
  official-responsibility
  organisational-sense-of-responsibility

  communication-link-countdown
  collaboration-link-countdown

]

EA-own
[count-anglers-message]

project-group-own
[direct-action-project-time]

;;;;;;;;;;;;;;;;Patches-own variables;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
patches-own
[
  pollution-level
  countdown ; countdown to tell how long patch stays solved before it can become polluted
again
  decay ; to end the pollution event
  ]



;;;SETUP;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

to setup
  ca

  setup-watercourse
  setup-stakeholders
  create-pollution-event

  set tick-count 2

  reset-ticks
end

;;SETUP PROCESSES;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

to setup-watercourse
```

```
  set river-patches patches with [pycor <= -9 and pycor >= -12]
  ask river-patches
  [set pcolor blue
    set pollution-level 0]

  set north-riparian-patches patches with [pycor >= -8 and pycor <= -5]
  ask north-riparian-patches
  [set pcolor green]

  set south-riparian-patches patches with [pycor <= -13]
  ask south-riparian-patches
  [set pcolor green]

  set non-spatial-patches patches with [pycor >= -4]
  ask non-spatial-patches
  [set pcolor black]

  ask river-patches
  [set countdown pollution-fix-memory
    set decay 5]

end

to setup-stakeholders

  create-EA 1; turtle 0
  [
    set label "EA"
    set shape "circle"
    set xcor random-xcor
    set ycor random-float 16
    set beliefs []
    set intentions[["check-messages" "false"]];starting intention - always present unless
actively stopped
    set incoming-queue []

    set duration-of-pollution-event 0
    set spatial-sampling-frequency 20
    set working-partners ["NWL" "WRT" "angler" "CoalAuth" "NE" "AONB"]

;    ;effectiveness variables
    set avialable-resources-to-tackle-minewater  (8 * available-resources)
    set data-on-water-qual  9
    set eyes-and-ears-on-the-ground  5
    set ability-to-change-physical-environment-or-infrastructure  6
    set capacity-to-identify-and-tackle-source  5
    set official-responsibility  10
    set organisational-sense-of-responsibility  10

  ]
```

```
 create-NWL 1; turtle 1
[
  set label "NWL"
  set shape "circle"
  set xcor random-xcor
  set ycor random-float 16
  set beliefs []
  set intentions[["check-messages-NWL" "false"]]
  set incoming-queue []
  ;set official-responsibility 7
  set duration-of-pollution-event 0
  set working-partners [ "EA"]

   ;effectiveness variables
  set avialable-resources-to-tackle-minewater  (5 * available-resources)
  set data-on-water-qual  5
  set eyes-and-ears-on-the-ground  2
  set ability-to-change-physical-environment-or-infrastructure  8
  set capacity-to-identify-and-tackle-source  3
  set official-responsibility  6
  set organisational-sense-of-responsibility  5
]

 create-WRT 1; turtle 2
[
  set label "WRT"
  set shape "circle"
  set xcor random-xcor
  set ycor random-float 16
  set beliefs []
  set intentions[["check-messages-WRT" "false"]]
  set incoming-queue []
  ;set official-responsibility 0
  set duration-of-pollution-event 0
  set spatial-sampling-frequency 10
  set working-partners  ["EA" "Farmer" "LandAgent" "NWL" "NE" "angler" "CommEnvi"]

   ;effectiveness variables
  set avialable-resources-to-tackle-minewater (3 * available-resources)
  set data-on-water-qual  5
  set eyes-and-ears-on-the-ground  5
  set ability-to-change-physical-environment-or-infrastructure  6
  set capacity-to-identify-and-tackle-source  1
  set official-responsibility  0
  set organisational-sense-of-responsibility  8
]

 create-angler 1; turtle 3
[
  set label "angler"
```

```
  set shape "circle"
  set xcor random-xcor
  set ycor random-float 16
  set beliefs []
  set intentions[["check-messages-anglers" "false"]]
  set incoming-queue []
  set spatial-sampling-frequency 5
  set duration-of-pollution-event 0
  set working-partners  ["WRT" "EA" "NWL"]

  ;effectiveness variables
  set avialable-resources-to-tackle-minewater   (2 * available-resources)
  set data-on-water-qual  2
  set eyes-and-ears-on-the-ground  8
  set ability-to-change-physical-environment-or-infrastructure  4
  set capacity-to-identify-and-tackle-source  0
  set official-responsibility  0
  set organisational-sense-of-responsibility 7
 ]

 create-CoalAuth 1; turtle 4
 [
  set label "CoalAuth"
  set shape "circle"
  set xcor random-xcor
  set ycor random-float 16
  set beliefs []
  set intentions[["check-messages-CA" "false"]]
  set incoming-queue []
  set official-responsibility 5
  set working-partners  ["EA" "AONB"]


   ;effectiveness variables
  set avialable-resources-to-tackle-minewater  (9 * available-resources)
  set data-on-water-qual  6
  set eyes-and-ears-on-the-ground  2
  set ability-to-change-physical-environment-or-infrastructure  7
  set capacity-to-identify-and-tackle-source  8
  set official-responsibility  9
  set organisational-sense-of-responsibility 9
 ]


;  create-DCC 1; turtle 5
;  [
;    set label "DCC"
;    set shape "circle"
;    set xcor random-xcor
;    set ycor random-float -3
;    set beliefs []
```

```
;    set intentions[]
;    set incoming-queue []
;    set official-responsibility 5
;    set working-partners  ["NWL" "EA" "angler" "LandAgent" "NE"]
;  ]

  create-LandAgent 1; turtle 6
  [
   set label "LandAgent"
   set shape "circle"
   set xcor random-xcor
   set ycor random-float 16
   set beliefs []
   set intentions[["check-messages-LandAgent" "false"]]
   set incoming-queue []
    set working-partners  ["WRT" "Farmer"]
   set spatial-sampling-frequency 2

   set avialable-resources-to-tackle-minewater  (0 * available-resources)
   set data-on-water-qual  0
   set eyes-and-ears-on-the-ground  2
   set ability-to-change-physical-environment-or-infrastructure  3
   set capacity-to-identify-and-tackle-source  0
   set official-responsibility  0
   set organisational-sense-of-responsibility 2
  ]

  create-AONB 1; turtle 7
  [
   set label "AONB"
   set shape "circle"
   set xcor random-xcor
   set ycor random-float 16
   set beliefs []
   set intentions[["check-messages-AONB" "false"]]
   set incoming-queue []
   set official-responsibility 5
   set working-partners  ["EA" "Farmer" "WRT" "CoalAuth"]
   set spatial-sampling-frequency 5

   set avialable-resources-to-tackle-minewater  (4 * available-resources)
   set data-on-water-qual  4
   set eyes-and-ears-on-the-ground  5
   set ability-to-change-physical-environment-or-infrastructure  6
   set capacity-to-identify-and-tackle-source  6
   set official-responsibility  2
   set organisational-sense-of-responsibility 6
  ]

  create-NE 1; turtle 8
  [
```

```
  set label "NE"
  set shape "circle"
  set xcor random-xcor
  set ycor random-float 16
  set beliefs []
  set intentions[["check-messages-NE" "false"]]
  set incoming-queue []
  set official-responsibility 5
  set working-partners  ["WRT" "EA"]

  set spatial-sampling-frequency 7

  set avialable-resources-to-tackle-minewater  (3 * available-resources)
  set data-on-water-qual  2
  set eyes-and-ears-on-the-ground  4
  set ability-to-change-physical-environment-or-infrastructure 5
  set capacity-to-identify-and-tackle-source  1
  set official-responsibility  2
  set organisational-sense-of-responsibility 6
 ]

 create-CommEnvi 1; turtle 9
 [
  set label "CommEnvi"
  set shape "circle"
  set xcor random-xcor
  set ycor random-float 16
  set beliefs []
  set intentions[["check-messages-CommEnvi" "false"]]
  set incoming-queue []
  set working-partners  ["WRT" "EA"]
  set spatial-sampling-frequency 6

  set avialable-resources-to-tackle-minewater  (1 * available-resources)
  set data-on-water-qual  0
  set eyes-and-ears-on-the-ground  5
  set ability-to-change-physical-environment-or-infrastructure  3
  set capacity-to-identify-and-tackle-source  0
  set official-responsibility  0
  set organisational-sense-of-responsibility 6
 ]

 create-farmer 1; turtle 10
 [
  set label "Farmer"
  set shape "circle"
  set xcor random-xcor
  set ycor random-float 16
  set beliefs []
  set intentions[["check-messages-farmer" "false"]]
  set incoming-queue []
```

```
    set official-responsibility 5
    set spatial-sampling-frequency 5
    set working-partners  ["WRT" "AONB"]

    set avialable-resources-to-tackle-minewater  (1 * available-resources)
    set data-on-water-qual  1
    set eyes-and-ears-on-the-ground  3
    set ability-to-change-physical-environment-or-infrastructure  7
    set capacity-to-identify-and-tackle-source  0
    set official-responsibility  0
    set organisational-sense-of-responsibility 2
  ]


;  create-DWT 1; turtle 11
;  [
;    set label "DWT"
;    set shape "circle"
;    set xcor random-xcor
;    set ycor random-float 16
;    set beliefs []
;    set intentions[]
;    set incoming-queue []
;    set official-responsibility 5
;    set working-partners  ["WRT" "LandAgent" "DCC"]
;  ]

ask turtles
[  set color grey

   if any? other turtles in-radius 2
    [set xcor random-xcor
     set ycor random-float 16]


 set effectiveness   avialable-resources-to-tackle-minewater + data-on-water-qual
                + eyes-and-ears-on-the-ground
                + ability-to-change-physical-environment-or-infrastructure
                + capacity-to-identify-and-tackle-source
                + official-responsibility
                + organisational-sense-of-responsibility
  ]

end

;;pollutoion creation

to create-pollution-event
  ask patch -16 -11
  [become-polluted]
  reset-ticks
```

```
end

to become-polluted
   set pcolor 26
   set pollution-level 1
   set decay 5
end

;to  hide-communication-links
;  ask links with [color = green] [die]
;end

;to setup-links
;  ask share-exchange
;  [set color blue]
;  ask communication
;  [set color green]
;end


;;;;;;;GO;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

to go

ifelse ticks > 5 and count river-patches with [pcolor = 26] <= 5
   [ask river-patches with [pcolor = 26]
     [ set pcolor blue
      set pollution-level 0]
   ]
   [
    propagate-pollution
   ]

   ask turtles
   [ execute-intentions
     set pollution-extent count river-patches with [pcolor = 26]
     if duration-of-pollution-event >= 1
          [set duration-of-pollution-event duration-of-pollution-event + 1]
   ]

     ask NE

     [show intention-name get-intention
      show intentions
     ]

layout-spring turtles links 0.02 10 0.01
```

```
if pollution-extent = 0
[set tick-count tick-count - 1
  if tick-count = 0
  [stop]
   ]

tick
end

;..................................................................

to propagate-pollution
repeat pollution-propagation-rate
[

ask river-patches with [pollution-level = 1]
[
  ifelse not any? neighbors with [pcolor = blue and pollution-level = 0]
  [do-nothing]
  [ask one-of neighbors with [pollution-level = 0 and pcolor = blue]
  [become-polluted]]
   set pollution-extent count river-patches with [pcolor = 26]


   set decay decay - 1 ;
   if decay <= 0
   [ set pollution-level 0
     set pcolor blue]
]
]

ask river-patches with [pollution-level = 3]
[
  set countdown countdown - 1
  if countdown <= 0
  [set pcolor blue
    set pollution-level 0]
]

ask river-patches with [pcolor = 26]
[
if ticks > 5 and count river-patches with [pcolor = 26] <= 5 ;and count river-patches with
[pcolor = 26] > 1
    [ set pcolor blue
      set pollution-level 0
    ]
]


end
```

Appendix G

Model initialisation

Initialisation

Table G1 *Working-partners and spatial-sampling-frequency values used for the core model.*

	working-partners	spatial-sampling-frequency (no. of patches)
EA	NWL, WRT, angler, CoalAuth, NE, AONB	15
NWL	EA	Rely on others for WQ information
WRT	EA, Farmer, LandAgent, NWL, DCC, NE, angler, CommEnvi	6
Farmer	NWL, EA, angler, LandAgent, NE	10
Anglers	WRT, EA, NWL	20
CommEnvi	WRT, EA	10
AONB	EA, Farmer, WRT, CoalAuth	**5**
CoalAuth	EA, AONB	Rely on others for WQ information
LandAgent	Farmer, WRT	Rely on others for WQ information
NE	WRT, EA, DWT	7

Table G2 *Table shows the initial values for the seven characteristics that make up the effectiveness score.*

	EA	NWL	WRT	Farmer	Anglers	CommEnvi	AONB	CoalAuth	LandAgent
Avialable-resources-to-tackle-minewater	8	5	3	1	2	1	4	9	0
data-on-water-qual	9	5	5	1	2	0	4	6	0

eyes-and-ears-on-the-ground	5	2	5	3	8	5	5	2	1
ability-to-change-physical-environment-or-infrastructure	6	8	6	6	4	3	6	7	3
capacity-to-identify-and-tackle-source	5	3	1	0	0	0	6	8	0
official-responsibility	10	6	0	0	0	0	2	9	0
organisational-sense-of-responsibility	10	5	8	2	7	6	6	9	2
Total	**53**	**34**	**28**	**14**	**23**	**15**	**33**	**50**	**6**

Table G3 *Table shows the initial thresholds set for the use of the timeout_expired function (the length of time an action is repeated until it stops). .*

	Timeout_expired	No. of ticks
Anglers	Initial “direct-action-anglers”	2
	Act-together “direct-action-anglers”	5
AONB	Initial “direct-action-AONB”	3
	Work-with-partners - "act-together-AONB"	5
CoalAuth	work-with-other-partners "direct-action-CA"	5
CommEnvi	"direct-action-CommEnvi"	5
EA	"direct-action”	10
	Work-with-partners – after finding wider partners "direct-action”	10
	Work-with-partners – before finding wider partners	2

	"direct-action"	
	In reaction to info from WRT before creating collaborative link "do-nothing"	2
Farmer	"direct-action-farmer"	5
	Agree-to-work-together "direct-action-farmer"	5
LandAgent	Responding to WRT "do-nothing"	3
NE	Initial "direct-action"	2
	Act-together "direct-action"	4
NWL	"direct-action-NWL"	10
	In response to request from EA to collab "do-nothing"	1
	In response to request from WRT to collab "do-nothing"	3
	In response to request from anglers to collab "do-nothing"	1
	In response to request from CoaAuth to collab "do-nothing"	
WRT	"direct-action-WRT"	3
	"act-together-WRT"	5

Table G4 *Table shows the initial thresholds set for certain processes to be enacted given certain levels of pollution.*

	Action if pollution-threshold reached (may be part of a combination of conditions)	Thresholds	Notes
Anglers	Short term fix "angler-attempt-to-fix" if threshold reached	pollution-extent < 33	Anglers have less capacity to act alone and will inform others who may be able to react (such as the EA) until the pollution is fairly extensive and they feel compelled to act

AONB	Short term fix if threshold reached	if pollution-extent > 5	The AONB would weigh up the risk of a very low level of pollution against the costs and resources required to act (but have a very low threshold at which they will react).
	Inform others	Pollution-extent > 1	Symbolises a care for others to know about the problem, even if the pollution levels are small
CoalAuth	To work-with-other-partners (rather than the immediate partners)	if pollution-extent > 5	
	Inform others	Pollution-extent > 10	To check that the pollution is still problematic
	Long term fix	Pollution-extent >10	To check that the pollution is still problematic
CommEnvi	Direct action (if collaboration links aren't made)	pollution-extent > 66	CommEnvi is mostly very sensitive to small pollution levels, so has a lack of thresholds apart from if there is no collaboration and they feel compelled to act alone. The threshold is high as they have few resources to react unless the problem is very large.
EA	Inform others	Pollution-extent > 1	Act at the existence of pollution, regardless of extent
	Short-term-fix	Pollution-extent > 1	Act at the existence of pollution, regardless of extent
	Find-wider-partners	Pollution-extent > 10	It is hypothesised that the EA would prefer to act with their core partners first as much as possible and only bring in wider partners if the problem persists and is above negligible.
	Create project-group	Pollution-extent > 5	The threshold to create the project-group is the lowest possible as even if the pollution is reducing the stakeholders might believe a more structured response to another similar event might be needed, therefore there is no significant threshold needed for the formation.

Farmer	Short term fix if threshold reached	pollution-extent > 66	Farmer perceives the problem differently to some stakeholders and will only act if the pollution appears to be severe.
	Agree-to-work-together	Pollution-extent > 5	Only act if the pollution is still evident
LandAgent			Rely on others for thresholds
NE	Short-term-fix	Pollution-extent > 5	
NWL	Short term fix if threshold reached	if pollution-extent > 10	NWL will only react if there is still a problem.
WRT	Inform others	Pollution-extent > 1	WRT will always communicate with others no matter how small the pollution.

Appendix H

Photo credits for Figure 3.2

Killhope Burn
Copyright Mike Quinn
http://www.geograph.org.uk/photo/3875788

Burnhope Burn
Copyright Mike Quinn
http://www.geograph.org.uk/photo/1436408

The River Wear at Stanhope ford
Copyright M J Richardson
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River Browney near Sunderland Bridge
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River Wear at Durham
https://commons.wikimedia.org/wiki/File:Durham_Millburngate_Bridge.jpg

Confluence of the Cong Burn and the Wear
Copyright Mick Garratt
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River Gaunless
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River Wear at Sunderland
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Smallhope Burn
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Appendix I

Glossary of key terms

CaBA (Catchment Based Approach)

An approach to water resource management developed as part of the ongoing delivery of the WFD in England. CaBA, focuses on management at the catchment scale and aims to localise environmental improvement actions and bring a smaller, community-based focus to the management of water resources. It focuses on involving a wide range of stakeholders in decision making processes within each catchment and encourages them to work collaboratively to identify issues, outcomes and actions that will lead to healthier and more accessible water environments (Environment Agency, 2011).

Complexity/ Complex system

Complexity is a characteristic of a system and arises because of the interaction between the components of a system (Cilliers 1998). Properties of the system emerge as a result of the interactions between individual components (Cilliers et al., 2013). Complex systems are characterised by a large number of components, interactions that are non-linear and create feedback loops, and by uncertainty alongside spontaneous self-organisation and emergence (Waldrop, 1992).

Emergence/Emergent phenomena

"Emergence refers to the arising of novel and coherent structures, patterns and properties during the process of self-organisation in complex systems" (Goldstein, 1999:49). Emergence can be understood in terms of the complex system's organizational structure and the dynamic nature of interactions between components in a system (Cilliers et al., 2014: 2). Emergent phenomena can be loosely defined as "somehow constituted by, and generated from, underlying processes, as well as autonomous from underlying processes" (Bedau, 1997:2). Emergent phenomena are therefore conceptualised to occur at the macro level and arise from the components and processes at the micro level (Goldstein, 1999).

Strong emergence

Where there is strong emergence, emergent phenomena are autonomous from the underlying processes that generate them through interactions that render processes unpredictable and non-linear (Bedau, 1997).

Weak emergence

Weak emergence couples emergent structures more closely to changes in constituent parts, based on macro-states being derivable from external conditions (even if non-deterministically) (Bedeau, 1997).

Function/ functionality

Functionality relates to a notion of effectiveness, in relation to the ability to produce the desired result or the ability to reach the organisational objectives (Sandström, 2008). In this thesis it relates to notions of stakeholder satisfaction and approval of processes, and to universally understood conceptualisations of success in natural resource management and governance.

Governance

Rhodes (1996:652-3) describes governance itself as "a change in the meaning of government, referring to a new process of governing; a changed condition of ordered rule; or the new method by which society is governed". Specifically, governance concerns the self-organising and interorganisational processes, networks and structures that shape individual and collective action, solidified through formal and informal rules (Rhodes, 1996; Lebel et al., 2006; Young, 1992.).

Environmental Governance

Environmental governance is focused on the mechanisms and processes of organisation amongst political actors aimed at influencing environmental actions and outcomes through changes in environmental incentives, knowledge, institutions and decision-making behaviour (Lemos and Agrawal, 2006).

Environmental Governance Approach

CaBA is an example of an environmental governance approach that attempts to set up processes of organisation (catchment partnerships) supported through political actors (EA and Defra support and funding) that aim to change actions (encourage projects and schemes) and outcomes (create cleaner, healthier rivers and streams that meet WFD targets). It encourages changes to knowledge and decision-making behaviour by promoting collaboration and sharing.

Water resource governance

Water resources governance refers to "the rules under which a management system operates and the different actors and networks that help develop and implement water policies" (PahlWostl, 2009: 1). As such, water governance is seen as a set of actions implemented collectively, which work towards a common goal and coordinate among diverse stakeholder groups (Lubell & Fulton, 2008). This involves diverse social, political, economic and administrative systems in place to regulate management of water resources (Rogers & Hall, 2003). Water governance is "explicitly distinguished, on the one hand side, from government activities, and on the other hand side, from management activities (e.g., by water utilities), both of which indicate activities of specific actor groups and goals" (Wiek and Larson 2012: 3156).

Catchment Governance

Governance can have multiple scales, and within water governance catchments are a spatially bounded system in which processes of governance can take place. The catchment is the space in which decision-making plays out (although it is acknowledged that there is often multi-level governance links to national and international actors and influences). The governance element refers to the sharing of power within that spatial scale between diverse actors through partnership and collaboration.

Management

The term "water management" refers to "operational activities including the operation, monitoring, strategic planning, and implementation of measures," (Pahl-Wostl, 2009: 1). Management relates to strategic operational decisions, where there is a central and purposeful steering.

Integrated water resource management

IWRM promotes the integration of all water-related management activities, including land and forests, with a view to ensuring water is used in fair, sustainable and economically beneficial ways (Global Water Partnership, 2011). The main goal of IWRM is to facilitate cooperation, joint responsibility and integration within fragmented governance systems (Teisman and Edelenbos, 2011).

Catchment management

Processes and strategies and mechanisms of decision-making within the catchment implemented and acted in order to meet specific goals and enact particular actions again expected outcomes, specifically derived in and for a particular spatially bounded area containing a particular set of stakeholders with particular needs and aims and a particular set of physical conditions and problems.

Network

"In its simplest form, a network is nothing more than a set of discrete elements (nodes or vertices), and a set of connections (links or edges) that link the elements, typically in a pairwise fashion." (Newman et al., 2006: 2) In a social context, a network is defined as "a set of goal-oriented interdependent actors that come together to produce a collective output (tangible or intangible) that no one actor could produce on his or her own" (Keast, et al., 2014: 16).

Network perspective

A network perspective focuses explicitly on the structure of the interactions between the components of social-ecological systems and the ways in which this structure affects the performance of the system (Janssen et al., 2006: 15).

Network structure

Network structure is seen as the observable and potentially measurable characteristics of an interconnected system based on interactions amongst a given set of entities (Bodin et al., 2006). It relates to the pattern of connections between actors within a network and how those connections are arranged (Sandström, 2008).

Governance network/ network governance

A governance network is "a set of relatively stable relationships of communication between actors or organisations involved in resource management, and based on degrees of mutual trust, reciprocity and cooperation" (Chaffin et al., 2016:114 also Torfing, 2005; Newig et al.,2010). Sørensen & Torfing, (2007) define a governance network as made up of (1) interdependent, but operationally autonomous actors from the public and/or private sector; (2) who interact with one another through ongoing negotiations; (3) which take place within a relative institutionalised framework with regulative, normative, cognitive and imaginary elements; (4) facilitate self-regulation in the shadow of hierarchy (a kind of 'bounded autonomy'); and (5) contribute to the production of public purpose in the broad sense of public values, visions, plans, standards, regulations and concrete decisions.

Social-ecological system

Social-ecological systems consider that in complex resource situations social and ecological systems are intertwined, so much so that the delineation between the two is arbitrary and artificial (Norgaard, 1994). Interactions in social-ecological systems can create dynamic feedback loops in which humans both influence and are influenced by ecosystem processes (Levin, 1999; Cumming et al., 2006). Included in the conceptualisation of a SES is the idea that the components of the systems are coupled in complex, non-linear and potentially irreversible ways, through multiple feedbacks (O'Brien, 2012). Such feedbacks mean that social-ecological systems are seen as complex adaptive systems made up of sub-systems, themselves embedded in larger sub-systems (Anderies et al., 2004).